








Hydrogeochemical processes and evaluation of groundwater in Al-Salman area – Iraqi Southern Desert

Kareem Ghafel Al-Mutawqi¹⁾ , Salam Hussein Ewaid²⁾ , Salwan Ali Abed¹⁾  ✉ , Nadhir Al-Ansari³⁾ ,
Mudhafar A. Salim⁴⁾ , Ameer J. Kadhim⁵⁾ 

¹⁾ University of Al-Qadisiyah, College of Science, Iraq

²⁾ Technical Institute of Shatra, Southern Technical University, Basra, Iraq

³⁾ Luleå University of Technology, Laboratorievägen 14, 971 87 Luleå, Sweden

⁴⁾ Arab Regional Center for World Heritage, Manama, Bahrain

⁵⁾ Ministry of Water Resources, General Commission of Groundwater, Baghdad, Iraq

RECEIVED 10.10.2020

REVIEWED 19.10.2020

ACCEPTED 15.12.2020

Abstract: A field survey has been conducted for the study area using the Global Positioning System (GPS) and geological and geomorphological maps of the area. The study area is one of the important areas in Iraq characterized by scarce water resources. The purpose of the study is to determine the hydro-chemical processes and their relationship to groundwater quality carried out in the southwestern desert region of Iraq, where the region lacks extensive studies of water resources. Twenty-eight groundwater samples were collected from wells distributed between the eastern borders of Saudi Arabia and the West Bank of the Euphrates River. For the purpose of hydrogeochemical analyses, the Fetter method was used to collect and examine samples. A large part of the recharge area is located in Saudi Arabia, where the groundwater bearing aquifer represented by the Dammam formation extends to Iraq and Saudi Arabian International borders. The analysis determined the order of cations ($\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$) and anions ($\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$). High values of the variation coefficient (CV) correspond to the concentration of potassium, sodium and chloride ions (CV: 68.7, 64.7 and 64 respectively). To identify the hydrochemical water facies, the Piper diagram was used. It was found that 53% of the water samples belong to the Na-Cl type and 40% are of the Ca-Mg-Cl type, while the rest of the samples are the Ca-Cl type. To identify geochemical processes, it was found that ion exchange processes via chloroalkaline indices 1 and 2 are prevalent between Ca^{2+} , Mg^{2+} in the groundwater and Na^+ , K^+ in water bearing rocks. To learn more about the processes that led to the concentration of certain ions, such as sodium, it was found that they tend to be of silicate minerals related to surface runoff of water in recharge areas and carbonic rocks. It was also found that rock / soil-groundwater interaction and evaporation processes were the formal processes in the saturated zone and evaporation in the unsaturated zone are prevalent processes of groundwater ion concentration.

Keywords: Dammam formation, Durov diagram, facies, Gibbs diagram, groundwater, hydrogeochemical processes, Iraqi Southern Desert, major ions, Piper diagram

INTRODUCTION

Groundwater is an important water source on our planet, which accounts for 97% of fresh water. Half of water is allocated for drinking and half for watering [VADIATI *et al.* 2018]. Many diseases and environmental problems are caused by improper

water quality. Water quality is as important as its availability and quantity to meet human and other needs [JKEMAN *et al.* 2016].

The physical and chemical properties of groundwater depend on both natural factors such as rock type, groundwater velocity, geochemical reactions, soluble salts and the quality of water recharged into aquifers as well as factors resulting from

human intervention, such as agricultural activities, industrialization, etc. [SWARNA LATHA, NAGESWARA RAO 2011]. The interaction between these factors leads to the difficulty of understanding and management of water [LI *et al.* 2017]. Therefore, it is necessary to get acquainted with the geochemical processes that happen with the groundwater movement, which controls and determines the groundwater quality, its use, and its management methods. While identifying pollution sources, it is important to determine appropriate treatment methods [CHRISTENSEN *et al.* 2018]. The analysis of hydrochemical properties of water can help to identify mechanics and nature of chemical reactions that occur between water and water bearing rocks, thus providing a clear vision for better and easier protection, and the use of water for drinking and watering purposes [UMAR *et al.* 2001]. Moreover, water quality determines the type and suitability of soil for the production of agricultural crops and the establishment of population centres [CHEN *et al.* 2017]. This study aims to assess the quality of water and factors controlling its properties because water is crucial for the nomads and border guards.

MATERIALS AND METHODS

THE STUDY AREA

The study area is located between longitudes 46°3'5.89" to 43° 45'29.67" E and latitudes 31°10'29.65" to 29°18'1.72" N, as it extends from western borders of the Kingdom of Saudi Arabia to the west bank of the Euphrates River in Muthanna Governorate – Iraq (Fig. 1). The study area is an important part of the southwestern Iraqi desert. There are no permanent rivers in the

area. All rivers are seasonal from the rainy season through winter. Therefore, it is important to conduct extensive studies of groundwater, which is the main source of water used for drinking and other purposes. The height of the area ranges between 10 and 400 m a.s.l., and the most elevated area is at the Saudi-Iraqi international border. The depths of the dug wells range between 42 and 330 m a.s.l. The groundwater level from the surface of the earth ranges between 0 and 132 m, and the water level ranges between 10 and 290 m a.s.l. Higher values are recorded in the recharge area at the international border. The amount of discharge for wells ranges between 5 and 11 m³s⁻¹. The climate of the region is dry, and the average annual rainfall is 103 mm. The average temperature ranges between 17.2 and 44.7°C, and sometimes during the summer, it exceeds 50°C and rarely reaches sub-zero during winter season [AL-SHAMMA' A, AL-MUTAWKI 2014].

GEOLOGY AND TECTONIC OF THE SOUTHERN DESERT

The Southern Desert comprises stratified sediments that were deposited during Triassic, Jurassic, Cretaceous, Palaeocene, Eocene, Oligocene and Pliocene periods sequentially. The formal formations bearing groundwater which date back to the Eocene period, represented by the Umm-Radhuma Formation, Dammam Formation, and between them is the Rus Formation, which is represented by evaporated facies. Umm-Radhuma consists of marly limestone, recrystallized and dolomitized limestones and thin layers of anhydrite, while the Dammam Formation consists of numulitic limestone which is recrystallized and dolomitized [JASSIM, GOFF (eds.) 2006; BUDAY 1980 in JASSIM, GOFF (eds.) 2006]. The main formations in the study area are outcropped at Arabian

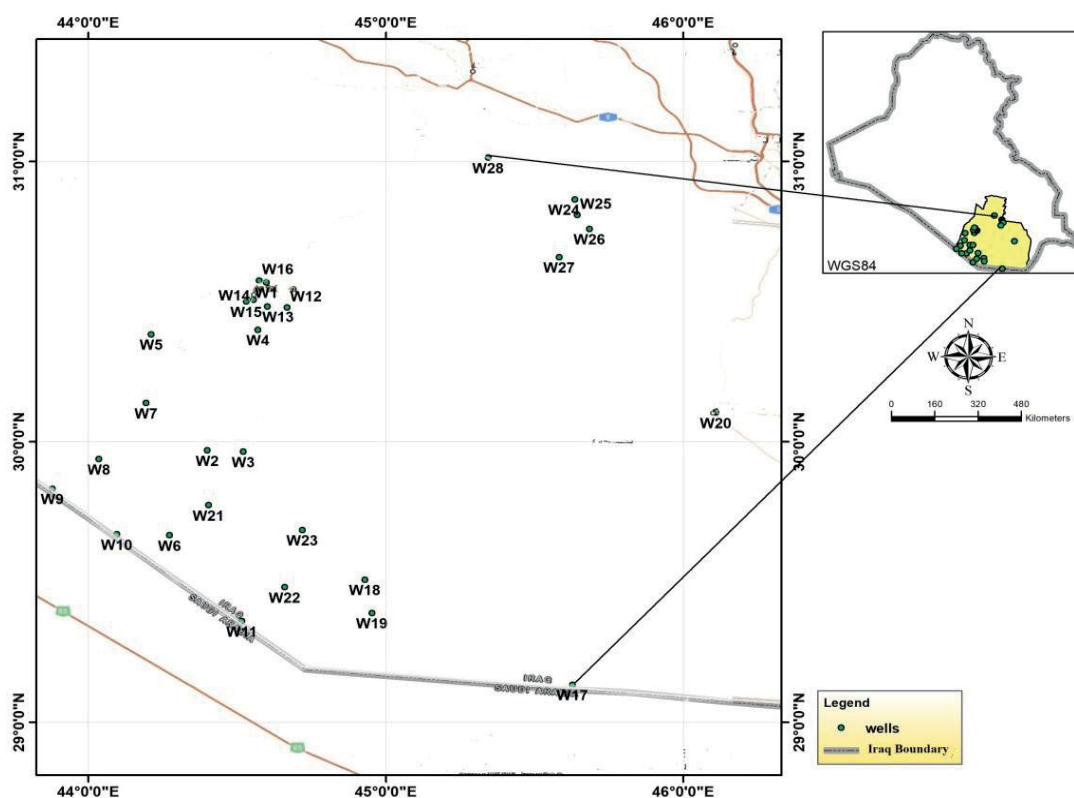


Fig. 1. Location of the study area within the Southern Desert of Iraq; W1–W28 investigated wells; source: AL-JIBURI and AL-BASRAWI [2009] and Satellites Pro [undated], modified

Saudi border that represent the main recharge area [JASSIM, GOFF (eds.) 2006] – Figure 2.

Southern Desert tectonics is very simple when studied extensively. The simple inclination of the rock layers towards the north-east is the main tectonic characteristic. There are some geomorphological features in the area represented by the depressions. There are two hypotheses to explain the presence of these depressions. The former is likely to be formed by tectonic processes, while the latter is likely to be formed by the dissolution of the lower formations, especially the Rus Formation.

According to the above, there are no clear geological structures, and the hydraulic properties follow or are related to the nature of the terrain [JASSIM, GOFF (eds.) 2006].

HYDROGEOLOGY

Groundwater in the study area is represented by unconfined aquifers which became confined to the discharge area direction to the NE and represented by the Umm Er Radhuma Formation and Dammam Formation (Fig. 2). As these formations outcropped near the international border area of Iraq, which are relatively high areas, to form the main recharge areas for the water bearing aquifers. The direction of water movement is from the recharge area in the southwestern direction towards the discharge area at the borders of the Euphrates River and towards the northeast. There wells are distributed from deep in the recharge area to low depth in discharge areas.

GROUNDWATER SAMPLING AND ANALYSIS

To evaluate the hydrogeochemical processes which control the water quality of the study area, cations (Na^+ , Ca^{2+} , Mg^{2+} and K^+) and anions (SO_4^{2-} , Cl^- , HCO_3^- and NO_3^-) concentration in

groundwater needs to be determined. To perform the analysis, twenty-eight productive wells were selected from the study area (Fig. 1). The locations of wells were determined by a GPS device (GARMIN, GPS62st). The groundwater samples were collected during 2019 to sealed polyethylene bottles. Bottles were rinsed four times with water before they were filled with samples to be analysed. The groundwater samples were kept at 4°C [FETTER 1980]. Their chemical composition was analysed in the General Commission of Groundwater Laboratories.

Statistical parameters (mean, standard deviation, variance coefficient, maximum and minimum values) were calculated for all physical-chemical variables of groundwater samples.

In general, understanding and assessment of the groundwater geochemical pathway can be verified through the use of the Piper diagram [PIPER 1944] and the Durov diagram [DUROV 1948]. To implement these models, Rockware Aq-QA version 1.1 was used. Both diagrams show similarity and variation when analysed because they have the same quality of data presentation [TODD 1995]. The purpose of using the Piper plot is to determine the water type / hydrogeochemical facies, while the Durov plot gives us an idea about hydrogeochemical processes in addition to the water type in all wells and the geochemical changes along the path of the groundwater movement.

Ion exchange processes can be inferred by calculating chloroalkaline indices (CAI) 1 and 2, which were calculated according to the equations (1 and 2) [SUBRAMANI *et al.* 2009]:

$$CAI1 = Cl^- - (Na^+ + K^+) / Cl^- \quad (1)$$

$$CAI2 = Cl^- - (Na^+ + K^+) / (SO_4^{2-} + HCO_3^- + NO_3^-) \quad (2)$$

Some functions can be used to infer the sources of major ions dissolved in water, through which the sources of these ions

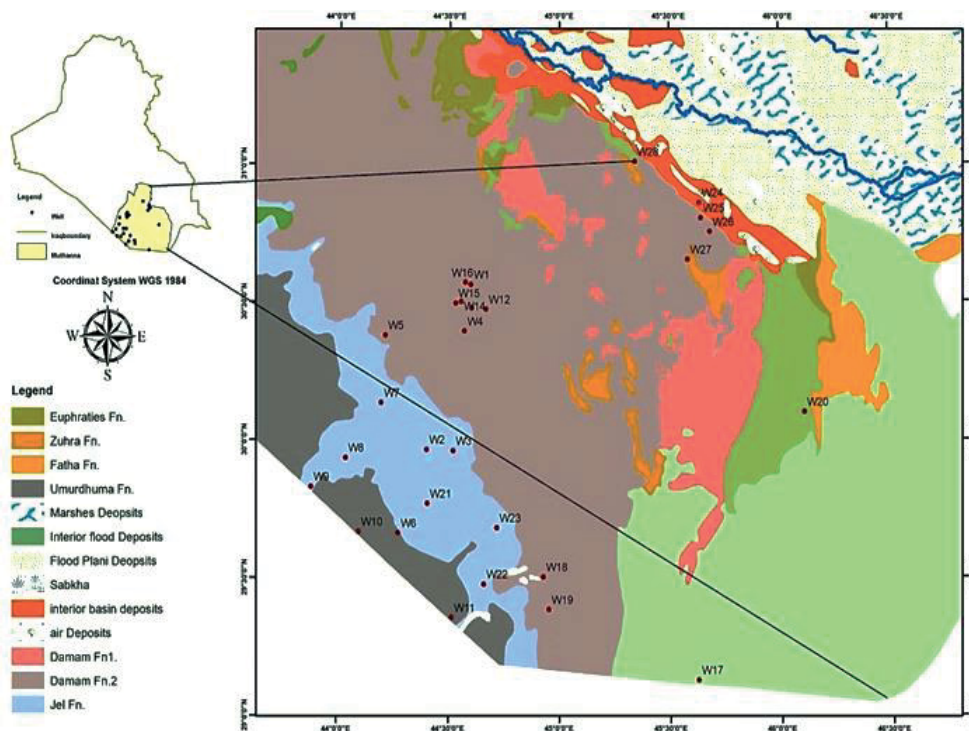


Fig. 2. Geological map of the study area; source, modified from geological map of Iraq; source: SISSAKIAN and FOUAD [2012]

can be identified. One of these functions is the ratio of the sodium ions to calcium ions ($\text{Na}^+/\text{Ca}^{2+}$) and calcium ions to magnesium ($\text{Ca}^{2+}/\text{Mg}^{2+}$) [SARIN *et al.* 1989]. Additionally, to identify ion sources in groundwater, the ratios index was certified between $(\text{Cl}^-) / (\text{Cl}^- + \text{HCO}_3^-)$ and $(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ as a function of (*TDS*).

The Gibbs plot is broadly used to identify the origin and nature of interactions that occur between groundwater and rocks within aquifers [GIBBS 1970]. Depending on the soluble elements function, the diagram can be divided into three fields. Sometimes precipitation processes prevail, other times evaporation or the interaction between soil and rocks with groundwater.

RESULTS AND DISCUSSION

GROUNDWATER HYDROCHEMISTRY

The data from the groundwater sampling showed major ion concentrations, as illustrated in Table 1. Precise analyses were also performed and the results were encouraging as they ranged better than ± 5 . Changes in ion concentrations can be inferred from one well to another depending on the variation coefficient (*CV*) and the standard deviation (*SD*). Since the spatial changes of pH values are small (*CV*: 4.54), while the high values of the variation coefficient correspond to the concentration of potassium, sodium and chlorine ions (*CV*: 68.7, 64.7. and 64 respectively) – Table 2. However, it cannot be adopted for potassium ions as these are found only in four wells (W15, W18, W20 and W21) with a mean of 97, while the distribution and spreading values of other ions is consistent with the expression of variation coefficients (Tabs. 1, 2). The values of pH and ion concentrations in a number of wells was within the limits allowed by the World Health Organization [WHO 2011]. These wells were located in the recharge area, and some of them gave results beyond the permissible limits. This was common in and near the discharge area, and it was found that the water property was shifted toward alkalinity with mean value of 7.5. The total dissolved solids ranged from 250 to 4655 $\text{mg}\cdot\text{dm}^{-3}$ with a mean of 2127.2 $\text{mg}\cdot\text{dm}^{-3}$. Electrical conductivity fluctuated from 388 to 6820 $\mu\text{S}\cdot\text{cm}^{-1}$ with an average for all groundwater samples 3213.4 $\mu\text{S}\cdot\text{cm}^{-1}$. The minimum *EC* value was found in well 3 (W3) located within the recharge area where the aquifer was exposed, while the maximum *EC* value was determined in well 27 (W27) located within the discharge area.

During its movement towards the discharge area, groundwater is exposed to different hydro-chemical processes as well as a longer retention time in the aquifer. It was found that predominant cations (86%) in the groundwater samples are in the order $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$, while the anions are in the order $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$ which expressed in $\text{epm}\cdot\text{dm}^{-3}$, in spite of the concentration of sulphide ion which maximum was in well 27.

HYDROCHEMICAL FACIES

The Piper diagram was used to determine the water type and hydrochemical facies, as shown in Figure 3. The number of groundwater samples within field 2 is equivalent to 53%, while the water quality is the Na-Cl type, which proves that there is a prevalence of alkali over alkaline earth ($\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} + \text{Mg}^{2+}$).

The samples within field 3 account for 40% and the water quality, which type is Ca-Mg-Cl. There is a dominance of alkaline earth over alkali ($\text{Ca}^{2+} + \text{Mg}^{2+} > \text{Na}^+ + \text{K}^+$), while the rest of samples within field 5 accounted for 6%, and the water quality was the Ca-Cl type. This demonstrates the dominance of alkaline earth over alkali. According to the Piper diagram, cations are mainly distributed into two main families (A and B). As for the anions, they appear distributed over three families (A, B and C) that are almost connected. This distribution is related to the change in the ion concentration in well water samples between the recharge in the west and discharge areas to the north-east. Groundwater seeks to achieve chemical equilibrium through chemical reactions between water-bearing rocks and water within the aquifers [TODD, MAYS 2005].

When examining the Durov diagram (Fig. 4), it is clear that 67.8% of the water samples are in the field 5 within the Durov diagram. It indicates that there are simple dissolutions of rocks, while it is clear that 21.4% of groundwater samples within field 4 and 10.7% in field 7 show the prevailing processes of simple dissolution or mixing. According to the Lloyd and HEATHCOAT [1985] classification, this pathway is attributed to recent fresh-water penetrations, where simple mixing or dissolution takes place, without the dominant of major ion concentrations [AL-SHAMMA'A, AL-MUTAWKI 2014].

HYDROCHEMICAL PROCESSES AND IONS SOURCES OF GROUNDWATER

The quality and concentration of salinity in groundwater depends on the environment, groundwater movement and groundwater source, where the environment is related to the nature and solubility of rocks and materials of water bearing rocks and water retention time. Solubility of minerals plays a major role in increasing salinity. All these processes increase as result of the interaction between water and the surrounding environment as described below:

• Ions exchange processes

Ion exchange is one of the essential processes responsible for the concentration of ions in groundwater. Chloroalkaline indices (1 and 2) have negative values in all groundwater samples except (W2, W5, W7, W8 and W1) which represents 18% of all groundwater samples.

The prevalence of negative results, which constitutes 78% of the total groundwater samples, indicates that ion exchange processes were prevailing. The sodium and potassium ions which are present in the groundwater are exchanged with calcium and magnesium ions in the aquifer rocks (Fig. 5).

• Dissolved ions sources as indicator of chemical processes

The primary source of dissolved ions in groundwater is the result of the interaction between the reservoir and water bearing rocks. Some functions can be used to infer the sources of these ions dissolved in water, through which the sources of these ions can be identified.

A. Ions ratio

One of these functions is the ratio of sodium ion concentration to calcium ions ($\text{Na}^+/\text{Ca}^{2+}$) and the calcium ion concentration to magnesium ($\text{Ca}^{2+}/\text{Mg}^{2+}$) and a scatter plot for ($\text{Ca}^{2+} + \text{Mg}^{2+}$) and ($\text{Na}^+ + \text{K}^+$) vs. total cations [SARIN *et al.* 1989].

It was found that the ratio of $\text{Na}^+/\text{Ca}^{2+}$ ranges between 0.62 and 7.93, while the ratio of $\text{Ca}^{2+}/\text{Mg}^{2+}$ ranges between 0.75 and

Table 1. The physical-chemical properties of groundwater samples of the studied area

Well No.	pH	EC ($\mu\text{S}\cdot\text{cm}^{-1}$)	TDS ($\text{mg}\cdot\text{dm}^{-3}$)	K ⁺	Na ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	NO ₃ ⁻
				ppm							
W1	7.4	2300	1510	5.0	230	35.0	120	200	529	110	3.1
W2	7.66	1473	1008	8.0	73	82.0	102	142	490	51.0	0.4
W3	8.0	388	250	0.6	31	12.0	20	46	620	42.0	0.2
W4	7.3	1760	1250	2.0	192	43.0	86	320	270	96.0	3.0
W5	7.8	3770	2468	4.4	350	110	214	530	614	480	4.2
W6	7.7	2860	1746	5.0	225	112	190	470	430	392	2.0
W7	7.0	3640	2388	5.5	335	44.0	120	696	566	153	2.5
W8	7.7	2300	1560	2.99	337	25.0	52	376	451	61.0	0.44
W9	7.4	4080	2876	6.4	237	38.0	98	852	172	54	0.3
W10	7.4	4020	2615	12.0	700	45.0	150	920	640	126	1.2
W11	7.4	3720	2436	8.0	604	30.0	130	750	553	112	1.2
W12	7.2	2880	2100	15.0	321	61.0	141	261	756	182	6.0
W13	7.2	3120	2340	46.0	322	88.0	187	330	681	446	8.0
W14	7.4	4330	3830	113.0	521	151	321	696	1241	495	4.0
W15	7.8	2990	2272	3.1	238	54.0	162	303	520	208	3.1
W16	7.72	3630	2801	12.0	370	103	240	484	926	243	1.2
W17	7.27	4170	3237	101.0	485	145	308	639	1150	459	2.8
W18	7.51	3540	2778	74.0	401	121	251	519	981	420	4.5
W19	7.15	4050	3650	100.0	459	137	296	620	1139	470	4.0
W20	7.19	3330	2289	8.3	492	50.0	114	620	139	72.0	0.93
W21	7.7	4380	2855	14.0	720	50.0	160	920	660	132	1.2
W22	8.88	2150	1450	5.52	364	16.0	40	373	413	31.0	0.42
W23	7.35	3220	2160	4.0	273	85.0	170	400	600	240	0.1
W24	7.4	1136	810	1.11	95.0	20.0	46.0	88.0	230	50.0	0.25
W25	7.2	4970	3220	5.4	591	100	296	674	1014	427	2.11
W26	7.77	2670	1754	3.5	441	33.0	75.0	560	435	45.0	1.4
W27	7.4	6820	4665	65.0	780	185	366	809	1584	817	3.0
W28	7.43	4020	2930	3.0	440	108	195	493	807	492	2.1

Explanations: EC = electrical conductivity, TDS = total dissolved ions / solids.
Source: own study.

Table 2. Statistical parameters of hydrogeochemical parameters of groundwater

Parameter	pH	EC ($\mu\text{S}\cdot\text{cm}^{-1}$)	TDS ($\text{mg}\cdot\text{dm}^{-3}$)	K ⁺	Na ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	NO ₃ ⁻
				ppm							
Max.	8.88	6820	2930.0	34.9	780	185	366	920	1584	817	8
Min.	7.00	388	250	0.6	31	12	20	46	62	31	0.1
Mean	7.51	3213.4	2127.2	22.1	368.9	74.6	163.8	490.7	639.4	239.8	2.1
SD	0.3	1997.8	1327.4	15.2	238.9	44.3	101.7	314.5	408.2	139.9	1.3
CV %	4.54	62.1	62.4	68.7	64.7	59.3	62	64	63.8	58.3	64.1

Explanations: SD = standard deviation, CV = variation coefficient.
Source: own study.

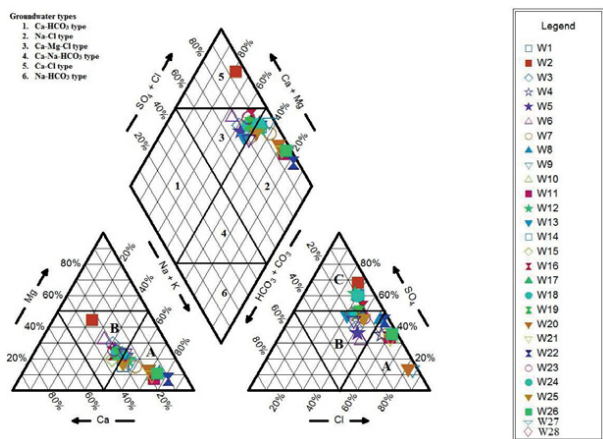


Fig. 3. Piper diagram explaining the type of groundwater; W1–W28 = wells; source: own study

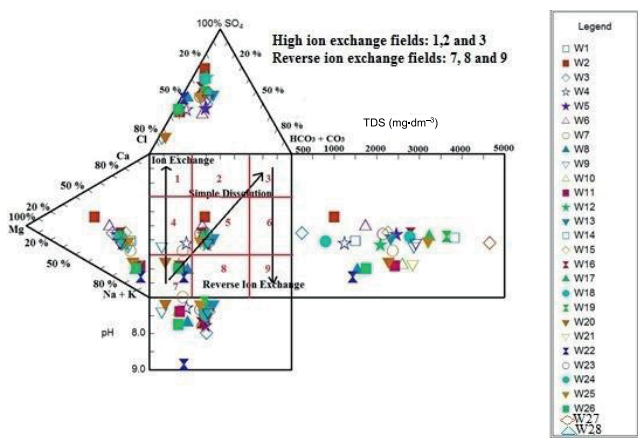


Fig. 4. Durov diagram explaining the geochemical processes of groundwater; W1–W28 = wells; source: own study

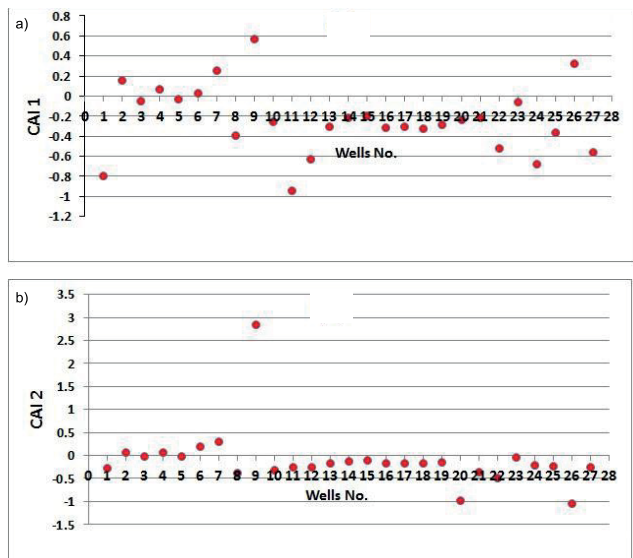


Fig. 5. Chloroalkaline indices 1 and 2 after Subramani *et al.* [2009] (all values are expressed in meq·dm⁻³): a) CAI 1, a), b) CAI 2; source: own study

2.62. The Na⁺/Ca²⁺ ratio prevails and sodium ions are predominant over calcium ions. This leads to infer that the main source of sodium ions is the result of weathering minerals rich in sodium, e.g. silicate minerals, such as albite, plagioclase, pyroxenes

and further igneous rocks. This can be attributed to the fact that recharged water is mostly from the Arabian Shield areas in the Kingdom of Saudi Arabia [JASSIM, GOFF (eds.) 2006]. Additionally, ion exchange processes can also be a source of sodium ions, as previously mentioned (Fig. 5). Note that this ratio is equal to one when sodium ions originate from halite minerals. Since the ratio is far from one, this indicates the presence of various sources of sodium ions [CHEN *et al.* 2019]. The ratio of calcium to magnesium indicates the dominance of calcium ions over magnesium ions, which shows that the secondary source of these dissolved elements is the weathering of carbonate rocks [SARIN *et al.* 1989]. Moreover, when we plot the sodium ion concentration with the chlorine ions (Na⁺/Cl⁻), most of the groundwater samples have the Na⁺/Cl⁻ ratio around “1”. The Na⁺/Cl⁻ ratio nearly equal to “1” indicates the melting of halite, and if in some wells the ratio is greater than “1”, it usually indicates the presence of other sources of sodium, e.g. the weathering of silicate minerals. A ratio lower than “1” indicates the increase in the concentration of chlorine due to the rise in the groundwater level that leads to the dissolution of more salts or the occurrence of ion exchange processes with sodium. This leads to a decrease in the concentration of the latter (Fig. 6c) [KUMAR 2013].

B. Cations scatter plot

The results of the chemical analyses with respect to cations were plotted with the total cations (Ca²⁺ + Mg²⁺) and (Na⁺ + K⁺) vs. total cations as indicated in the scatter plot. The graphs show that the distribution of ions around the theoretical line (1:1) indicates that the sources of these ions are different processes of ion exchange, weathering of silicate minerals or the dissolution of salts as a result of evaporation (Fig. 6 a, b).

• Gibbs plot

Several factors that control groundwater chemistry could be related to physical properties of the aquifer and the mineralogy of water bearing rocks. The Gibbs diagram should be used to indicate the important hydrogeochemical processes that control the chemical composition of groundwater through its movement path [GIBBS 1970]. Figure 7a and b show that most of water samples were from the weathering field. It indicates that aquifer rocks play an important role in the geochemistry of the groundwater in the study area.

Additionally, evaporation is also an important climate factor, which has direct impact on water sources in the study area. It has been noticed that well W3 show the presence of evaporation processes, in addition to rocks/soil groundwater interaction. Evaporation processes that occur in surface water and moisture in the unsaturated zone lead to the concentration of ions in the unsaturated zone, and when leaching processes occur in the zone, water infiltrates toward the saturated zone.

GROUNDWATER QUALITY

The results of the groundwater analyses were evaluated in order to identify the suitability of water for drinking and watering crops. The suitability of water was evaluated by comparing the results with international standards. The comparison was based on parameters set by the WHO [2011]. According to these standards, the total dissolved ion concentrations are considered to be 500 mg·dm⁻³. Thus, the water is considered suitable, since the maximum permissible limit is 1500 mg·dm⁻³. Depending on this classification, only one sample from well No. 3 show good

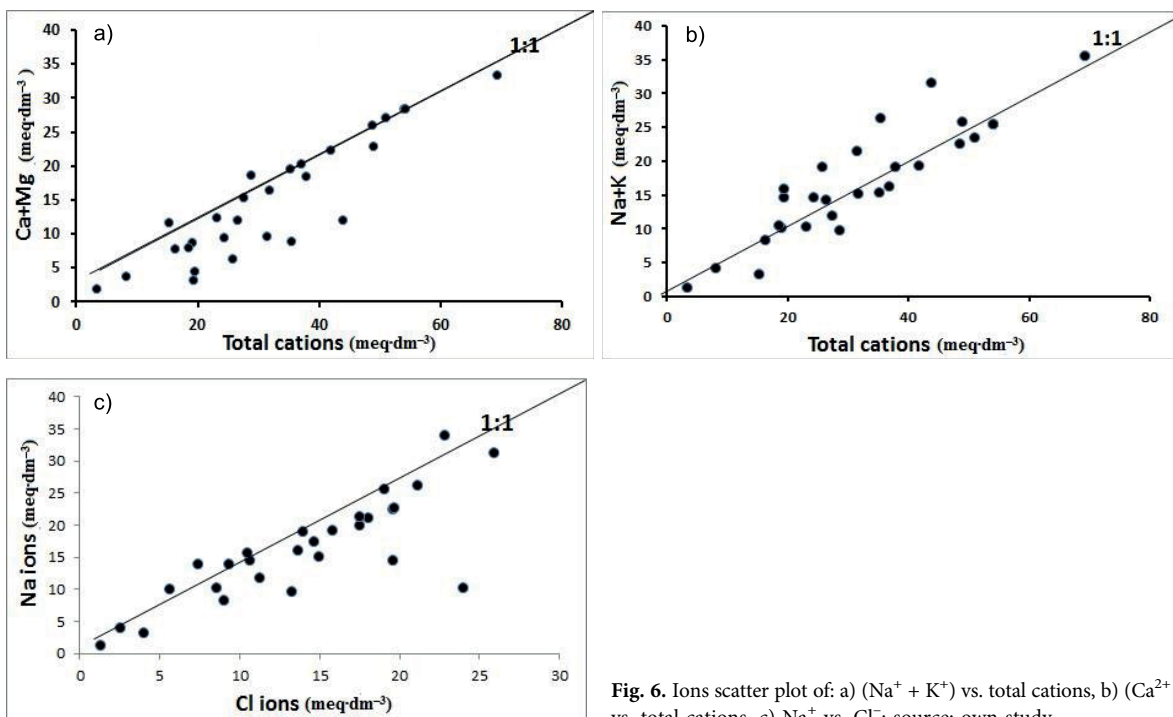


Fig. 6. Ions scatter plot of: a) (Na⁺ + K⁺) vs. total cations, b) (Ca²⁺ + Mg²⁺) vs. total cations, c) Na⁺ vs. Cl⁻; source: own study

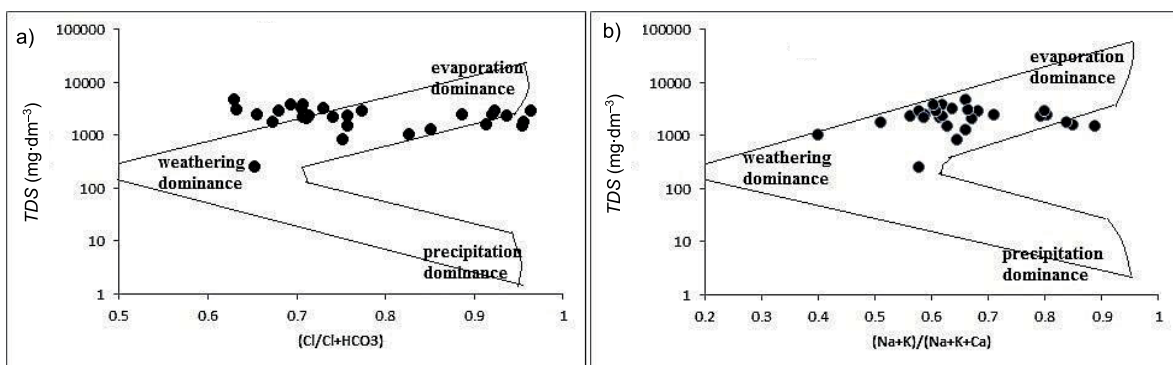


Fig. 7. Gibbs plots for process controlling groundwater chemistry; source: own study

suitability, while five samples are within the permissible maximum. The latter samples are from wells W2, W4, W5, W23 and W25, while the rest of the samples are outside permissible limits for human consumption.

The maximum allowable limit for total hardness (TH) is 500 mg·dm⁻³ and the desired limit is 100 mg·dm⁻³ [WHO 2011]. It was found that 38% of the water samples were within the permissible limits, and the remainder of 62% outside the permissible limits. The remaining water cannot be used because of its high hardness which leads to the coagulation of soap. One of important factors in determining the suitability of water for irrigation is the sodium adsorption ratio (SAR). It is an irrigation water quality parameter. The SAR was defined by KARANTH [1987], according to Equation (3):

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \quad (3)$$

All concentrations are stated in meq·dm⁻³. The SAR for all water samples range between 1.3 and 12.7, and according to the

Richard's classification [RICHARD 1954], that based on SAR values, 85.7% of the water samples are considered excellent and the rest (14.3%) are suitable for irrigation (Tab. 3).

ENVIRONMENTAL IMPLICATIONS

The Southern Desert of Iraq is one of the key habitats at the national level [MORENO, MUELLER 2015]. It supports considerable

Table 3. Water suitability for irrigation according to the Richard's classification based on sodium adsorption ratio

Category	Range	Percent of current study samples
Excellent	<10	85.7
Good	10–18	14.3
Doubtful	18–26	0
Unsuitable	>26	0

Source: RICHARD [1954], and own study.

number of flora and fauna species that are unique on the national and regional levels, with millions of passerines and other migratory bird species passing through oases and temporary water bodies in this area during their passage between Eurasia and Africa [IMoEN 2014]. The waterbodies on their migration routes, of which most are temporary surface water sources, are very necessary for their life-cycle as they are located on their migration routes [SALIM *et al.* 2006].

Water resources, including groundwater, are very useful indicator for assessing the status of biodiversity and ecosystem [JANINE *et al.* 2009]. Therefore, in order to adopt new approach when aiming at assessing the environmental conditions in the desert habitats, it would be very useful to include hydrology as one of key assessment elements in the study area.

CONCLUSIONS

It was found that the order of most cations is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$, while anions $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$. Approximately 67.8% of the water samples are in field 5 within the Durov diagram. It indicates that there are simple dissolutions of rocks. Chloroalkaline indices show that ion exchange processes are the predominant in the groundwater in the studied area. It was found that the ratio of $\text{Na}^+/\text{Ca}^{2+}$ is predominant over calcium ions and this refers to that the main source of sodium ions. It is the result of weathering of minerals rich in sodium. Additionally, ion exchange can be a source of sodium ions, while the ratio of $\text{Ca}^{2+}/\text{Mg}^{2+}$ indicates the dominance of calcium over magnesium ions. It shows that the secondary source of these dissolved elements was the weathering of carbonate rocks. According to Gibbs diagrams, more samples indicate weathering and evaporation. The results confirmed that there are different hydrogeochemical processes to which the groundwater has been exposed during its movement. These include dissolving, mixing, weathering of carbon rocks and silicate minerals, as well as ion exchange. Moreover, 62% of the water samples are outside of the permissible limits for drinking water. Based on SAR values, 85% of the groundwater samples are considered excellent and the rest of the groundwater wells provide water which is good for irrigation.

REFERENCES

- AL-SHAMMA'A A.M., AL-MUTAWKI K.G. 2014. Estimating of groundwater age and quality of Al-Shanafiya Area Southwest Iraq. *Iraqi Journal of Science*. Vol. 55. No. 3A p. 1061–1070.
- BUDAY T. 1980. The regional geology of Iraq. Vol. 1. Stratigraphy and palaeogeography. Baghdad. State Organization for Minerals, Directorate General for Geological Survey and Mineral Investigations pp. 445.
- CHEN J., HUANG Q., LIN Y., FANG Y., QIAN H., LIU R., MA H. 2019. Hydrogeochemical characteristics and quality assessment of groundwater in an irrigated region, Northwest China. *Water*. Vol. 11(1), 96. DOI 10.3390/w11010096.
- CHEN J., QIAN H., GAO Y., LI X. 2017. Human health risk assessment of contaminants in drinking water based on triangular fuzzy numbers approach in Yinchuan City, Northwest China. *Expo. Health*. Vol. 10 p. 155–160.
- CHRISTENSEN J.N., DAFFLON B., SHIEL A.E., TOKUNAGA T.K., WAN J., FAYBISHENKO B., DONG W., WILLIAMS K.H., HOBSON C., BROWN S.T. 2018. Using strontium isotopes to evaluate the spatial variation of groundwater recharge. *Science of the Total Environment* Vol. 637–638 p. 672–685. DOI 10.1016/j.scitotenv.2018.05.019.
- DUROV S.A. 1948. Classification of natural waters and graphical representation of their composition. Reports of the Sciences Academy USSR. Vol. 59(1) p. 87–90.
- FETTER C.W. 1980. Applied hydrogeology. Columbus, Ohio. Charles Merrill publ. Co., A. Bell and Howell Company. ISBN 0675081262 pp. 488.
- GIBBS R.J. 1970. Mechanism controlling worlds water chemistry. *Science*. Vol. 170 p. 1088–1090. DOI 10.1126/science.170.3962.1088.
- IMoEN 2014. The 5th National Report to the Convention on Biological Diversity in Iraq. March 2014. Baghdad. Iraqi Ministry of Environment pp. 174.
- JANINE G., DAVID C., MARIE-JOSE D., FLORIAN M., MARY C., LOUIS D. 2009. Assessing and conserving groundwater biodiversity synthesis and perspectives. *Freshwater Biology*. Vol. 54 p. 930–941. DOI 10.1111/j.1365-2427.2009.02201.x.
- JASSIM S.Z., GOFF J.C. (eds.) 2006. Geology of Iraq. Dolin. ISBN 8070282878 pp. 341.
- JKEMAN A., BARRETEAU O., HUNT R.J., RINAUDO J.D., ROSS A. 2016. Integrated groundwater management. Concepts, approaches and challenges. Berlin, Germany. Springer. ISBN 978-3-319-23576-9 pp. 762.
- KARANTH K.R. 1987. Groundwater assessment development and management. New Delhi. Tata McGraw Hill. ISBN 0-07-451712-0 pp. 720.
- KUMAR S.P.J. 2013. Interpretation of groundwater chemistry using piper and Chadha's diagram: A comparative study from Perambalur Taluk. *Elixir Geoscience*. Vol. 54 p. 12208–12211.
- LI P., QIAN H., ZHOU W. 2017. Finding harmony between the environment and humanity: An introduction to the thematic issue of the Silk Road. *Environmental Earth Sciences*. Vol. 76, 105. DOI 10.1007/s12665-017-6428-9.
- LLOYD J.A., HEATHCOTE J.A. 1985. Natural inorganic hydrochemistry in relation to groundwater. An introduction. Oxford University Press. ISBN 0198544227 pp. 296.
- MORENO S.P., MUELLER M. 2015. Societal participatory processes in the revision of National Biodiversity Strategies and Action Plans (NBSAPs) January 2015. IUCN pp. 58.
- PIPER A.M. 1944. A graphic procedure in the geochemical interpretation of water analysis. *American Geophysical Union Transactions*. Vol. 25 p. 914–928.
- RICHARDS L.A. (ed.) 1954. Diagnosis and improvement of saline alkali soils: Agriculture. Vol. 160. Handbook. No. 60. Washington. US Department of Agriculture pp. 182.
- SALIM M.A., PORTER R., SCHIERMACKER-HANSEN P., CHRISTENSEN S., AL-JBOUR S. 2006. Field guide to the birds of Iraq. Baghdad. Nature Iraq/BirdLife International. ISBN 0988651408 pp. 374. [In Arabic].
- SARIN M.M., KRISHNASWAMY S., DILL, S.B.L.K., MOORE W.S. 1989. Major ion chemistry of the Ganga-Brahmaputra River system: Weathering process and fluxes to the Bay of Bengal. *Geochimica and Cosmochimica Acta*. Vol. 53. Iss. 5. DOI 10.1016/0016-7037(89)90205-6.
- Satellites Pro undated. Iraq map [online]. [Access 11.09.2020]. Available at: https://satellites.pro/Iraq_map
- SISSAKIAN V.K., FOUAD S.F. 2012. Geological Map of Iraq scales 1: 1000 000. 4th ed. Baghdad, Iraq. Iraq Geological Survey (GEOSURV) publications.

- SUBRAMANI T., ELANGO L., DAMODARASAMY S.R. 2009. Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. *Environment Geology*. Vol. 47 p. 1099–1110. DOI 10.1007/s00254-005-1243-0.
- SWARMA LATHA P., NAGESWARA RAO K. 2011. An integrated approach to assess the quality of groundwater in a coastal aquifer of Andhra Pradesh, India. *Environmental Earth Sciences*. Vol. 66 p. 2143–2169. DOI 10.1007/s12665-011-1438-5.
- TODD D.K., MAYS L.W. 2005. *Groundwater hydrology*. 3rd Ed. Wiley and Sons Inc. New York, U. S. ISBN 978-0-471-05937-0 pp. 656.
- UMAR A., UMAR R., AHMED M.S. 2001. Hydrogeological and hydrochemical framework of regional aquifer system in Kali Ganga sub-basin India. *Environmental Geology*. Vol. 40(4–5) p. 602–661. DOI 10.1007/s002540000215.
- VADIATI M., ADAMOWSKI J., BEYNAGHI A. 2018. A brief overview of trends in groundwater research: Progress towards sustainability? *Environment Management*. Vol. 223 p. 849–851. DOI 10.1016/j.jenvman.2018.06.086.
- WHO 2011. *Guide lines for drinking water quality*. Geneva. World Health Organization. 4th. Ed. ISBN 978-92-4-154815-1 pp. 515.