JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 1, Issue No. 1 (June-2015)

ISSN: 2413-5267

Hydrochemical Characteristics and Water Quality Assessment of Groundwater in Khor Adeit Area, Northeastern Sudan

E. M. Babiker[1,*], and F. A. Mohammed [2]

[1] Faculty of Marine Resources, Al-Asmarya Islamic University, Zliten, Libya.
[2] Faculty of Earth Sciences, Red Sea University, Portsudan, Sudan.
*Corresponding author: elgailymb@hotmail.com

الخواص الهيدروكيميائية وتقييم جودة المياه الجوفية في منطقة خور أدين (شمال شرق السودان)

الجيلي محمد بابكر[1]، فضل السيد محمد[2]

[1] كلية الموارد البحرية، الجامعة الأسمرية الإسلامية، ليبيا.
[2] كلية علوم الأرض، جامعة البحر الأحمر، السودان.

Abstract

The present study was carried out in Khor Adeit area, northeastern Sudan with the objectives of discussing the hydrochemical characteristics of groundwater in alluvial aquifer, and assessing groundwater quality and suitability for drinking. Twelve groundwater samples were collected and analyzed for physical and chemical parameters. Water temperature exhibited normal range. Remarkable temporal variation in groundwater quality in terms of salinity during wet and dry season was observed. Groundwater of the study area was soft to very hard, and it could be grouped into two hydrochemical faces namely: Group (A) K-Na Cl-HCO_3-SO_4-water type and group (B) Na-K-Cl SO_4-water type. Hydrolysis of potash feldspar and plagioclase found to be responsible for high concentration of K and Na respectively. While the oxidation of ferromagnesian minerals was a possible source for Mg. Remarkable spatial variation in groundwater composition was attributed to variable recharge of the aquifer and different lithology. Groundwater quality parameters for group (A) fell within the acceptable range of the local and the WHO Guidelines for drinking water; while group (B) parameters did not. The study has recommended for drilling of water wells to be conducted in parts of the wadi occupied by fresh groundwater.

Keywords: *Groundwater, Hydrochemical, Water quality, Sinkat and Gebeit.*

الملخص

أُجريت هذه الدراسة في منطقة خور أديت في شمال شرق السودان. هدفت الدراسة الى مناقشة الخواص الهيدروكيميائية للمياه الجوفية في الخزان الجوفي الغريني في المنطقة، بالإضافة الى تقويم نوعية المياه الجوفية ومدى صلاحية استخدامها للشرب. أُخذت اثنا عشرة عينة من المياه وتم تحليلها لأجل تحديد المعاملات الفيزيائية والكيميائية. حيث وُجدت درجة الحرارة في المدى المعتاد للمياه الجوفية بينما تفاوتت درجة جودة المياه معبراً عنها في شكل الملوحة الكلية تفاوتاً مكانياً وزمنياً خلال الفصل الرطب والفصل الجاف من السنة. تراوحت عسرة المياه بين يسرة وعسرة جداً. وأمكن تصنيف المياه الجوفية في منطقة الدراسة الى مجموعتين هما، مجموعة (A) K-Na-Cl-HCO_3-SO_4–water type ومجموعة (B) Na-K-Cl- SO_4–water type. عملية الانحلال المائي لمعادن الفلسبار البوتاسي والبلاجيوكليز هي المسبب الرئيس لزيادة أيونات البوتاسيوم وأيونات الصوديوم على التوالي. بينما تأكسد المعادن الحديدية الماغنيسية رُجّح أن يكون مصدراً محتملاً لأيونات الماغنيسيوم. أُرجع الاختلاف المكاني الكبير في التركيب الكيميائي

للمياه الجوفية الى تباين معدل التغذية للخزان الجوفي وكذلك لاختلاف التركيب الصخري من مكان لآخر. معاملات جودة المياه الجوفية للمجموعة A تقع ضمن المدى المقبول والمحدد بواسطة المعايير القطرية والخطوط التوجيهية لمنظمة الصحة العالمية، لكن قيم معاملات المجموعة B تخطت المدى المقبول. أوصت الدراسة بأن تُحفر الآبار لمياه الشرب في منطقة المياه العذبة من الوادي.

الكلمات الدلالية: المياه الجوفية، الهيدروكيميائية، المياه الجوفية، مدينة سنكات، مدينة غبييت.

1. Introduction

The quality of water is vital concern of mankind since it is directly linked with human health. Generally the main aquifers of Sudan are characterized by the presence of good quality water that is fit for all purposes because the water contains low chemical constituents and lacks toxic contents (Ahmed et al., 2000). The alluvial aquifer depends on direct recharge from rainfall (Al-Ahmad, 2013). In northeastern part of Sudan shallow alluvial aquifers and fractured Precambrian basement rocks are available with the most important renewable water resource (Elsheikh, 2002; and Babiker, 2008). Khor Adiet is a seasonal inter-mountainous wadi in northeastern part of Sudan. It is important for its water resources that supply two towns in the wadi basin. Groundwater represents one of the main sources of water supply for drinking and domestic uses in the two towns and surroundings. Limited surface water which is harvested during rainy season, by means of earth dams is another source, but it is only available for few months during the year. In the last decades there is a tremendous increase in number of residents because the area has an advantage of temperate weather compared to its surrounding, and being a center for cultural activities and tourism. In addition, a noticeable increase of population has occurred during this period of time and new extensions have developed. In arid regions such as the study case, relatively high salinity and ionic concentrations are expected due to low recharge and absence of effective natural flushing activity (Geirnaert & Laeven, 1992). The enrichment of groundwater in ionic constituents depends on the rock type in which the water is found, residence time of water in the rock and the water circulation processes which take place in the rock (Hem, 1991). Groundwater quality is as important as quantity, poor quality adversely affect human health. In this context, the present study is aiming at evaluating the hydrochemical characteristics of groundwater in the alluvial aquifer, and assessment of groundwater quality and its suitability for drinking and other domestic uses.

1.1 The Study Area

The study area comprises an alluvial basin of a seasonal wadi named as Khor Adeit which is bounded by coordinates: 36°45´E / 36°55´E and 18°45´N /19°00´N, and covers an area of 532 square kilometer. It lies 120 *km* south west of Portsudan –the capital of the Red Sea State- in northeastern Sudan (Figure.1). Two towns named Sinkat and Gebeit are located in the study area with a population number of about 60,000 people. The area is of hilly topography has moderate elevation, of about 900 *m* (a.m.s.l.). It is dissected by small tributaries pouring in

ISSN: 2413-5267

Khor Adiet (Figure. 2). The area is characterized by semi-arid climate with annual mean rainfall of 100 *mm*, and high evaporation where potential evapotranspiration (PET) was estimated to be between 1500 and 2400 *mm* (Awadalla, 1983; Eltoum,1991; and Osman, 1996). The geology of the study area is mainly controlled by the regional geologic and tectonic settings of the Red Sea region, The lithostratigraphic sequence comprises of the Pre-Cambrian basement rocks and Phanerozoic sedimentary cover of age Quaternary to Recent (Abu Fatima et al., 1986; and Satti, 2007) Phanerozoic sedimentary cover includes alluvial sediments deposited by the drainage system, they rest unconformably on the Precambrian basement rocks. Groundwater occurs in an aquifer which basically consists of the alluvial sediments of the Khor Adiet basin, and often the aquifer extends to include the upper most fractured and weathered basement rocks. The thickness of the aquifer is varied from (10 to 30 *m*) with greatest thickness at the axial trough of the stream channels. The depth to water-table is varied from 9 to 30 *m* (Mohammed, 2012; and Babiker & Mohammed, 2015).

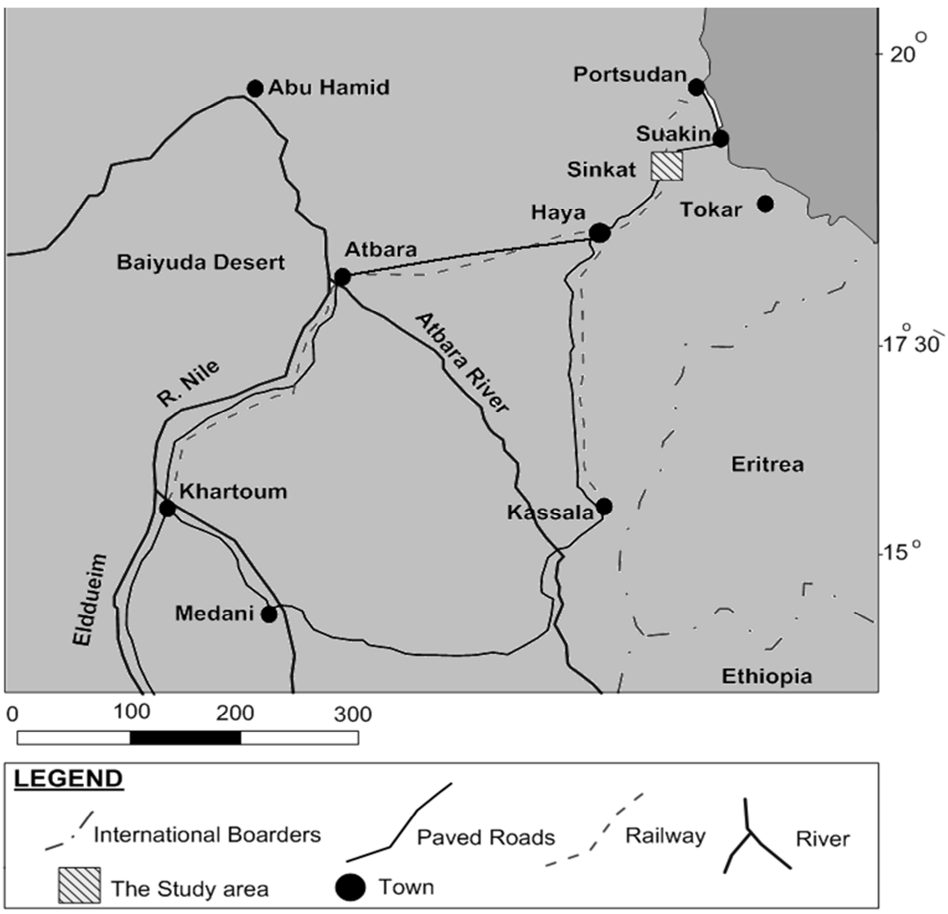

Figure 1. Location map

ISSN: 2413-5267

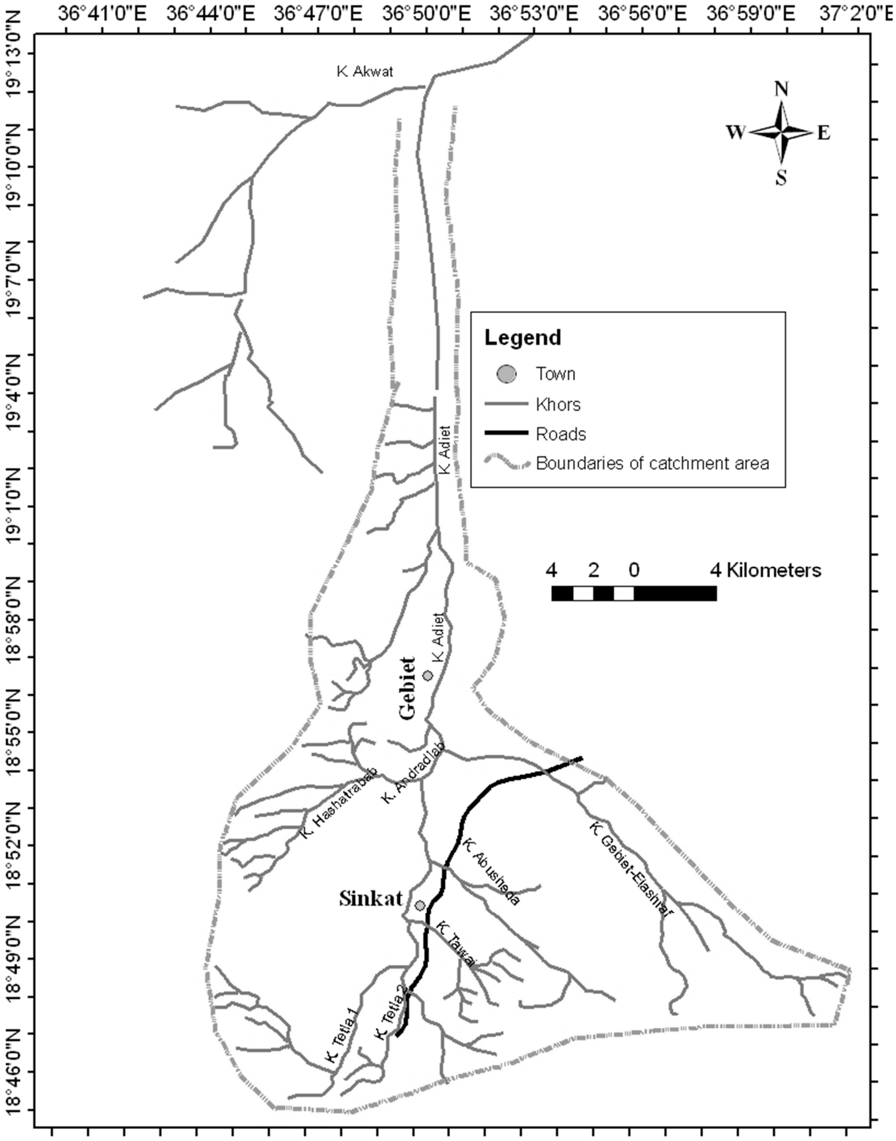

Figure 2. Drainage system in the study area.

2. Methods and Techniques

Groundwater samples were collected from 12 wells and boreholes in the study area (Figure 3). A water sample of 1litre was taken from each site in a cleaned polyethylene bottle for the analysis of major cations and anions. Samples for cations analysis were acidified with nitric acid which prevents precipitation and sorption keeping the sample total dissolved element load in solution during transport. The samples were kept air tight and then sent to the laboratory for standard chemical analysis in the laboratories of the Ministry of Irrigation and Water Resources in Khartoum. The chemical analysis was carried out using the methods given by Lenore et al. (1998). Analysis of cations Na^+, K^+, Ca^{2+}, and Mg^{2+} was carried out

ISSN: 2413-5267

using Atomic Absorption Spectrometer (AAS), (Model 1100). The anions SO_4^{2-}, Cl^- were determined using (HACH DR/4000U) spectrophotometer by comparing the sample with a blank HCO_3^- and CO_3^{2-} were analyzed using standard titration. In situ measurements of temperature, pH and electrical conductivity (EC) were carried out twice in wet and dry seasons . The results of analyses were assessed using the ionic balance ratio (Ia). Results of the analyses were presented in Piper trilinear and Schoeller semi logarithmic diagrams. PLOT CHEM software was used for the processing of water chemistry data. Microsoft Excel was used for statistical analysis and softwares: Surfer version 9, ArcMap version 9.3 and Free-Hand were used to produce maps and figures.

3. Results and Discussion

The results of chemical analyses were shown in Tables (1-3) and they were discussed below.

3.1 Temperature

The groundwater temperature was not varying significantly; the mode of these measurements is around 29°*C*. The temperature of groundwater in the study area is mainly controlled by the atmospheric temperature because the water-table is shallow (9-24 *m*) and the aquifer is unconfined.

3.2 pH

Hydrogen-ion activity, or pH, is an important chemical characteristic of water. pH is the most common measure of the acidity/alkalinity balance in water. It is being given as the negative logarithm of Hydrogen ion activity ($-\log[H^+]$). The pH values were found to be in a range from 6.7 to 9.8 indicating neutral to slightly alkaline nature of water samples.

3.3 Electrical Conductivity

The electrical conductivity (EC) values are directly related to the amount and nature of soluble electrolytes. It is a direct measure of water salinity. Measurements of the EC were depicted in (Table 1). A maximum value of EC was measured to be 9490 *µs/cm* whereas the minimum value 100 *µs/cm*. (Figure 3), shows spatial variation of the EC in the study area. Freshwater was confined to the central part of the wadi basin because of continuous recharge and replenishment of the aquifer. On the contrary brackish water occur at the basin peripheries could be attributed to poor recharge and to water-rock interaction since the peripheries are dominated by basement crystalline rocks. EC measurments have shown seasonal variation (Figure 4), which is attributed to diluation effect due to direct recharge of groundwater by rain water.

Table 1. Measurements of temperature, pH and EC of groundwater

Well No.	T (^oC)	pH	EC ($\mu s/cm$) in wet season	EC ($\mu s/cm$) in Dry season
Ty1		-	2800	4392.0
Ty2	29.3	7	1530	6626.3
Ty3	-	-	3910	-
Ty8	-	-	3655	6069.7
Ab3	-	-	-	6101.0
Ab4	-	-	-	834.8
Ab7	30.2	9.8	1852	5744.8
An3	-	-	419	435.6
An4	-	-	1800	3400
An5	-	-	586.7	989.9
An6	29	7.4	490	2440
An7	-	-	-	3020
An8	-	-	-	2190
Ad4		-	391.8	-
Ad9	29.1	6.7	5738	-
Ad11	29	8.7	214.5	461.6
Ad12	29	7.6	1545	-
Ad16	-	-	-	6800
Ad17	-	-	-	610
Ad18	-	-	-	660
Ad19	-	-	-	1710
Ad20	-	-	-	890
Ad86	-	-	721.7	-
Ab86	30	7.7	5257	-
Ab87	29	7.8	6643	-
Ab88	29	7.8	7133	-
Ab89	29.1	7.9	2800	-

(-) means no measurement

ISSN: 2413-5267

Table 2. Results of chemical analyses and ionic balance of groundwater samples

Well No.	Units	HCO_3	Cl	SO_4	NO_3	Σ(An.)	Ca	Mg	Na	K	Σ (cat.)	TDS	Balance
Ty1	mg/l	210	1618.8	700	0.021	1078.82	0.8	4.4	322	1800	2127.2	3206.	-
	meq/l	3.44	45.65	14.57	0.00	63.77	0.04	3.64	14	45.88	63.56	-	-
	meq%	5.44	71.63	22.93	0.00	100	0.06	5.73	22.03	72.18	100	-	0.21
Ab3	mg/l	317.2	1597.5	380	14.96	2310.13	392	151.63	411.2	332.35	2143.47	4453.6	-
	meq/l	5.20	45.05	7.91	0.24	58.4	19.56	12.47	17.88	8.5	58.41	-	0.01
	meq%	8.90	77.14	13.54	0.42	100	33.49	21.35	30.61	14.55	100	-	-
Ab4	mg/l	219.5	159.75	7	27.22	414	88	41.8	59.2	6.37	195.37	609.37	-
	meq/l	3.60	4.51	0.15	0.44	8.70	4.39	3.44	2.57	0.163	10.56	-	1.86
	meq%	41.38	51.84	1.72	5.06	100	41.57	32.58	24.34	1.54	100	-	-
Ty2	mg/l	280	1883	420	6.7	2589.7	1.4	0.5	321.9	1923.72	2247.52	4837.2	-
	meq/l	4.59	53.102	8.74	0.11	66.542	0.07	0.041	13.99	49.32	63.421	-	-
	meq	6.9	79.8	13.13	0.17	100	0.11	0.06	22.06	77.77	100	-	3.12
Ad3	mg/l	97	53.96	38	30.8	219.76	4.4	4.3	21.9	67.643	98.243	318.00	-
	meq/l	1.57	1.522	0.791	0.497	4.38	0.22	0.354	0.95	1.73	3.254	-	-
	meq%	35.84	34.75	18.06	11.35	100	6.76	10.88	29.19	53.17	100	-	1.13
Ad4	mg/l	87	59.64	43	14.3	203.94	2.7	6.6	20	52.785	82.085	286	-
	meq/l	1.43	1.68	0.895	0.021	4.026	0.135	0.523	0.998	1.35	3.006	-	-
	meq%	35.52	41.73	22.23	0.52	100	4.59	17.40	33.20	44.91	100	-	1.02
Ad5	mg/l	91.5	204.5	74	13.4	383.4	0.29	0.33	104	234.6	339.22	722.62	-
	meq/l	1.5	5.77	1.53	0.22	9.02	0.015	0.0271	4.53	6.00	10.57	-	1.55
	meq%	16.63	63.97	16.96	2.44	100	0.14	0.26	42.86	56.76	100	-	-
An8	mg/l	51	852	100	2.3	1005.3	1.6	8.6	391	430.1	831.3	1836.6	-
	meq/l	0.84	24.03	2.08	0.037	26.99	0.08	0.71	17	11	28.79	-	1.8
	meq%	3.11	89.03	7.71	0.14	100	0.28	2.47	59.05	38.21	100	-	-
Ab7	mg/l	225	360	1871	62.2	2518.2	30	79	552	1014.5	1675.5	4193.7	-
	meq/l	3.69	10.15	38.95	1.00	53.787	1.50	6.50	24	25.95	57.90	-	4.11
	meq%	6.86	18.87	72.42	1.86	100	2.59	11.23	41.45	44.82	100	-	-
Ab8	mg/l	54	1704	600	6.6	2364.6	1.1	7.8	690	1368.5	2066.3	4430.9	-
	meq/l	0.89	48.05	12.49	0.11	61.53	0.055	0.64	30.10	35.00	65.795	-	4.27
	meq%	1.45	78.08	20.30	0.17	100	0.008	0.97	45.75	53.20	100	-	-
Ty8	mg/l	67	2414	700	21.7	3202.7	8.7	2.6	977.5	1564	2552.8	5755.5	-
	meq/l	1.10	68.08	14.57	0.35	84.10	0.434	0.214	42.5	40.00	83.148	-	-
	meq%	1.31	80.95	17.32	0.42	100	0.52	0.26	51.11	48.11	100	-	1.00
Ad11	mg/l	53	76.7	25	13.9	118.6	10.3	4.8	2	181.815	219.064	337.66	-
	meq/l	0.869	2.163	0.520	0.224	3.78	0.514	0.395	0.963	4.65	6.522	-	2.74
	meq%	23	57.22	13.76	5.93	100	7.88	6.06	14.76	71.30	100	-	-

ISSN: 2413-5267

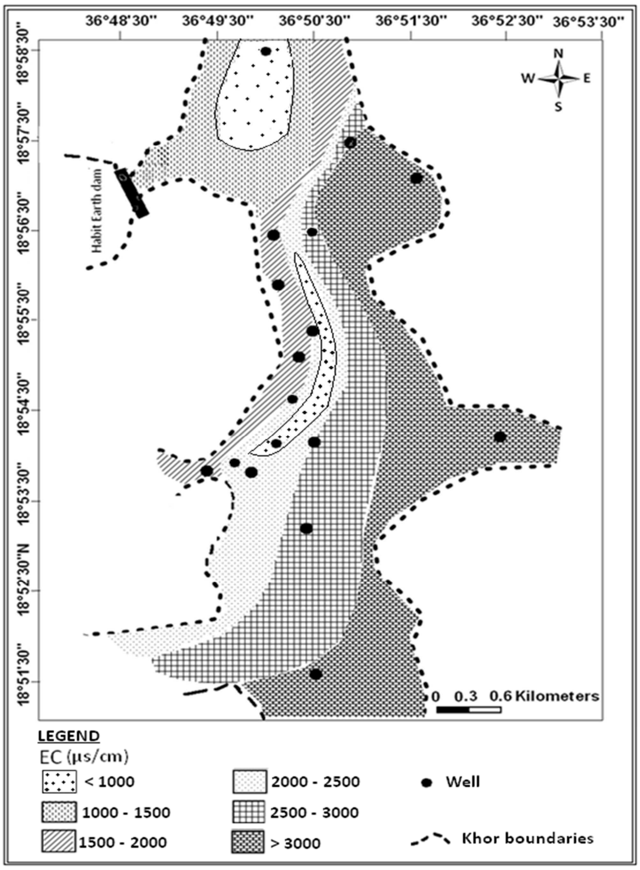

Figure 3. Electrical conductivity map

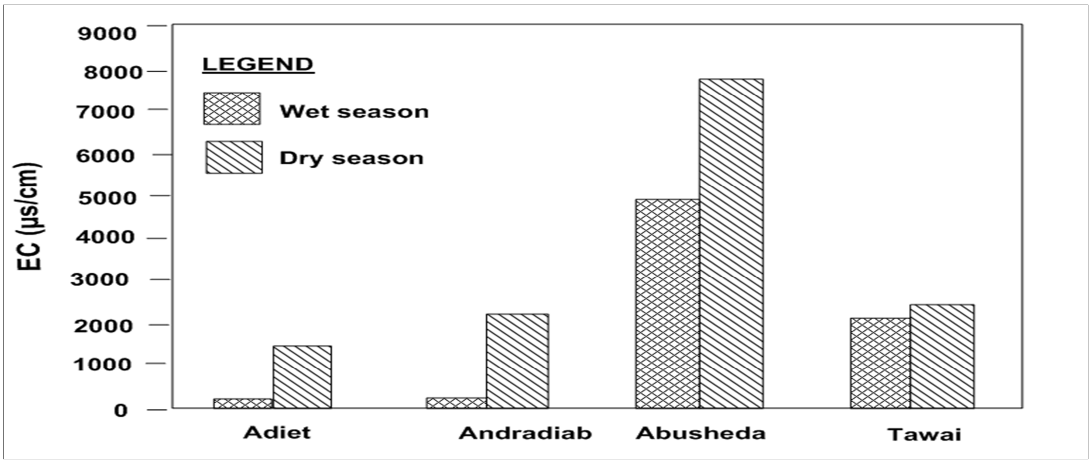

Figure 4. Seasonal variation of EC in 4 tributaries in the study area

3.4. Total Hardness

Hardness of water is mainly attributed to the presence of *Ca* and *Mg* in water, which can react with soap to form a lowly soluble scum, and with bicarbonate ions to precipitate scale in kettles and boilers, (Kresic, 2009). The total hardness of groundwater in the study area is

ISSN: 2413-5267

ranges from 1.88 to 4404 *mg/l* with mean value of 644.5 *mg/l* and standard deviation of 1229 *mg/l*. Table (3) shows classification of groundwater in the study area based on total hardness into soft and very hard according to Sawer and McCarty (1968) classification.

Table 3. Classification of groundwater samples according to total hardness

T.H. range	*Water type*	*No. of sampling sites*	*Percentage*
0 – 75	Soft	Ty1,Ty2,An3,,An4,An5, An6,Ty8,Ad11,Ad12,Ad13,Ad14,Ad16	63%
75 – 150	Moderately hard	No site	0%
150 – 300	Hard	No site	0%
Over 300	Very hard	Ab7, Ad15, An90, Ab86, Ab87, Ab88, Ab89	37%

3.5 Major Cations and Anions

The results presented in Table (1), have revealed that K^+ and Na^+ were the dominant major cations having average values of 748.04 *mg/l* and 157.8 *mg/l* respectively. While Ca^{2+} and Mg^{2+} has relatively low concentration with mean value of 15.3 *mg/l* and 10 *mg/l* respectively. Major dominating anions include Cl^-, SO_4^{-2}, and HCO_3^-. The Processes which are considered responsible for the chemical composition of water are: Weathering of the rocks; Na^+, K^+, and Ca^{2+} could be product of chemical weathering of basement rocks due to hydrolysis of feldspars as shown by the following equation. Potassium could be Calcium and/or Sodium depending on the type of feldspar minerals. On the other hand oxidation of ferromagnesian minerals could be responsible for the occurrence of *Mg* and *Fe* cations in groundwater.

$$4KAlSi_3O_8 \; + \; 4H^+ \; + \; 2H_2O \; \rightarrow \; 4K^+ \; + \; Al_4Si_4O_{10}(OH)_8 + 8\,SiO_2 \quad \text{……..(1)}$$

Ortoclase Hydrogen ions Water Potassium ions Kaolinite (clay mineral) quartz

In igneous and metamorphic rocks, weathering releases calcium from such minerals as apatite, wollastonite, fluorite, various members of feldspar, amphibole, and pyroxene groups, (Drever, 1982).The possible sources of magnesium in groundwater are olivine, biotite, hornblende, and augite. The primary sources of most sodium in groundwater are from the release of soluble products during the weathering of plagioclase feldspars (Davis and DeWiest, 1966).

Cation exchange with aquifer materials: Sodium surplus in groundwater is often indicative of a former flushing of aquifer water by rain water; *Ca* expels adsorbed *Na*, *K*, and *Mg* ions from

ISSN: 2413-5267

the exchange complex, thus causing an (Na^+, K^+, and Mg^+) surplus. Also high concentration of Na^+ in groundwater results when Ca^{2+} of the infiltrated water is absorbed by clay, and Na^+ of the clay is taken into groundwater, (Drever, 1982).

Dissolution of marble, gypsum ($CaSO_4.2H_2O$), anhydrite, ($CaSO_4$) and limestone ($CaCO_3$) in surface water considered to be a possible process causing (SO_4^{2-}, and HCO_3^-) enrichment in groundwater.

3.6 Hydrochemical Facies

The concept of hydrochemical facies was developed in order to understand and identify the water composition in different classes. Hydrochemical facies are distinct zones that possess cation and anion concentration categories, (Kumaresan et al., 2006). A common practice in interpreting the results of chemical analyses is to present the concentrations of major ionic species graphically. Piper Diagram (1944) is one of the most useful graphs for representing and comparing results of water analyses. Piper diagram is convenient for plotting the results of multiple analyses on the same graph, which may reveal grouping of certain samples and indicate their common or different origin, (Kresic, 2009). Based on the plotting of the major ionic constituents on Piper tri-linear diagram (Figure 5) groundwater in the study area has been classified into two water groups, namely are:

Group A: *Na-K-Cl* SO_4-water type: This group is represented by 7 water samples from wells No. 5, 6, 8, 9, Ty_1 and Ty_2. This group characterized by moderate to very high salinity from 723 to 5756 *mg/l* and ionic sequence $Na > K > Mg > Ca$ and $Cl > SO_4 > HCO_3$.

Group B: *K-Na Cl*-HCO_3-SO_4-water type: This group is represented by three water samples from wells No. 3, 4 and 11. It characterized by low salinity TDS 286 to 338 *mg/l* and ionic sequence $K > Na > Mg > Ca$ and $HCO_3 > Cl > SO_4$.

The hydrochemical patterns characterize each group are shown in Schoeller semi logarithmic diagram (Figure 6).

3.7 Water Quality

Range of values of different parameters of the groundwater hydrochemical groups and WHO guidelines (1984) for drinking water are presented in Table 4. It indicates that all the concentration values of group B falls within the permissible limits of WHO guidelines and therefore considered to be suitable for drinking and other domestic uses. On the other hand most of the concentration values of group A are greater than WHO guidelines, hence, it is not suitable.

ISSN: 2413-5267

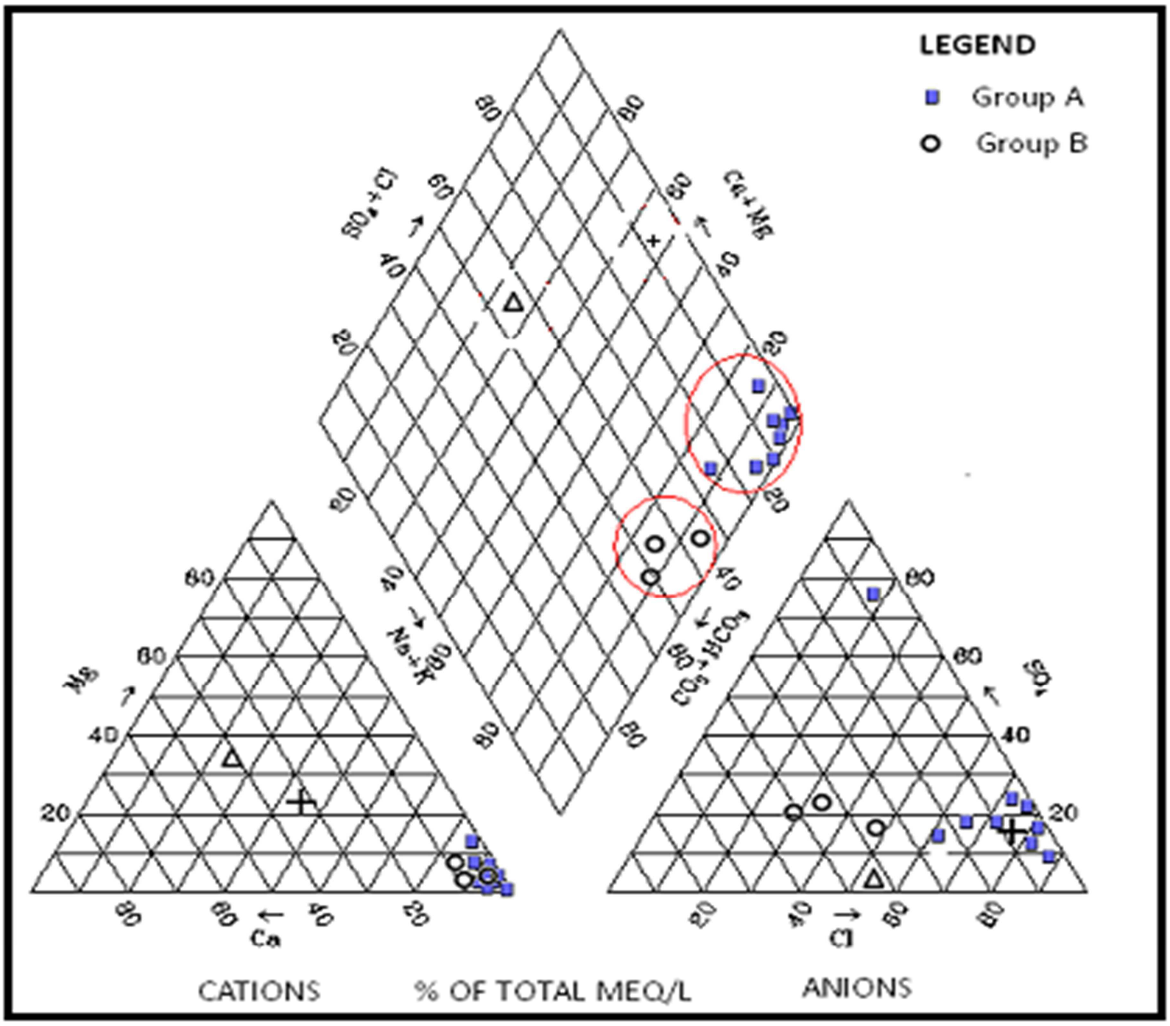

Figure 5. Plotting of groundwater samples on Piper trilinear diagram showing possible groundwater grouping

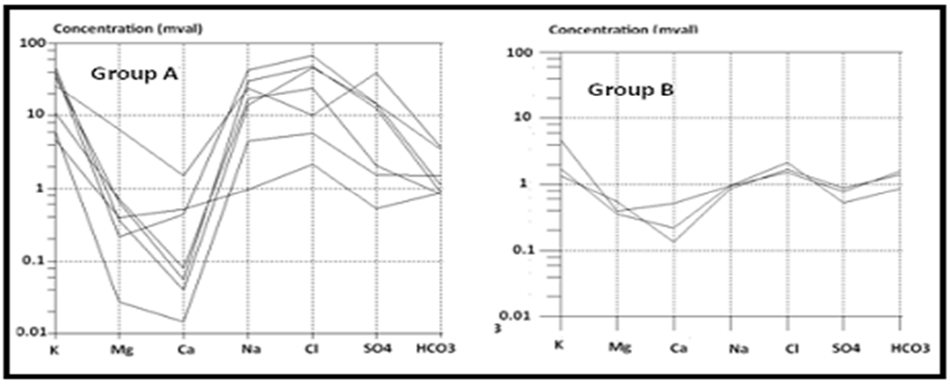

Figure 6. Schoeller semi logarithmic diagrams showing the hydrochemical pattern groundwater groups.

ISSN: 2413-5267

Table 4. Ranges of chemical parameters compared to WHO guidelines (1984)

Parameters	**WHO standards** (*mg/l*)	**Group A**	**Group B**
pH	6.5 – 8.5	6.5 – 9.8	7.2 – 8.5
EC (*μ/cm*)	< 250	490 – 7049	392 – 463
TDS	< 1000	587-5738	286 – 338
T.H.	200 – 500	1.9 – 350	25.9 – 29.6
Calcium	75 – 200	0.29 – 30	2.7 – 10.3
Magnesium	50 – 150	0.33 – 79	4.3 – 6.6
Sodium	100 – 200	322 - 977.5	13 – 22
Potassium	0 – 10	234.6 – 1015	53 – 182
Chloride	200 – 600	204.5 – 1883	42 – 77
Bicarbonate	0 – 500	51 – 280	53 – 97
Sulfate	500	74 – 19871	25 – 43

4. Conclusion

Generally the groundwater of the study area is soft to very hard, neutral to slightly alkaline and can be classified according to the salinity into Fresh and brackish-water. The fresh-water is located at the central and northwestern parts of the study area with an EC values of 500 to 1500 *μs/cm* and TDS values of 200 to 500 *mg/l*). While the brackish water situated at the southern and eastern part of the study area (Abusheda - Tawai area), which has EC values of 2500 to 9500 *μs/cm* and TDS value of > 4000 *mg/l*. variable groundwater salinity and chemical composition were mainly attributed to variable annual recharge and variation in lithology. Groundwater of the study area could be classified into two water types namely group A: Na-K-Cl SO_4-water type and group B: K-Na Cl-HCO_3-SO_4-water type. Group B is suitable for drinking and domestic use because most of the parameters fall within the permissible limits stated by WHO, while Group A is not suitable because many parameters have values greater than the permissible limits of WHO Guidelines. The study recommends for drilling of water wells to be conducted in the central part of the wadi which is occupied by fresh groundwater.

References

Ahmed A.M., Sulaiman W.N., Osman M.O., Saeed E.M., & Mohamed Y.A. (2000). Groundwater quality in Khartoum State, Sudan. *J. Envir. Hydrol.*, 8, 1-7.

ISSN: 2413-5267

Abu Fatima M., Shaddad I.A.I., Kazim M., Almahi S.M., Sakota S.S.A., Awad Alkarim A.A., & Imam A.A. (1986). *Explanatory report on the geology, structural and mineral aspects of southeastern Sinkat Sheet (NE-46E), Red Sea Hills.* (Unpubl.) Report, Sudan Geol. Surv., Khartoum, Sudan.

Al-Ahmad M.E. (20013). Hydrochemical characteristic and evaluation of groundwater quality in Wadi As Sabaan, western Saudi Arabia. *Inter. J. of Scientific & Engineering Research*, 4(1): 201-210.

Awadalla S.A. (1983). *Potential evapotranspiration over the Sudan: an application of penman's model over dense spatial pattern Scientific Not*, 3. Meteor. Dept., Sudan.

Babiker E.M. (2008). *Characteristics, assessment and management of groundwater resources of the coastal aquifer in Tokar Delta, Eastern Sudan.* PhD Thesis, Khartoum University. Sudan.

Babiker E.M., & Mohamed F.A. (2015). Geo-electrical and hydrogeological investigation of Khor Adeit basin aquifer, Sinkat Locality, Northeastern Sudan. *Inter. J. of Engineering and Technical Research*, 1(3): 288-295.

Davis S.N., $ M. DeWiest R.J. (1966). *Hydrogeology*. John Wiley & Sons, Inc., New York.

Drever J.I. (1982). *The Geochemistry of natural waters*. Prentice-Hall, INC., Englewood Cliffs, N.J.

Elsheikh A.E. (2002). *Water resources development and management-Red Sea State, Sudan.* PhD Thesis, Al-Neelain University, Khartoum, Sudan.

Eltoum M.A. (1991). *The climate of the Red Sea Region: an outline*. RESAP Techno. Paper, 1. The Reasp., University of Khartoum, Sudan.

Geirnaert W., & Laeven M.P. (1992). Composition and history of groundwater in the western Nile Delta, *J. Hydrol.*, 138: 169-189.

Hem J.D. (1991). *Study and interpretation of the chemical characteristics of natural water.* Scientific publishers, Jodhour, India.

Kresic N. (2009). *Groundwater resources, sustainability, management and restoration*. McGraw-Hill companies.

Kumaresan M., Riyazuddin P., Kumaresan M., & Riyazuddin P. (2006). Major ion chemistry of environmental samples around sub-urban of Chennai city. *Current Science*, 91(12): 1668-1677.

Lenore S.C., Arnold E.G., & Andrew D.E. (1998). Standard methods for the examination of water and wastewater. *American Public Health Association. American Water Works Association and World Environment Federation. 20th Edition, Washington DC.*

Mohammed F.A. (2012). *Groundwater Resource Evaluation in Sinkat Area, NE Sudan.* M.Sc. Thesis, Red Sea University, Sudan.

Osman B.T. (1996). *GIS-hydrological modeling in arid lands: A geographical synthesis of surface water for the African Red Sea Region in the Sudan*. PhD Thesis, Lund University, Sweden.

Piper A.M. (1944). A graphical procedure in the geochemical interpretation of water analysis. *Trans. Amer. Geophy. Union*, 25: 914-923.

Satti A.M. (2007). *Geological and lithochemical studies to prospect for mineralization in Sinkat area, Red Sea State – NE Sudan*. M.Sc. Thesis, Al-Neelain University, Sudan.

Sawer G.N., & McCarty D.L. (1968). *Chemistry of sanitary engineers*. 2nd Ed., McGraw-Hill, New York.

WHO-World Health Organization (1984). *Guidelines for drinking water quality*, World Health Organization. Geneva.