

Hydrochemical Characteristic and Ground Water Quality of the Aquifers in area around Aldamer Town-River Nile Sate – Central Sudan

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Abstract: This paper emphasized on the hydrochemistry of ground water as it is vulnerable resources to many environmental risks and is essential to sustainable development. The main geological units in the study area are Pre-Cambrian Basement Complex, Upper Cretaceous sedimentary formation, Oligocene Hudi Chert and Quaternary superficial deposit. There are two types of aquifers in the study area namely; the alluvial aquifer and Cretaceous sedimentary aquifers. The thickness of the two aquifers varies between the 3 - 30 m (for the upper aquifer) and 13 – 55 m (for the lower aquifer). The upper aquifer is semi confined. The field collected groundwater samples were analyzed for the major ion chemistry, using the standard laboratory methods. Arc GIS software is used for spatial distribution of the chemical components. Most of chemical species concentration of groundwater are within the permissible limits of local and international (WHO) standards with the exception of small pockets at Aldamer town where high concentration were detected and some village in West of study area where salinity was recorded.

Keywords: aquifers, chemical species, groundwater, hardness, ion concentration, salinity

1. Introduction

The study area lies in the River Nile state in the North Central of Sudan Bounded between the River Nile at the west and Atbara River in the east and north and bounded in the south by the Mukabrab wady. Study area lie between latitudes 17° 4 -17° 20 E and longitudes 33° 49 – 34° 13 N. it cover an area of 597 Km², Figure (1). The area is extremely flat; the elevation ranges between 380 to347 meter a.m.s.l. It is dipping gently to the North West. River Nile and Atbara river and seasonal wades (e.g. Wady Mukabrab) are the main geomorphologic feature which drain the water to the River Nile and Atbara river which is flowing from south east to north west it is characterized by meandering drainage system depositing huge amount of sediments at the stream valley on the inside of beds. This process is clear in construction and maintaining a flood plain [8] .The study area lies in semi desert climate with long summer) and low rainfall intensity and cold dry winter. Study area always affected by the wind for most of the year (northern and southwest wind).

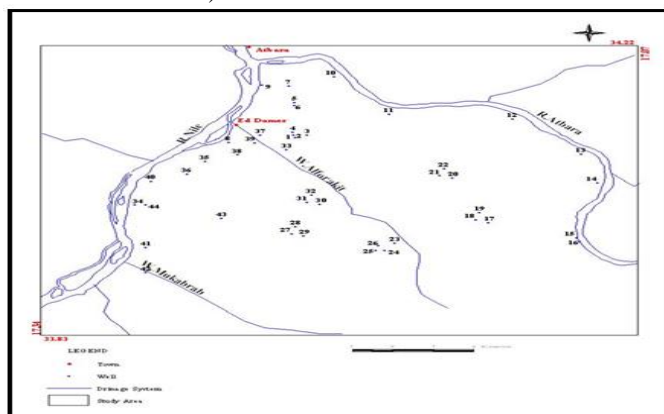


Figure (1) location map of the study area

2. Geological Setting

The geological setting of the study is composed of Basement Complex (Pre-Cambrian), Nubian sandstone formation (upper Cretaceous), Hudi Chert (Oligocene) and superficial deposit (Quaternary) (Figure 2.1) in ascending chronological order [7], [4] and [8]. The basement complex is composed of highly deformed and multi metamorphosed gneisses and schist, characterized by different types of structure and fracture systems.

The Basement rocks are unconformable overlain by the rudaceous and arenaceous beds of the Cretaceous sedimentary Formation of continental origin [1], [7], [10]and [9] . Cretaceous sedimentary Formation is mainly composed of sandstone, conglomerates intercalated by gravel, grits Iron-Shale and mudstone [8].These formations appear as an escarpment and isolated scattered inselbergs. Along river Atbara the Cretaceous sedimentary Formations are characterized by thick layers of mudstone (300 m) where the total thickness of the Formation reached by drilled wells is over 400 m [8].

Hudi Chert (Tertiary) formation occurs as fossiliferous (gastrobods) boulders mixed with quartz pebbles of gravelly and breccias form, consisting of cherty deposits or as bedded strata. They are very hard frequently possessing a concoidal fracture, of yellowish, brownish to reddish in color [7]. The Hudi Chert rock overlying the Nubian sandstone formation covering large area in the south east of Atbara town and in the eastern bank of Atbara river near Elnikhela villages.

Superficial deposits include dark clays and silt of the river terraces and unconsolidated layers of gravel, sand ,clays and sandy clay with kanker nodules as well as extensive sand dunes that almost occupy the southern part of the River Atbara . The thickness of superficial deposits at east and northeast of the area varies from 30 meter up to 70 meters where the lithology

is dominated by sands and gravelly sand separated by layers of clay. Kanker nodules occur in the upper zone mixed with gravels and sands particularly in the Middle East part of the area. The top surface blanket in the study area consist of fluvial and lacustrine facies Figure (2). There are two types of aquifers in the study area namely; alluvial (recent deposits) aquifer and Cretaceous sedimentary (Nubian sandstone) aquifers. The former one consists of pebbles, gravels, sands, silt and clay as well as kanker nodules in the most-top of the aquifer zone. It is an unconfined with high permeability and good water quality. The Cretaceous sedimentary aquifer, forming the lower aquifer zone, is characterized by good hydraulic properties and fresh water quality, except at the central part of the study area where poor hydraulic conductivity and bad water quality were encountered, confirming the poor interaction between surface water and ground water. The aquifers are partially hydraulically interconnected. The thickness of water potential zones vary between 90 to 220 m Figure (2).

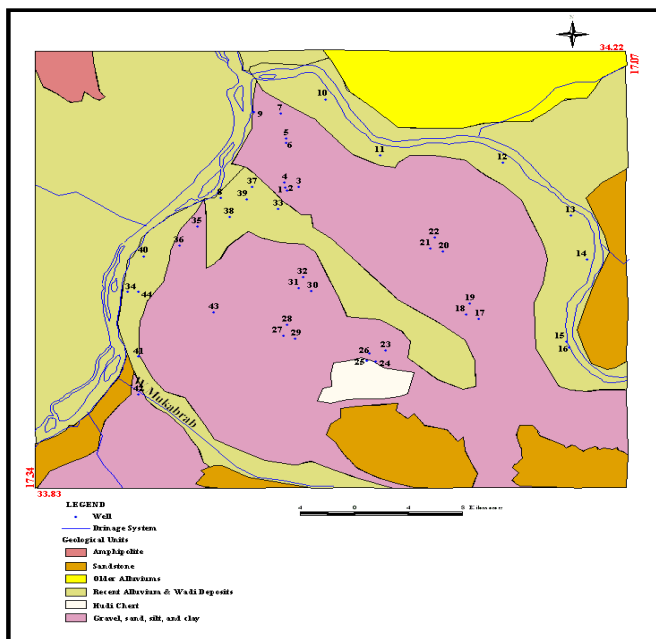


Figure (2) Geological map of the study area

3. METHODOLOGY

The field collected groundwater samples were analyzed for the major ion chemistry, using the standard methods. Electric conductivity (EC) and hydrogen ion concentration (pH) were measured immediately at the field site, using portable Orion EC- and pH -meters. Further analyses for major ions were performed in the water research central Laboratories: total dissolved solids (TDS) were measured by sample evaporation techniques. Bicarbonate (HCO_3^-) and total alkalinity (T. Alk.) were estimated by titration with HCl acid. Total hardness (TH) and calcium (Ca^{2+}) were analyzed titrimetrically. Sodium (Na^+) was analyzed by flame photometry. Chloride (Cl^-) was estimated by titration with AgNO_3 . The analytical precision for the measurements of cation-anion is indicated by ionic balance error, which is observed to be within the stipulated limit of 5%. All values were in milligram per liter (mg/l) unless otherwise indicated. The hydrochemical characteristics of groundwater in the study area were summarized in Table (1, 2). Arc GIS software was used for spatial distribution of the mentioned chemical species as plan view hydrochemical maps.

The mixing of ground water with different chemical composition is brought to about by two physical processes diffusion result from the thermal motion of molecular and ions and hydrodynamic dispersion, caused by flow through the net work of interconnected channel also different of specific density may either induce or impeded mixing. The water quality is the result of these physical processes which give the different concentration of element in the water and determine the water quality for different use.

Source of salinity

All ground water contain salts carried in solution. The kinds and concentration of salts depend upon the environments, movement, and source of ground water. Ordinarily, high proportion of dissolved constituent is found in ground waters than in surface water because of greater exposure to soluble materials in geologic strata. soluble salts found in ground water originate primarily from solution of rock materials, in areas recharging large volumes of water underground such as alluvial streams or artificial recharge area, the quality of the infiltration surface water can have a marked effect on that of the ground water locally, absorbed gases of magma tic origin contribute dissolved mineral products to ground water mineralized thermal springs furnish an excellent example. Connate waters are usually highly mineralized as they originate from isolated pockets of residual waters entrapped in sedimentary rocks since geologic times. Even rain water entering the ground contains minor salt concentration picked up in the atmosphere.

Salts are added to ground water passing through soils by soluble product of soil weathering and erosion by rain fall and flowing water. Excess irrigation water percolating to the water table may contribute substantial quantities of salt. Water passing through the root zone of cultivated areas usually contains saline concentration several times that of the applied irrigation water. Increase result primarily from the evapotranspiration process which tend to concentrate salt in drainage waters. in addition, soluble soil material , fertilizers and selective absorption of salts by plants will modify salt concentrations of percolating waters , factors governing the increase include soil permeability, drainage facilities, amount of water applied, crops, and climate. Thus high salinities are found in soils and ground water of arid climates where leaching by rain water is not effective in dilution the salt solutions. Similarly, poorly drained areas, particularly basins having interior drainage, contain high salt concentration. Also, some regions contain remnants of sedimentary deposition under saline water; the designation (bad land) implies the lack of productivity resulting from excess salt contents of the soil and water. Ground water passing through igneous rocks dissolves only very small quantities of mineral matter because of the relative insolubility of the rock composition. Percolating rain water contains carbon dioxide derived from atmosphere, which increases the solvent action of the water. The silicate minerals of igneous rocks result in silica being in predominate constituent, although small, of the ground water in contact . Sedimentary rocks are more soluble than igneous rock. Because of their high solubility, combined with their great abundance in the earth s crust, they furnish a major portion of the soluble constituent to ground water. Sodium and calcium are commonly added cat ions, bicarbonate, carbonate, and sulfate are corresponding nions. chloride occurs to only a limited extend under normal condition , important source of chloride , however , are from sewage , connate waters ,and intruded sea water. Nitrate is only rarely an important natural

constituent high concentration may indicate source of past or present pollution. In limestone terrenes calcium and carbonate ions are added to ground water by solution.

3.1 The Electrical conductivity (EC)

This is a measure of the ability of water to conduct, (carry) an electrical current. It is highly dependent of the amount of dissolved solids (mainly salts) in solution (water). Pure water, such as distilled water has a negligible or very low EC, while sea water has a high EC. Rainwater often dissolves airborne gasses and dust, and thus will have an EC higher that of distilled water. EC is an important water quality measurement because it gives a good indicator for the amount of total dissolved solids (TDS) in the water. The EC is easily measured in the field by EC meter and the unit is micro siemens per cm or micro mhos per cm which are equal to each other. A factor in the range (0.55 -0.75) when multiplied by the measured EC value gives approximation to the TDS content of the expressing the EC range .in the study area the EC in the range between 217 to 2364 micro Siemens.

3.2 Total dissolved solids (TDS)

TDS make up the minerals constituent dissolved in water which include the soluble anion and cat ion s .the cat ions and anion are combined to give the salts commonly found in natural water, the sum of these salts should approximate to the total dissolved salts measured by evaporating the water. TDS distribution in the study area range between (110 to 1635 ppm) Table (1, 2) is high in the south west of study area and less level in south middle also. The west and north of the area has low ratio of TDS with gradual increase to the middle Figure (3).

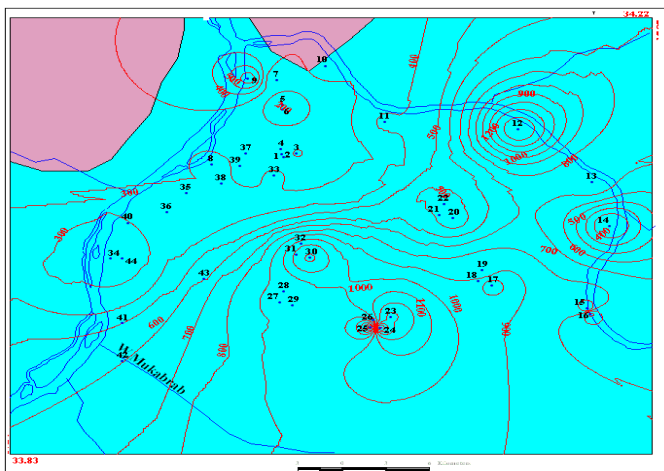


Figure (3) spatial distribution of TDS in the study area

3.3 Acidity and alkalinity (pH)

The ph is measure of the acidity and alkalinity of water, pH is measure of the inverse of hydrogen ion concentration ($\text{pH} = -\log_1/\text{H}^+$) range from 0 to 14 where neutral solution have 7 PH in 25° C .The measure of relative amount of free hydrogen ions and hydroxyl ions the water indicate basic reactions of water which showing pH more than 7, and water showing pH less than 7 is acidic in reaction. In the study area groundwater is characterized by pH between 7 to 9.9. Table (1, 2)

3.4 Hardness (TH)

Total hardness is a measure of the calcium and magnesium content, and is customarily expressed as the equivalent of calcium carbonate .thus

$$\text{TH} = \text{Ca} \times \text{CaCO}_3 / \text{Ca} + \text{Mg} \times \text{CaCO}_3 / \text{Mg}$$

Hardness is of two types:

- Temporal hardness.
- Permanent hardness.

In the study area total hardness range between (70 to 600 ppm) (Table 1, 2)

3.5 Chemical constituent of water

The common determined constituent in chemical analysis of water are the cat ions (Ca, Na, Mg and potassium and anions HCO_3 , Cl, SO_4 , CO_3 and NO_3 some minor and trace constituents may also determined.

3.6 Calcium (Ca)

Ca usually occurs in water as HCO_3 , CO_3 and SO_4 although in high salinity water CaCl_2 and CaNO_3 can also be found. Although there is no health objection to high content of Ca in drinking water, the WHO recommended maximum level of (200 ppm) as because above these level can cause major to water vessels. Ca enters the water mainly through the dissolution of the carbonate rocks, which are abundant among sedimentary rocks. In the study area Ca ranged between (15 to 158 ppm) Table (1, 2).

3.7 Sodium (Na)

Because sodium compounds are very soluble in water element this element is abundant in all natural water, a level of 20-150 mg/l of sodium in drinking water is permissible while above 200 mg/l is not recommended. Sodium range in the study area (minor to 290 ppm), sodium is high concentration in south middle of the area and less concentrate in the east and less in the north and North West of the study area Figure (4).

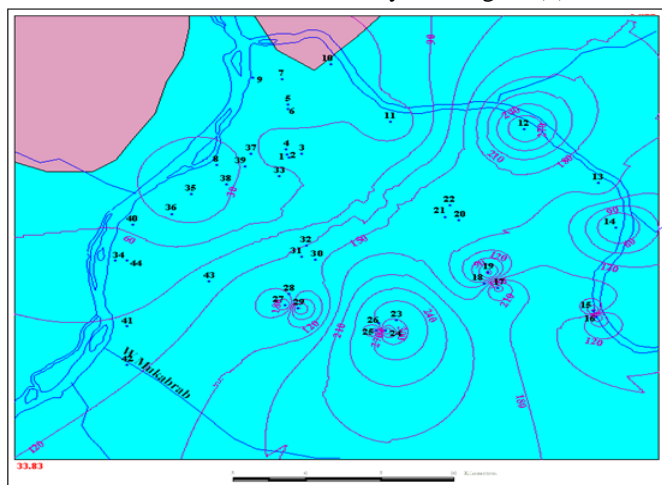


Figure (4) spatial distribution of sodium in the study area

3.8 Magnesium (Mg)

Mg and Na are found in sedimentary rocks especially the carbonates and the evaporate .magnesium composes one of the most common and soluble element in water, excessive of magnesium are un desired in domestic water (hardness) .as magnesium and sulphate are interrelated, the maximum allowable level of magnesium is 150 mg /l providing that the SO_4 concentration is less than the Mg. (7.7-126 ppm) is the range of magnesium in study area Table (1, 2).

3.9 Potassium (K)

Although potassium is one of abundant element in the earth it is concentration in most natural water rarely exceed 20 mg/l probably because most K bearing minerals are resistant to decomposition by weathering. Potassium is commonly

associated with Na in its distribution in water, some standard set a maximum of 15 mg/l as an upper limit for drinking water. In the study area is rarely exist and almost it is less than 10 ppm Table (1, 2).

3.10 Carbonate (HCO₃) and Bicarbonate (CO₃)

The carbon species occurs in naturally water cycle as HCO₃ and CO₃ where within the normal pH range of the fresh waters, they mostly occur as HCO₃. This is why the HCO₃ is predominant anion in most surface and ground water source in many part of the world. Generally bicarbonate linked with recent flow from the river. The bicarbonate is high in west and north of the study area in the side of river Nile towards middle and in the east side of study area it is very high level in south east and less in the middle east with a limit extension. Carbonate contour lines in the study area is very high toward the west north of the study area with gradual decrease towards the middle and the other directions Table (1, 2) Figure (5).

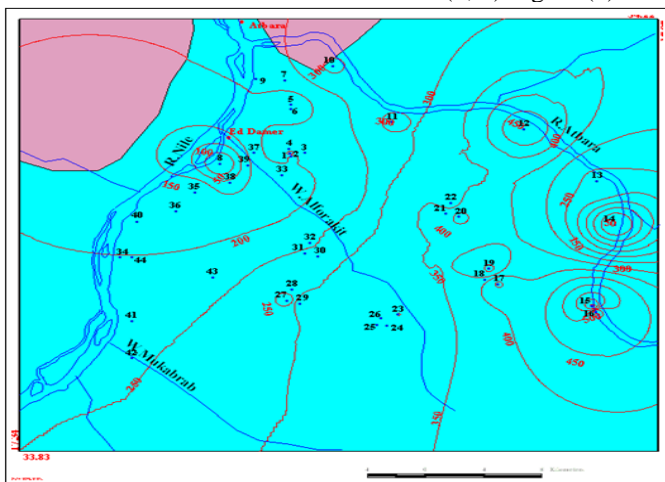


Figure (5) spatial distribution of bicarbonate in the study area

3.11 Sulphate (SO₄)

The concentration of sulphate has a wide range in natural water from a few mg/l to several thousand mg/l the source of SO₄ in water is the dissolution of gypsum and other sulfur deposit as well as from sea water intrusion, oxidation of sulfur compound in well-aerated surface water and from some industrial effluent in water, the SO₄, contribute the major part of permanent hardness. It range between 2 to 220 ppm Table (1, 2) in the study area with high increase in the north east of the study area and less in the south east, south, and south west. In the middle and north west of study area the sulphate is very low Figure (6).

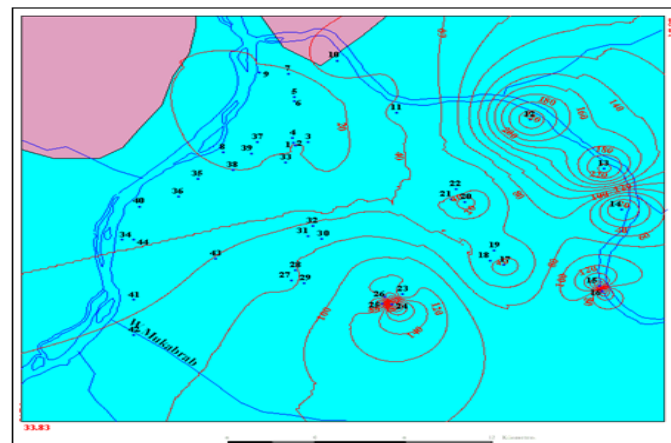


Figure (6) spatial distribution of Sulphate in the study area

3.12 Chloride (Cl)

Most river and fresh lake have less than 50 mg /l, while excessive concentration are indicative of intrusion of sea water or pollution the Cl combination which commonly with Na and less with Ca and Mg are very stable in water and lesser with Ca and Mg. Chloride in the study area range between (11.4 to 290 ppm) Table (1, 2). It is high increase in the south middle of the study area with a decrease towards west south. The north west of the study area is almost minor concentrate of chloride Figure (7).

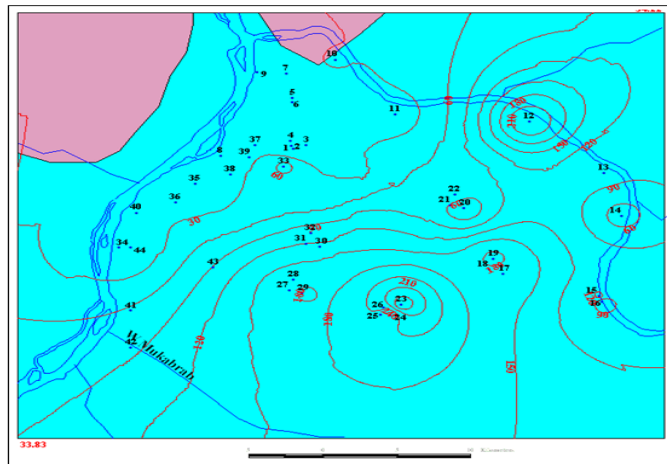


Figure (7) spatial distribution of chloride in the study area

3.13 Nitrate (NO₃) and Nitrite (NO₂)

Are not primarily derived from minerals soil or rocks but rather from organic matter NO₃ (the high range in the study area is 15) is the final stage of oxidation of ammonia NH₄ (the high range in the study area is 2.3) Table (1, 2) while NO₂ (the high range in the study area is 5) is the intermediate one, which when farther oxidized give NO₃.

3.14 Fluoride (F)

As a result of solubility of fluoride – rich rock f is naturally found in water it is now recommended that water supplies would contain 1 mg/l as optimum because it is effected in reduction decay, excessive fluoride concentration may lead to staining of teeth with reddish color also may cause of the damage of skeleton of the children or even adult. In the study area fluoride is always less than 1ppm.

4. RESULTS AND DISSCUTION

In order to obtain hydrogeology information from chemical data it is necessary to reconstruct the path of geochemical evolution i.e. the processes through which the water aquires it is chemical composition since each analysis can be explained by several different methods of evolution the most plausible method has to be selected on the basis of hydrogeologic evidence. In other words, chemical data cannot be interpreted without reference to geo hydrologic data or assumptions the interpretation of brine s is difficult because many processes including precipitation intervened in their formation. Fresh ground waters are under saturated in all. Dissolution from the aquifer material is a dominated process hence the interpretation of chemical characteristics of ground water is comparatively simple.

A. The Trilinear diagram (Piper)

Piper trilinear diagram consist of three fields of plotting Figure (7). Two triangular fields are constructed at the lower left and the lower right of a diamond – shaped field. The captions are

plotted on the lower right triangle while the anions are plotted on the lower right triangle. The hydrochemical composition of each water samples is represented by one point on the diamond-shape field by making a detailed and convenient hydro chemical classification of water. According to this diagram Fig (7) saline water from the middle south and slightly in the east area, from the Nubian sand stone aquifer are encountered at the center. And south west of the study area and in two far distant point in the east of the study area Atbara river well no (14,17,26,43) more over the aquifer is characterized by alkali carbonate water near type (well 20,15,4,22) near Manasir village 3 in the east side of the study area west Atbara river which gradually change to Cl-bicarbonates and HCO₃-SO₄-Chloridic (42,10,11,16) near Atbara River Shalia Um ajaja this water is slightly alkaline in chemical reaction and moderately to highly saline . The aquifer is concened moderately saline water can be found south west of the study area well no (24, 28, 23, 25) .alkalinity decrease from chloride bicarbonates water well no (42, 33,) slightly alkalinity and moderately saline. It can be concluded that the salinity in the study area may be attributed to evaporite such as NaCl and stagnation of water.

B. Water suitability

Generally, the ground water quality in Nubian and alluvial aquifers is fit for human and agriculture purpose with a few exceptions [1]. Chemical investigation in the study area indicate that water from generally acceptable to good for domestic uses, however in some location is poor for the domestic use because of high salinity and contamination of some wells in Aldamer town.

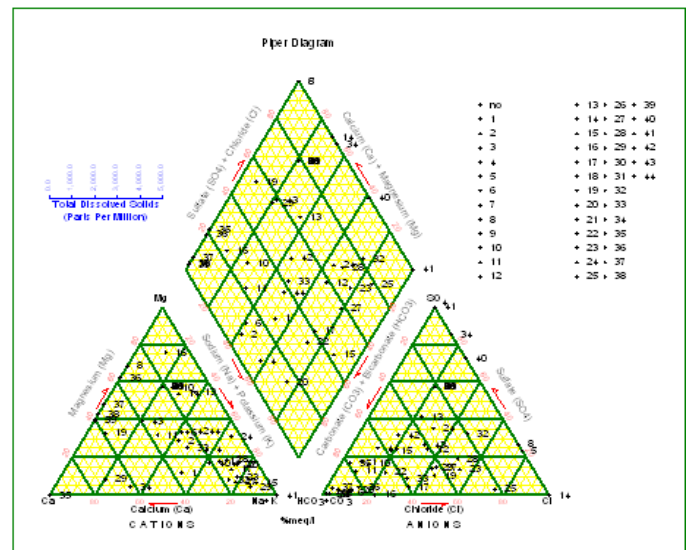


Figure (8) piper diagram me in study area

5. CONCLUSION

Most of chemical species concentration of groundwater are within the permissible limits of local and international (WHO) standards with the exception of small pockets at Atbara town where high concentration were detected and some village in West of study area where salinity was recorded due to palaeohydrological change prevailing in the past and Sabkhas deposits. The water quality in the study area is suitable for domestic, agriculture, and industrial use.

Table (1) Chemical and physical Analysis of the study area

Well No	Location	pH	EC	TDS	TH	K	Na	Mg	Ca	So ₄	Cl	CO ₃	HCO ₃	F	NH ₃	NO ₂	NO ₃
1	Altahil 1	7	340	217	142	9.9	66	8.7	42.4	31	11.4	3	158.6	0.4	0.096	1.65	0.17
2	Altahil2	8.3	364	254.8	185.2	-	62.18	22.4	37.2	3	12.78	16.8	285	0.47	0.805	0.1551	8.36
3	Alshariga	-	-	190	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Altahil3	8.4	289.9	202.93	142.8	-	87.53	19.488	25.04	8	12.07	46.2	235.46	0.4	1.049	0.231	7.48
5	Alsalam fa	7.07	240	110	80	-	-	7.7	19.2	5	12	-	-	-	0.7	0.01	
6	Alsalm fa2	7.4	217	151.9	114.4	-	36.88	15.89	19.6	2	12.78	-	170.8	0.64	0.549	0.39	19.8
7	Awadalah	-	-	200	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Uwc damer	8	-	320	260	-	-	40	30	10	20	-	-	0.4	-	-	-
9	Maspio	-	-	650	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Umajaaja	9.3	482	344	260	0.8	41	48.5	24	56.7	31.2	-	305	0.3	-	-	-
11	Alshalia	7.8	587	410.9	208	-	44	23.47	44.3	41	19.88	6	305	-	0.098	0.132	-
12	Abu amar 2	8	1970	1379	328	-	289.8	42.4	62.4	230	234.3	-	488	0.6	0.1	0.53	704
13	Kangary	8.9	1112	756	600.6	1.6	159	126.1	32	224	92	-	244	0.4	-	-	-
14	Albisli	8.4	-	200	123	2	30	30	15	0	50	-	-	0.07	0.39	0.2	-
15	Alamrab	9.9	1528	1016	76	2	252.5	9.7	14.4	218.9	127.6	-	671	0.8	0.656		-
16	Alamrab 2	7.2	812	568.4	360	-	25.5	76.8	17.6	1	69.5	-	400.2	0.2	0.878	0.099	0.44
17	Manasir 2c	8.37	1507	1043	192.4	-	248.1	24.592	38.48	27.5	170.4	14.4	456.28	0.33	1.744	0.0264	-
18	Manasir2a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	Manasir2b	8.3	1194	835	411.8	-	24.5	53.654	158.24	60	187.44	18.6	291.58	0.07	1.342	-	11.88
20	Manasir3c	8.4	633	443.1	121.2	-	163.6	18.66	17.76	11	36.92	19.2	409.92	0.57	0.866	0.0231	-
21	Manasir3a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	Manasir3b	8.38	668	467	141.2	-	176	20.5	22.72	54	72.42	16.2	337.94	0.05	2.147	-	14.52
23	Manasir6h	7.6	1890	1323	189.4	-	299.5	19.28	42.8	100	289.8	0	298.9	0.31	1.637	0.0033	5.72
24	Manasir6d	8.4	2335	1635	444	-	387.9	99.43	23.52	295	192.6	14.4	323.3	0.89	2.782	0.0294	3.08
25	Manasir6f	8.3	668	407.6	70	-	195	5.475	18.64	42	717	9	345.3	0.98	0.891	0.0528	12.32

Table (2) Chemical and physical Analysis of the study area

26	Manasir6b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	Manasir5a	8.4	1384	922	122	-	207.9	9.8	32.7	73.7	156.9	18	226.9	0.13	0.52	0.05	7.04
28	Manasir5b	8.41	1143.1	-	265.8	-	262.5	38.29	42.08	135	262.2	10.8	252.5	0.65	1.74	0.066	23.76
29	Manasir5c	8.4	1203	-	109.2	-	27.24	5.99	83.44	87.5	186.7	-	344	0.88	0.9272	0.025	8.8
34	Hasaya ho	7.2	0	220	220	10	65	5	115	40	5	-	-	-	2.3	-	25
35	Hedeba n	9.6	363	304	124	-	-	0	49.62	37.8	6.4	18	183	0.2	-	-	-
36	Almesiabl	7.8	382	220	80	-	-	24.3	24	8.2	21.3	-	207	1.5	0.096	0.33	-
37	Alsenaat	8.7	542	426	166	-	-	19.6	34.4	11.5	5.7	-	353.8	0.8	0.12	0.528	-
38	Shadenap	8.6	532	372.4	390	-	-	31	68	3	10.65	90	437	0.5	1.23	-	3.52
39	Block13	8.6	553	401	140	-	-	13.7	33.6	2	4.2	-	402	0.8	0.148	4.95	-
40	Aljbarab	8.7	600	420	90	5	65	10	20	145	40	-	-	0.9	-	-	15
41	Wadmkabr	8	-	-	-	10	-	-	-	1680	0	-	-	0.5	-	-	-
42	Mkab east	8.9	974	618.5	312	3.3	110	45.6	50.4	201.6	81.5	6	390		0.246	-	-
43	Mkabrab	8.7	1596	1024	220	-	27.5	26.9	44	116.8	102.9	-	231.8	0.8	0.573	-	-
44	Hasaya n	8.2	479	352	120	5	51	19.6	16	76.5	27.7	-	244	-	0.861	1	-

AUTHOR PROFILE

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REFERENCES

- [1] Afaa, A. E.Osman; (2005). Assessment and simulation of ground water potential in the area east of the river Nile .Khartoum state- Sudan.
- [2] Ahmed and Abdrahman; (1996) studied the capacity of ground water wells around Atbara area and the use of ground water for different purposes.
- [3] Awad; (1982). General survey for natural resources in central north including Kenedra basin.
- [4] Ayed, M.A. (1994); Assessing ground water using electrical resistivity technique to delineate the contact of Nubian and basement in Atbara basin.
- [5] Freeze, R.A., and Cherry, J.A. (1979). Groundwater, Prentice-Hall, 604 pp.
- [6] Haggaz .Y and other ;(1990). Ground water in north and West Africa (natural resources/water series no.18).
- [7] Kheiralla; (1981) has carried out comprehensive study of ground water resources of the northern Sudan.
- [8] Mukhtar, M ;(1999). Evaluation of ground water in Atbara basin by resistivity methods.
- [9] Vail, J. R. ;(1971). Geological reconnaissance in part of Berber District, Northern Province, Sudan. - Bull. Geol.Surv. Sudan,18, 76 pp., Khartoum.
- [10] Whiteman, A. J. (1971). The geology of the Sudan Republic.-290 pp., Oxford (Clarendon press).