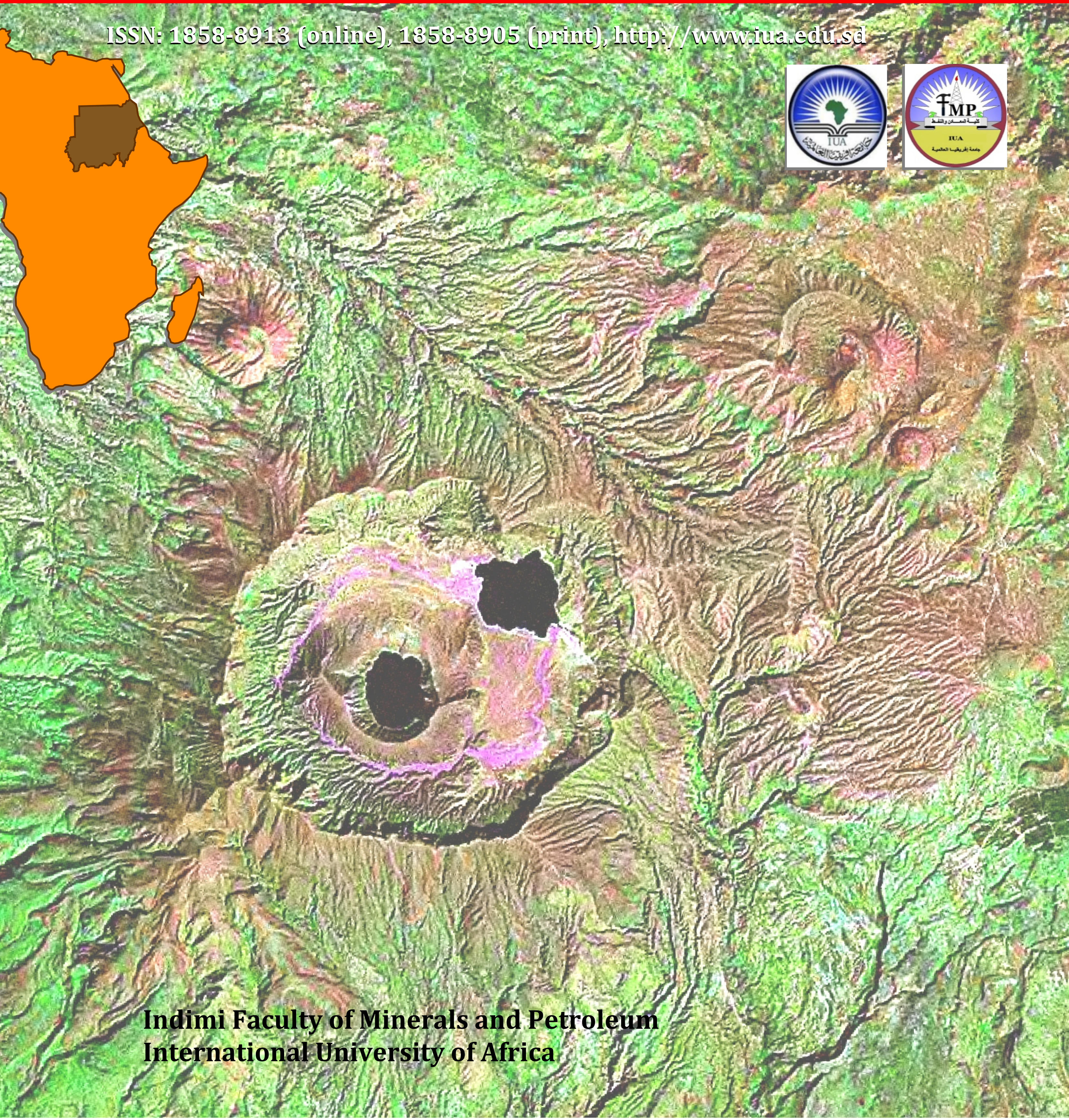
Africa Journal of Geosciences

Refereed scientific journal

Volume 2, 2019

ISSN: 1858-8913 (online), 1858-8905 (print), http://www.iua.edu.sd



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Africa Journal of Geosciences (AJG)
Vol-2, No. 1, 2019
ISSN: 1858-8913 (online), 1858-8905 (print), http://www.iua.edu.sd

Hydro-chemical Characteristics and Groundwater Quality in the East Nile Area, Khartoum State, Sudan.

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Received: 08/10/2019; Revised: 11/10/2019; accepted: /11/2019

Abstract

The objective of this study is to identify, describe and assess the groundwater chemistry based on geological, hydrogeological and hydrochemical data of 65 supply wells in eastern side of the Khartoum state. The methodology used in this study included the fieldwork and the laboratory investigation enhanced by computer software's. The area is occupied mainly by the semi confined and confined aquifers, (the piezometeric surface below the ground water level is less than 20 m). The boreholes have yield ranging between 9 to 68 m^3 /h, the tow aquifers are the lower aquifer contain fresh water because the aquifer contains very low soluble salt Content. The most frequent values of the (TDS) vary from240 to3200 ppm, however the hardness values range between 125 to 366 ppm including very hard to hard water. This water is alkaline in nature with an average pH value of 8.6. The study area is characterized by four water types' facies. The sources of the cations ($Ca^{+2,}$ Mg^{+2}) are related to hydrolysis processes (chemical weathering) dissolution of carbonates (kanker deposits) and limited ions exchange processes. The analysis of flow system indicated a regional flow direction towards the south-west direction with local flow regime towards the east- north, preliminary assessment of groundwater chemistry was investigated by using different statistical techniques such as x-y plots, correlation, cluster, principal components, and factor analysis the result by this technique showed negative correlation between exchange ion $SO4^-$ & Cl^- Which suggests ion exchange, processes is active, the strong correlation among Na^+ & SO_4^- ions, TDS &EC indicate that the Stalinization is related to increase of concentration of these ions by Dissolution process on minerals is suggested by strong positive correlation between Ca^{+2}, Mg^{+2}, & SO_4^-. Multivariance analysis indicate that the salinity of groundwater is due to factor one which constitutes 30%. The groundwater of the study area is quite suitable for municipal and irrigation purposes, however because of its high hardness the water should be treated to become suitable for industrial uses.

Key words: Multivariance, statistic hydrochemistry, water analysis.

1. Introduction

The study area lies entirely in the eastern part of the Khartoum state. It occupies mainly a vast area east of the Blue and River Niles. Which is located between latitudes 15.56-15.99 N and longitudes 32.56-32.93 E (Fig 1), with an area of 18,997,262 Square kilometers, Generally the elevation varies between 400 to 420 m above main sea level (a.m.s.l.). Where the mean annual precipitation is 167 mm, and evaporation is about 10mm/day (Haggaz and Kheirallah, 1988). The main annual daily mean maximum air temperature is 37°C with extremes of 42.2°C.

The area is regarded as semi—arid zone, which is characterized by its scanty vegetation that can increase along the seasonal drainage pattern and the river banks in the study area. It is covered by the savanna vegetation type, such as acacias, shrubs and grasses, which grow in the wadies and the low land.

According to the FOA-UNESCO soil maps of the world in the 1974 there are three units Soil which occur in the study area. Xerosols are soils of dry regions. They have a surface horizon containing very little organic matter. These soils usually result from the slow operation of the soil forming possesses in arid environment. They cover about 45% of the study area. Vertisols which have a significant clayey texture; the presence of smectite (montmorillonite) clay minerals also means that the soil surface has micro-relief of 20-30cm. The soils are normally calcareous and fall into two subgroups according to color. Black (pellic) vertisol has developed in the island clay. Fluvisols, these are soils with weak developed profiles which occur in the recent river alluvial. They have no diagnostic horizons other than an organic-enriched and this decrease irregularly with depth. These soils are classified as calcaric fluvisol. They occurs near and long the rivers, covering about 13% of the study area.

The population are mainly concentrated along the Nile and the Blue Nile rivers. People away from the Niles are distributed in small villages and settlements. Most of the inhabitants work in the towns, people living along the rivers depend on irrigated agriculture from the rivers water as well as from ground water. The most populous area in Khartoum state is facing a demand for additional water resource due to it is rapid expansion far away from the Niles, and the consequent high cost of the infrastructures required to purify and transfer the Nile water.

As a consequence, ground water is utilized in the area for domesticity, irrigation and industry. So development in the study area depends largely on the availability of sufficient amount of fresh water. To achieve these objectives the author refers to existing drilled boreholes. So many obstacles in front of the researchers on the groundwater resources in the study area like weakness of geological and hydrogeological data. Hence a needful of the assessment and description of groundwater quality is important for proper planning.

To achieve the proposed objective, the data of 66 boreholes range in depth from 30 meters up to 222 meters with an average depth around 80 meters, which include location , lithology, well design , depth to the piezometric water level, and physical and physcio-chemical properties of water samples. For measuring the properties of the water samples were taken and sent immediately to the laboratory for analysis. The measurements include : electrical conductivity (EC), total dissolved solids (TDS), acidity (pH), bicarbonate (HCO_3), hardness(TH), Chloride (Cl), Sulphate (SO_4) and (Sodium, Magnesium, Calcium and Potassium).

2. General geology and hydrogeology

The topography of the study area is generally flat and peneplained. This plain rises in the north east (Jebel Elkabashi, 535m) .the slope of the land surface starts from a conspicuous water-shed beyond the studied area in the north 535m. It gradually merges into the Nile valley where an average altitude of 380m is reached (Haggaz and Kheiralla, 1988). The land surface is covered with superficial deposits. These deposits are formed by heavy braided fast flowing and highly seasonal paleo-channels of the blue Nile carrying sediments of both local as well as Ethiopian sources, it was estimated that the final stages of aggradations took place between 5000 and 8000 years ago (from William 1982).

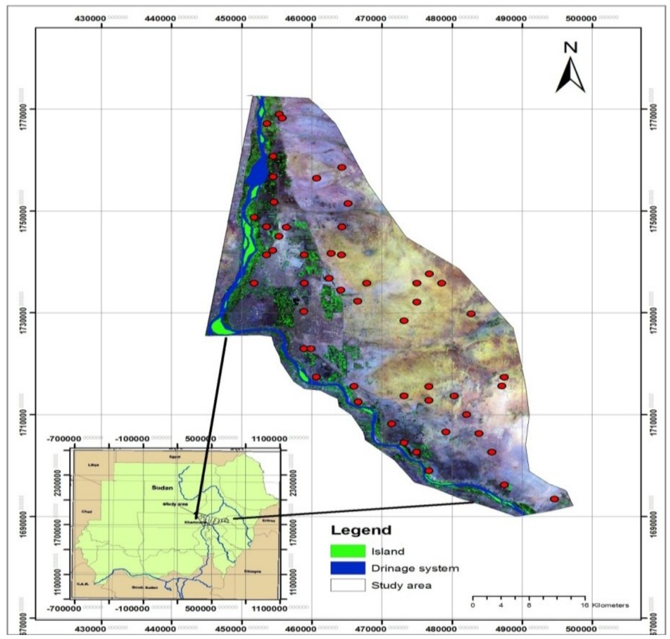


Fig. (1): Location map of the study area

The most important geomorphologic features in the study area are Jebel-el-selitat (418m) and Jebel-al-sufur (450m).The Nile and Blue Nile Rivers dominate the drainage of the area. The geological units in the study area from recent to oldest are the superficial deposits and the Nubian sandstone in which can be divided into aeolian deposits, the Nile silts and Wadi alluvium (fig. 2). The Aeolian deposits are present as Qoz deposits and associated sand sheets which extend from the Buttana to the Nile valley (Whiteman, 1971).

The Nile silts and the wadies deposits are the youngest sediments encountered in the study area. The alluvial deposits consist of poorly sorted clay and silts with sandy and gravelly lenses which are believed to be of Quaternary age (Whiteman, 1971). The Nile silts contain fine micaceous sands, the silts are deposited annually after the Nile flood from material carried largely as suspension load, and these deposits occur as narrow belt (Fig. 3). The Nile has a maximum width of 8km and variable thickness of 5-20m (Haggaz and Kheiralla, 1988).

The Nubian sandstone formation is of upper Cretaceous age (Whiteman, 1971). It occupies much of the studied area. The Nubian sandstone formation contains the great Nubian aquifer of North Africa, which mainly lies in the northern Sudan and extends into Egypt and Libya. The thickness of the Nubian sandstone formation in the study area varies from a few meters in the north to more than 400m in the south. It consists of flat-lying or gently dipping rocks made up of continental sediments which include sandstone grits, mudstones extra formational and intra-formational conglomerates (Kheiralla, 1966; Whiteman, 1971; Table 1).

The geological units in the study area from the recent to the oldest is the superficial deposits, the Nubian sandstone formation, and Basement Complex Rocks are oldest rocks in the study area belong to the basement complex system (Whiteman, 1971). They consist of granites, gneisses and schist which crop out at surface outside the area, mainly to the north and east (Fig. 3a).

Table (1): Geological units of the study area

Formation	lithology	Thickness	Age
Wind Blown sand qoz	Eolin deposits	few	Recent
Nile silts	sand	few	Quaternary
Wadis deposits	Sandy gravely deposit	Above 40 meters	Quaternary
Nubian formation	Sandstone formation	More than 400 meters	upper Cretaceous
Basement Complex	Different rocks	varies	Precambrian

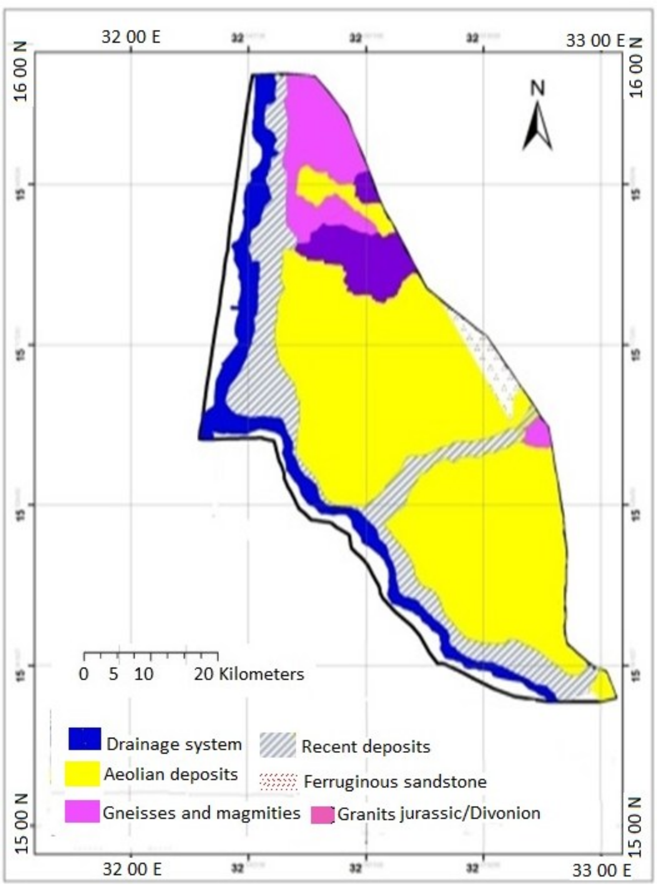


Fig. 2: Geological map

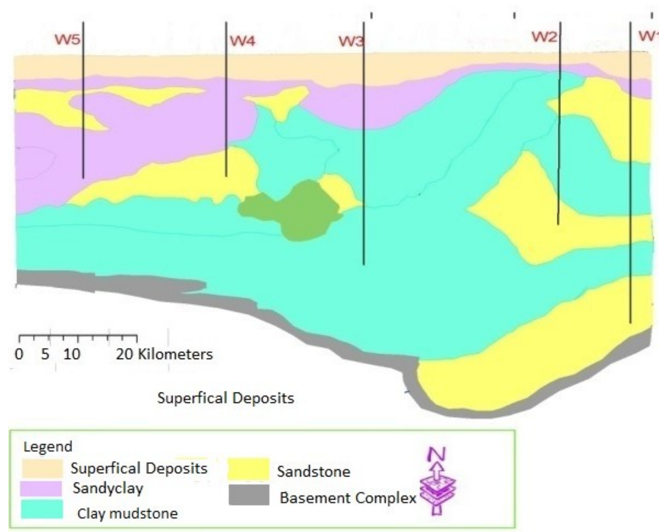


Fig. 3a: Lithological section in the area (E-W)

Hydrogeochemical study seeks to determine the origin of the chemical composition of groundwater and the relationship between water and rock chemistry, particularly as they relate to groundwater movement. Continuous decrease of water level in almost all of the aquifer confused the problem of the quality and the renewal of the water resources in the semi-arid area. Hence, Eastern Nile area is characterized by a semi-arid climate, where groundwater sustains an important component of the water supply. In Khartoum groundwater sharing in domestic supplies was estimated to be about 60%

from the total water supplies in rural areas (GDGW)) whereas the Blue and the River Niles represent the main sources of groundwater replenishment in limit distances far from the rivers in the study area (Fig. 5)

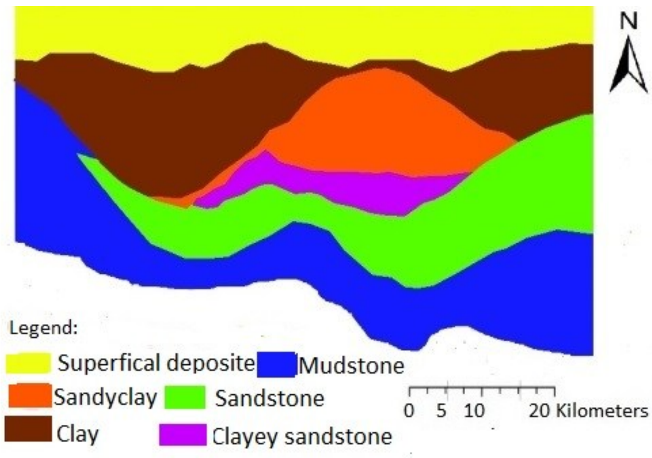


Fig. 3b: Lithological section in the area (N-S)

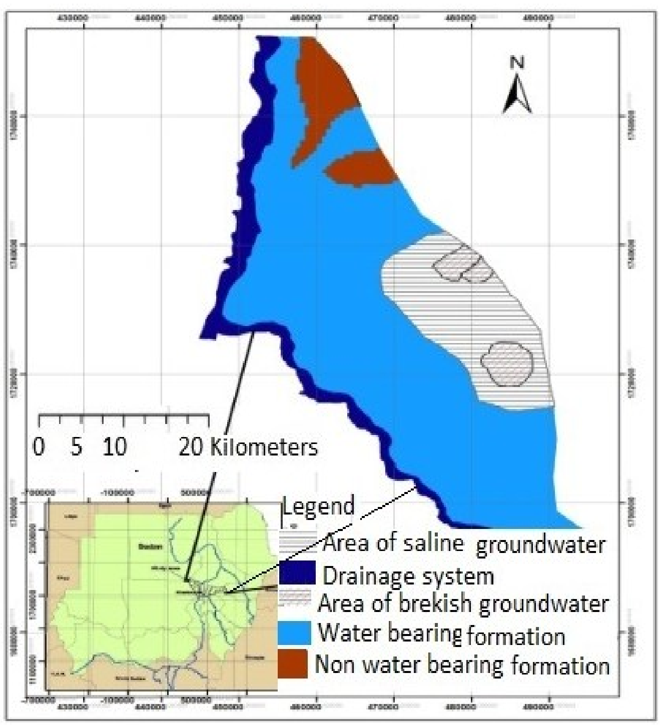


Fig. 4: Hydrogeology Basins

In order to evaluate the suitability of water for drinking, domestic, irrigation, and industry uses, the chemical characteristics of groundwater in area under investigation is a crucial task to be performed. Climatic condition, unplanned expansion and the rapid growth of population in the area under study may lead to serious changes in the physical and chemical constituents of the ground water. The sources of water supply are exposed to alterations of its physical and chemical characteristics due to its access to different rates of salinity or other pollutant with higher degree that exceeded its permitted average from the World Health organization (WHO) and the Sudanese national Standard (SNS).We can formulate the statement of the problem as in characteristics, purity state, salinity and pollution of groundwater in East Nile area.

In terms of Hydrogeology, to understand the geochemistry of groundwater is important for maintaining the water quality, effective utilization and development of this finite resource. The classical use of water analyses in groundwater hydrology is to produce information concerning the water quality. Interest in geochemistry of groundwater has increased during the past decade as evidenced by hydrogeochemical studies, which are becoming a firm part of regional hydrogeological studies. There are four basins in terms of hydrogeology point of view as follow water-bearing formation, area of brackish groundwater, area of saline groundwater and non-water bearing formation as shown in fig. (4). In the study area can be generally categorized into two main aquifers of the Nubian sandstone, upper aquifer and Deep or lower aquifer, this classification is supported by the lithological section in figure 3a, the upper aquifer is separated from underlying lower one by partial and sometimes completely impermeable overlying mudstone horizons (Fig. 3a).The horizons are varying considerably in their thickness and content throughout the area. In addition, the thickness of each aquifer is generally; variable in the average thickness of upper aquifer between 10-40 m while that of the lower aquifer is greater than 50m. Generally, the upper aquifer is of a semi-confined nature in areas far from the River Nile and tends to be water table in the areas close to the Nile the nature of the lower aquifer is almost confined due to the pressure exerted by the thick mudstone layer. Groundwater occurs mainly in the Nubian sandstone formation and the alluvial deposits of the Nile. They are believed to be hydraulically interconnected (Kheiralla, 1966). The static water level range between7-9 meters and 24 meters depending upon the distance from the Niles and lower one has static water level range from 26-40 up to 37 meters in some area, with higher values of tarnsmissivity and permeability (Bureau of Geological Research). The depth of the saturated zone is variable, ranging from 10m near the rivers to 60m at a distance of about 2-3km east of the Blue Nile (Mukhtar, 2000). The flow direction map to investigate the difference in the chemical contents (Fig. 5).

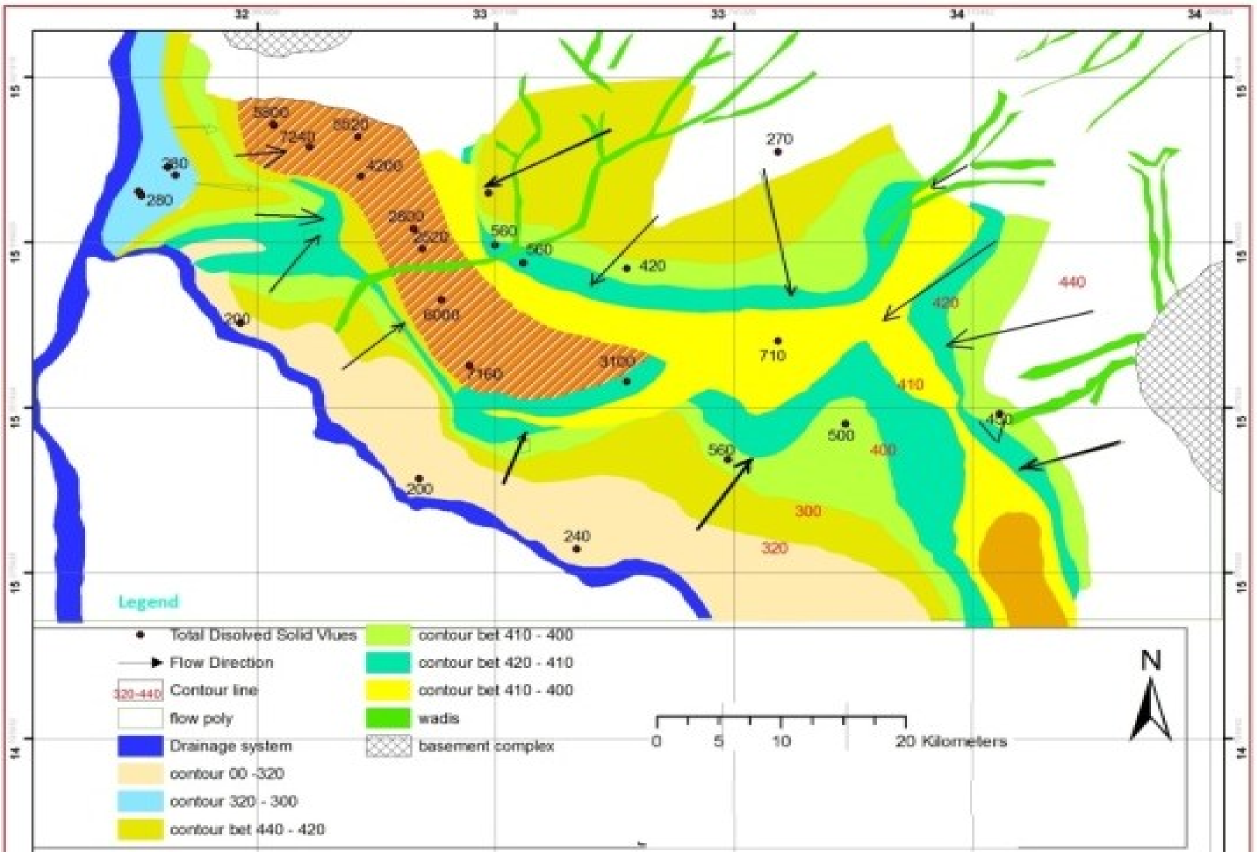


Fig. 5. The water flow directions (modified after Haggaz and Kheiralla, 1988).

Table (2): Chemical analysis data used in study.

No.	LOCAL	EC	pH	TDS	Cl	SO_4	Ca	Mg	Na	K	HCO_3	NO_3	TH
1	ELIDDELGA	2500	8	1840	5600	560	80	97	52	9	31	0	240
2	ELSIDAIR	1200	8.6	960	1800	245	10	40	320	40	389	0.1	325
3	ELGESMLA	900	7.6	720	125	205	20	15	240	10	285	0.1	185
4	ALSALAMA	4200	8.4	2950	180	150	25	10	65	0	354	0.1	330
5	EL GHAR	650	8.6	400	50	0	30	50	98	5	299	0.1	165
6	HALFAYAT	420	7.6	280	6	6	88	27	20	6.4	342	0.1	250
7	ELSAGGAI	350	8	260	25	40	35	15	20	5	199	0.6	312
8	ELTHUMANI	445	7.8	320	10	25	45	30	25	10	325	0.1	189
9	EL HALFAY	280	7.6	230	22	5	56	15	20	1.9	278	0.8	220
10	EL HALFAY	400	8.3	290	25	10	50	25	30	5	329	0	196
11	EL SAGGAI	350	8	260	20	40	35	5	20	5	402	0	178
12	EL SHIGLA	342	8	240	30	25	30	20	63	6.9	369	0.1	98
13	EL GIRAIF	428	7.7	300	30	30	40	15	25	5	296	0.1	125
14	EL FAZARR	560	7.6	3200	200	50	4	29	28	4	247	0.1	109
15	UMM DUREI	478	8.9	335	10	20	30	38	75	5	315	0.1	199
16	EL KADARO	645	8.7	356	40.4	51	36	33	159	0.4	198	0.1	234

17	AL KARADA	1219	7.1	853	92.3	100	38	19	204	5.4	354	0	169
18	EL SIDAIR	1820	7.7	1247	167	300	30	15	345	3.9	299	0	258
19	EL AULIAB	1034	7.4	723	17	195	45	21	437	5	185	0.1	402
20	EL NAYA N	1311	7	917	19.9	105	42	35	135	3.5	325	0.1	258
21	ELSIDER	1820	7.7	1247	114	300	39	35	345	2.2	178	0	367
22	ABO TELEH	408	7.4	286	22	9	29	33	58	3.9	358	0.1	342
23	EL ALOIAB	1034	7.4	723	26.3	195	33	16	437	6.5	346	0.1	198
24	WAWISSI(2	377	7.8	264	22.8	225	30	22	25	5.2	312	0	366
26	AISAILAT	444	7.7	311	9.2	17	43	18	17	4	402	0	195
27	ELSHEKH A	1500	8.3	1040	180	36	65	42	240	3	356	0.1	227
28	ELSH MUST	160	8.4	140	10	15	25	10	10	15	289	0	325
29	ELHIDEIBA	410	7.8	240	20	25	80	10	40	5	198	0.1	315
30	ELSHIREIK	350	7.8	240	10	25	34	10	25	5	288	0.1	299
31	AL MASEED	400	7.7	280	25	25	35	10	30	5	319	0.1	310
32	UMMASHUS	440	8	240	10	25	35	20	20	15	275	0.1	265
33	TAYBA ELM	550	8.1	360	10	40	25	20	50	5	271	0.1	342
34	UMM DOME	900	8.4	685	50	140	40	15	190	5	300	0.1	288
35	EL SHIAKH	457	8.3	320	40	95	45	25	40	7	328	0.1	362
36	UM DAWAN	1100	8.1	680	190	150	45	20	400	20	289	0.1	188
37	EL DEBABA	571	7.8	400	25	40	35	30	70	10	355	0	328
38	EL EILAFU	350	7	200	14	32	60	26	89	0	349	0	294
39	ELSHAIKH	1260	8.3	910	120	290	55	45	200	10	299	0	255
40	SOBA	242	7.6	170	12	11	35	12	25	11	320	0.1	318
41	WADI AL H	800	7.6	510	80	19	78	29	95	3	325	0.1	309
42	ELBAGAIR	300	8.1	230	24	34	26	14	155	3	325	0.1	322
43	ABU GRON	1260	8.6	865	66	104	13	12	235	15	369	0.1	287
44	SIREIW	950	8.4	540	140	115	24	39	146	6	366	0.1	222
45	Hattab west	795	7.9	557	62	130	30	28	199	6	300	0.1	289
46	AL KARDAB	1214	7.1	833	92	100	38	32	200	3	354	0.1	326
48	AL GHAR	496	7.5	248	19	53	53	96	35	4.9	375	0.1	
49	EL ZAKIAB	588	7.5	412	11	37	49	88	88	3.9	268	0	
50	AL FAKI H	1672	7.7	###	99	275	46	57	584	5.3	354	0	
51	EL AOLYAB	1001	0	701	45	112	30	54	101	9.7	269	0	
52	HATTAB	3000	8.2	###	620	620	75	95	500	11	314	0	
53	ELIDDELGA	2500	8	###	560	518	80	97	325	9	196	0	
54	EL KABASH	1004	8.7	672	38	109	15	17	142	12	254	0	
55	ESSILET	500	8.4	400	74	90	29	30	211	8.6	365	0.1	
56	EL SILET	750	8.4	525	155	151	31	10	20	2.3	425	0.1	
57	EL KHOGAL	900	7.9	800	140	260	60	55	312	4.6	400	0.1	
58	EL SAMRA	300	8.4	220	12	225	32	14	156	5.2	358	0.1	

59	SOBA	400	8.1	280	130	36	48	56	122	3.5	297	0.1
60	AL KARAAB	1219	7.1	853	92	100	38	38	204	4	266	0.1
61	EL KASR E	622	7.2	435	14	50	37	19	72	3	396	0.1
62	AWLAD KHI	931	7.2	652	99	115	50	22	85	5	385	5
63	EL AISAB	1810	7.2	###	87	90	52	51	161	10	268	0.1
64	EL AULIAB	1034	7.4	723	114	195	39	19	437	8.9	311	0.1
65	EL KANDAB	1210	7.1	853	93	100	38	38	204	4	300	0
66	ABO TELEH	408	7.4	286	20	9	42	16	58	5.7	345	0.1

Table (3): with imbalance ratio less than 10%

No.	EC	PH	TDS	Cl	SO_4	Ca	Mg	Na	K	HCO_3	NO_3	TH	Imbalance Ratio
1	2500	8	1840	5600	560	80	97	52	9	31	0	240	-6.04%
2	1200	8.6	960	1800	245	10	40	320	40	389	0.1	325	1.65%
3	900	7.6	720	125	205	20	15	240	10	285	0.1	185	-9.75%
4	4200	8.4	2950	180	150	25	10	65	0	354	0.1	330	0.63%
5	650	8.6	400	50	0	30	50	98	5	299	0.1	165	0.63%
6	350	8	260	25	40	35	15	20	5	199	0.6	312	-0.52%
7	445	7.8	320	10	25	45	30	25	10	325	0.1	189	-5.25%
8	280	7.6	230	22	5	56	15	20	1.9	278	0.8	220	-7.68%
9	400	8.3	290	25	10	50	25	30	5	329	0	196	: 0.45%
10	342	8	240	30	25	30	20	63	6.9	369	0.1	98	1.70%
11	428	7.7	300	30	30	40	15	25	5	296	0.1	125	7.62%
12	478	8.9	335	10	20	30	38	75	5	315	0.1	199	7.20%
13	645	8.7	356	40.4	51	36	33	159	0.4	198	0.1	234	6.62%
14	1219	7.1	853	92.3	100	38	19	204	5.4	354	0	169	6.65%
15	1820	7.7	1247	167	300	30	15	345	3.9	299	0	258	8.33%
16	1034	7.4	723	17	195	45	21	437	5	185	0.1	402	0.61%
17	1820	7.7	1247	114	300	39	35	345	2.2	178	0	367	7.20%
18	1034	7.4	723	26.3	195	33	16	437	6.5	346	0.1	198	0.29%
19	377	7.8	264	22.8	225	30	22	25	5.2	312	0	366	6.62%
20	410	7.8	240	20	25	80	10	40	5	198	0.1	315	0.48%
21	400	7.7	280	25	25	35	10	30	5	319	0.1	310	-4.88
22	1100	8.1	680	190	150	45	20	400	20	289	0.1	188	9.73%
23	800	7.6	510	80	19	78	29	95	3	325	0.1	309	-6.91%
24	1260	8.6	865	66	104	13	12	235	15	369	0.1	287	0.53%
25	1214	7.1	833	92	100	38	32	200	3	354	0.1	326	8.32%
26	496	7.5	248	19	53	53	96	35	4.9	375	0.1		4.30%
27	900	7.9	800	140	260	60	55	312	4.6	400	0.1		2.99%
28	1034	7.4	723	114	195	39	19	437	8.9	311	0.1		0.06%
29	408	7.4	286	20	9	42	16	58	5.7	345	0.1		5.39%

3. Results and discussions

3.1 Results

The range of desirable limit of pH of water prescribed for drinking purpose by and WHO is 6.5–8.5 while that of EEC [Environment European Commission] is 6.5–9.0.The analyzed groundwater samples are within the limit prescribed by WHO (world health organization),SNS [Sudanese National Standard] and EEC [Environment European Commission]. Salinity is contributed by , factor 1 or Component 1- It is contributed by sodium Na^+, sulphate (SO_4^-) ,electrical conductivity bicarbonate (HCO_3^-), this indicate that mineralization of water which are all related to groundwater salinization, which explain 29.74% of variance of data(Table 4).

Component 2- It is contributed by strong correlation between sulphate (SO_4^-) and chlorides(Cl^-) this indicate that mineralization of water which are all related to groundwater salinization due to sulphate (SO_4^-) and chloride(Cl^-). Calcium (Ca) and magnesium (Mg), were explain 15.696 % of variance of data. This factor may be related to the dissolution of Ca^+ & Mg^+ bearing minerals. Component 3**-** which explains 10.027 of variance, is contributed by Potassium (K^+) and Total dissolve solid (TDS) which reflect the dissolution of minerals. Component 4**-**, which explain 9.642 % of variance, is contributed by nitrate (NO_3^-) and bicarbonate (HCO_3^-), which reflects the groundwater mineralization.

Table 4: Factors of water constituents

No. of Component	Present Percentage of each	Cations and Anoins
Component 1	29.74%	Na^+ ,SO_4^- , EC , and HCO_3^-
Component 2	15%	SO_4^- , CL^- , Ca^+ , and Mg^+
Component 3	10%	k^+ , TDS
Component 4	9%	NO_3^- , HCO_3^- , and SO_4^-

There is no much distinct variation in the components. The concentrations increasing to the North and South-West of the study area based on Hill- Piper trilinear diagram (Fig. 6). Four chemical water types were product Mg-Na-Ca- HCO_3-SO_4-CL Facies, Mg- Ca-Cl-HCO_3, Facies Mg-Cl-HCO_3, and Facies Ca-Na-Mg-HCO_3 Facies forming the dominant water types in the area. Strong correlation between SO_4 and chloride Cl this indicate that mineralization of water is due to SO4 and Cl.

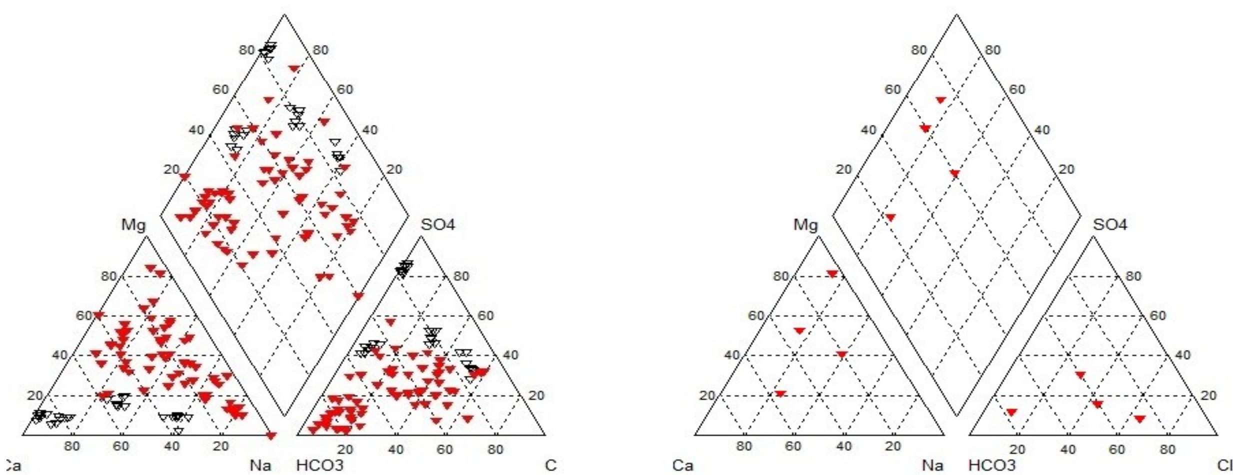


Fig. (6): Interpretation of Piper diagram for the four chemical water types

3.2 Discussions

The chemical analyses of 66 boreholes are shown in Table (2) the pH values of groundwater are varies from 7.1 to 8.9 indicating slightly alkaline nature. Groundwater's with pH value above 10 are exceptional and may reflect contamination by strong base such as NaOH and Ca $(OH)_2$. The slight alkaline nature of groundwater may be due to the presence of fine sediments in the aquifer mixed with clay and mud, which are unable to flush off the salts during the monsoon rain and hence retained calcareous material (Kanker) in the sediments of the aquifer. Hence (Table 2) show carried out where concentration of total dissolved solids (TDS), pH, electric conductivity (EC) and the major constituents (Ca^{2+}+, Na,$^{2+}$$Mg^{2+}$, K^{2+}, HCO_3, SO_4^{2-}, Cl-, NO_3^-). It gives a General outline of the results for measured values of individual wells.

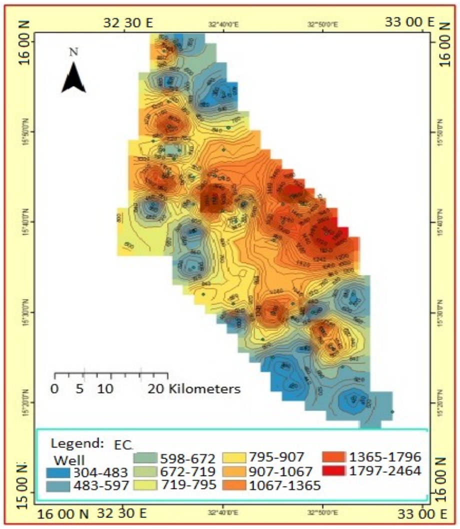
To characterize groundwater quality in study area, spatial distribution maps below were constructed and examined it were shown similar distribution patterns. Electrical Conductivity (EC) (Fig.7a), according to Langengger (1990), the importance of the electrical conductivity is a measure of salinity, which greatly affects the test and thus has significant impact on the user's acceptance of the potable water, according to Millville and Suffer (1987), the single most important class of consumer complain's with regard to water supplies. The EC varies from 284 to 4200 Ω/cm, these measurements indicate that there are fresh water (<500 Ω/cm) and brackish water (1500 -5000 Ω/cm). Moreover, the electrical conductivity (EC) value of the groundwater in the upper aquifer indicates lateral and vertical distribution almost similar to that of the TDS.

The hardness in the upper aquifer ranges from moderately hard (60-120ppm) along the Nile, to very hard (450ppm) towards northeast of the study area. The hardness increases eastward and gradually decrease towards the River Nile and Blue Nile due to effects water replenishment. Total hardness (TH^+) the mean values range and a standard deviation were measured as 69 mg/L. Accordingly, the groundwater quality in study area is generally of medium hardness where is hard to very hard water is shown in the north –south trending trough parallel to the Nile River (Elkalashib,). This could be attributed to natural dissolution processes of carbonate mineral (kankar nodules) at the upper soil zone, weathering of host rocks.

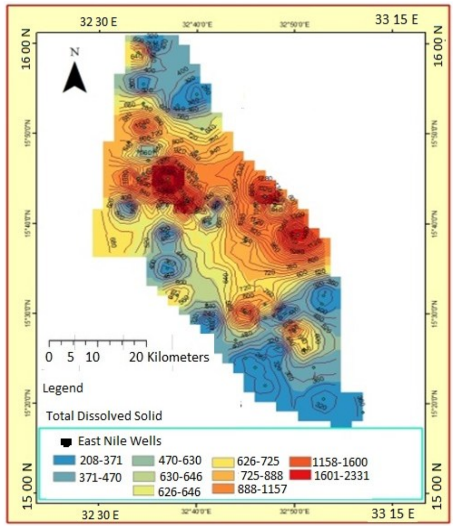
The TDS were determined by evaporating the water samples to dryness (at 180c) or by computing them from the electrical conductivity values using the conversion factor 0.65 (According to Robinove et. al, 1958). Based on the TDS values, a restricted zone of slightly saline water (>1000ppm) within the upper aquifer is observed in the northern part of the area. This value is reported in well Elmahalab, where the upper aquifer contains fresh and suitable water (< 1000 ppm). Total dissolved solids and major concentration of water at any point in the upper aquifer are related to flow and approximately to the fresh and saline water interface, as recognize in the sharp contact of the two aquifers. This indicates that, in the unconfined to semi confined aquifers TDS is low and in area where the system is confined to semi confined in lower aquifers zone the TDS is high (Table 2). However, Saeed (1976) found that the hydro chemical composition of the basement rock water north of Jebel EL-Seilietat is characterized by TDS ranging from 1170 to 3200 ppm, in the water of the upper aquifer increases towards the southeast of the area. The TDS values (Fig. 7b) varied widely form 280ppm near the Niles to 2950 ppm (Hattab) towards the southeast cornet. While, in the lower aquifer TDS increase towards the northeast (3200ppm)(EL FAZARR) and gradually decreases towards the Niles (<500 ppm) and southeast(>1000 ppm).This may be related to dense mudstones beds intercalation and low groundwater circulation rate, The high values were recorded at the western side (EL Fazarr, Hattab and Elsider) wells and south-west as well as anomalous zones at the central part of the area (Elsamara E). These may be attributed to leaching processes along the flow direction, high rates of evaporation and anthropogenic activities prevailing in the area Total dissolved solids in the area varies from 140 to 3200 mg/l with a mean 684.5046 and a standard deviation of 600.44758 mg/l,(Table 2) .

The concentration of TDS is more than the maximum permissible limits in the wells the western side of the study area Eelshegla. Table 2 shows changes in the values of TDS and EC in water samples. The TDS and EC decreased with pumping, which show the effect of dilution due to income of fresh water in the same well. This because that, the first coming water is stagnant water in the column of the well. The mean values of (TH^+) ranges and a standard deviation were measured as 69.40531 mg/L (Table 2) and the Skewness is ranging between the -0.466 to 0.297 as well as for Kurtosis between -0.538 to 0.586. Accordingly, the groundwater quality in study area is general of medium hardness where hard to very hard water visualized in the north –south trending trough parallel to the Nile River and western part of the area. This could be attributed to natural dissolution processes of carbonate mineral (kankar nodules) at the upper soil zone, weathering. The high values were at the western side (El Fazarr, Hattab and Elsider) wells and south-west as well as anomalous zones at central part of the area (Elsamara E). These may be attributed to leaching processes along the flow direction, high rates of evaporation and anthropogenic activities prevailing in the area. The Sodium in the upper aquifer is highly anomalous of Sodium toward the southeast part as shown in table 2. The anomaly at the east the sodium ion shows a high degree of conformably with the TDS distribution due to the ion exchange with calcium ion, in which Na^+ released.

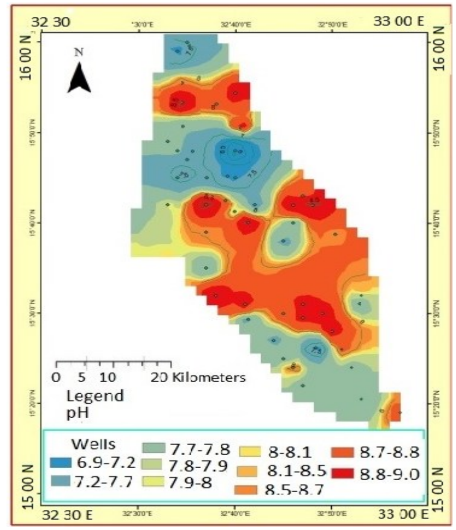
From the clay minerals such ion exchange could show. The sodium ion (Na) also can produce from the dissolution of halite (NaCl). The chloride concentration is rather uniform over the study area and the most it varies generally between 9.5 to 560 ppm. In the upper aquifer has a chloride concentration of more than 560 ppm which observed as recorded in the Table (2) at the eastern part of the study area, it is gradually decreased towards the south and west in the lower aquifer. It can be seen that, higher concentrations were in the east decrease towards the western and southern part of the study area.



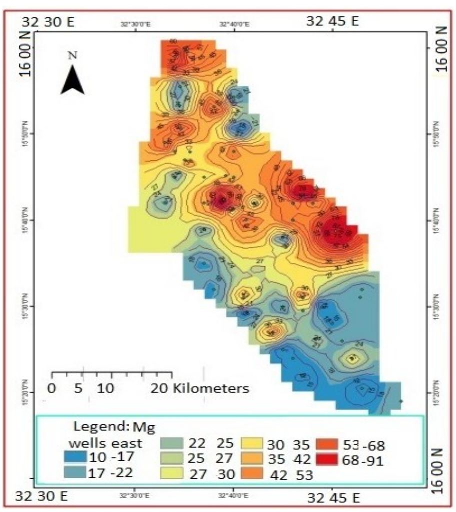
Spatial distribution of EC



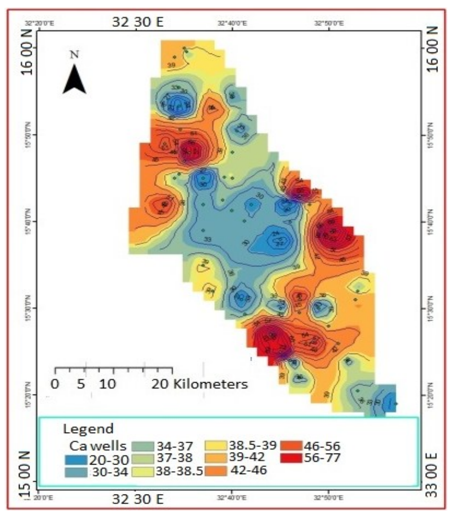
Distribution of TDS



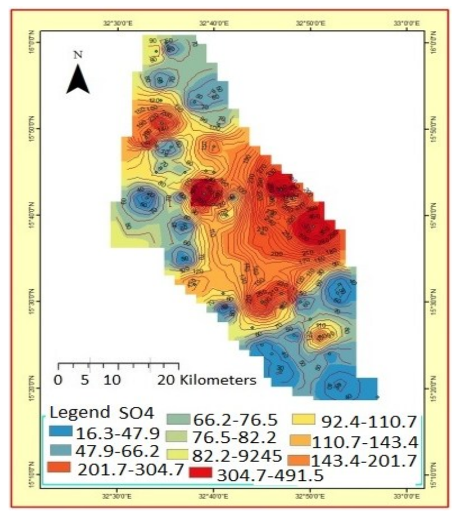
Distribution of pH



Distribution of Mg



Distribution of Ca



Distribution of SO_4

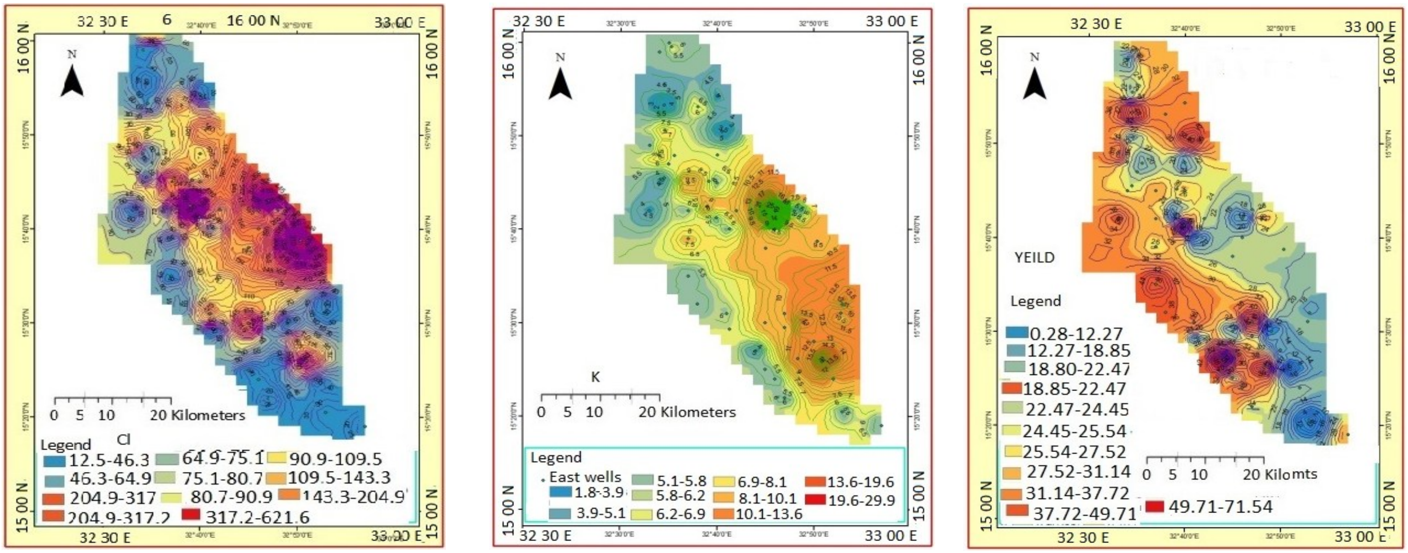


Fig. 7. Spatial distribution of physic-chemical properties of groundwater in the upper & lower aquifers

Whereas Table (2) shows the minimum, maximum, mean concentration, standard deviations, Kurtosis and Skewness of all parameters studied, Table (5 and 6) show the Correlations Descriptive and Frequencies Statistics. The multivariate statistical technique aims to reduce number of variables and to detect in structure in the relationships between these variables, to classify them (Davis, 1986). Principle component analysis is the most commonly used approached in factor and principle analysis reduce the dimensionality of data by finding out associations between variables, using few components that explain the major variations within the data. The correlation matrix of hydrochemical parameters shown in Table (5) was used in the factor analysis. To determine the number of principal components to extract, a scree plot (Table 6) of all components (variables) against their eigenvalues was constructed, and then only components having eigenvalues greater than one were chosen to be extracted. Extraction was performed by principle component analysis, using variance- maximizing (varimax) method the first component or factor explains 37. 8 % of the data variance it is contributed by sodium, chloride and sulphate and electrical conductivity, which are all related to groundwater Calcium, sulphate and magnesium form a second compound which explain15.7% which reflects groundwater mineralization shown in Table (7).

Table (5): Frequencies, statistical parameters of the groundwater analysis of the study area

	Econd	pH	TDS	Cl	SO4	HCO3	NO3	Ca	Mg	Na	K	TH
Mean	918.3	7.74	685	89.5	122.9	40.59	31	152	6.68	311.5	0.15	###
Std. Deviation	722.5	1.09	601	123.6	131.4	17.26	22.6	140	5.64	67.34	0.62	69
Skewness	2.2	-5.79	2.36	3.02	1.95	0.83	1.72	1.17	3.59	-1.35	7.66	-0.5
Minimum	160	0	140	6	5	4	5	10	0	31	0.01	98
Maximum	4200	8.9	3200	620	620	88	97	584	40	425	5	402

Table (3): Pearson Correlations Statistics

Correlations				Pearson Correlation							
	TDS	ECOND	PH	CA	MG	Na	K	CL	SO4	HCO3	NO3
TDS	1	.811**	-0.003	-0.004	.320**	.366**	0.015	.685**	.574**	-0.228	-0.036
ECOND	.811**	1	0.008	0.18	.385**	.506**	0.039	.722**	.705**	-0.186	-0.033
PH	-0.003	0.008	1	-0.034	-0.122	0.027	0.066	0.104	0.053	0.065	-0.054
CA	-0.004	0.18	-0.034	1	.466**	0.049	-0.205	.353**	.253*	-.247*	0.072
MG	.320**	.385**	-0.122	.466**	1	0.239	0.07	.597**	.503**	-.292*	-0.083
Na	.366**	.506**	0.027	0.049	0.239	1	0.213	.424**	.631**	-0.018	-0.097
K	0.015	0.039	0.066	-0.205	0.07	0.213	1	0.177	0.198	0.016	-0.063
CL	.685**	.722**	0.104	.353**	.597**	.424**	0.177	1	.838**	-.302*	-0.016
SO4	.574**	.705**	0.053	.253*	.503**	.631**	0.198	.838**	1	-.282*	-0.043
HCO3	-0.228	-0.186	0.065	-.247*	-.292*	-0.018	0.016	-.302*	-.282*	1	0.106
NO3	-0.036	-0.033	-0.054	0.072	-0.083	-0.097	-0.063	-0.016	-0.043	0.106	1
	** Correlation is significant at the 0.01 level (2-tailed).										
* Correlation is significant at the 0.05 level (2-tailed).											

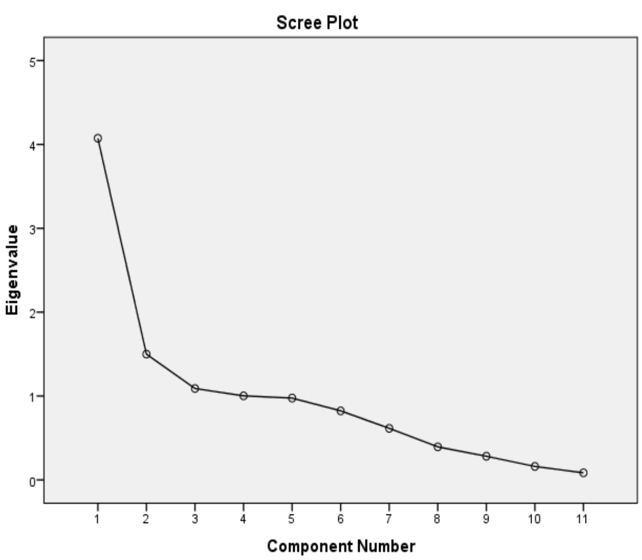


Fig. (8a): The Scree plot

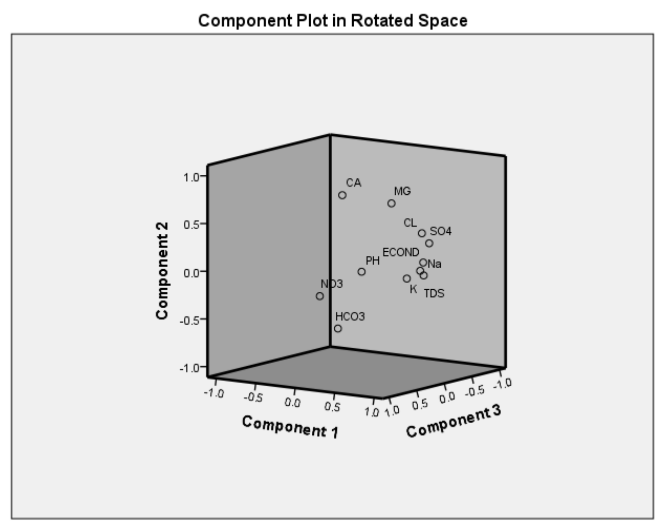


Fig. (8b): The components score coefficients in rotated space.

Table (4): Total Variance Explained

Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	3.569	29.741	29.741
2	1.883	15.696	45.436
3	1.203	10.027	55.464
4	1.157	9.642	65.106
Extraction Method: Principal Component Analysis.			

To investigate the relationships among the different hydrochemical parameters of the area, scatter diagram (x-y plots) were constructed using logarithmic scale in most cases and arithmetic in the others. The correlations between sodium as cation and chloride, HCO_3 and SO_4 (Fig. 9 a-e) respectively.

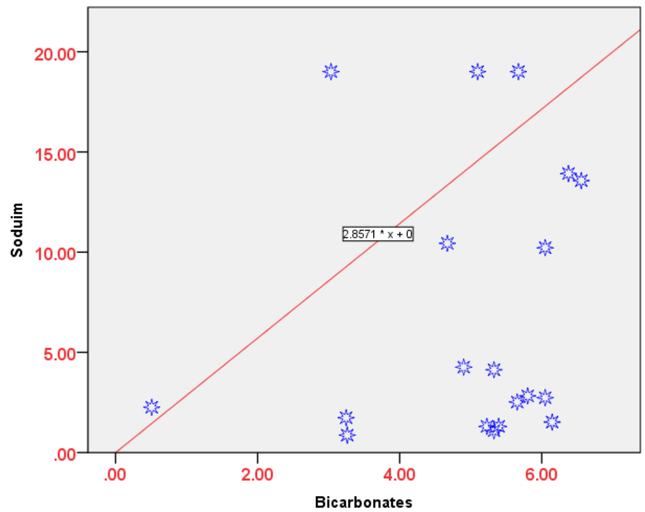


Fig. (9a): Sodium exchange ratio with Bicarbonate

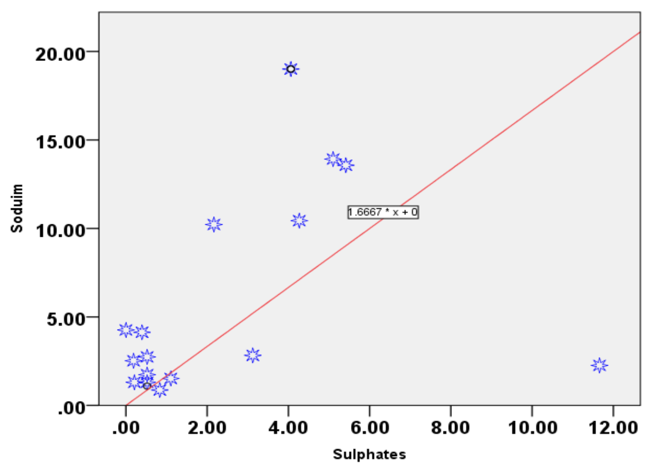


Fig. (9b): Sodium exchange ratio with Sulphate

All plotted ionic concentration are in mg/l and below one are in meq/l. Correlation coefficient is commonly used to measure the strength of relationships between the two variables, and whether one variable increase and the other decrease or the opposite. Different measure of correlation were devisedby Pearson,s R, (1992, 1995) which is a simple and most commonly used . A Pearson correlation matrix was calculated for different pairs of major ions.

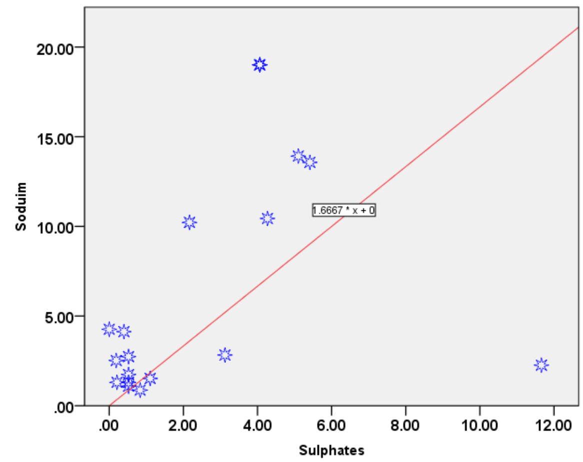


Fig (9c): Soduim with Sulphate

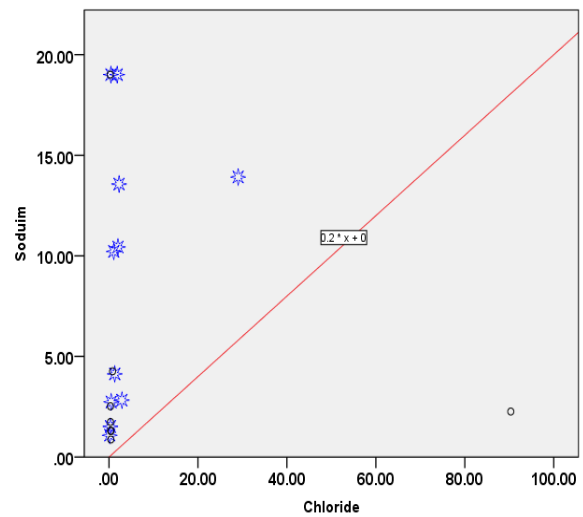


Fig (9d): Sodium with chloride

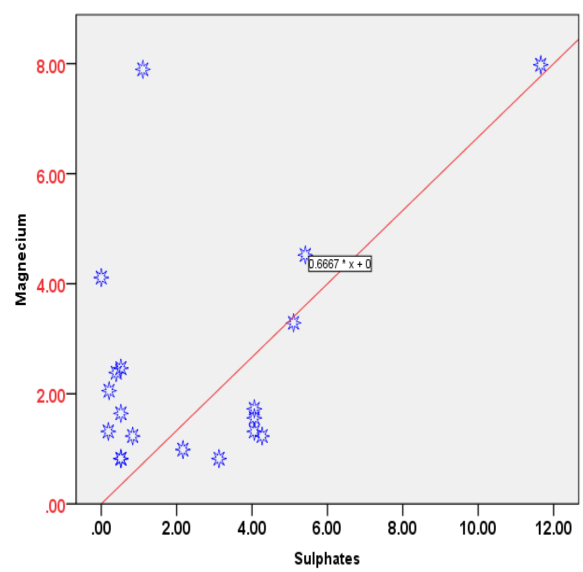


Fig (9e): Magnesium with Sulphate

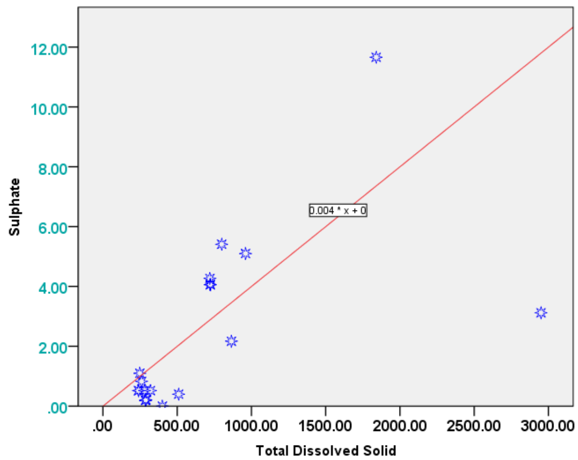


Fig (9f): TDS with Sulphate

Plots of Na against, SO_4 (Fig.9c) approximately shows similar pattern, almost all points are close and fall above ratio 1:1. In case of Na^+ versus Cl (Fig 9d), EC, and SO4 these relationships indicate that groundwater salinization is result of increasing Na^+ and Cl Concentrate. There is strong positive correlation between Mg and SO_4 (Fig 9e) suggest that the process of dissolution of evaporitic minerals is active, also the correlation between TDS and SO_4 (Fig.9f) which indicate the hydrolysis result. Cluster Analysis is an assortment technique designed to classify objects by assigning observation in each object to groups in away is less homogenous and distinct from other groups. This technique provides graphic output dendogram (Fig. 10).

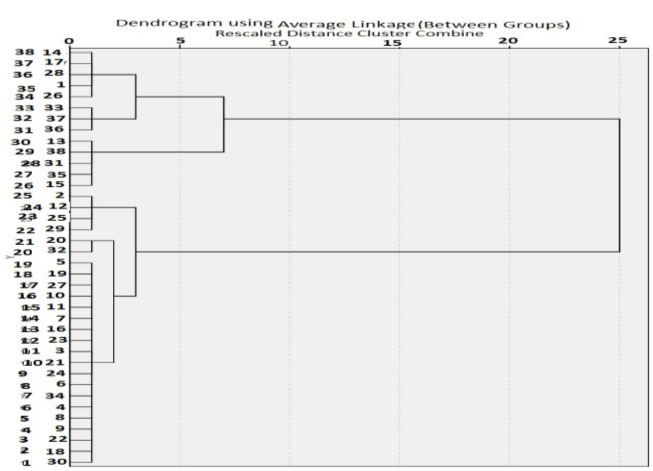


Fig. (10): The Cluster in Dendogram diagram

Ionic ratios in Nubian aquifers in study area are characterized by calcium, magnesium and sodium bicarbonate water type. This is attributed to the presence of high soluble salts calcite and dolomite, which are completely dissolved during resolution. Less soluble salts, such as halite and anhydrite, may only be partially dissolved, depending on the volume of infiltrating water and its contact time with salts.

Mg_m / Ca_m ratio (Fig. 11a), and the ratio of magnesium with chloride (Fig 11b) are normally in range between 0.5- 0.7 (Schoeller, 1956), whereas the ratio in the range of 0.7 – 0.9 are commonly associated with dolomite or dolomatic aquifers (Hsu, 1963). Figure (12) indicate Mg- Ca/ SO4+HCO_3+NO3: This ratio detects the relationship between the calculated lithologic Ca and Mg component and the HCO_3 by adding or subtracting Ca and Mg originating from cation exchange (Sami 1992). Mg- Ca/ SO4+HCO_3: Is more than 0.5 and less than 1.4. As weathering reaction of Mg and Ca produces HCO_3 in a ratio of 1:2 and 1:1 there is an accessory source of Mg and Ca. This indicates beside albite weathering some calcium –sodium plagioclase may contribute to weathering.

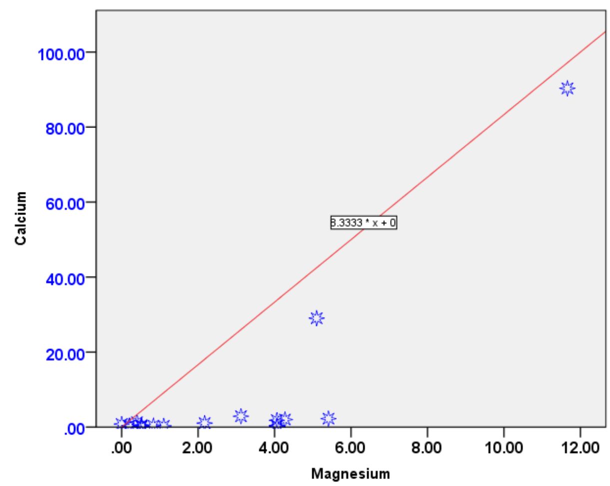


Fig. (11a): Magnesium with Calcuim

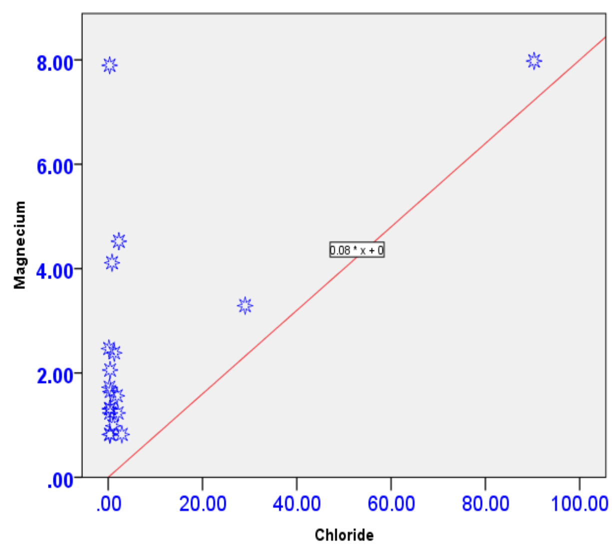


Fig. (11b): Magnesium with Chloride

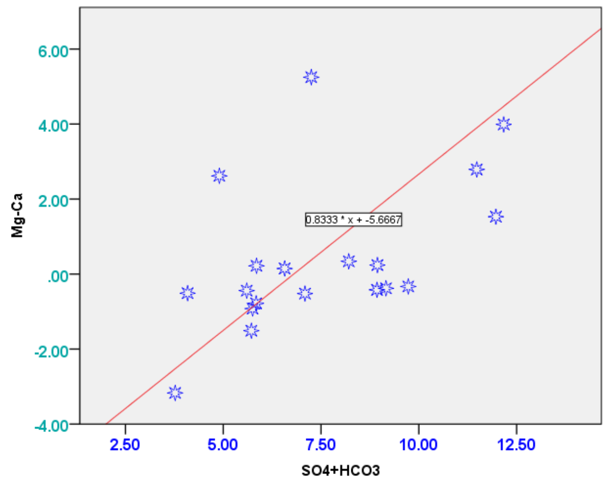


Fig. (12): Mg-Ca /SO_4+HCO_3+NO_3

Graphical Representation: The important task in hydrochemical investigation is the compilation and presentation of chemical data in convenient manner for visual inspection several commonly used graphical methods were available. These graphs were easy to construct and provide quick visual comparison of individual chemical analysis two diagrams were used in the present day. the chemical composition of groundwater types of the study area were distinguish and grouped by their position on the Piper diagram, where the concentration is assigned in %meq/l.

Interpretation of Piper diagram: Piper diagram was used to distinguish the groundwater types in the study area (Fig.13).

The distribution of the relative proportions of the main constituents is illustrated in the diagram. The dominant ion constituents characterized the ground water. In the study area four chemical water types were observed: Mg-Na-Ca-HCO_3-SO_4-Cl - facies; Mg-Ca-Cl-HCO_3 - facies, Mg-Cl-HCO_3 - facies and Ca-Na-Mg-HCO_3 facies, forming the dominant water types in the area (Fig 14).

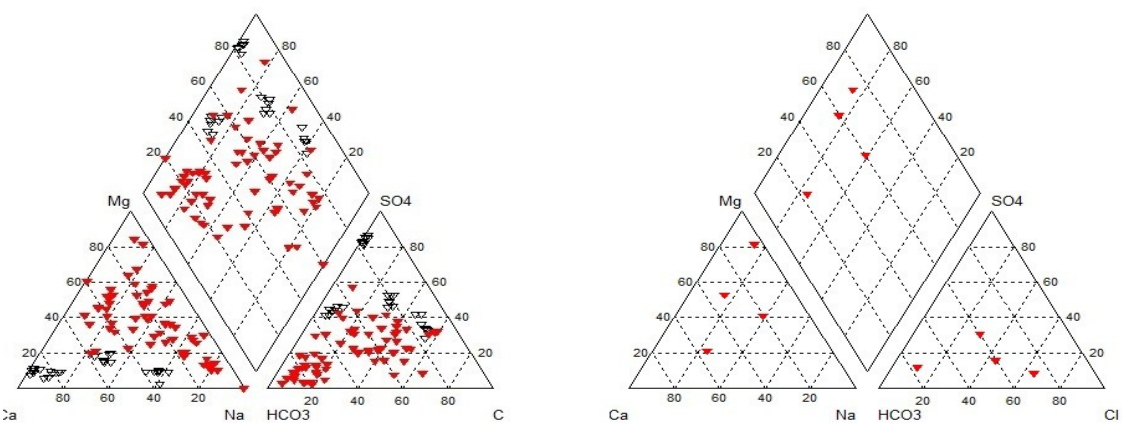


Fig. (13): Piper diagram used to distinguish the groundwater types

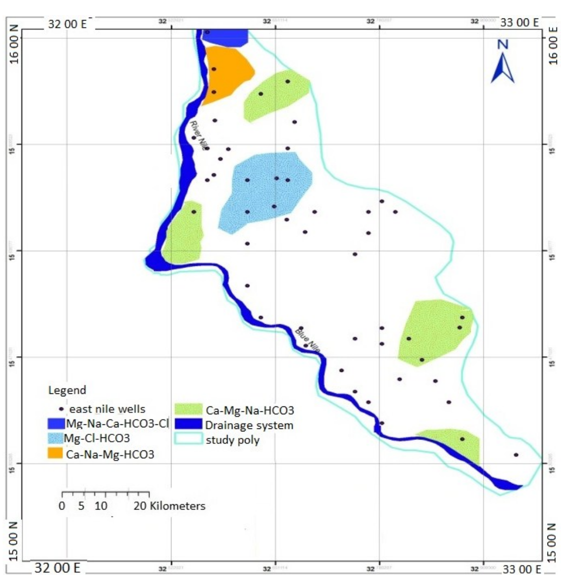


Fig. (14): Spatial distribution of hydrochemical facies based on Piper diagram

The quality of groundwater is a measure of its suitability for human and animal consumption and for use in agricultural that is the drinking and irrigation was assessed by calculation of sodium adsorption ratio (Fig 15).

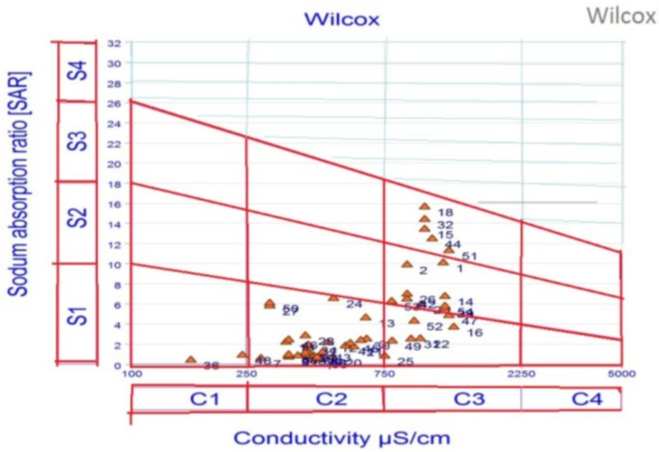


Fig. (15): SAR Diagram for water quality

Almond, D.C. (1996) found out the water quality is the result of input from atmosphere, aquifer minerals and pollutant sources such as industrial and urban waste and agricultural practice. Changes in groundwater quality may affect use and development of an aquifer. Except few samples having TDS greater than 1000 mg/l, most of the sample fall within the acceptable standard for drinking water of WHO (1993) and Sudanese National Standards. Generally, the groundwater has acceptable standards for irrigation except at high salinity zone (Fig.16).

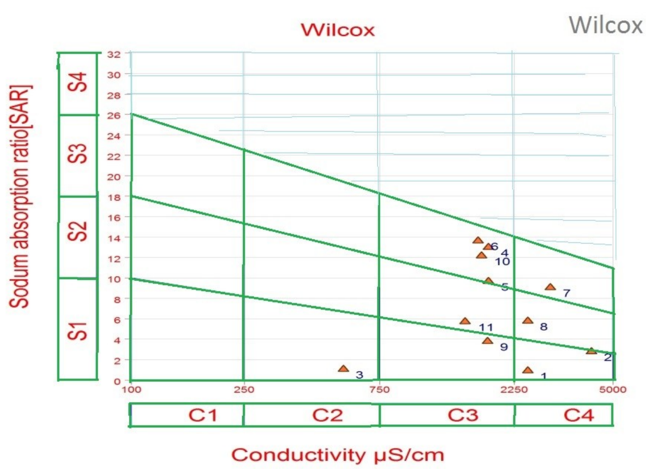


Fig. (16): SAR Diagram for salty water quality

4. Conclusions

Based on analytical results obtained from the groundwater chemistry and the hydrochemical processes the following were obtained, The concentration of salts by dissolution of minerals and cations- exchange the replacement of Ca and Mg by sodium, hydrochemical is modified by recharge from the Niles and the climatic factors and semi-arid of the study area) The water type near the river is Ca-HCO_3 and Ca-Mg-HCO_3 water. This indicates that the river is the main source of the recharge process.

The Ca++ and Mg++ ions are replaced by Na+ with distance from the River Nile due to the ion exchange processes, while HCO_3 is displaced and replaced by Cl- and SO_4— the process of dissolution. Generally, the groundwater quality which lies in the Nubian aquifer is fit for human and agricultural purpose except as few localities; conclusion can be given which contain ionic species as well as high electrical conductivity. Hydrochemical investigations in the study area indicate that water from the aquifer ranges from generally acceptable to good for domestic uses. However, as at certain locality form the lower aquifer is comparatively poor for both drinking and household purposes. The main water bearing units are sandstone and conglomerate in the Nubian sandstone formation with an average saturated thickness of about 20-80m. The mudstone in the area separated the aquifer into upper and lower ones, but regionally connected. The superficial deposit is generally thin layer and discontinuous which formed the alluvium aquifer of limited contribution

Groundwater is an important source for human consumption, and other uses in the study area, changes in its quality can have serious consequences on health. It is thus important to monitor any change on its quality. It is recommended to use the following steps to safeguard and improve groundwater quality

- Establishment a monitoring program for the chemistry of boreholes.
- Implementation of flow and hydrochemical models to facilitate detection of changes in quality every five years.
- Hazardous waste disposal practice in industrial and municipal site through deep wells should be stopped

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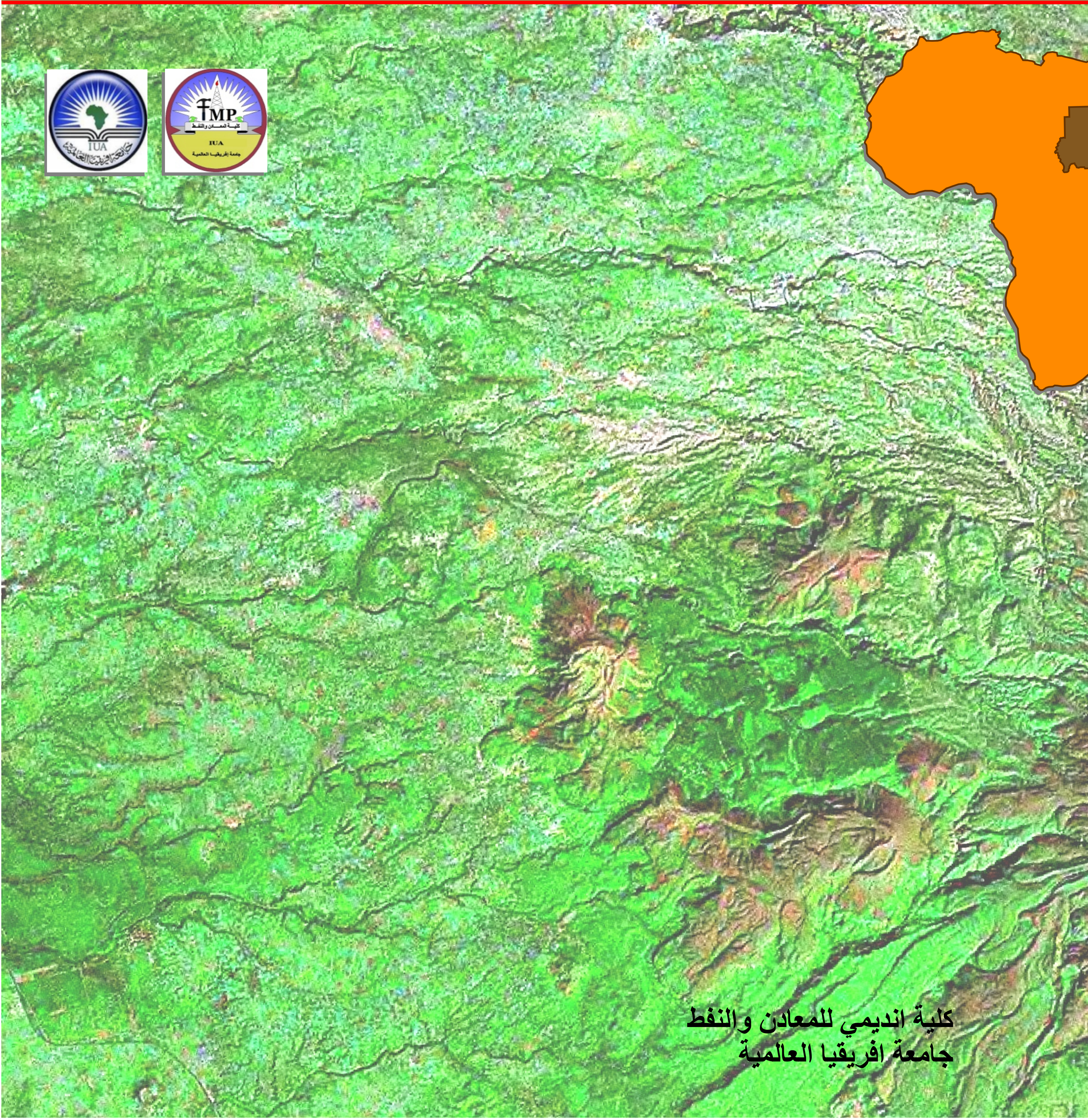
مجلة افريقيا لعلوم الأرض

مجلة علمية محكمة

المجلد الثاني ، ٢٠١٩



كلية انديمي للمعادن والنفط
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