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Research Paper

Rock-Water Interaction, Hydrochemical Facies and Salinity of Groundwaters from Al Bauga Area, River Nile State, Sudan

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ABSTRACT:- Rock-water interaction, hydrochemical facies and salinity of groundwaters at Al Bauga area were investigated. The chemistry of groundwater from the region is controlled by chemical and mineralogical composition of both basalts and basement rocks, while the waters characterized by medium to high salinity. The groundwater is characterized by high values of pH, EC and TDS. The high value of pH is affected by the hydrolysable salts and by change in the carbonate equilibrium due to the bioactivity of plants. High values of EC and T.D.S. are due to the process of washing of solids and other inorganic matter in the area. The source of sodium, magnesium, potassium and sulphate in the groundwater refer to the feldspar content of the basement complex and clastic sedimentary rocks and to the basaltic lava in the study area. The high concentration of chloride value in some places of the study area indicates the aridity of depositional environment.
The groundwaters in the Al Bauga sediments area show the dominance of Ca+Mg, Na+K cations hydrochemical facies and HCO_3, $Cl+CO_3$ anion hydrochemical facies. The high salinity conditions have resulted in the precipitation of mineral salts that occur as gypsum crystals near the surface in the area.

Keywords:- Hydrochemistry facies, Gypsum, salinity, water-rock interaction, Al Bauga.

I. INTRODUCTION

The sediments in the study area classified as Nubian Sandstone (Late Cretaceous- Palaeogene) which is the most important water bearing formation in the Sudan. This fact causes the attraction of the geologists and many scientists working in the fields of hydrogeology, sedimentology and engineering. This work reports for the first time an occurrence of brackish waters in the Al Bauga sediments area. In view of this, the present paper is completely dedicated to the chemistry of groundwaters from the region of Al Bauga area. In the region of study area, River Nile, main streams and little rain water constitutes the main sources to the recharge of groundwaters.

Of the total amount of rain water received by the region, majority of it is lost as run off, a little part of it is lost by evaporation and an insignificant part of it is percolated down into soils. The little amount of rain water that seeps into the soil causes an increase in the soil moisture content. If the soil moisture content is in excess of the field capacity, the excess amount of water subsequently percolates down into the sub soil and/or rock and may reach the saturated zone- the aquifer. During the process of seepage of water into the soil and its migration downward to the zone of saturation, the meteoric water undergoes a number of physico-chemical change by various reaction with soil/rock material through which it passes, this usually leads to the changes in the chemistry of water, which will constitute till the water acquires a steady dissolved minerals/salts content (**Siddig, 1992**). The change in the chemistry of water are generally, governed by such factors as the climatic conditions, nature of vegetation cover, chemistry and mineralogy of the host rocks, topography, time and human activity, which usually have complex inter- relationships (**Patil et al, 1990**). The changes in chemical equilibrium, many times, lead to the precipitation of certain salts that may eventually develop into a distinct lithotype (**Siddig, 1992**). Thus chemical characteristics of groundwater in various aquifers over space and time proved to be an important technique in solving many geochemical problems (**Adams et al., 2001**; **Alberto et al., 2001**; **Atteia et al., 2006**; **Grassi and Cortecci, 2005**; **Lopez-Chicano et al., 2001**; **Zanini et al., 2000**). In the Al Bauga sediments area, at a number of places, subsurface accumulation of evaporites minerals deposits of secondary precipitates, chiefly of calcareous and siliceous minerals. In view of this, it was felt necessary to study the role of groundwaters as well as that of the mineralogical and chemical composition of the host rocks in

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the precipitation of such secondary salts. The major purposes of this paper are to demarcate the water- rocks interaction, reveal hydrochemical facies and to determined salinity of groundwaters in the area.

II. GEOLOGY OF AREA AROUND AL BAUGA

Al Bauga area is situated in lower Easter part of Bayuda Desert (**Fig.1**). The general geology of Bayuda Desert according to **Vail, 1979**; **Barth & Meinhold, 1979**; **Almond, et al., 1983**; **Meinhold, 1983**) consists of Precambrian basement complex, Paleozoic sedimentary formation, Paleozoic igneous rocks, Mesozoic sedimentary formation, Cenozoic volcanic rocks and Pleistocene to recent deposits. Precambrian complex around A Bauga area includes Abu Harik and Kurmut Series. Nubian Sandstone formation of Late Cretaceous to Palaeogene ages is excellently exposed in the area of study (**Fig 2**). Volcanic lava flow is very huge with 20 km maximum long and average diameter 15 km and cover both Precambrian rocks and Nubian Sandstone formation. The lava flow classified as Alkali volcanic

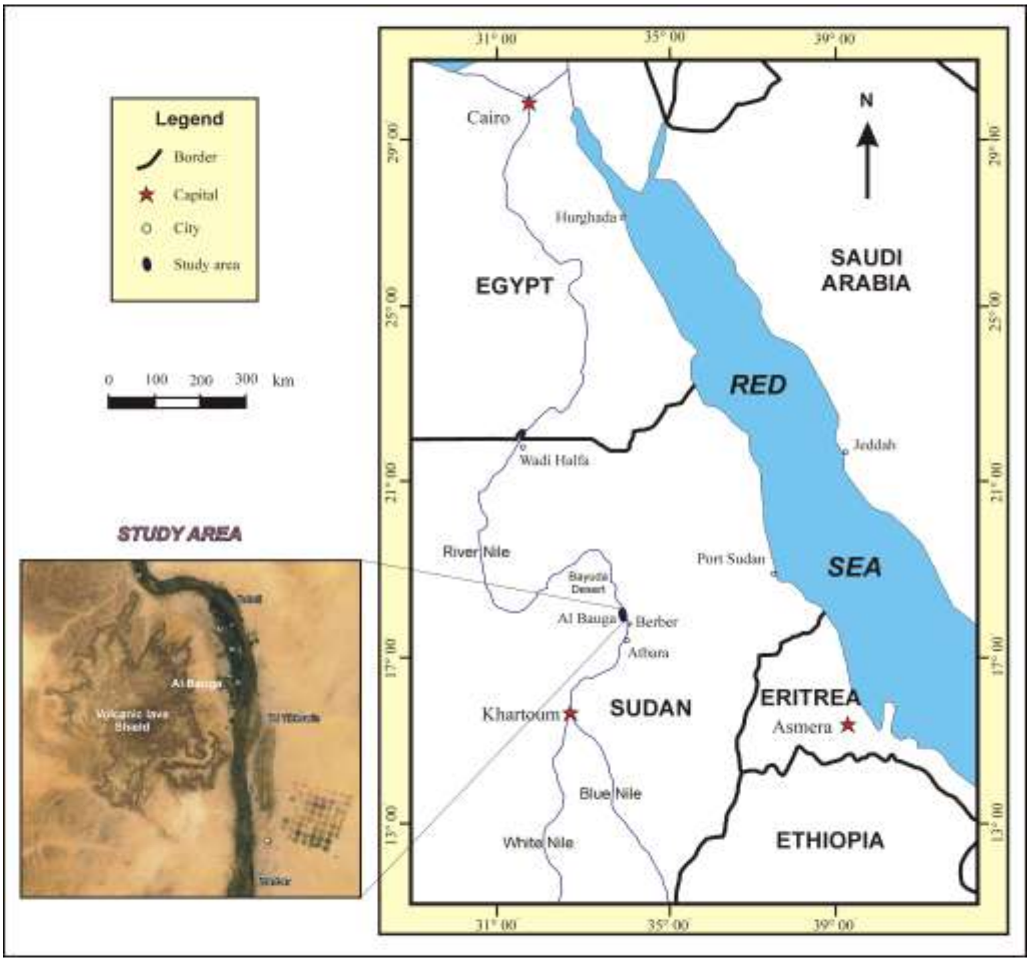


Fig. 1: Sketch map and landsat image show location of the study area.

Association that comprises of olivine basalts, trachyte and phonolite and dated from the Late Cretaceous to the Palaeogene (**El Nadi, 2015**). The Cretaceous sediments (Nubian Sandstone) in Al Bauga area were detailed investigated by **Hamed** (**2005**) and **Elzien, et al.,** (**2013**), whose instated that the depositional environment are including fluvio-lacaustrine, aeolian and fluvial systems. Geochemistry and tectonic setting of the Cretaceous sediments in Al Bauga were investigated in detailed by **Hamed,** (**2005**) and **Elzien, et al**., (**2015**).

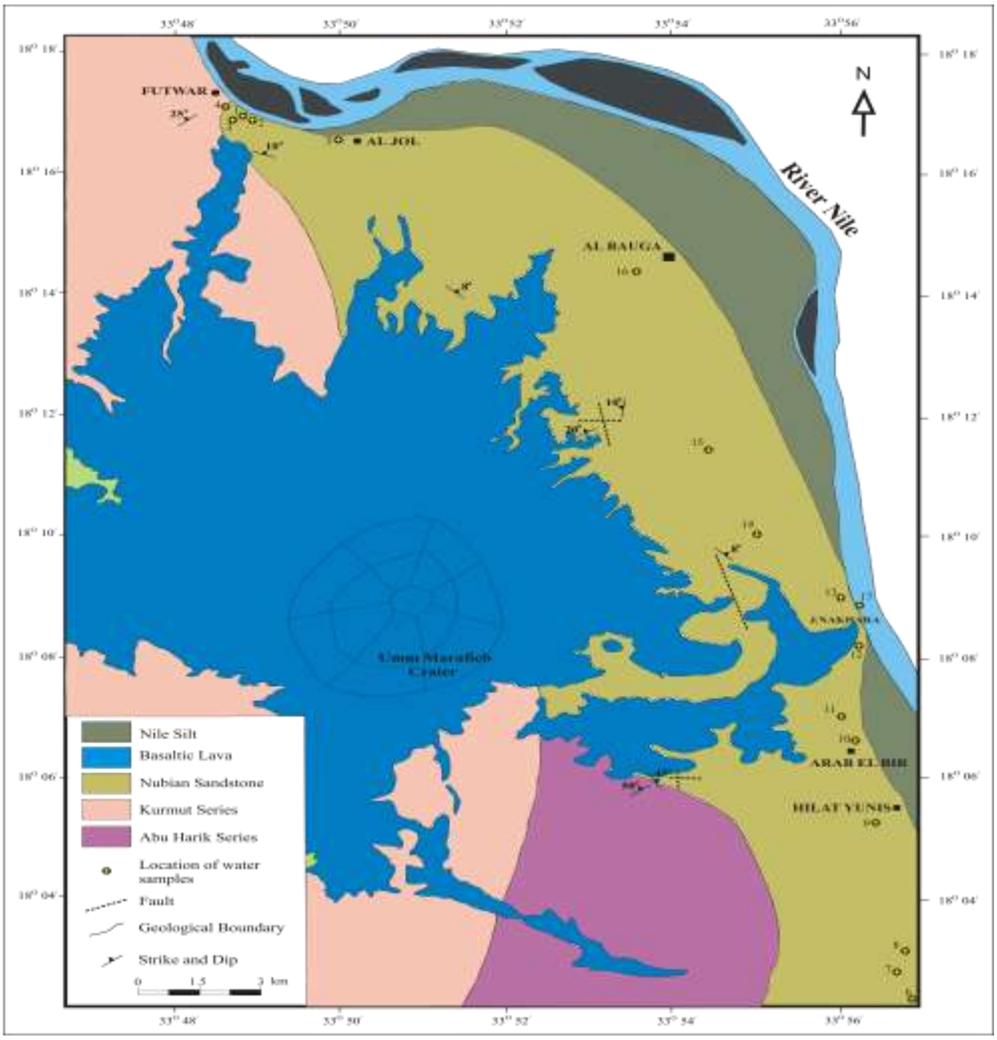


Fig. 2: Geological map of the study area includes locations of groundwater samples.

III. METHODS

In order to collect geological information, field surveys were conducted out in the area north, west and south of Al Bauga area. 17 water samples of dug wells distributed in the area from Futwar village in the north to khor Abu Haraz in the south of the area were collected. The results were obtained from the chemical analysis of the dug wells water samples are presented. **Table 1** showing locations, coordinates and static water levels of this dug wells and **Fig. 2** showing location of groundwaters samples in the study area. The water samples were collected from dug wells were analyzed and obtained results are presented in **Table 2**. Temperature, pH and EC were recorded in the field. Major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), and anions (HCO_3^{-}, CO_3^{2-}, SO_4^{2-} and Cl^{-}), in addition Fe^{2+}, F, NO_2 and NO_3 were reading in ppm. Sulphate, nitrate, nitrite, iron and fluoride were reading using spectrophotometer model 2400 DR / Hatch. Carbonate, chloride, magnesium and bicarbonate were reading using titration method. Sodium and potassium were reading using flamephotometer model PEP7. The water samples were analyzed for various parameters that define the quality of water, by standard analysis techniques of **American Water Works Association** (**A.W.W.A, 1984**) and **American Public Health Association** (**A.P.H.A, 1992**).

IV. RESULTS AND DISCUSSION

4.1. Chemistry of groundwaters

From the data presented in **Table 2**, it is observed that, the parameters including Potential of Hydrogen (pH), Electrical Conductivity (E.C), Total Dissolved Solids (T.D.S.), Total Hardness (T.H), Total Alkalinity (T.A), Temperature ($T^{o}C$) and anions like Chloride (Cl^{-}), Sulphate (SO_4^{2}) and cations like Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} show wide variation in their concentration. The pH value of the groundwaters in the study area are varying from 7.01 to 8.30 (**Table 2**), Abu Kebaida and Wawsi areas showing a

Table1: Locations, coordinates and static water levels (S.W.L.) in meters of the dug wells in th study area.

Well No.	Well name	Latitude	Longitude	S.W.L (m)
W.1	Futwar 1	18° 17′ 00.″	33° 48′ 50.4″	**5.90**
W.2	Futwar 2	18° 16′ 56.6″	33° 48′ 55.1″	**8.00**
W.3	Futwar 3	18° 16′ 55.2″	33° 48′ 45.8″	**7.80**
W.4	Futwar 4	18° 17′ 12.2″	33° 48′ 45.0″	**4.20**
W.5	Al Jol	18° 16′ 25.8″	33° 49′ 50.5″	**4.80**
W.6	Almaseed	18° 02′ 01.2″	33° 56′ 55.1″	**9.00**
W.7	Abu Haraz	18° 02′ 47.6″	33° 56′ 45.0″	**6.70**
W.8	Gad Allah	18° 05′ 09.6″	33° 56′ 50.8″	**6.30**
W.9	Hilat Yunis	18° 05′ 09.5″	33° 56′ 30.0″	**8.00**
W.10	Arab Albir	18° 06′ 35.9″	33° 56′ 18.6″	**7.60**
W.11	Alsalama	18° 07′ 06.3″	33° 56′ 00.0″	**6.00**
W.12	Nakhara	18° 07′ 55.3″	33° 56′ 11.3″	**6.60**
W.13	Abu Kebaida	18° 09′ 00.0″	33° 56′ 05.4″	**5.30**
W.14	Al Essiyab	18° 10′ 09.1″	33° 55′ 04.9″	**5.80**
W.15	Wawsi	18° 11′ 29.4″	33° 54′ 26.5″	**12.40**
W.16	Al Kahola	18° 14′ 20.9″	33° 53′ 46.9″	**7.25**
W.17	**The River Nile**	**18° 08′ 55.4″**	**33° 56′ 11.3″**	**--**

Higher pH value (**Fig. 3/A**). The desirable limit of pH value for drinking water as given by **World Health Organization** (**W.H.O., 1984**) is varies from 7.0 to 8.5 (in pH unit), while the maximum permissible level is 9.2 pH value. The pH of natural water is usually governed by the carbon dioxide / bicarbonate / carbonate equilibrium and lies in the range of 4.5 and 8.5. The high value of pH may be affected by the hydrolysable salts and by change in the carbonate equilibrium due to the bioactivity of plants. The values of EC in the study area ranges between 511 to 27500 µs/cm (**Table 2**) and Wawsi area showing a higher E.C value (**Fig. 3/B**). The E.C value depends on the ionic strength of water, it is related to the nature of various dissolved substances, their actual and relative at which the measurement made (**W.H.O., 1984**). In the study area the higher value of E.C refer to the washing of solid material. The concentration of total dissolved solids (T.D.S.) in the study area ranged between 358 ppm in Arab Albir area and 19250 ppm in Wawsi area (**Fig. 3/C**). The total dissolved solids include all materials in solution, whether ionized or not. It dose not include suspended sediments, colloids or dissolved gasses (**Davies** and **De wiest, 1966**- cited in **Rudwan, 2000**). The amount and type of dissolved solids depend upon the chemical composition of the solid rocks through which water percolates or in contact, the duration of contact and the temperature and pressure. Except dug well No. 3 and No. 15 (NE Futwar and Wawsi respectively) the values in the study area showed that all values fall within the permissible limit of standard given by **W.H.O.** (**1984**). The high concentration of T.D.S. is due to the process of washing of solids and other inorganic matter in this area.

The concentration of total hardness (T.H) in water wells of study area varies from 172 ppm to 5100 ppm, **Table** (**2**). Well No. 9 (Futwar) has a lowest value whereas; well No. 15 (Wawsi) shows the highest (**Fig. 3/D**). Hardness results from the presence of divalent metallization of which calcium and magnesium are most abundant in groundwaters. According to **Todd** (**1980**) the hardness in water is derived from the solution of carbon dioxide released by bacterial action in the soil, in percolation rainwater. The high concentration of total hardness in most of the study area is due to the washing of calcium and magnesium presents in the mother rocks. The concentration of sodium (Na^{+}) in water wells of study area varies from 8.0 ppm to 1774 ppm (**Table 2** and **Fig. 3/F**). The lowest is that of well No. 5 (Al Jol) and the highest is that of well No. 15 (Wawsi). In the study area the sodium concentration is high. Sodium is important member of alkali metal group in natural waters. The major natural sources of sodium are feldspar (albite), clay minerals, evaporites (such as halite, NaCl) and industrial wastes **(Todd, 1980)**. Hence, it can be considered that, the source of sodium in the groundwater of the study area refer to the feldspar constitute of the basement complex and clastic sedimentary rocks in addition to the Tertiary basaltic lava in the study area. In the study area, calcium (Ca^{2+}) concentration varies from 20 ppm to 508 ppm (**Table 2**). The lowest value is that of well No. 9 (Hilat Yunis), whereas, the highest value is that of well No. 15 (Wawsi), (**Fig 4/A**). Generally, calcium concentration is high in the study area specially Wawsi area which is showing a very high concentration of calcium. Amphiboles, feldspars, gypsum, pyroxenes, aragonite, calcite, dolomite and clay minerals are the major natural sources of calcium **(Todd, 1980).** So, it can be considered that, the basement complex and clastic sedimentary rocks are the main sources of calcium in the study area. The concentration of magnesium (Mg^{2+}) varies from 33 ppm, well No. 5 (Al Jol 2) to 1116 ppm, well No. 15 (Wawsi). From the data in **Table 2** and **Fig. 4/B** it is observed that, most of areas are showing high concentration of magnesium. The major natural sources of magnesium are amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals **(Todd, 1980**). Hence, it can be considered that, the sources of magnesium in the groundwater of the study area the Tertiary basaltic lava and the basement complex in addition to clastic sedimentary rocks in the study area.

Table 2: Geochemical characteristics of groundwaters in Al Bauga area.
TDS: Total Dissolved Solids. EC: Electrical Conductivity in µS/cm. TA: Total Alkalinity.
TH: Total Hardness.T: Temperature ^{O}C. Except pH and EC all values are in ppm

S. no.	Well name	pH	EC	T.D.S.	T.H	T.A	T	Na^+	Ca^{2+}	Mg^{2+}	K^+	SO_4^{2-}	Cl^-	Fe^{2+}	NO_3^-	NO_2^-	F^-
1	Futwar 1	7.40	561	393	174	255	37	80	25	36	2.03	105	36	0.01	2.2	0,02	0.92
2	Futwar 2	7.36	1051	736	172	178	35	150	22	36	5.76	205	114	-	1.32	0.02	0.00
3	Futwar 3	8.3	2350	1645	422	121	35	470	70	60	3.00	715	415	0.02	5.3	0,05	0.07
4	Futwar 4	8.2	754	528	188	232	38	60	33	38	3.98	105	43	0.02	12.3	0.91	0.0
5	Al Jol	7.8	553	387	208	183	37	8.0	48	33	8.00	70	35	0.0	29	0.04	0.41
6	Almaseed	8.1	713	499	176	220	40	92	32	35	3.51	165	46	-	7.5	0.08	0.31
7	Abu Haraz	7.41	953	667	342	220	37	44	77	63	9.00	210	110	0.11	2.6	0.01	0.79
.8	Gad Allah	7.93	941	659	-	268	37	112	64	28	4.95	185	68	0.02	4.4	0.03	0.0
9	Hilat Yunis	8.0	1026	718	292	520	38	177	20	55	8.50	145	60	0.0	1.76	0.04	0.07
10	Arab Albir	8.3	511	358	196	366	37	42	39	38	8.91	18	14	0.08	5.7	0.04	0.0
11	Alsalama	7.01	1043	730	364	414	40	31	40	77	9.50	30	83	0.01	2.2	0.05	0.98
12	Nakhara	7.4	1042	729	264	622	39	80	55	75	9.00	135	05	-	1.32	0.03	0.88
13	Abu Kebaida	8.3	751	526	306	439	37	128	23	66	3.55	100	102	0.03	1.76	0.06	0.07
14	Al Essiyab	8.2	595	417	250	350	39	56	30	54	4.44	65	36	0.0	0.88	0.23	0.0
15	Wawsi	7.61	27500	19250	5100	225	38	1774	508	1116	12.29	400	6461	0.07	0.88	0.01	1.23
16	Al Kahola	8.2	699	489	264	237	37	53	54	51	5.67	115	96	0.02	0.44	0.03	0.00
17	The River Nile	7.02	187	131	68	134	-	20	21	11	4.11	4.0	12	0.1	1.76	0.03	0.57

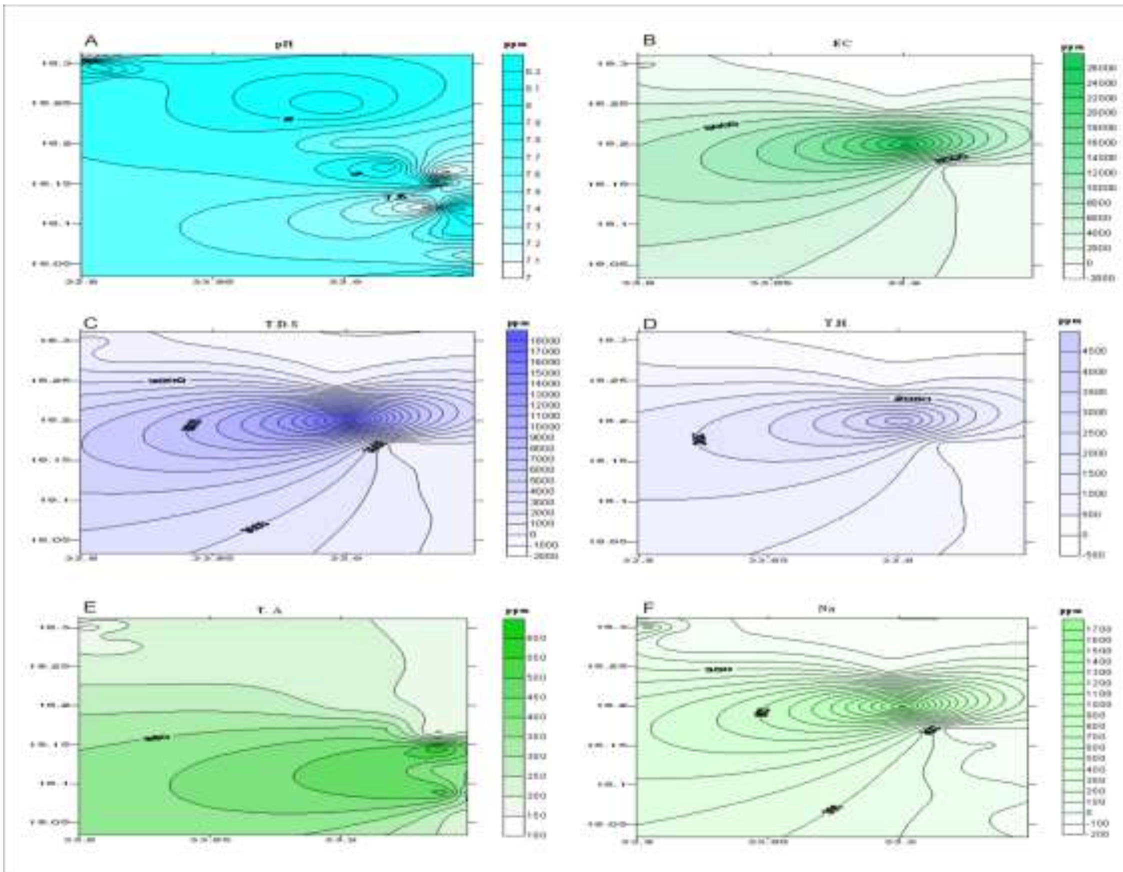


Fig. 3: Aerial distributions of pH, EC, T.D.S, T.H, T.A and Na.

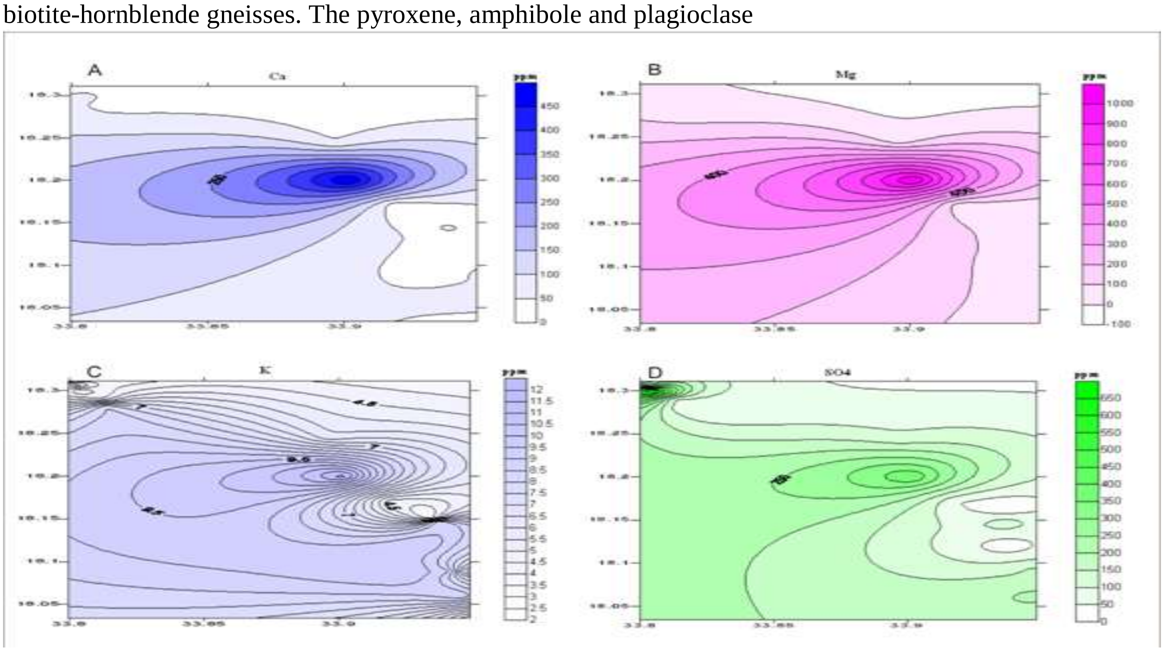
In the study area, potassium (K^+) ranges between 2.03 ppm and 12.29 ppm (**Table 2**). The lowest is that well No. 3 and the highest is that well of Wawsi (**Fig4/C**). Compare with sodium, except Wawsi area, generally, the concentration of potassium is very low in the study area. According to **Todd** (**1980**), the major natural source of potassium is feldspar (orthoclase and microcline), feldspathoids, some micas and clay minerals. Hence, it can be considered that, the source of potassium in the groundwater of the study area refer to the feldspar constitute of the basement complex and clastic sedimentary rocks. The concentration of sulphate (SO_4^{2-}) in water wells varies from 18 ppm to 715 ppm in the area of study (**Table 2**). It is noticed from **Table 2** and **Fig. 4/D** that, the concentration of sulphate is generally high. Sulphate is an important constitute of groundwater leaching from the upper soil layers. The major natural sources of Sulphate are oxidation of sulfide ores, gypsum and anhydrite (**Todd, 1980**). Hence, the Tertiary basaltic lava (Ummurafien Crater) is the source of sulphate in the groundwater of the study area. Chloride (Cl^-) concentration varies from 05 ppm (Nakhara) to 6461 ppm (Wawsi) in the study area (**Fig. 4/E**). The limit of chloride according to **W.H.O.,** (**1984**) is 250 ppm have been put more from the point of view of taste rather than its adverse effect on human health. Chloride in excess of 100 ppm imparts a salty taste. In nature of water chloride commonly less than 10 ppm in humid region, but to 1000 ppm in more arid regions (**Todd, 1980**). Hence the high concentration of chloride value in some places of the study area indicates the aridity of depositional environment.

4.2. Hydrochemical Facies

In addition to the climatic factors, it is generally observed that the chemistry of groundwaters is mostly governed by the mineralogical and chemical composition of various lithology with which the rain water interacts during its passage through rocks/soil down to the aquifer (**Siddig, 1992**). In view of this, the chemical data (**Table 3**) obtained for groundwaters from the Al Bauga sediments area were further processed in terms of hydrochemical facies. The concept of hydrochemical facies is formulated by **Back (1960**) to denote the diagnostic chemical characteristics of groundwaters. A review of literature carried out by **Pawar** (**1985**) in this regard, has shown that the concept of hydrochemical facies was, further developed by **Back** (**1961**), **Morgan** and **Winner** (**1962**), **Seaber** (**1962**) and **Back** (**1966**). The hydrochemical facies reflect the effect of chemical reaction between the rocks and mineral and the groundwaters (**Pawar, 1986**) and their classification can be shown with the help of trilinear diagram developed by **Piper** (**1953**). In order to understand and assess the hydrochemical facies of groundwaters from the Al Bauga sediments area, the chemical data for the selected samples (**Table 2**), were plotted on the trilinear diagram of **Piper** (**1953**). From the trilinear plots (**Fig. 5**), it is seen that the groundwaters in the Al Bauga sediments area show the dominance of Ca+Mg, Na+K cations hydrochemical facies and HCO_3, Cl+CO_3 anion hydrochemical facies.

4.3. ROCKS-WATER INTERACTION

The changes in hydrochemical facies have been show to be controlled by such factors as the mineral composition of parent material, physiography of the area, climatic conditions, nature of groundwater circulation and vegetation cover (**Pawar, 1986**). The Al Bauga sediments area is constitute chiefly of basalts, which are considered to be highly susceptible to chemical weathering, sandstone and calc-silicate rock in addition to biotite-hornblende gneisses. The pyroxene, amphibole and plagioclase



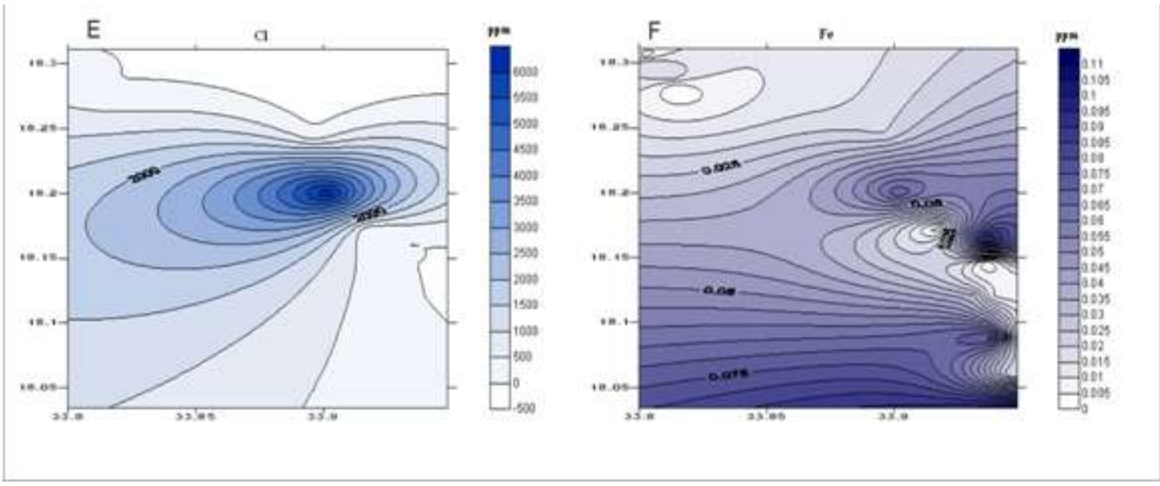


Fig. 4: Aerial distributions of Ca, Mg, K, SO_4, Cl and Fe.

Considered the chief constituent minerals of basalt, when come in contact with water, undergo chemical alteration involving a variety of chemical reactions. The rain water charge with CO_2, when infiltrates down into the rock mass through joints, cracks, fractures and other voids, comes into contact with the mineral matter. The initial pH of meteoric water is generally of acidic nature due to incorporation of atmospheric CO_2 and organic matter. At this pH, the minerals of the parent rock, breakdown and base

Table 3: The Cl/Cl+HCO_3, Na+K/Na+K+Ca ratio and SAR of the groundwaters from the Al Bauga sediments area.

Well No.	Cl/Cl+HCO_3	Na+K/Na+K+Ca	SAR
1	0.1	0.8	2.40
2	0.4	0.9	4.58
3	0.7	0.9	9.96
4	0.2	0.7	1.85
5	0.1	0.3	0.22
6	0.2	0.7	2.68
7	0.3	0.5	0.90
8	0.2	0.6	2.64
9	0.1	0.9	4.64
10	0.04	0.6	1.15
11	0.2	0.5	0.66
12	0.008	0.6	1.65
13	0.2	0.9	3.07
14	0.1	0.7	1.41
15	1.0	0.8	10.09
16	0.3	0.5	1.24
17	0.1	0.5	0.88

cations (Ca2+, Mg2+, Na+ and K+), being highly soluble in water, are taken into solution (Birkeland, 1984). This is leads to the change in the pH of percolating waters that become alkaline and eventually facilitate the mobilization of Si4+. In this process, the chemistry of percolation waters, change to a considerable extent during their passage through the rock mass (Siddig, 1992).

It has been further shown that the crystal size of the minerals, rock structure, porosity, regional structures, degree of jointing, length of previous exposure, time and other environmental factors such as faunal and floral activity to a great extent, influence the composition of groundwaters (Hem, 1970) and thereby, define the rate of reaction between the water and rock particles. The change in hydrochemical characters of water have also been shown to be governed by alkali and alkali earth elements. In this regard, Matthess and Harvey (1982) have shown that Cl- and SO42- are very mobile; Ca2+, Mg2+ and Na+ are moderately mobile, Si4+, P5+ and K+ are

Mobile and Fe^{2+} and Al^{3+} are slightly

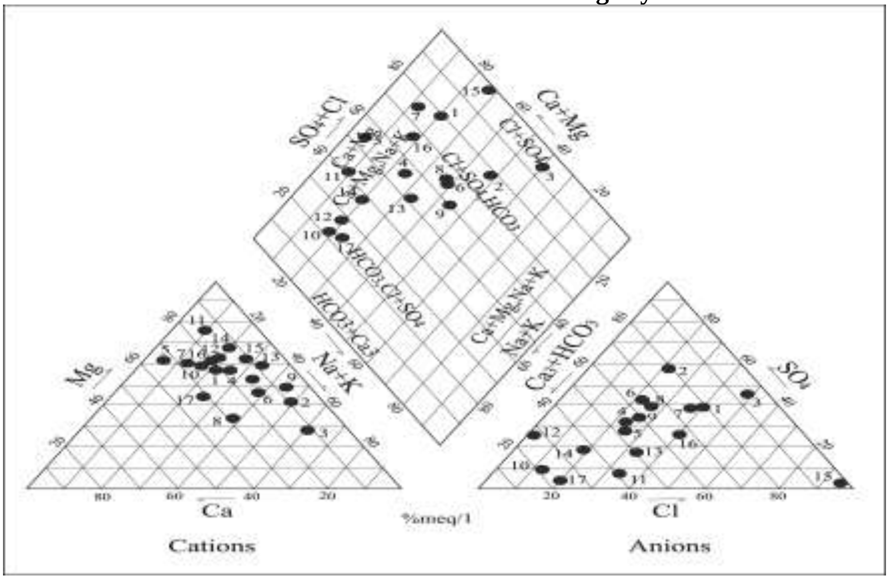


Fig.5: Trilinear diagram shows hydrochemical facies of groundwaters from the study area.

Mobile or inert substances of igneous rock. If this is taken into consideration, the mobile Ca^{2+}, Mg^{2+} and Na^{+} cations and mobile cations like K^{+} and Si^{4+} dominate the river and groundwaters, Ca^{2+} constitutes the most dominant ions in the river water, while Na^{+}, Mg^{2+}, CO_3^{2-}, SO_4^{2-} and Cl^{-} occur in decreasing amounts in river water (**Mason and Moore, 1982**).

Gibbs (**1970**) has pointed out that chemistry of water is generally controlled by the rate of evaporation, chemistry of rocks and chemistry of rain water. In order to evaluate the sources of various ions, the chemical data of waters from the Al Bauga sediments area (**Table 3**) were plotted on Gibbs diagram. The plots of the total dissolved solids (TDS) versus $Cl/Cl+HCO_3$ (**Fig. 6/1**) suggest that the ions are chiefly derived from the basalts and basement rocks and their concentration in groundwaters is mostly due to evaporation. Similar results have been obtained when total dissolved solids (TDS) plotted against Na+K/Na+K+Ca (**Fig. 6/2**). Precipitation, indicating contribution from the rain water, however, has not played any role in the concentration of ions in the waters from the area under study. It is, thus, evident that the chemistry of groundwater from region of Al Bauga sediments is controlled by the chemical and mineralogical composition of both the basalts and the basement rocks.

4.4. Salinity of groundwaters

The Al Bauga sediments area experiences arid to semi-arid climate which is characterized by excessive evaporation over total annual precipitation that has ultimately resulted in the equilibrium with respect

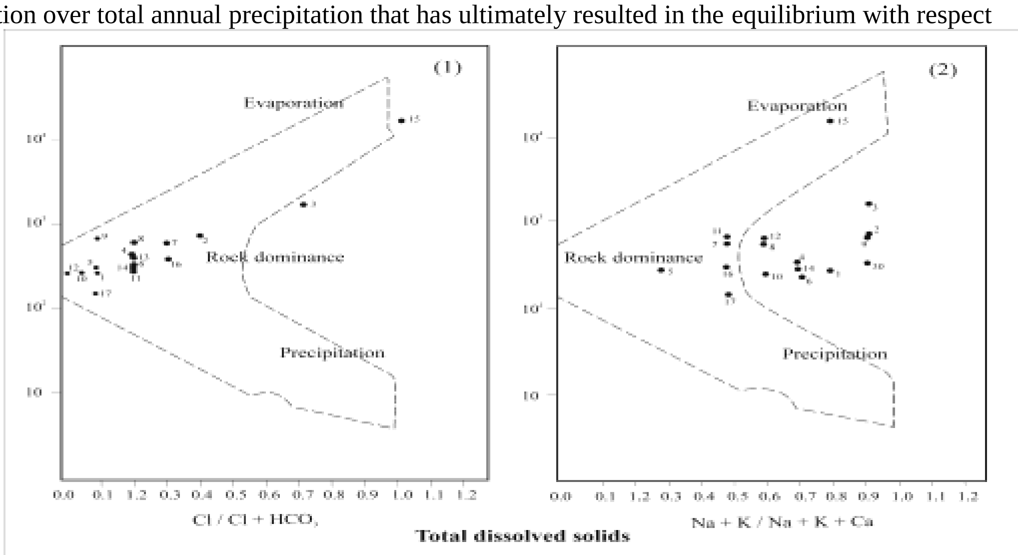


Fig.6: Gibbs diagrams for the groundwaters from the study area.

To the soil moisture budget. During the dry season, there always exists soil moisture deficiency and the rainy season does not provide any excess waters required for the leaching of highly soluble cations like Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. As a result, these cations remain in the system and eventually contribute to salinization of both the surface- and ground waters.

It is pointed out earlier that the Al Bauga sediments area shows in some places the presence of saline/brackish groundwaters especially in the area of Al Bauga profile. This supported by the data on the hydrochemical facies of groundwaters from this region. In order to find out salinity hazards for the study area electrical conductivity EC has been plotted against sodium absorption ratio SAR (**Table 4)**. The sodium absorption ratio (SAR) was determined according **U.S. Department of Agriculture** (**1954**) definition:

$$SAR = Na^{+} \Big/ \sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}$$

Table 4 is shown values of electrical conductivity (EC) and sodium absorption ratio (SAR) and **Fig. 7** represents plotting of the representative water samples from the study area. In the plots of electrical conductivity (EC) against sodium absorption ratio (SAR), it is evident that waters are medium to high saline. The high salinity conditions have, thus, resulted in the precipitation of mineral salts (evaporites mineral) that occur as gypsum crystals near the surface in the area of Al Bauga profile. The precipitation of salts from waters may take place rapidly with evaporation and degassing of water (**Eugster and Jones, 1979**).

The concentration of iron (Fe) varies from 0.01 ppm to 0.1 ppm (**Fig. 4/F**). The lowest is that of well No.3 (Futwar 3), whereas, the highest is that of well No.20 (Abu Haraz 2), **Table 2** is also showing that, the groundwater in the study area has very low concentration of iron. The concentration of nitrate (NO_3^-) in the study area varies from 0.44 ppm to 29 ppm. The lowest is that of well No. 39 (Al Kahola), whereas, the highest of well No. 14 (Al Jol 2). Atmosphere, legumes, plant debris and animal excrement are the major natural sources of nitrate (**Told, 1980**).

Table 4: Values of electrical conductivity (EC) and sodium absorption ratio (SAR) in water wells.

Well No.	EC (μs/cm)	SAR
1	561	2.40
2	1051	4.58
3	2350	9.96
4	754	1.85
5	553	0.22
6	713	2.68
7	953	0.90
8	941	2.64
9	1026	4.64
10	511	1.15
11	1043	0.66
12	1042	1.65
13	751	3.07
14	595	1.41
15	27500	10.09
16	699	1.24
17	187	0.88

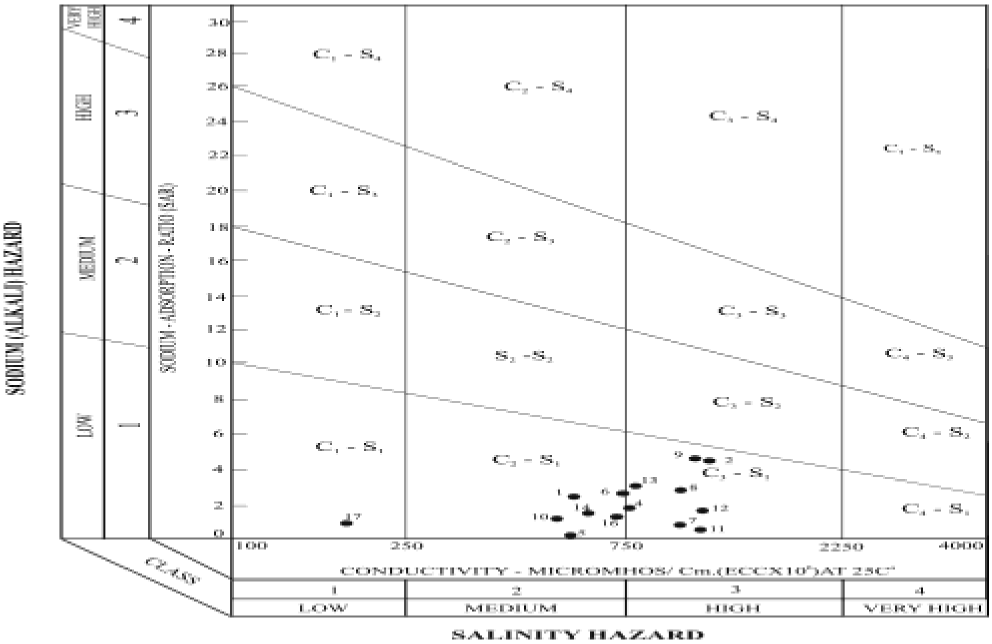


Fig. 7: Plot shows relationship between SAR and EC of the groundwaters From the study area (After USDA, 1954).

IV. CONCLUSION

During the field trip to the area under study a number of water samples from dug wells were collected and submitted to different laboratories for chemical analysis. To determine the chemical properties of groundwater and rock water interaction in the study area, major anions and cations, some trace elements were analyzed using different methods. From the chemical data for groundwaters, it is evident that the water is characterized by a high value of pH, EC and TDS. The high value of pH may be affected by the hydrolysable salts and by change in the carbonate equilibrium due to the bioactivity of plants. The higher value of EC and T.D.S. is due to the process of the washing of solids and other inorganic matter in this area. The source of sodium, magnesium, potassium and sulphate, in the groundwater of the study area refer to the feldspar content of the basement complex and clastic sedimentary rocks in addition to the Tertiary basaltic lava in the study area. The high concentration of chloride value in some places of the study area indicates the aridity of depositional environment. The groundwaters in the Al Bauga sediments area show the dominance of Ca+Mg, Na+K cations hydrochemical facies and HCO_3, Cl+CO_3 anion hydrochemical facies. From chemical measurements of the groundwater it is evident that the chemistry of groundwater from region of Al Bauga sediments is controlled by the chemical and mineralogical composition of both the basalts and the basement rocks and the waters are medium to high saline. The high salinity conditions have, thus, resulted in the precipitation of mineral salts (evaporite minerals) that occur as gypsum crystals near the surface at the study area.

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