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Research Paper

THE GEOLOGY AND HYDROGEOCHEMISTRY OF OLD ARUGBADU-GIDA AND ENVIRONS, NORTH CENTRAL NIGERIA

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The Study area lies within latitude 08°45'00''N to 08°52'30''N and longitude 008°37'30''E to 008°45'10''E, and a total area of 49 km^2. The geological mapping indicated five (5) different rock types namely; foliated migmatite, gneiss, granite gneiss, quartzite and pegmatite. A detailed geological mapping was carried out on a scale of 1:12,500 and structural features registered in the study area are foliation, joints, veinlet, spheroidal weathering and faults; where the major structural trends were in the NE-SW, NNE-SSW directions, corresponding to that of the underlying Basement Complex. The hydro geochemistry of the ground water samples obtained from shallow hand dug wells within Arugbadu- gida area and its environs were investigated to determine the suitability of the water for human consumption. A total of twenty-six (26) shallow hand-dug wells, two (2) boreholes, a stream and a spring were analysed for water quality. The water Spectrometric analysis was carried out at the Nigerian Geological Survey Agency Kaduna using Hach Digital Spectrometer Model 2400. Piper and Ion spatial distribution diagrams were plotted using the analytical data obtained from the water chemistry analysis. The major constituents are those whose concentrations range from 1.0 ppm-1000 ppm (parts per million). From the result of the analysis, the major constituents analysed are: Na^+, Ca^+, $Mg2^+$, and Cl^-.

Keywords: Geology, Hydrogeochemistry, Arugbadu-gida, Piper diagram, Spatial distribution

INTRODUCTION

The study area encompasses Arugbadu Gida and Arikiya Tsauni in Nassarawa Eggon Government Area and Langi I and II in Lafia Local Government Area of Nassarawa State. It is located in the south western end of the study area with hills which are about 400 meters above sea level. This study is aimed at investigating the general geology of the area and the hydrogeochemical analysis of some water sources including boreholes, hand-dug wells, streams and springs, classify the analysed water samples into classes based on the cations and anions present in the water, determine the interaction of the waters with their environment, genetic relation of the water samples and the economic potentials of the rocks in the study area.

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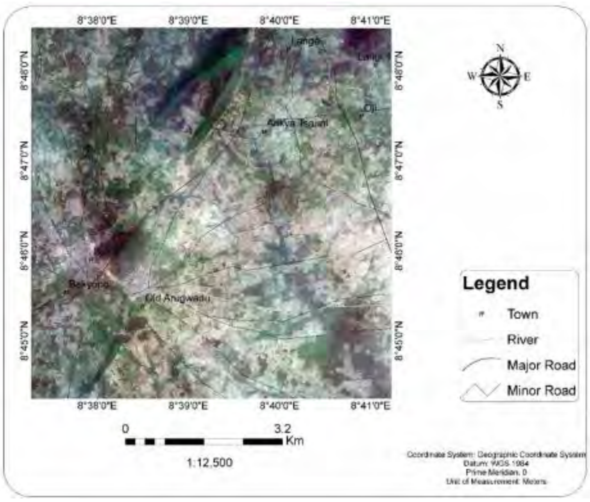
Water chemistry analysis is used extensively to determine the possible uses water may have or to study the interaction it has with its environment. Water chemistry analysis is often the ground work of studies of water quality, pollution, hydrology, geothermal waters; and can also be used to aid in prospecting for ore deposits. A detailed geological study of this area was carried out which include the study of the different lithology; the major rock types found within the study area constitute the Basement Complex rocks (foliated migmatite, gneiss, granite-gneiss, quartzite and pegmatite), with the pegmatite and quartzite occurring in form of ridges. The study area is characterized by conspicuous structural features such as dykes, joints, fractures, veins, foliations, spheroidal weathering and faults.

Location and Accessibility

Geographically, the study area lies between latitude 8º45'0''N to 8°52'30''N and longitude 8°37'30''E to 8°45'10''E and a total area of 49 km^2. The study area and its adjoining towns is accessible through the secondary road that branches off at Nassarawa Eggon along the Akwanga-Lafia road. The untarred road passes through Bekyano, Arugbadu, Arikya Tsauni, Langi II and Arikya. Other local hamlets can be accessed through foot paths that crisscross as shown in Figure 1 below. Rock exposures are accessible with the use of motorcycles, available footpaths and stream channels.

Figure 1: Satellite Image of the Study Area Showing the Road Network



METHODOLOGY

The environment of origin of water as well as the path at which it flows, human activities and nature (evaporation, precipitation, weathering, erosion, runoff leaching, etc.), will affect the chemical composition of water. One of the aims of carrying out this research is to determine the interaction the waters have with their environment. The weathering of the rocks that come in contact with the water bodies contribute immensely to the chemical constituents of waters.

In order to achieve the said aim, a total of 20 water samples were collected at different locations within the study area in the month of February 2018. Two (2) water samples were gotten from boreholes, two (2) from spring and stream and the remaining water samples were gotten from hand-dug wells within the study area.

The bottles were first taken to the laboratory where they were washed and disinfected with H_2SO_4, dried in the oven before taking them to the field. The bottles were rinsed with the water samples, filled and closed air-tight. While proper labelling was done, the location co-ordinates were taken using a hand-held GPS. Depths to the water table of the hand dug wells were also taken.

Analysis of major cations and anions was carried out at the Nigerian Geological Survey Agency Kaduna. Spectrometry using Hach Digital

Spectrometer Model 2400 for the analysis of the Cations and Anions. Piper, and Ion spatial distribution diagrams were plotted using the analytical data obtained from the water chemistry analysis.

Geomorphology and Drainage

The area is generally a flat land, but few undulating hills and ridges exist in the north eastern and western ends of the study area (Figure 2). The topography of the study area is controlled by numerous ridges of quartzite and pegmatite, some of which are highly weathered. The drainage pattern in the area is dendritic and trellis as shown in the Figure 2.

Geology of the Study Area

The study area is underlain by the crystalline rocks of the Precambrian basement of central Nigeria. There are occurrence of massive ridges that form part of the Basement Complex, they comprise of mainly Migmatite, gneiss, granite-gneiss, aplite dyke, quartzite and pegmatite. They occur either as hills or outcrops and are scattered within the study area especially around the North-eastern part as shown in Figure 3.

Figure 2: Digital Elevation Model and Drainage Pattern of the Study Area

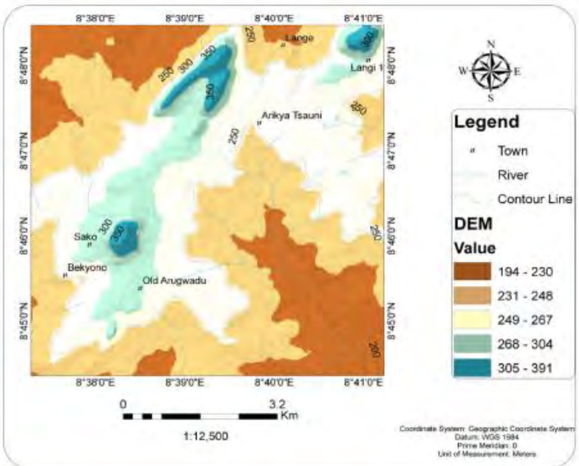
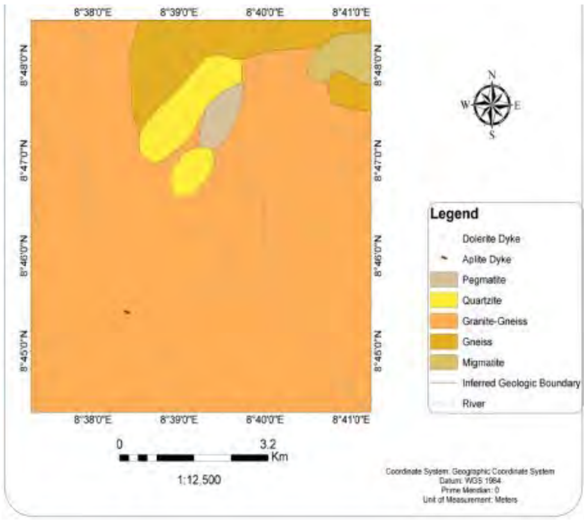


Figure 3: Geological Map of the Study Area



Migmatite

The migmatite occur around Lange II. They are massive, highly weathered rocks occupying low plains. The components of this rock are separated into bands as the magmatic and metamorphic components are separated into different bands showing evidence of ductile deformation (Figure 4). The migmatite is characterized by felsic minerals such as quartz and feldspar, and mafic minerals such as biotite and has structures as foliation, joints, veins, etc.

Figure 4: Field Occurrence of Migmatite Rock in the Study Area

Gneiss

In the study area, the gneisses are least exposed when compared to the migmatite and are found occurring with Granite-gneiss in Langi I and as an outcrop in Langi II. In hand specimen, some of the bands differ in colour and composition with some bands rich in feldspar and quartz (light coloured bands), and others rich in hornblende or mica (the dark coloured bands) (Figure 5). Texturally the gneisses are medium to coarse grained (feels rough when rubbed on the palm) and it is mostly dark in colour indicating the presence of mafic minerals.

Granite Gneiss

The rock is coarse grained and segregated into light and dark bands (Gneissocity). The light band is mostly composed of creamy-white feldspar and quartz while the dark band is mostly composed of dark minerals of which the most abundant is biotite. The dark minerals are arranged in a streaky parallel banding, giving the rock a gneissic texture (Figure 6). The flakes of the biotite are occurring in form of sheets and aligned with their long dimensions parallel to the mineral banding. However, the rock is not fissile, that is, it does not break easily along this direction.

Figure 5: Gneiss in the Study Area

Figure 6: Granite Gneiss

Quartzite

The quartzite within the study area occurs in the form of ridges. The interlocking crystalline structure of quartzite makes it a hard, tough and durable rock. It is so tough that it breaks through the quartz grains rather than breaking along the boundaries between them. It is characterized by structures such as joints and fractures (Figure 7).

Figure 7: Quartzite in the Study Area

Pegmatite

Pegmatites are extreme igneous rocks that form during the final stage of a magma's crystallization.

Figure 8: Pegmatite Within the Study Area

The Pegmatites in the study area occur mainly as a ridge, trending predominantly in the NE-SW direction and has typical structures as veinlets, joints and quartz intergrowths (Figure 8).

The Water Chemistry of Hand-Dug Wells And Borehole

Water is a transparent fluid which forms the world's stream, lakes, oceans and rain, and is the major constituent of the fluids of organisms. Water is important to man and could send a man to his early grave if contaminations are inclusive, and that is the major essence of water chemistry.

Water chemistry analysis is often the ground work of studies for water quality, pollution, hydrology, geothermal waters; and it can also be used to aid in prospecting for ore deposits.

Basement Complex generally forms a poor source of groundwater. The decomposed mantle is often too thin to contain quantities of water and is usually too clayey to be sufficiently permeable. Shallow-dug wells if carefully sited however will normally provide adequate supply for few residents. The yields of shallow hand-dug wells and boreholes depend largely on the amount of recharge and depth of weathering. Meanwhile, below the weathered mantle lies fractured rocks which are usually good aquifers although at depths over 100 m, fractures will normally disappear (Aga *et al.*, 2010).

DISCUSSION

The environment of origin of water as well as the path at which it flows, human activities and nature (evaporation, precipitation, weathering, erosion, runoff leaching, etc.), will affect the chemical composition of water. One of the aims of carrying out this research is to determine the interaction the waters has with their environment. The weathering of the rocks that come in contact with the water bodies contribute immensely to the chemical constituents of waters.

Water Table

Depths to the water table in the study area are shown on Table 1. The measurements indicate that the water table in the area is generally shallow below ground surface and range from 3.7 metres to 13.5 metres. The shallowness of the wells lead to easy contamination and pollution by pit latrines which in some places are almost of the same depth with the wells.

Water Analysis Plots

From the Trilinear plot made in Figure 9, two types of water emerge; a sodium chloride rich water and a sodium chloride deficient water type. The sodium rich water type can be found in wells 19, 20, 21, 22, 23 and 24. The sodium deficient water type is found in wells 1- 9, 15-18, 27 and 28.

Interpretation of Data using Spatial Distribution Model

Calcium (Ca^{2+})

Ca^{2+} content obtained from all the selected wells in the Old Arugbadu Gida and environs, are below the International recommended limits of 75 ppm (Table 3). Wells around the north-eastern end of

Table 1: Depth of Water Table and Sample Locations				
Sample Id	**Water Source**	**Static Water Level**	**Northings (Latitude)**	**Eastings (Longitude)**
AGE 1	Well	4.2 m	$08^0$47'48.8''	$008^0$40'32.5''
AGE 2	Well	4.65 m	$08^0$47'50.3''	$008^0$40'29.1''
AGE 3	Well	8.6 m	$08^0$47'40.1''	$008^0$40'07.5''
AGE 4	Stream	-	$08^0$47'21.6''	$008^0$39'39.4''
AGE 5	Well	5.3 m	$08^0$48'23.7''	$008^0$39'35.8''
AGE 6	Well	3.7 m	$08^0$48'21.5''	$008^0$39'43.5''
AGE 7	Borehole	-	$08^0$45'51.8''	$008^0$38'33.6''
AGE 9	Well	6.45 m	$08^0$45'47.6''	$008^0$38'35.3''
AGE 15	Well	8.2 m	$08^0$45'49.7''	$008^0$38'28.7''
AGE 16	Spring	-	$08^0$45'44.6''	$008^0$38'28.5''
AGE 17	Borehole	-	$08^0$45'39.7''	$008^0$38'26.2''
AGE 18	Well	4.4 m	$08^0$45'51.9''	$008^0$38'11.4''
AGE 19	Well	5.9 m	$08^0$45'38.6	$008^0$38'17.7''
AGE 20	Well	5.6 m	$08^0$45'38.2''	$008^0$38'22.7''
AGE 21	Well	5.3 m	$08^0$45'35.9''	$008^0$38'22.5''
AGE 22	Well	8.33 m	$08^0$45'33.1''	$008^0$38'22.2''
AGE 23	Well	4.4 m	$08^0$45'32.8''	$008^0$38'28.0''
AGE 24	Well	13.5 m	$08^0$45'39.5''	$008^0$38'26.3''
AGE 27	Well	7.5 m	$08^0$45'32.5''	$008^0$38'33.5''
AGE 28	Well	5.6 m	$08^0$45'37.6''	$008^0$38'27.5''

the study area shows high concentration (Figure 10), with the Sample ID AGE 5 and AGE 6 having the highest concentration of Ca^{2+} to be 20.2166 mg/l and 20.0130 mg/l (Table 2).

Water from wells with low concentration of Ca^{2+} for example in wells with Sample ID AGE 7, 17.8031 mg/l and AGE 15, 17.9323 mg/l, can cause endocrine abnormalities or intestinal malabsorption. However no report on this was observed or confirmed. Calcium concentration in the groundwater is due to the dissolution of amphibole (actinolite).

$CaMg_5Si8O_{22}(OH)_2$(Actinolite) + H_2O + H_2CO_3 $\rightarrow Ca^{2+} + Mg^{2+} + HCO^{3-} + 8H_4SiO_4$

Magnesium (Mg^{2+})

Magnesium (Mg^{2+}) concentration in wells with Sample ID AGE. 19 and 21 are 16.0577 mg/l and 15.9008 mg/l respectively (Table 2), still fall within the WHO acceptable maximum limits. Consumption of such wells water with relatively high concentration might not have any serious health implication. However, where the intake is deficient (low) as in Samples AGE 7 (4.0270 mg/l), AGE 9(3.9874 mg/l) and AGE 15(4.0118 mg/l)

Table 2: Showing Result of Water Analysis

Sample Id	Na^+ (mg/L)	K^+ (mg/L)	Ca^{++} (g/L)	Mg^{++} (g/L)	Cl^- (g/L)	$NO3^-$ (mg/L)	$SO3^-$ (mg/L)	$CO3^{--}$ (g/L)
AGE 1	6.3187	12.35	18.689	5.9189	132	20.14	107.13	30.21
AGE 2	6.289	10.65	19.7283	6.0321	197.21	19.32	211.12	28.64
AGE 3	5.9972	9.27	19.6392	6.0288	140.04	17.02	206.98	24.01
AGE 4	3.5054	7.32	19.9813	8.4782	117.01	21.18	197.56	32.55
AGE 5	2.8587	5.14	20.2166	8.4624	187.21	23.64	108.64	27.66
AGE 6	2.9011	5.87	20.013	8.5001	109.24	16.55	177.3	27.56
AGE 7	5.8372	9.44	17.8031	4.027	98.87	13.84	102.22	30.22
AGE 9	6.0057	11.05	18.0318	3.9874	205.11	26.32	216.73	28.99
AGE 15	6.0028	13.25	17.9323	4.0118	187.2	27.01	200.12	31.05
AGE 16	7.402	16.22	18.7334	5.8002	115	19.64	187	29.75
AGE 17	7.3557	17.08	19.0667	6.0027	250.01	30.55	245.44	32.68
AGE 18	6.9984	14	18.1003	6.004	183.7	21	208.21	34.65
AGE 19	102.5097	143.22	19.0263	16.0577	83.98	24.6	98.78	29.02
AGE 20	107.6754	147.8	18.7431	15.8655	102.65	18.77	124.05	25
AGE 21	108.3095	149.35	18.8896	15.9008	151.3	22.1	182.79	29.54
AGE 22	19.1816	30.56	18.6862	5.939	124.55	12.32	218.01	31.12
AGE 23	18.9799	28.4	18.3683	6.0261	188	17.84	548.15	29.89
AGE 24	19.1979	31.01	18.2632	6.0198	100.14	26.54	121.88	30.67
AGE 27	6.3187	10.65	18.689	5.9189	173.28	19.35	203.08	27.65
AGE 28	6.289	11.54	19.7283	6.0321	206.98	22.64	243.2	28.97

(Table 2 and Figure 11) will likely cause cardiac arrhythmias (irregular heart rhythms) and pathogenesis of cancer in human and animals. No such illness has been reported from the owners of the wells anyway. The source of the magnesium may be from weathering of olivine, biotite and hornblende.

$$Mg_2SiO_4 + 4H_2O \rightarrow 2Mg^{2+} + 4OH^- + H_4SiO_4$$

Sodium (Na+)

The well with Sample ID AGE 19, 20 and 21 has the highest concentrations of Na+ to be 102.5097 mg/l, 107.6754 mg/l and 108.3095 mg/l respectively as in (Table 2), as reflected in the upper north-western part of the area (Figure 12).

These concentrations even though are well below the NIS standard (Table 3) contribute to the saltiness of the ground water in the samples. The primary source of sodium in the ground water might be due to the dissolution (weathering) of sodium plagioclase from migmatite.

$NaAlSiO_3\ O_8$(Na$^-$ plagioclase) + 11/2 $H_2O \rightarrow Na^+ + OH^- + 2H_4SiO_4 + ½Al_2Si_2O_5(OH)_4$ (Kaolinite) OR $NaCl(s) + H_2O \rightarrow Na^+ (aq) + Cl^-$ (aq)

Table 3: Recommended Drinking Water Standard Limits					
S/N	**Parameter**	**NIS (2007)**	**WHO (2010)**	**US and WHO (2010)**	**USEPA (2016)**
1	Na^+	200	-	-	-
2	K^+	-	-	-	-
3	Mg^{2+}	0.2	50	50	-
4	Ca^{2+}	-	75	-	-
5	Cl^-	250	200	150	250
6	F^-	1.5	0.5	-	2.5
7	HCO_3^{2-}	-	-	-	-
8	SO_4^{2-}	100	200	250	250
9	CO_3^{2-}	-	-	-	-
10	SiO_2	-	-	-	-
11	Total Alkalinity	-	-	-	-
12	Total Hardness	-	-	-	-
13	Total Fe	0.3	0.3	3	0.3
14	TDS	500	500	-	500
15	PH	6.5-8.5	7-8.5	-	-

Note: WHO = World Health Organization Standard for Drinking Water. USEPA = United State Environmental Protection Agency Standard for Drinking Water. NIS = Nigerian Industrial Standard for Drinking Water.

Figure 9: Chemical Analysis of Water Presented as Percentage (%) Concentration for the Major Cations and Anions as in Piper (1944) Trilinear Diagram

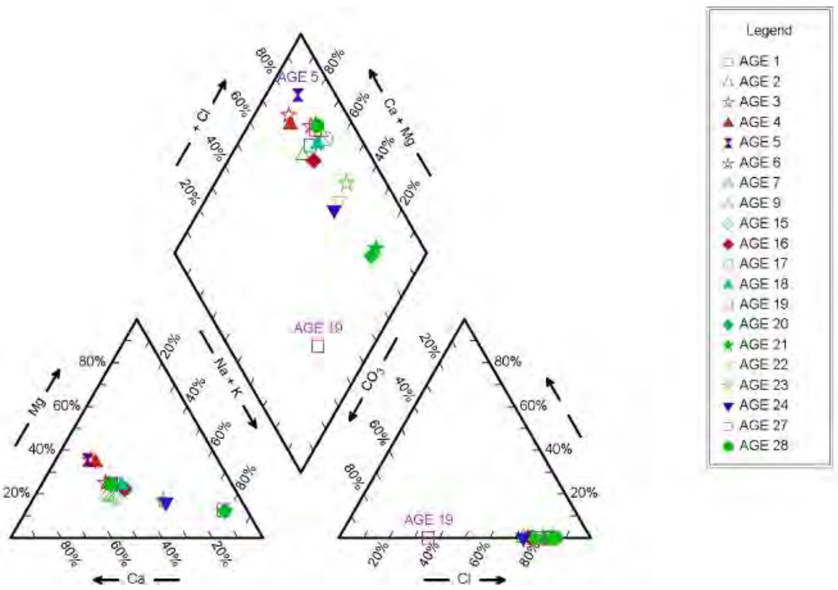


Figure 10: Spatial Distribution of Ca^{+} Ion Concentration

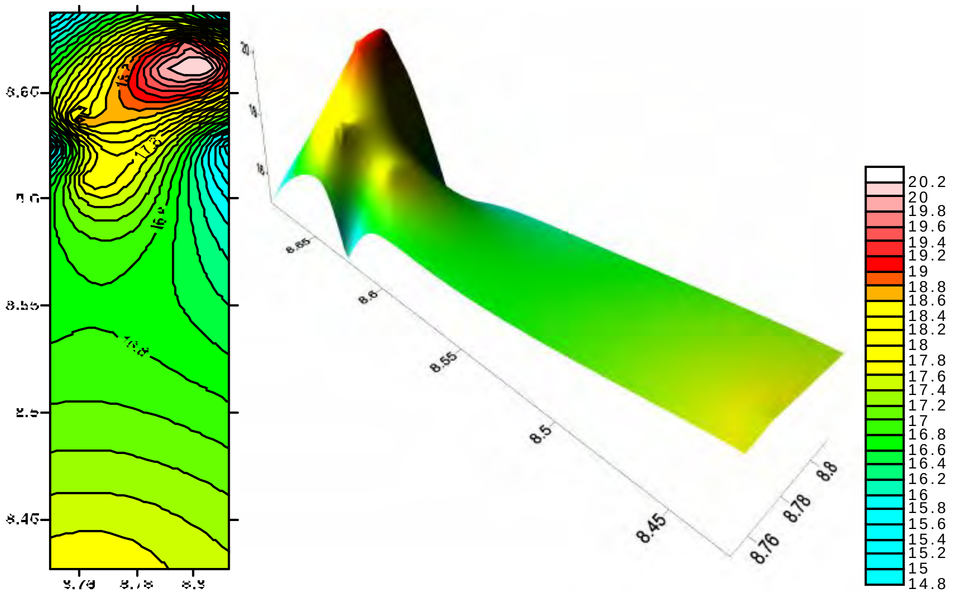
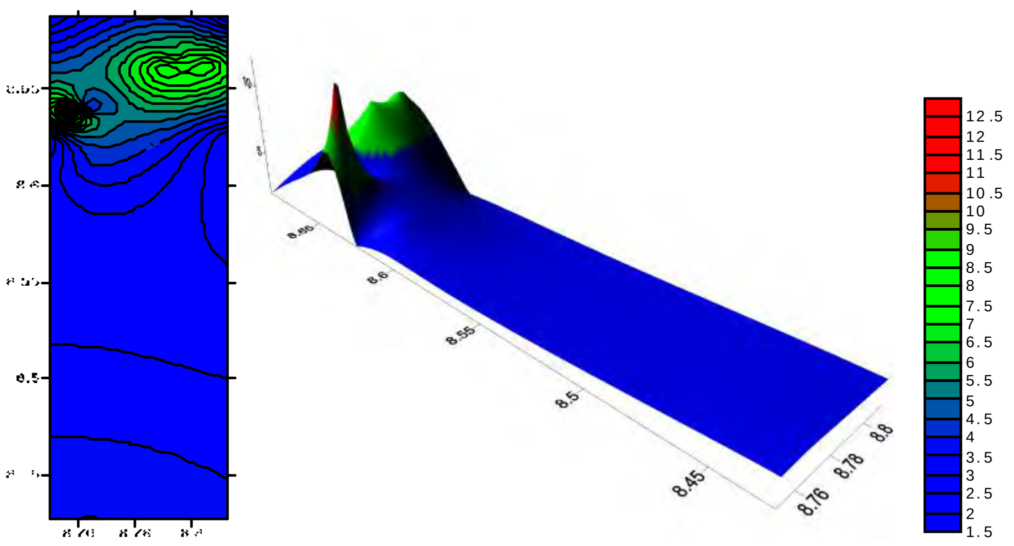


Figure 11: Spatial Distribution of Mg^{+} Ion Concentration



Potassium (K^{+})

Potassium (K^{+}) in wells with Sample ID AGE 19, 20, 21 is in high concentration of 142.22 mg/l, 147.80 mg/l,149.35 mg/l as reflected in (Table 2 and Figure 13). The lowest concentrations, 5.87 mg/l and 5.14 mg/l were obtained in wells with sample ID AGE 5 and 6. The Deficiency in potassium intake can cause hypokalemia in human though not common to most people although, deficiency of potassium is rare because; it can be found in animal and vegetable foods.

The source of potassium ions in groundwater is perhaps due to weathering of orthoclase, microcline, or biotite.

Figure 12: Spatial Distribution of Na^+ Ion Concentration

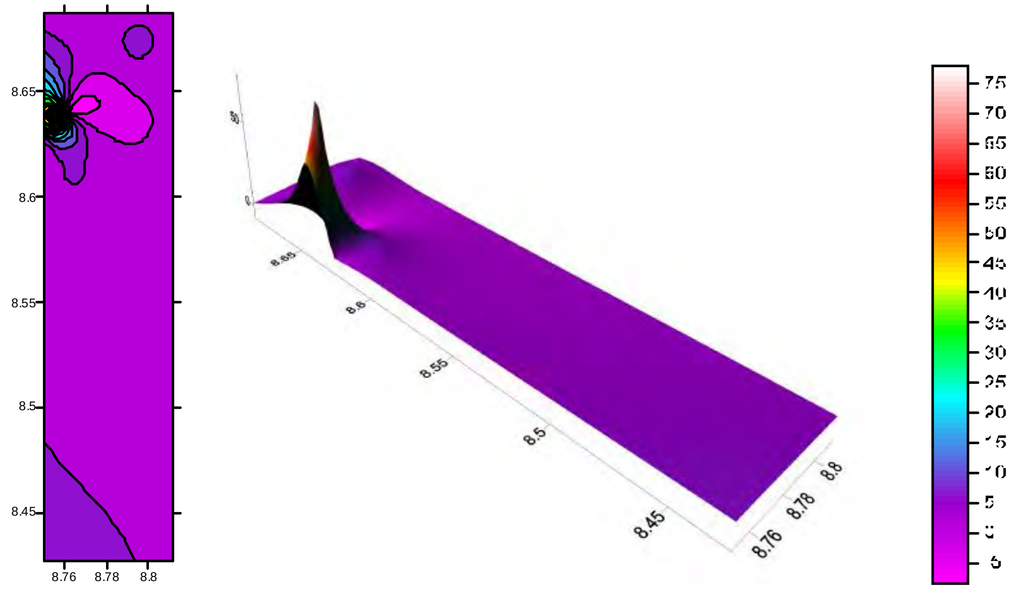
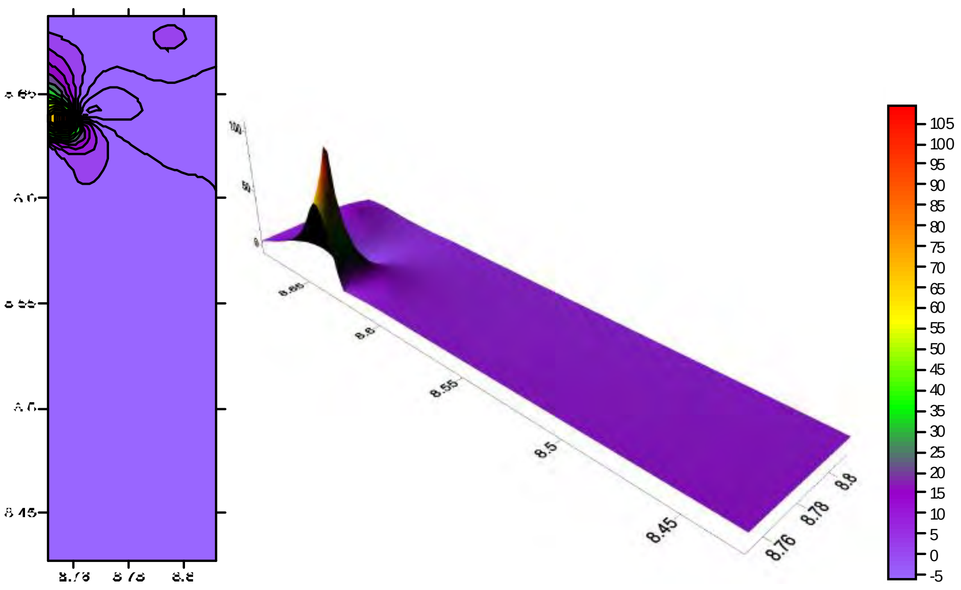


Figure 13: Spatial Distribution of K^+ Ion Concentration



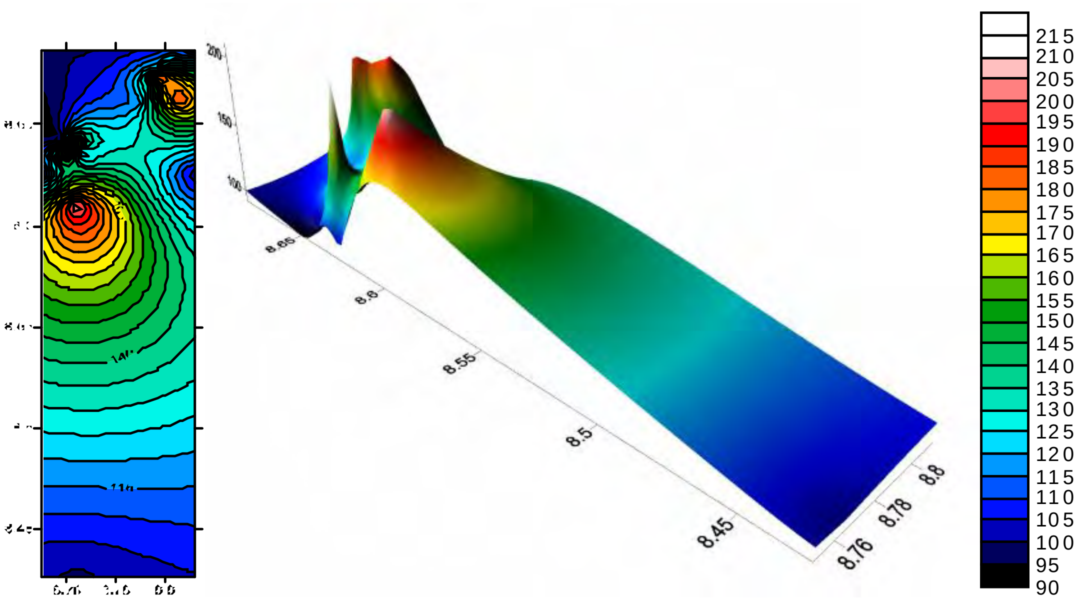
$4KAlSi3O_8$(Orthoclase) + $22H_2O \rightarrow 4K^+ + OH^-$ + $Al_4SiO_4O_{10}(OH)_8$ + $8H_4SiO_4$

Chlorine (Cl^-)

Cl^- content obtained from all the selected wells in the Old Arugbadu Gida and Environs, are below the International recommended limits of 250 ppm (Table 3).

Cl^- content in the wells under study vary slightly from well to well. However, wells with Sample ID AGE 9, 17 and 28 show exceptionally high concentration of 205.11 g/l, 205.01 g/l and 206.98

Figure 14: Spatial Distribution of Cl^- Ion Concentration



mg/l respectively compared to other wells in the area as reflected in the spartial distribution diagram (Figure 14).

$NaCl \rightarrow Na^+ + Cl^-$

Excessive consumption of chloride has no human health implication as long as salt diet is available except to individuals restricted to a low salt diet as in the case for some cardiovascular disorders.

CONCLUSION

The major rock types found within the study area constitute the Basement Complex (quartzite, pegmatite, foliated migmatite, gneiss and granite gneiss), the pegmatite and quartzite occurring in form of ridges. All the wells studied are shallow, with the highest depth to water table been 13.5 meters. Water chemistry analysis shows that the factors controlling the concentration of calcium and magnesium and sodium and potassium are similar, as implied by the similarities of their spartial distributions. It implies that the ground water in the study area is influenced by the geology, natural water recharge and soil/water interactions. The water in the area is suitable for consumption as non of the analysed ions is beyond the NIS, WHO or US EPA standards, though there is need to create public awareness regarding the health risk associated with some of the elements.

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