GEOELECTRICAL AND HYDROGEOCHEMICAL CHARACTERISATION OF THE BASEMENT COMPLEX AQUIFERS IN THE AREA AROUND THE ABUJA CITY CENTRE, NIGERIA.

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(Received: 21[st] Feb., 2016; Accepted: 4[th] April, 2016)

ABSTRACT

Geophysical and hydrochemical data had been acquired and analysed in the area around Abuja Centre, Nigeria. This was with a view to characterizing the Basement Complex aquifers and assessing its groundwater quality. Secondary parametric Vertical Electrical Soundings (VES) were acquired at fifteen previously drilled borehole locations within the study area. Groundwater samples were also collected from same boreholes and analysed for physio-chemical and microbiological parameters. The VES data were quantitatively interpreted for subsurface sequence delineation and aquifer identification while the chemical elements were analysed using histograms. The VES interpretation results revealed three (H and K-type), four (KH, HA and AA-type) and five (HKH-type) layers geoelectric models. The VES interpretation results delineated five subsurface layers composed of the topsoil, laterite, weathered layer, partially weathered/fractured basement and fresh basement. The resistivity of the topsoil ranged between 36 Ωm and 924 Ωm with thicknesses of between 0.3 m to 3.5 m. The laterite layer resistivity ranged between 408 Ωm and 1878 Ωm, with thicknesses of 2.2 m to 8.5 m. The resistivity of the weathered layer ranged from 15 Ωm to 509 Ωm while the thickness ranged between 3.7 m and 64.7 m. The partially weathered/fractured basement had resistivity values that ranged from 14 Ωm to 734 Ωm and thicknesses of 7.9 m to 22.1 m. The resistivity of the fresh basement ranged between 414 Ωm and 99061 Ωm with depth to bedrock of between 7.9 m and 73.5 m. All the analysed chemical elements had concentrations that were within the WHO permissible levels with the exception of very few boreholes showing relatively high nitrate and total iron concentrations. The study concluded that the study area was characterized by both the weathered layer and partly weathered/fractured basement aquifers. The groundwater was also found to be generally potable.

INTRODUCTION

The geometric increase in population, most especially in the developing countries of the world has raised the demand for potable water. However, the provision of potable water through the public water supply system (water works) has been very inadequate both in the urban cities and worse still in the rural areas. Since the safest kind of water supply is the groundwater, most people have resulted to development of independent water supply scheme through hand dug wells, tube wells and boreholes. Although the available quantity of groundwater is comparably small to the available quantity of water resources, a major challenge is that groundwater is not readily available where it is needed and when it is available, it may not be in sufficient quantity (Raghunath, 2006). This problem is more pronounced in crystalline basement complex environment due to low primary porosity and permeability. However, discontinuities in rock mass due to weathering and fracturing can aid groundwater development in these places. Since groundwater generally has good quality and boreholes can give appreciable quantity of water for domestic uses, techniques and instrumentation for investigating the occurrence of groundwater in the subsurface have improved over time and our understanding of the subject has also improved considerably (Aderibigbe *et al.*, 2008). Another factor that makes groundwater development of interest is the fact that it is usually free from dangerous pathogen that causes water borne diseases like cholera, typhoid, dysentery, guinea worm and many others. This is because the soil usually serves as a filtering agent for contaminated surface water before reaching the aquifer at considerable depth (Sharma and Sharma, 2007). However this is not the case for shallow and permeable water table aquifers as they are most susceptible to contamination which results in poor groundwater quality. In addition, the improper management of waste generated by human and industrial activities which eventually finds their way via drainages into the water bodies is another major challenge to groundwater quality. This makes it necessary to analyze the composition of groundwater in order to ascertain if its physical and chemical composition are within the permissible limits for consumption as proposed by relevant authorities (Ayolabi *et al.*, 2015). As the worldwide extraction of groundwater is accelerated to meet increasing demand, the significance of its quality also increases, relative to its economic value and usefulness (Adhikari *et al.*, 2009).

To characterize the aquifer types and determine the quality of groundwater in the Abuja City Center, the electrical resistivity method which is now an established tool for environmental site investigation related to pollution studies (e.g., Daily *et al.,* 1998; Goes and Meekes 2004) and aquifer characterization (e.g., Olorunfemi and Fasuyi, 2003) was employed. Using this method, we characterized the aquifer types in the study area and determine its geoelectric properties using one dimensional models of the subsurface obtained by inverting resistivity data acquired beside already dugs wells. The ground resistivity is then related to various geological parameters such as the mineral and fluid content, porosity, nature and degree of water saturation in the rock. Likewise the potability of groundwater in the delineated aquifers and possible sources of pollution were determined by collecting groundwater samples from these boreholes and carefully analyze their physical and chemical composition and compare them with standardized values from the World Health Organization (WHO) and other relevant regulatory bodies.

The Study Area

The study area is City Center area of the Federal Capital Territory (FCT), Abuja, Nigeria. It is situated between Latitudes 8° 55' and 9° 08' North and Longitudes 7°21.6' to 7°32.4' East (Figure 1). The area is accessible by good road network that connect the city. The topography of the study area varies from place to place with lowest elevations in the territory around the extreme south-west at the floodplains of River Gurara. From there, the land rises irregularly eastwards, northwards and north-westwards. The highest part of the territory is located in the northwest where there are many peaks of about 760 meters above the sea level.

The description of the Geology of the study area has variously been attempted in the works of Truswell and Cope (1963), Oyawoye (1970), McCurry (1970, 1976), ABU (1978), Turner (1978) and Alagbe (1979) to mention a few. The study area lies within the north central part of the Nigerian Precambrian Basement Complex which forms part of the Pan-African mobile belt placed in-between the West African and Congo Cratons (Black, 1980). Generally the Basement Complex of Nigeria is composed of four major petro-lithological units namely: the Migmatite – Gneiss Complex; the Schist Belt (Metasedimentary and Metavolcanic rocks); the Older Granites (Pan African granitoids) and the Undeformed Acid and Basic Dykes. These basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The basement rocks are intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and Younger Sediments (Figure 2). According to A.B.U. (1978), the rocks that underlie the study area include the metamorphosed supracrustal exogenetic rocks, migmatite complex, intrusive coarse grained granite, minor intusions such as rhyolites and dolerites and other small formations as quartzite, pegmatite and quartz vein. Structures such as foliations in mica schist, migmatites and gneisses; layering and planar orientation of flat xenoliths in migmatitic complex; folds in migmatites and gneisses and sometimes schist; crenulation and elongation of mineral grains or aggregates in the schist belt; joins and faults trending NNW-SSE and SE-NW respectively have been mapped in the study area while intrusions in rock outcrops were reported as trending in the same direction as most of the joints.

METHODOLOGY

This study uses an integrated approach involving the electrical resistivity method and hydrochemical analysis of groundwater samples from boreholes to characterise the aquifer types and potability of groundwater in the study area.

The geophysical investigation involved earth resistance (R) measurements made by injecting current into the ground through two current electrodes while the resulting voltage difference between two potential electrodes are measured. The apparent resistivity values were computed from the product of the resistance and the appropriate geometric factor (G) of the electrode array.

A number of techniques can be used with the electrical resistivity method depending on the aim of the survey and nature of subsurface target amongst other considerations. In this study, the Vertical Electrical Sounding (VES) technique was employed which measured the variations in apparent resistivity of an assumed, horizontally layered earth material, with respect to a fixed centre of the array. The survey is carried out by gradually expanding the electrode spacing about a fixed centre of the array until the maximum electrode spread AB/2 was reached. The Schlumberger array was used because of its sensitivity to vertical changes in the subsurface, its significant depth of investigation, ease of use, speed and convenience.

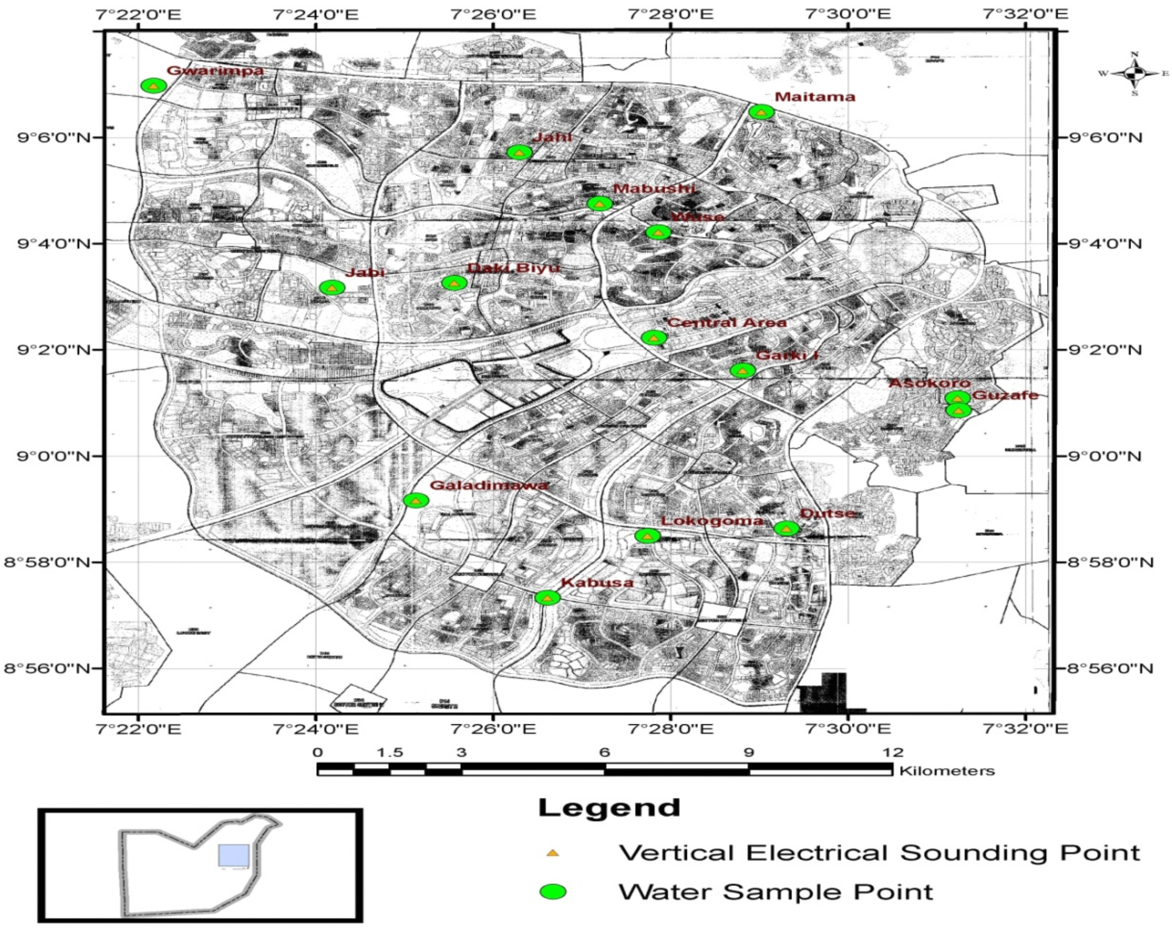


Figure 1: Map of the Federal Capital City Centre Showing the VES and Water Samples Points.

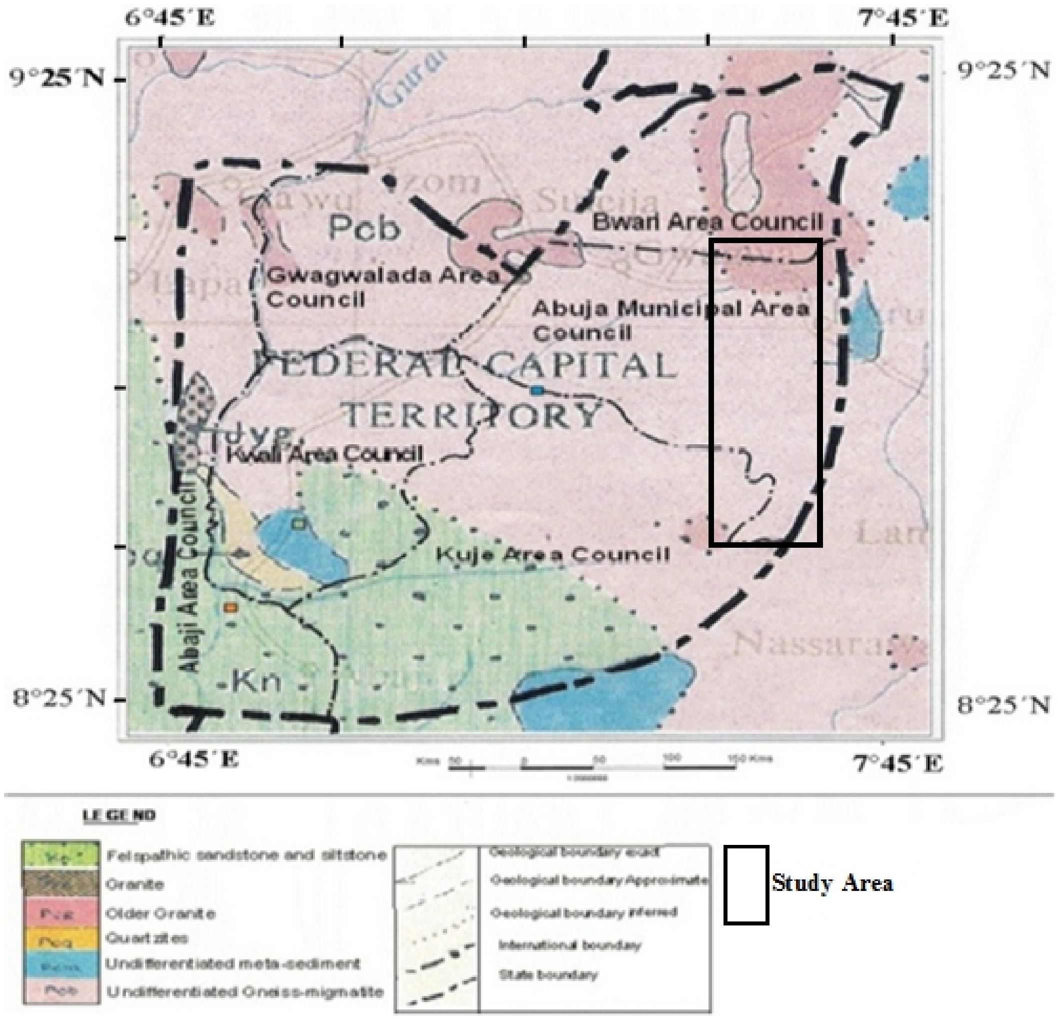


Figure 2: Geological map of the Federal Capital Territory, Abuja showing the different rock types (Modified after NGSA, 2004).

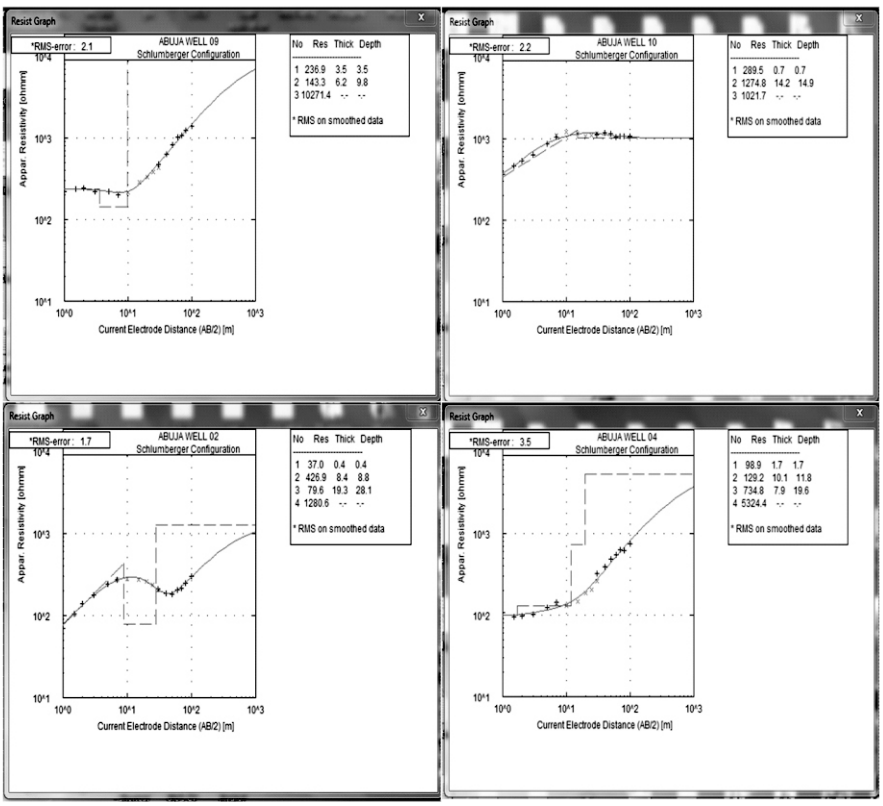
Since the computed apparent resistivity values are not the true resistivity of the subsurface, an inversion of the measured apparent resistivity values using a computer program was carried out to determine the true subsurface resistivity. The partial curve matching technique (Zohdy, 1965) was used to obtain the initial geoelectric model which was further refined through a least square iterative inversion scheme involving the WinResist software (Vander Velpen, 1988).

Water samples were collected from fifteen (15) boreholes and hydrochemical analysis of both the physical and chemical composition were carried out at the laboratory of the Bauchi State Rural Water Supply and Sanitation Agency (RUWASSA). Chemical characteristics tend to be more specific in nature than some of the physical parameters and are thus more useful in assessing the pollution/contamination of a water sample. Attention was paid to chemical parameters that are of concern in pollution/contamination assessment such as cations and anions, total dissolved solids (TDS), acidity and trace-elements (Heavy Metals). These elements were analysed for in the sampled groundwater. The cation and heavy metal analyses were done in accordance to APHA standard using the Atomic Absorption Spectrophotometry (AAS) while the anion analyses were carried out using the ion chromatography and titrimetric methods. Physical parameters which involved our senses of sight, smell, taste and touch were measured on the field using the Ec/pH Multi parameter instrument. The most important physical parameters that are indicative of pollution are temperature, Suspended Solids/Total Dissolved Solids and the salinity (electrical conductivity/resistivity). The values obtained for each element at each sample point were then compared to that of the WHO standard and other available guidelines. This comparison was used to assess the potability of the groundwater in each borehole and determine possible sources of contamination.

RESULTS AND DISCUSSION

The VES interpretation results for the fifteen (15) parametric sounding are presented in Table 1. The interpretation of the sounding curves resulted into a number of geoelectric models which revealed the presence of three, four and five layers in the subsurface. Six of the fifteen Schlumberger VES curves obtained from the study area showed a 3-layer while five (VES 5, 9, 13, 14, and 15) are H-type curves and one (VES 10) displayed K-type VES curve. Six of the fifteen Schlumberger VES curves (VES 1, 2, 6, 7, 8, and 12) are 4-layer KH-type while VES 3 and 4 are HA and AA type curves respectively as shown in Figure 3. VES 11 is a 5-layer HKH-type curve. Furthermore, the geoelectric characterization of the subsurface layers in the study area is presented in Table 2. This shows the general range of resistivities and thickness values for the different geoelectric layer delineated from the geophysical results.

The resistivity values obtained from the VES interpretation are representative of the lithology which varied from topsoil to laterite, weathered layer, partially weathered/fractured basement and fresh basement in the study area. The resistivity of the topsoil ranged between 36 Ωm and 924 Ωm with thicknesses of between 0.3 m and 3.5 m. The laterite layer resistivity ranged between 408 Ωm and 1878 Ωm, with thicknesses of 2.2 m to 8.5 m. The resistivity of the weathered layer ranged from 15 Ωm to 509 Ωm with thicknesses of between 3.7 m and 64.7 m. The partially weathered layer/fractured basement has resistivity values that ranged from 14 Ωm to 734 Ωm and thicknesses of 7.9 m to 22.1 m. The resistivity of the fresh basement ranges between 414 Ωm and 99061 Ωm with depth to bedrock of between 7.9 m and 73.5 m. Based on the interpretation results, the weathered and the partially weathered/fractured layers constituted the aquifer units in the study area. However, the frequency of occurrence of the weathered layer aquifer was higher than that of the partially weathered/fractured aquifer.



(a) (b) (c) (d)

Figure 3: Typical VES-type Curve in the Study Area. (a) 3-Layer H-type (b) 3-Layer K-type (c) 4-layer KH-type (d) 4-layer AA-type

Table 1: VES Interpretation Models and the Geologic/Hydrogeological Interpretation.

WELL NO	LAYER NO	LAYER RESISTIVITY (Ω-m)	LAYER THICKNESSES (m)	DEPTH (m)	TYPE CURVE	LITHOLOGY	REMARK
1	1	95	3.5	3.5	KH	Topsoil	
	2	1758	4.0	7.5		Laterite	
	3	56	14.3	21.8		Weathered Layer	Aquifer Unit
	4	9815	--	--		Fresh Basement	
2	1	37	0.4	0.4	KH	Topsoil	
	2	427	8.4	8.8		Laterite	
	3	80	19.3	28.1		Weathered Layer	Aquifer Unit
	4	1281	--	--		Fresh Basement	
3	1	210	0.3	0.3	HA	Topsoil	
	2	55	6.9	7.2		Weathered Layer	Aquifer Unit
	3	76	28.8	36.0		Partly Weathered Layer	Aquifer Unit
	4	276	--	--		Basement Bedrock	
4	1	99	1.7	1.7	AA	Topsoil	
	2	129	10.1	11.8		Weathered Layer	Aquifer Unit
	3	735	7.9	19.7		Partially weathered/ Fractured Basement	Aquifer Unit
	4	5324	--	--		Fresh Basement	
5	1	195	3.2	3.2	H	Topsoil	
	2	46	3.7	6.9		Weathered Layer	Aquifer Unit
	3	37092	--	--		Fresh Basement	
6	1	45	1.3	1.3	KH	Topsoil	
	2	408	4.6	5.9		Laterite	
	3	49	12.6	18.5		Weathered Layer	Aquifer Unit
	4	1811	--	--		Fresh Basement	
7	1	340	0.4	0.4	KH	Topsoil	
	2	1696	8.5	8.9		Laterite	
	3	254	64.7	73.6		Weathered Layer	Aquifer Unit
	4	1029	--	--		Fresh Basement	
8	1	180	3.2	3.2	KH	Topsoil	
	2	1878	2.8	6.0		Laterite	
	3	37	9.8	15.8		Weathered Basement	Aquifer Unit
	4	31135	--	--		Fresh Basement	
9	1	237	3.5	3.5	H	Topsoil	
	2	143	6.2	9.7		Weathered Layer	Aquifer Unit
	3	10271	--	--		Fresh Basement	
10	1	290	0.7	0.7	K	Topsoil	
	2	1275	14.2	14.9		Fresh Basement	
	3	1022	--	--		Fresh Basement	
11	1	89	3.2	3.2	HKH	Topsoil	
	2	15	4.3	7.5		Weathered Layer	Aquifer Unit
	3	441	1.8	9.3		Fresh Basement	
	4	14	22.1	31.4		Fractured Basement	Aquifer Unit
	5	99061	--	--		Fresh Basement	
12	1	36	0.4	0.4	KH	Topsoil	
	2	464	2.2	2.6		Laterite	
	3	67	7.1	9.7		Weathered Layer	Aquifer Unit
	4	414	--	--		Fresh Basement	
13	1	236	1.5	1.5	H	Lateritic Topsoil	
	2	28	6.5	8.0		Weathered Layer	Aquifer Unit
	3	14363	--	--		Fresh Basement	
14	1	924	3.5	3.5	H	Topsoil	
	2	509	13.3	16.8		Weathered Layer	Aquifer Unit
	3	1329	--	--		Fresh Basement	
15	1	166	1.9	1.9	H	Topsoil	
	2	40	6.1	8.0		Weathered Layer	Aquifer Unit
	3	7453	--	--		Fresh Basement	

Table 2: Geoelectric Characterisation of the Study Area

S/N	LITHOLOGY	RANGE OF RESISTIVITY (Ωm)	RANGE OF THICKNESSES (m)
1	Topsoil	36 - 924	0.3 - 3.5
2	Laterite	408 - 1878	2.2 - 8.5
3	Weathered Layer	15 - 509	3.7 - 64.7
4	Partially Weathered/Fractured Basement	14 - 734	7.9 - 22.1
5	Fresh Basement	414 - 99061	-----

The results of the hydrochemical analysis of groundwater samples obtained from fifteen boreholes (Figure 1) are presented in Table 3. Twenty four (24) hydrochemical parameters which could be categorized into physical, chemical and bacteriological tests were carefully analysed for. Colum one of Table 3 also presents the recommended permissible values of these hydrochemical parameters by the World Health Organization (WHO, 2004) and the Nigeria Standard for Drinking Water Quality (NSDWQ, 2007). Anomalous values were indicated with coloured circle in Table 3 for easy interpretation and presented sample histograms in Figure 4.

The results of the chemical analysis of the water samples as presented in Table 3 revealed that most of the chemical parameters that were analysed are found to be within the permissible limits except in wells 2 where the nitrate (NO_3^-) concentration of 77 mg/l is above the permissible limit of 50 mg/l and well 6 with a concentration of 87.5 mg/l. The high nitrate concentration in wells 2 and 6 (Figures 4a and 4b) is suspected to be as a result of anthropogenic sources such as sewage, waste disposal and agricultural practices at close range to the borehole. High nitrate levels in water have been reported to be responsible for diseases such as methemoglobinemia or blue baby syndrome, a condition found especially in infants less than six months.

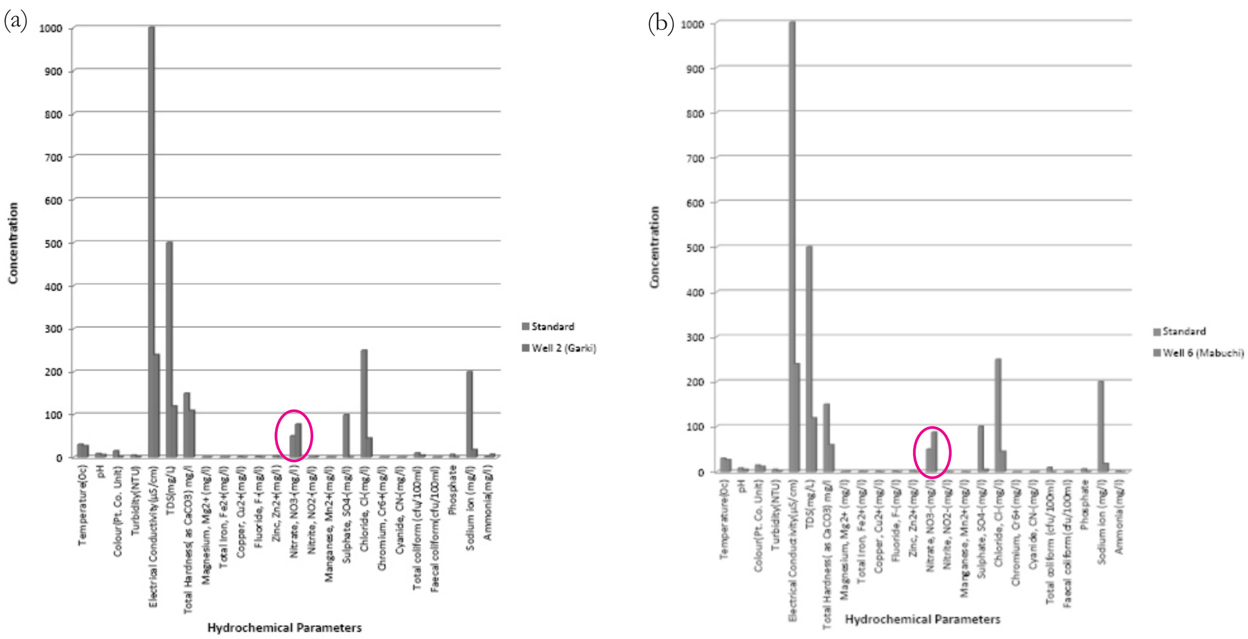
Wells 2, 10, 11, 12 and 15 also showed higher concentration of total Iron (Fe^{2+}) of 0.321 mg/l, 1.04 mg/l, 0.441 mg/l, 6.221 mg/l, and 0.362 mg/l respectively (Figures 4a and 4c). These values were found to be greater than the permissible limit for drinking water. For the reasons of taste, and also to avoid straining, the recommended maximum concentration of Iron in drinking water is 0.3 mg/l. When iron exists along with certain kinds of bacteria, a smelly biofilm that can clog plumbing and cause an offensive odour can develop.

The bacteriological test indicated that all the boreholes sampled were free from Coliform bacteria like E-Coli bacteria with the exception of well 7 (Figure 4d) which had Faecal coliform value of 8 (cfu/100 ml), which is higher than the standard value of 0 (cfu/100 ml). It is suspected that the closeness of the borehole to the hospital mortuary within the premises of the Abuja National Hospital might be responsible for such pollution. Well 12 (Figure 4c) showed high Total coliform of 23 (cfu/100 ml) higher than the permissible limit of 10 (cfu/100 ml). Total coliform bacteria are not likely to cause illness, but their presence in water indicates that the water supply may be vulnerable to contamination by more harmful microorganisms.

Table 3: Results of the Hydrochemical Analyses of Groundwater Samples.

S/N	PARAMETERS	Standard (WHO/NSDWQ)	Well 1 (Maitama)	Well 2 (Garki)	Well 3 (Asokoro)	Well 4 (Jabi)	Well 5 (Daki biyu)	Well 6 (Mabushi)	Well 7 (Central Area)	Well 8 (Galadimawa)	Well 9 (Lokogoma)	Well 10 (Dutse)	Well 11 (Wuse)	well 12 (Guzafe)	Well 13 (Gwarimpa)	Well 14 (Jahi)	Well 15 (Kabusa)
1	Temperature(0c)	30	26.6	26.7	27.8	26.5	26.6	26.7	26.6	26.7	26.7	26.6	26.3	26.3	26.3	26.3	26.2
2	pH	8.5	6.6	6	6.9	6.4	6	5.3	6	5.8	5.9	5.7	6.5	6.4	6.3	6.6	5.5
3	Colour(Pt. Co. Unit)	15	2	1	12	34	6	12	1	15	10	13	7	3	20	8	2
4	Turbidity(NTU)	5	1	1	1	1	1	2	2	1	1	1	1	2	1	1	1
5	Electrical Conductivity(µS/cm)	1000	180	240	260	110	110	240	150	60	60	70	80	110	110	80	60
6	TDS(mg/L)	500	90	120	130	55	55	120	75	30	30	35	40	55	55	40	30
7	Total Hardness(as CaCO3) mg/l	150	50	110	40	40	60	60	80	32	28	40	34	50	48	46	32
8	Magnesium, Mg2+ (mg/l)	0.2	0.221	0.172	0.213	0.16	0.165	0.251	0.213	0.171	0.142	0.143	0.112	0.131	0.212	0.141	0.211
9	Total Iron, Fe2+(mg/l)	0.3	0.081	0.321	0.04	0.03	0.142	0.162	0.02	0.06	0.081	1.04	0.441	6.221	0.1	0.142	0.362
10	Copper, Cu2+(mg/l)	1	0.251	0.05	0.05	0.03	0	0	0	0.32	0	0	0	0.05	0.003	0.04	0.021
11	Fluoride, F-(mg/l)	1.5	0.022	0	0.43	0.011	0	0	0.032	0.075	0.032	0.021	0	0.021	0.012	0	0.003
12	Zinc, Zn2+(mg/l)	3	0	0	0	0	0.09	0.112	0.541	0.181	0.1	0.123	0.122	0.35	0.07	0.261	0.221
13	Nitrate, NO3-(mg/l)	50	36.3	77	42.5	26.4	44.21	87.5	17.54	12.54	12.21	13.45	2.244	1.543	4.412	1.998	1.581
14	Nitrite, NO2-(mg/l)	0.2	0.025	0.723	0.0133	0.292	0.0264	0.0132	0.023	0.0232	0.0264	0.023	0.0165	0.396	0.0164	0.0161	0.0198
15	Manganese, Mn2+(mg/l)	0.2	0.061	0.123	0.001	0	0	0.002	0.01	0.021	0	0.002	0	0.002	0	0.021	0
16	Sulphate, SO4-(mg/l)	100	40	0	15	5	40	5	5	0	20	5	10	5	5	70	10
17	Chloride, Cl-(mg/l)	250	24.54	44.54	24.87	20.32	30.32	45.21	9.932	9.994	14.65	20.43	23.12	20.32	20.12	19.92	19.32
18	Chromium, Cr6+(mg/l)	0.05	0.03	0.102	0.05	0.153	0.03	0	0	0.04	0	0	0.05	0.013	0.04	0.05	0.154
19	Cyanide, CN-(mg/l)	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Total coliform (cfu/100ml)	10	10	5	8	9	0	0	10	0	0	7	0	23	0	0	0
21	Faecal coliform(cfu/100ml)	0	0	0	0	0	0	0	8	0	0		0	0	0	0	0
22	Phosphate	6.5	0.322	0.082	0.032	0.265	0.643	0.221	1.221	0.765	0.342	0.462	0.123	0.185	0.884	0.502	0.142
23	Sodium ion (mg/l)	200	9.166	17.816	9.948	8.128	12.128	18.084	3.998	3.987	5.86	8.187	9.248	8.092	8.048	7.965	7.728
24	Ammonia(mg/l)	1.5	0.114	6.624	0.123	0.085	0.482	0.064	0.482	0.364	0.056	0.097	0.054	0	0.076	0.254	0.221

WHO: World Health Organisation; NSDWQ: Nigeria Standard for Drinking Water Quality. Red, yellow, blue and black circle indicate anomalous values of Nitrate, Iron, Faceal Coliform and Total coliform respectively



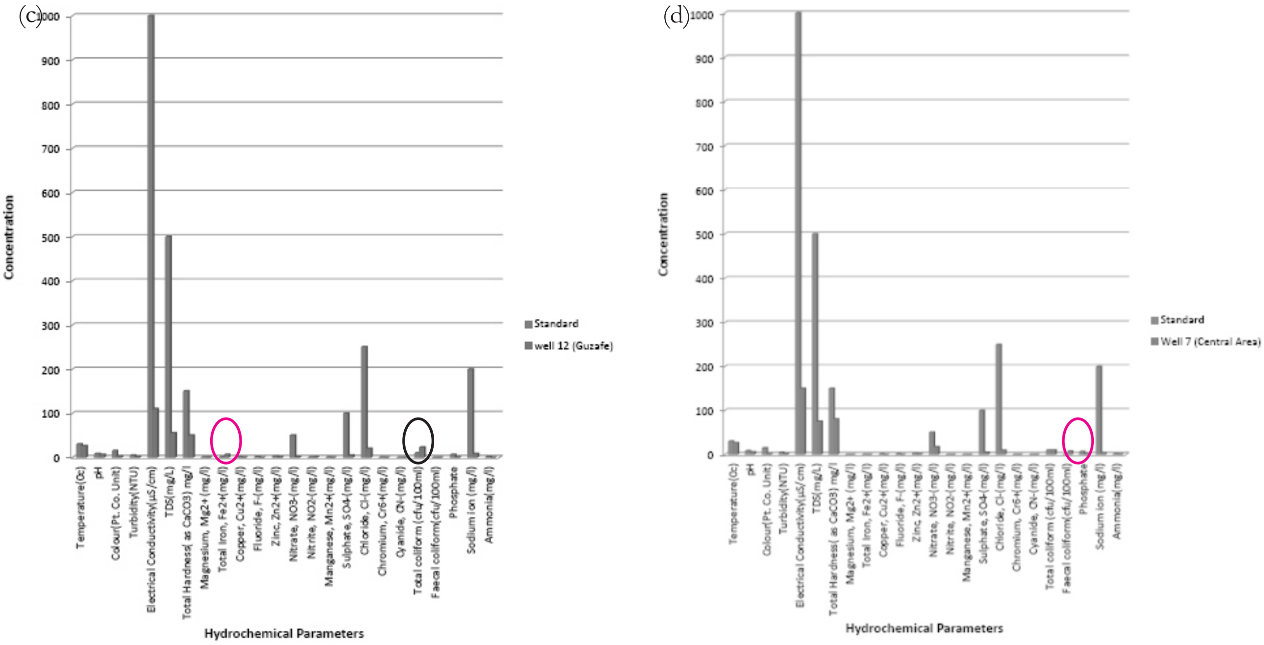


Figure 4: Anomalous Nitrate (NO_3^-) Concentration in (a) Wells 2 and (b) Well 6 Denoted by Red Cycle. (c) Anomalous Total Iron (Fe^{2+}) Concentration (red cycle) and High Total Coliform (blue cycle) in Well 12 (d) High Faecal Coliform in Well 7. Note: WHO standard is shown in Blue bars while concentration in well is shown in red bars.

CONCLUSION

Geophysical and Hydro-geochemical methods have been used to characterised the basement complex aquifers and assess probable pollution of groundwater in the area around the Abuja City Centre. This was achieved by interpreting 15 VES data and analysing water samples obtained in boreholes from the study area.

The VES curves vary from simple A, H, to more complex KH, HA, AA, and HKH-type curves. The KH and H type curves are predominant with frequencies of occurrence of 40 % and 33.3 % respectively. The K, A, AA and HKH have 6.7 % frequency of occurrence each of the total sounding curves. The predominant KH and H-type curves may be indicative of the fact that the basement rock has been subjected to limited tectonic activity with consequently low basement fracture frequency. The delineated aquifers in the study area are the weathered layer and the partially weathered/fractured basement, with the weathered basement aquifer occurring more frequently.

The hydrochemical analysis revealed that almost all the analysed parameters are within the permissible limit of drinking water quality based on World Health Organisation (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ) as shown in Table 3, except for wells 2 and 6 that showed high concentrations of nitrate, Wells 2, 10, 11, 12 and 15 showed higher concentrations of total Iron and Wells 7 and 12 showed significant amount of Faecal coliform and Total coliform respectively.

ACKNOWLEDGEMENT

The Scholarship from Petroleum Technological Development Fund (PTDF) to Mustapha Aliyu is gratefully appreciated. The authors would also like to thank Dr. M. A. Dan-Hassan of FCT Water Board for several useful information and data made available for this research work.

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