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Geophysical and Hydrochemical Evaluation of Groundwater Potential and Character of Abeokuta Area, Southwestern Nigeria

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Abstract

Hydrogeological assessment of groundwater resources of part of Abeokuta area was carried out with a view to highlighting the potential of the aquifers to provide portable water supply, chemical character and provenance of the groundwater resources of the area. Seventy-five Vertical Electrical Soundings (VES) were distributed across areas underlain by different rock types. This was complemented with fifty groundwater samples collected from wells and analyzed for the major ions and seventy two minor constituents. Three to five sub-surface geo-electric layers were delineated from the VES. The layers resistivities (Ωm) from top to bottom vary from 24.2 - 6428.3, 9.1-2250.0, 13.4-11563.1, 65.1-6654.5 and 400.2-9095.3 while the layers thickness (m) were 0.4-2.5, 0.6-30.0, 1.5-∞,3.4- ∞ and the undeterminable thickness respectively. The bedrock reflection coefficients vary from 0.4-1.0. Areas underlain by porphyritic granite and porphyroblastic gneiss have lower reflection coefficients, (0.82), higher lineament frequency, higher regolith resistivity (av. 119-167 Ωm) and fairly thick regolith (av. 9.2-13.76m). The relative abundance of the cations and anions in groundwater are Na>K>Ca>Mg and HCO_3>Cl>SO_4 correspondingly. The predominant water types include $CaNaHCO_3Cl$ and $NaHCO_3(Cl)$. High groundwater potential and yield were associated with areas underlain by porphyritic granite and porphyroblastic gneiss, with $CaNaHCO_3Cl$ and $NaHCO_3(Cl)$ dominant water-type in areas underlain by gneisses and granites respectively.

Keywords: geophysical, aquifers, groundwater

1. Introduction

Appraisal of groundwater resources of Nigeria dated back to as early as 1928 (Offodile, 2002) and over time evaluation of groundwater resources has covered different areas of hydrogeology. These among many others include geophysical (e.g Olorunfemi et al., 1999; Ako et al., 2005), hydrogeochemical (e.g Tijani, 1994; Tijani et al., 2005; Abimbola et al., 2002) and a few studies have employed some environmental isotopes in groundwater assessment, especially in northern part of Nigeria (Tijani, 2003 & Onugba, 2005).

These studies and many others have contributed tremendously to the development and management of groundwater resources. However, these studies are limited by their restriction to narrow area of hydrogeology. As noted by Okagbue (1998) a complete appraisal of groundwater will involve an integration of geophysical and hydro-geochemical studies.

Studies on groundwater resources in southwestern Nigeria have covered parts of many cities and rural communities such as Akure (Olorunfemi et al., 1999), Ikorodu (Olatunji et al., 2005), Ibadan (Olayinka et al., 1999; Tijani et al., 2002), Lagos (Ako et al., 2005; Tijani et al., 2005), Abeokuta (Abimbola et al., 1999) among many others. In spite of the wide coverage of these studies, important information on groundwater resources of these areas including Abeokuta and its environs are still largely unavailable. This study, therefore, employed geological, geophysical methods complemented with hydro-geochemical data to comprehensively evaluate the occurrences and character of groundwater in Abeokuta and its environs.

The city of Abeokuta and its environs have expanded over the last few years, from the central part spreading in all directions such that areas that were hitherto rural communities have developed into big towns. In addition, population explosion in recent years has seriously affected the efficiency of municipal water supply in areas covered by public water supply, such that the search for potable water has become a common challenge for the people of the town. Most of the inhabitants who are mostly artisans with the few employed populations (mainly civil servants), rely on the construction of hand dug wells to solve their water-supply need, due to the unaffordable cost of drilling boreholes. These wells are generally shallow, due to the geology and the rocky terrain of most part of the township, with a substantial number of the wells poorly constructed highly susceptible to pollution from surface sources as some of the wells are cited close to tombs, refuse dump sites and sewer.

2. The Study Area

The study area (Figure 1) is located between longitude 3.3000^0-3.4000^0 E and latitude 7.0875^0 and 7.2167^0. Notable settlements within the area include Lafenwa, Kuto, Ita-Elega, Kabo, Lafenwa, Igbo-Olodumare e.t.c. The climate is characterized by alternate wet and dry seasons. The amount of rainfall of varies between 750mm-1000m in the rainy season between March-October and 250mm-500mm in the dry season in the months of November-March (Akanni, 1992). Abeokuta area is characterized by an undulating topography with elevation ranging from 100 to 400m above sea level. In the area, the older granite masses and in some cases, the gneisses form rugged topography. It is underlain mainly by crystalline basement rocks described as older granites (Rahaman, 1988). The rocks underlying the area are hornblende-biotite gneiss, porpyroblastic gneiss, granite, porphyritic granite and pegmatitic intrusions (Figure 2).

3. Methodology

Geological mapping of the study area was carried out to delineate the boundary between the different rock types. The result of the mapping was used to produce the geological map (Figure 2). Seventy-five Vertical Electrical Soundings (VES) were carried out across areas underlain by diverse rock types, ensuring adequate coverage of the areas underlain by different rock types. The soundings were done using the Syscal Junior resistivity meter with a maximum current electrode spread (AB/2) of 100m. The field data were plotted on the log-log standard graphs and were curve-matched to extract the models for computer iteration. Lineament trace was extracted from Land sat Imagery of the study area to complement geo-electric parameters in the evaluation of groundwater potential of Abeokuta and its environs. The linear features were mapped by visual interpretation of the false colour composite of the first three principal components.

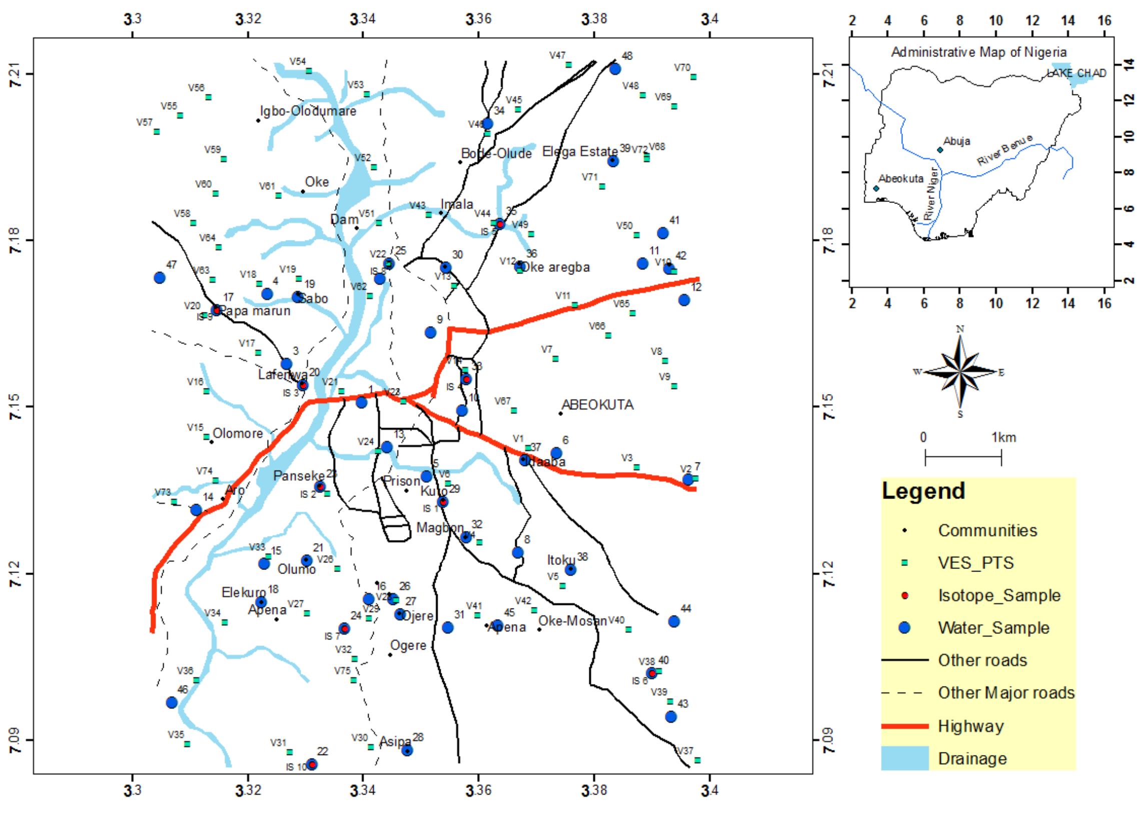

Figure 1. The study area showing VES and groundwater sampling points

Groundwater samples were collected from wells (Figure 1) distributed across the various underlying rock units from fifty locations. Two sets of samples were collected at each location in clean bottles; one set was acidified with HNO_3 while no preservative was added to the second set. Physical parameters (pH, TDS, Temperature, EC, water level and well depth) were measured on the field on groundwater samples using handheld pH-conductivity meter. The depth of wells was measured by electric water level sounder meter. Groundwater sampling was completed within three days. The samples were analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) for cations and 36 other elements while Ion Chromatography was used for the determination of the concentration of anions at Activation Laboratories, Ontario, Canada. Geochemical analysis of rock samples was carried out at Acme Laboratories, Canada, using the Inductively Coupled Plasma -Mass Spectrometry (ICP-MS) method to determine the elemental and major oxide content of the rock samples.

4. Results and Discussions

The summary of the geo-electric parameters of the Vertical Electrical Soundings (VES) is presented in Table 1. The reflection coefficient combined with the regolith resistivity and their thicknesses as well as lineament trace and other hydrogeological data were integrated and used to evaluate the groundwater potential of the area.

4.1 Geophysical Parameters

The sounding curves of Abeokuta area vary from 3 to 5 layers. Over 72% of the curves observed are the H-type while the KH, HKH curve types constitute 14.7% and 5.3% correspondingly. Other curves observed in the area are HA (2.7%), A (2.7%) and HK (1.3%). The H curve is a common curve type in this type of geological terrain (Olorunfemi and Oloruniwo, 1985). The intermediate layer in the H-type curve is usually characterized by low resistivity made up of clayey or sandy clay and is often water-saturated. This layer has high porosity, low specific yield and low permeability (Jones, 1985). The KH type has succession that consists of topsoil, sandy/gravel underlain by clay overlying weathered/fractured basement. The HA type consists of the topsoil, clay and sand regolithoverlying a weathered/fractured. Three geologic layers were identified in Abeokuta area, and these include the topsoil, weathered layer, fractured basement and/or fresh basement. The topsoil varies in lithology from clay, sandy clay, clayey sands, sands and gravelly lateritic soils.

The resistivity of the topsoil (Table 1) varies from 24.2 to 6428.3 Ohm-m with a mean of 830.8 Ohm-m and a standard deviation of 1130.8 Ohm-m, showing a very high degree of dispersion and a coefficient of variation of 173.8 %. The thickness of topsoil varies from 0.4 to 2.5m, with an average of 1.22±0.49 m. This layer is of little or no significance as a hydrogeological unit because of its low degree of saturation (Olayinka & Olorunfemi, 1992).

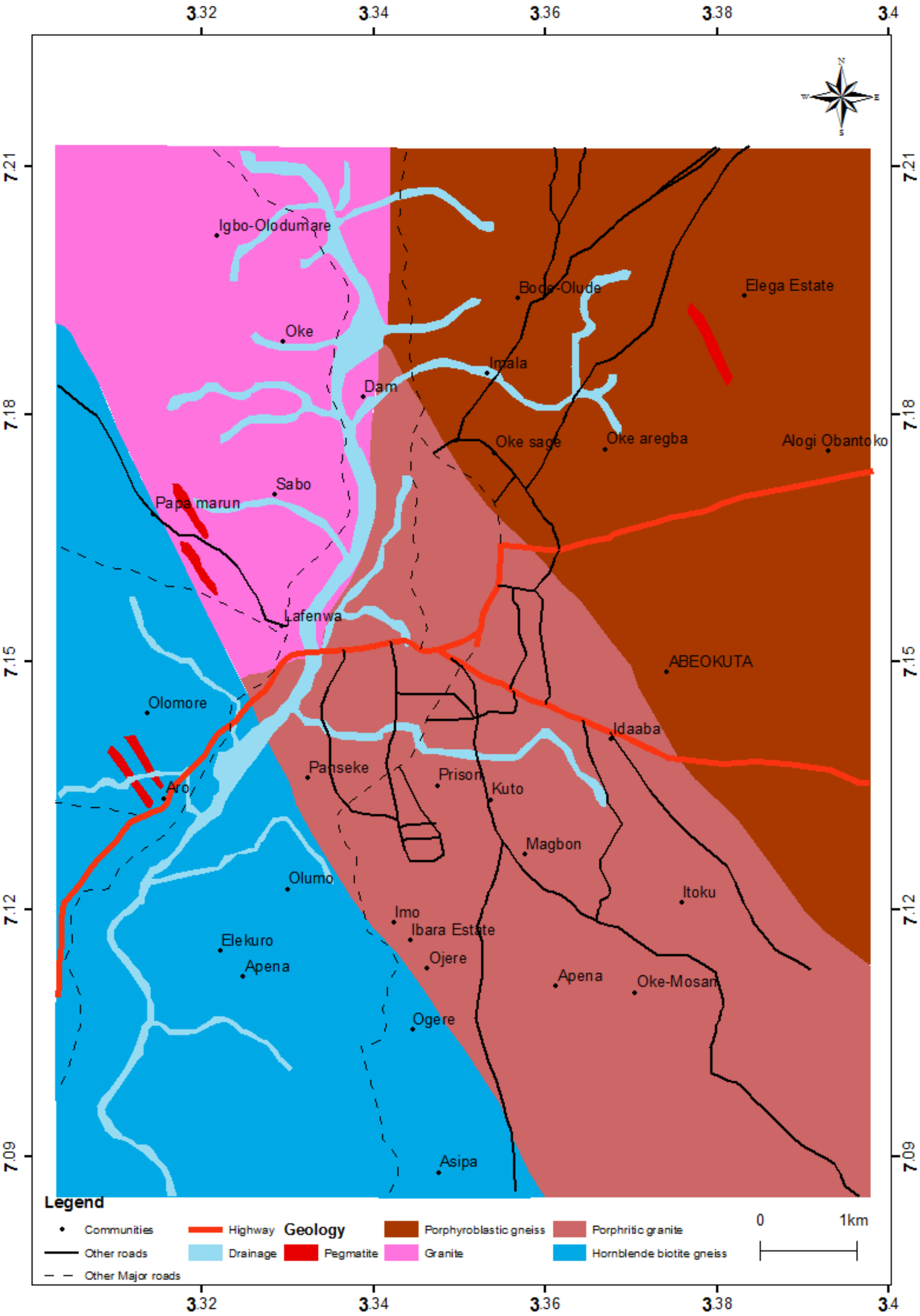

Figure 2. Geological map of Abeokuta area (This Study)

Table 1. Summary of the geophysical parameters based on underlying rock types in Abeokuta area

Rock types		Hornblende-biotite gneiss	Porphyroblastic gneiss	Granite	Porphyritic granite
No VES		17	23	15	20
Curve Types		H,HA,KH	H,HK,HKH,KH,A	H	H,HKH,KH,A
Top soil resistivity (ohm-m)	Range	24.2-2035.3	33.7-4095	311-6428	82.1-1233
	Mean± Standard deviation	460±540	943±1077	1866±1805	338±283
	coefficient of variation	117%	114%	97%	83%
Thickness of top soil (m)	Range	0.5-2.2	0.5-3.1	0.7-2.5	0.4-1.9
	Mean± Standard deviation	1.2±0.5	1.4±0.7	1.4±0.5	1.1±0.4
	coefficient of variation	41%	48%	33%	41%
Resistivity of the Regolith (ohm-m)	Range	11.9-212.4	14.8-518.6	22.2-368.2	9.1-731.5
	Mean± Standard deviation	72±63	119±124	91.2±92.5	167.5±196.9
	coefficient of variation	87%	104%	101%	117%
Thickness of Regolith (m)	Range	4.9-35.9	2.3-41.1	2.4-29.3	2.1-23.5
	Mean± Standard deviation	14.7±9.5	13.7±9.6	10.5±7.5	9.2±5.5
	coefficient of variation	65%	70%	71%	59%
Basement resistivity (Ohm-m)	Range	169-8816	126.1-9095	355-8319	400-11563
	Mean± Standard deviation	2397±24880	2272±2569	2318±2108	2533±2913
	coefficient of variation	103%	113%	91%	115%
Depth to geoelectric basement (m)	Range	2.2-39.8	1.9-55.4	3.5-31.2	3.6-46.6
	Mean± Standard deviation	15±10.3	17.8±13.4	12.0±7.8	13.8±11.6
	coefficient of variation	69%	75%	64%	84%
Reflection Coefficient	Range	0.640-0.988	0.548-0.991	0.635-0.995	0.418-0.996
	Mean± Standard deviation	0.895±0.108	0.827±0.139	0.881±0.107	0.824±0.151
	coefficient of variation	12%	17%	12%	18%
Nature of Regolith		Clay (53%), sandy clay (35%) and sands(12%)	Clay (63%),sandy clay (20%) and sands (17%)	Clay (71%), sandy clay (20%) and sands(9%)	Clay (42%), sands (29%) and sandy clay (29%)

The resistivity of the topsoil (Table 1) in most of the area (over 66%) varies from 100 to 1000 Ohm-m and in about a quarter of the study area; it is made up of gravels washed from the hilly areas. In the area with gravelly topsoil, the resistivity of the layer is mostly greater than 1000 Ohm-m. The resistivity of the weathered regolith varies from 9.1-731.5m Ohm-m and averages 116.8 Ohm-m. The resistivity of the regolith varies from 9.1-731.5m ohm-m and averages 116.8 Ohm-m. The areas underlain by hornblende-biotite gneiss and granite have low regolith resistivity of 11.9-212.4 ohm-m and 22.2-368.2 Ohm-m respectively. Averagely, the regolith resistivities of these areas correspondingly are 72 Ohm-m and 91.2 Ohm-m. The locations underlain by porphyroblastic gneiss and porphyritic granite, on the other hand have resitivities of 14.8-518.6 Ohm-m and 9.1-731.5 Ohm-m in that order. Averagely, the resistivity values of the regolith overlying the hornblende biotite gneiss (119 Ohm-m) and porphyritic granite (167.5 Ohm-m) are comparatively higher than the resistivity of the other areas. This implicitly suggests the occurrence of low clay content in the regolith compared to the other areas with lower resistivities (Figure 3a).

The regolith thickness varies from 2.1-35.9m in the study area. The gneisses have thicker regolith with an average of 17.8 m for the regolith overlying areas underlain by porphyroblastic gneiss and 15 m for area where the bedrock is hornblende-biotite gneiss compared to 12 m and 13.8 m respectively for areas underlain by granite and porphyritic granite. Generally, as noticeable in Figure 3b, there is an increase in overburden thickness away from either side of river Ogun, although there are other locations, especially those close to outcrops where the overburden thickness is thin despite being far away from river Ogun.

The resistivity of bedrock in the area varies from 126-11503 ohm-m, with an average of 2326 Ohm-m. The steeply rising terminal branch on a sounding curve and very high resistivity is not indicative of fresh bedrock (Olayinka, 1996). In place of resistivity of bedrock, the reflection coefficient (K) at the bedrock interface is a more reliable parameter in the identification of the nature of bedrock (Olayinka, 1996) emphasized. In the study area, the reflection coefficient at the bedrock interface in area underlain by porphyroblastic gneiss varies from 0.548 to 0.991. Similarly, the porphyritic granite has k of between 0.418 and 0.996 with an average of 0.824. Most part of the area underlain by porphyroblastic gneiss has low reflection coefficient compare with the other underlying rock types, with average k of 0.827. The similar nature of the reflection coefficient and the values of coefficient of variation for these two rocks may be largely due to their similarity in mineralogy and grain size, though while porphyroblastic gneiss is foliated the other has a porphyritic texture. The range of reflection coefficients for areas underlain by hornblende-biotite-gneiss and granite are 0.640 to 0.988 and 0.635 to 0.995 respectively. The average reflection coefficients in the areas are 0.895 and 0.881 respectively.

4.2 Lineament Frequency in Abeokuta Area

Lineaments are linear topographic features of regional extent. It may include valleys, rivers, streams, etc. controlled by faulting or jointing. Structural features associated with lineaments include fault zones, joint zones, fold axes. The lineaments trace in Abeokuta area was extracted from Landsat Imagery of the study area to complement geo-electric parameter in the assessment of the groundwater potential of Abeokuta area. The lineaments (Figure 4a) are mostly trending in the NW-SE direction, coinciding with the foliation trend in the area. Other lineaments are trending in and NE-SW direction. The frequency of the lineament traces in an area of 1.08sq km was determined and contoured to produce the lineament frequency map (Figure 4b). As observed in the reflection coefficient data, the area underlain by porphyroblastic gneiss has higher lineament frequency than other parts of the study area.

Groundwater Potential of the Basement Rocks of Abeokuta Area.

The groundwater potential of a basement complex area is determined by complex interrelationship between the geology, post emplacement history, weathering processes and depth and nature of the weathered layer, groundwater flow pattern, recharge and discharge processes (Olorunfemi et al., 1999). In order to assess the groundwater potential of the area, the regolith resistivity map (Figure 3a), the regolith thickness map (Figure 3b), the contour map of the lineament trace (Figure 4b) and the reflection coefficient map (Figure 5) were all combined to classify the study area into:

a) High groundwater potential

b) Medium groundwater potential

c) and Low groundwater potential

The groundwater potential of the area is defined by identifying areas with low reflection coefficient, high lineament frequency, high regolith resistivity and thick regolith. Areas with low reflection coefficients represent areas where the bedrock is weathered and/or fractured (Olayinka, 1996). Where the regolith resistivity is low (less than 100 Ohm-m), the regolith is essentially clay or clayey, which though has high porosity, but it has low specific yield and very low permeability (Olayinka and Olorunfemi, 1992 citing Jones, 1985) and thus will not yield appreciable quantity of water to wells. Where the resistivity is high, the materials are usually essentially sandy and can serve as either an aquifer or an aquitard. Barker et. al (1992) observed that highest yielding boreholes in the basement complex of Zimbabwe are associated with weathered layer resistivities of between 100-600 Ohm-m For the regolith to supply an appreciable quantity of water to wells, the regolith must be sufficiently thick. A minimum thickness of 10m was however recommended by White et al (1988) to ensure adequate yield to wells. Olorunfemi et al (1999) also indicated that the nature of weathered layer determines to a significant extent the yield of a borehole irrespective of the underlying fractured basement column, with area overlain by clay (resistivities <100 ohm-m), having low yield.

Lineaments largely represent the expression of linear structures in underlying rock on a regional topography on imagery. Commonly, this may represent straight streams, rivers and vegetation paths controlled by fractures in rocks. Areas with high lineament frequency are indicative of areas with higher fracture density.

A combination of these parameters with their maps super-imposed (Figure 6) was used to produce the groundwater potential map (Figure 7) of the area. High groundwater potential areas were defined by high regolith resistivity (100-730 Ohm-m), sufficiently thick regolith (>10m), low reflection coefficient and high lineament frequency.

The medium groundwater potential areas were defined by either;

I. Low reflection coefficient, high lineament frequency, combined with high regolith resistivity.

II. High regolith resistivity and thickness

The presence of combination of the parameters listed in I or II will provide fair to good groundwater yields in the wells.

Areas with low groundwater potential are classified by the presence of either;

I. High lineament frequency and low reflection coefficient or

II. High regolith resistivity and relatively thick regolith (greater than 6m).

Areas where all these criteria listed above are absent are classified as having poor groundwater potential.

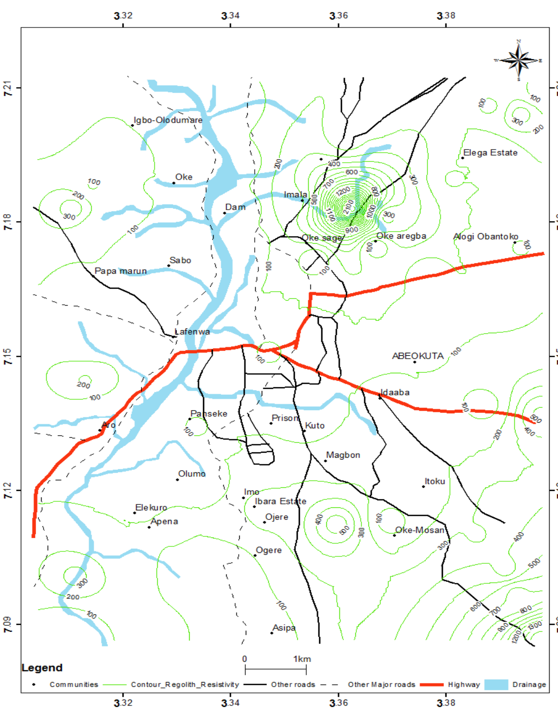

Figure 3a. Contour map of the regolith resistivity in Abeokuta area

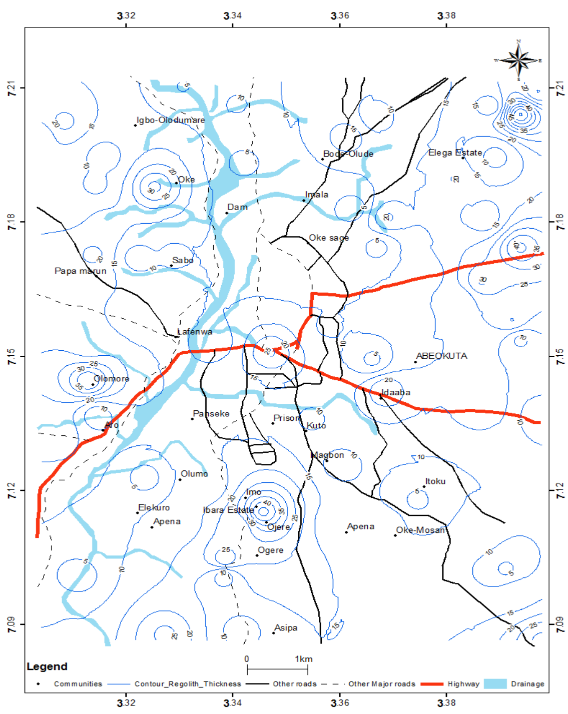

Figure 3b. Isopach map of the regolith thickness in Abeokuta area

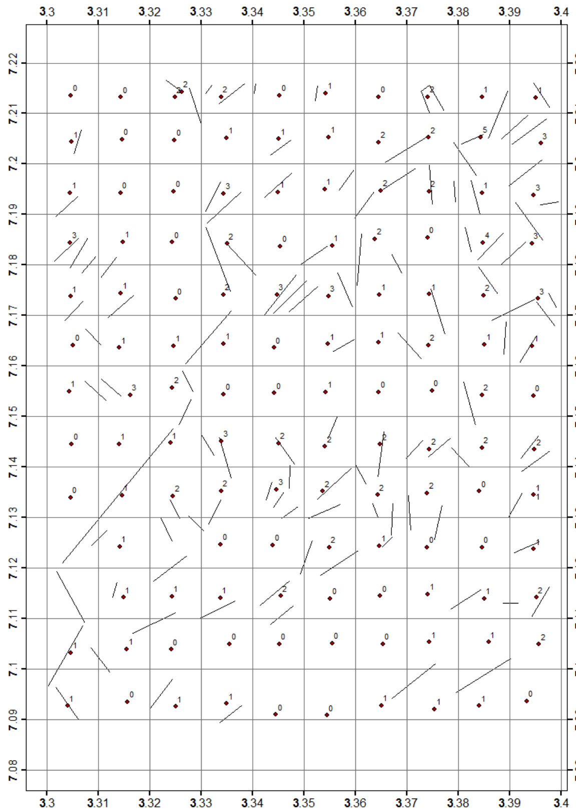

Figure 4a. Lineament trace of Abeokuta area

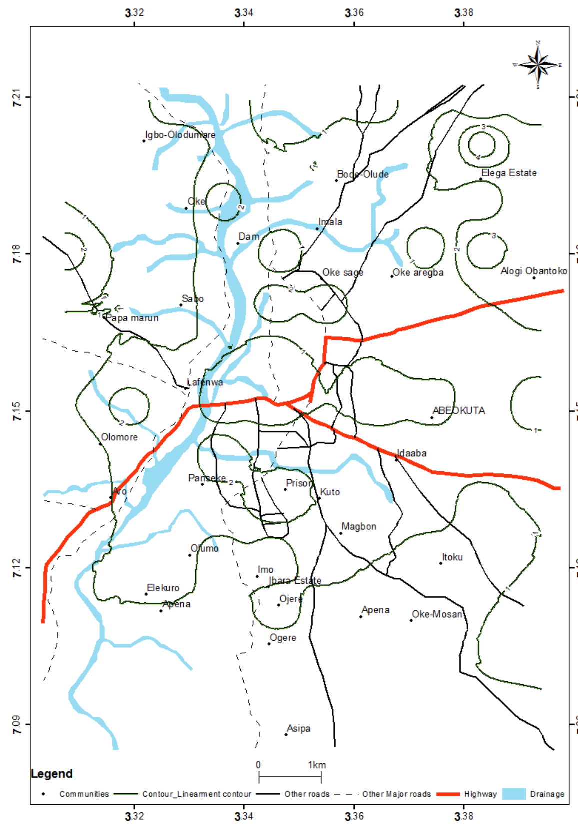

Figure 4b. Contour Map of Lineament trace in Abeokuta area

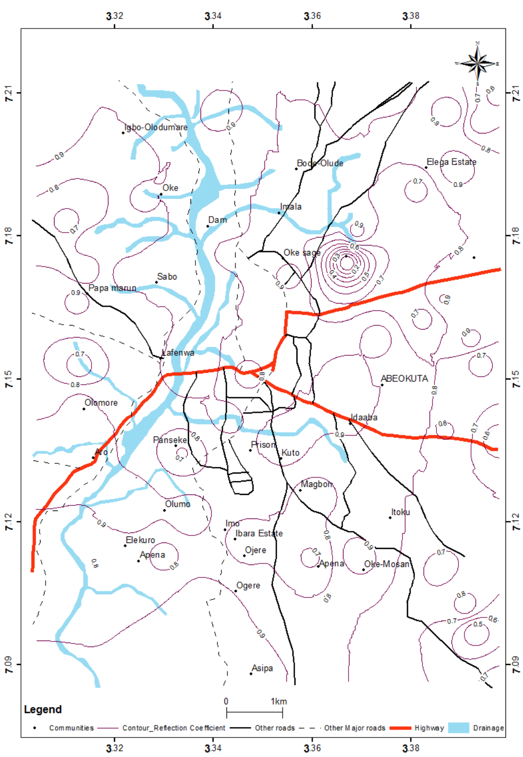

Figure 5. Reflection Coefficient (K) in Abeokuta Area

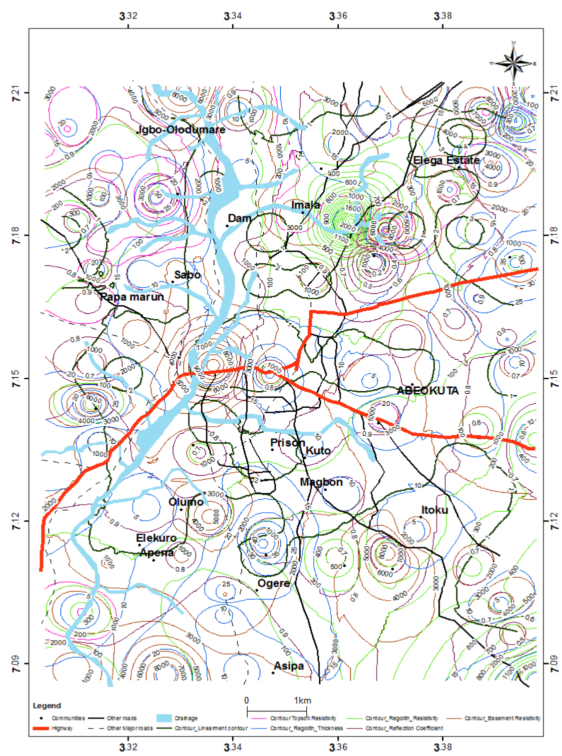

Figure 6. Combination of thickness and resistivity of Regolith, lineament contour map and reflection coefficients

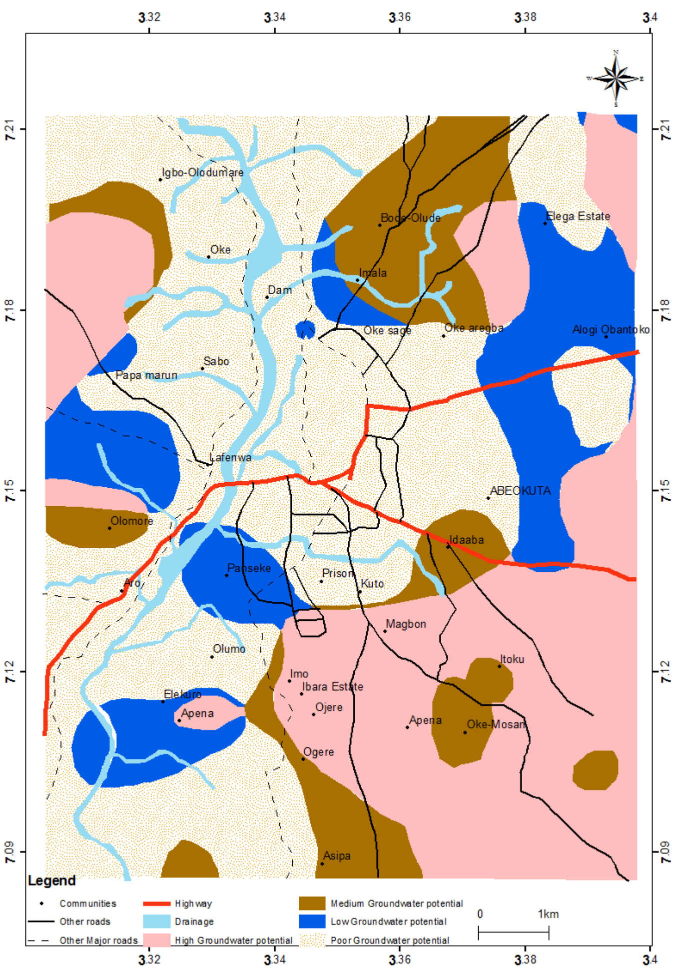

Figure 7. Groundwater potential map of Abeokuta area

Generally, less than 25% of the study area has high groundwater potential, restricted mostly to area underlain by porphyritic granite and porphyroblastic gneiss while over 50% of the area has poor groundwater potential. This invariably indicates the importance of detailed groundwater exploration in the study area for locating areas where successful boreholes can be drilled.

As noted in previous studies (e.g. Olorunfemi et al., 1999) the groundwater potential map which displays the regional groundwater potential scenario in this area based on the criteria defined above is subject to local variations as a result of the well documented discontinuous nature of basement aquifers. However, the map will serve as a reliable guide of the groundwater potential of the area, especially as this has been shown to be related to the bedrock type.

4.3 Groundwater Chemistry

The results of groundwater analyses (Table 2) revealed that the sampled groundwater is slightly acidic to alkaline (pH: 5.9-8.6), mostly fresh with Total Dissolved Solid (TDS) of between of 78-1504 mg/l and an average TDS of 518.6±322.3 mg/l. It is generally less than 1000mg/l, the cut-off value for fresh water (Todd, 1980). High TDS is mostly characteristic of groundwater in areas close to river Ogun and its tributaries. The sampled water is largely soft with a hardness that varies from 29-84 ppm and averages 59.4±13.3 ppm. The groundwater in the study areas is classified (Sawyer and McCarty, 1967), as soft (<75 ppm) to moderately hard (75-150 ppm). The electrical conductance (EC) in the groundwater varies from 119-2331 uS/cm with an average of 863.9±557.1 uS/cm and a coefficient of variation of 68%.

HCO_3^- is the dominant anion (in 98% of the groundwater samples) as shown by the shape and the spatial distribution of the polygons in Figure8 while Na^+ is the dominant cation (75% of the sample) and Ca^{2+} is predominant in 25% of the samples. The impact of River Ogun on the groundwater is indicated by relatively higher concentration of HCO_3^-, Cl and TDS in area contiguous to the river. Na^++K^+ constitute the dominant cation over Ca^{2+} around the central area of the map, mostly underlain by granite and porphyritic granite. In other areas, especially the area underlain by hornblende-biotite gneiss, Ca^{2+} is dominant cation over Na^++K^+. As shown by the Scholler diagram in Figure 9, the relative abundance of the cations and anions in groundwater are Na^++K^+>Ca^{2+}>Mg^{2+} and HCO_3^{-}>Cl^->SO_4^{2-} correspondingly.

NO_3^- is generally low though the range is 8 mg/l to 60.8 mg/l and the mean concentration is 17.mg/l. Few areas with concentration of nitrate greater than 30mg/l are also associated with high chloride concentration (>100mg/l). Interestingly, the maximum chloride concentration was obtained where the maximum nitrate (60.5 mg/l). This invariably suggests similar contamination sources. Only 16% of the groundwater samples have nitrate concentration of greater than 30 mg/l, the cut-off for possible nitrate from natural sources (Hernandez-Garcia and Custodio, 2004). NO_3^- concentration of greater than the standard of 45mg/l (WHO, 2006) was observed in less than 6% of the samples. Hence, nitrate pollution is a localized event rather than a regional pollution source. The elevated concentration of Cl^- and NO_3^- is largely due to downward percolation of water contaminated by livestock waste as well as washing activities of the inhabitants.

Table 2. Summary of the physical and chemical parameters of groundwater in the study area (No of samples =50)

		Minimum	**Maximum**	**Mean**	**WHO, 2006**	**SON, 2007**
Physical Parameters	Total Well Depth (m)	1.5	14	6.49		
	Static Water Level (m)	1.2	9.4	4.1		
	pH	5.9	8.6	6.9	6.5-8.5	6.5-8.5
	TDS (mg/l)	78	1504	476.41	1000 (mg/l)	500 mg/l
	EC (us/cm)	119	2331	863.95		
	Hardness (mg/l)	29	84	59.4		
Major ions and elements (mg/l)	Na(mg/l)	3.2	121	42.26		200
	K(mg/l)	1.2	126	14.73		
	Mg (mg/l)	0.8	19.8	7.46		
	Ca (mg/l)	0.1	83.8	31.57		
	Cl (mg/l)	9.1	222	70.52		250
	SO_4 (mg/l)	1.19	82.3	23.94	400	100
	HCO_3 (mg/l)	34.3	369.8	169.81		
	Fe (mg/l)	0.01	4.79	0.64		0.3
	Si (mg/l)	4.8	46.4	15.6		
	Al (mg/l)	< 0.1	4.1	0.69	0.2	0.2
	Mn (mg/l)	0.01	0.77	0.12	0.05	0.2
	S (mg/l)	< 1	29	8.95		
	NO_3 (mg/l)	0.8	60.8	17.14	50	50
Minor Constituents	Ba (ug/l)	20	2040	191.04	0.7 mg/l	0.7 mg/l
	Cu (ug/l)	2	78	16.3	2 mg/l	1 mg/l
	Sr (ug/l)	30	590	199.38		
	Zn (ug/l)	6	1000	97.5		
	Bi (ug/l)	< 20	60	50		
	Cd (ug/l)	< 2	19	10.1	0.005 mg/l	0.003 mg/l
	Co (ug/l)	< 2	10	4.7		
	Mo (ug/l)	6	10	8.3		
	P (mg/l)	0.02	1.62	0.23		
	Pb (ug/l)	10	20	14	0.01 mg/l	0.01 mg/l
	S (ug/l)	< 1	29	8.95		
	Sn (ug/l)	30	60	45		
	Sr (ug/l)	30	590	199		
	Te (ug/l)	10	30	20		
	Ti (ug/l)	< 10	180	50.6		
	Tl (ug/l)	20	100	60		
	U (mg/l)	< 0.05	0.19	0.12	0.015 mg/l	
	V (ug/l)	< 10	20	15		
	W (ug/l)	< 10	20	16		
	Y (ug/l)	< 10	30	16		
	Zn (ug/l)	6	1000	97.5	3 mg/l	3 mg/l
	F (mg/l)	< 0.01	1.5	0.554	1.5 mg/l	1.5 mg/l
	Br (mg/l)	0.1	0.31	0.16		

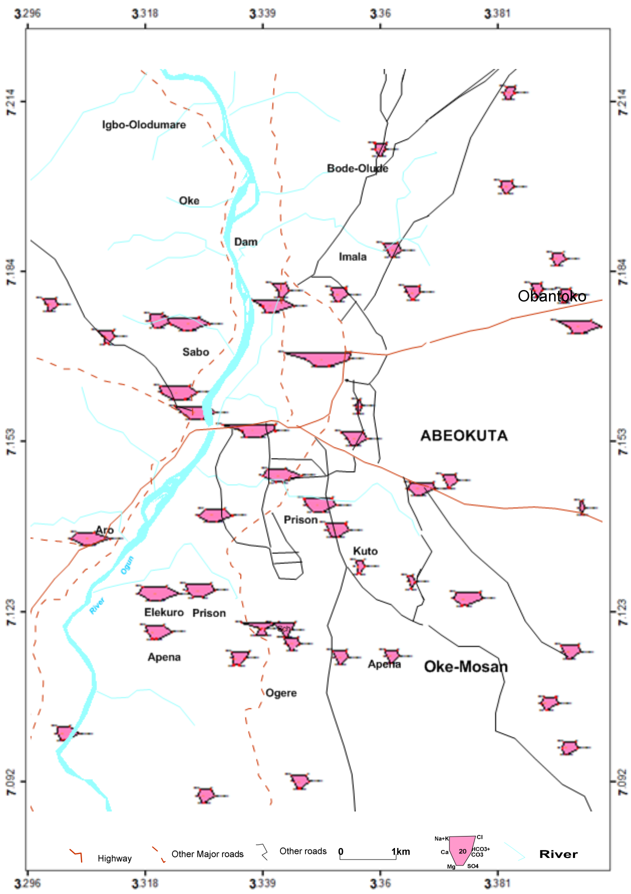

Figure 8. Stiff map of Abeokuta area

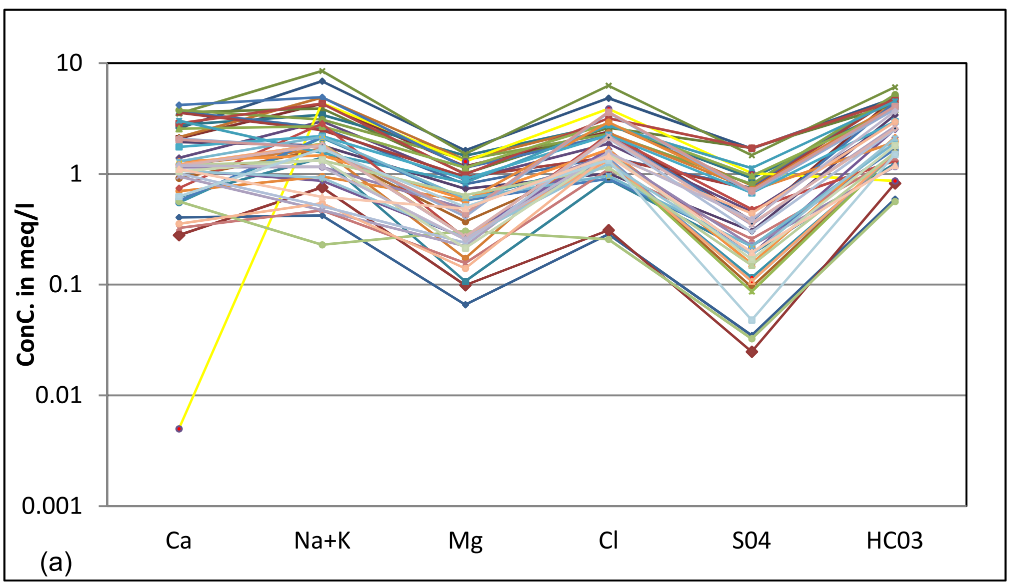

Figure 9. Scholler Diagram of groundwater in Abeokuta area

All the trace constituents of the groundwater in the study area are derived mainly from the weathering of the bedrock, as they are all detectable in the analyzed rock samples (Table 3b) from the area. Most of the constituents and trace elements in water are present within the permissible level (Table 2), with the exception of

Ba, Al, Pb and Mn, which are excessive in some areas while fluoride is deficient in most of the samples. Fluoride occurs in the range of between 0.1-1.5 mg/l with an average value of 0.55 mg/l. fluoride occurs below detection limit in large percentage of the groundwater, while in the remaining samples, the groundwater is generally deficient in fluoride (Table 2) compared with a range of 0.5-1.5 mg/l recommended for the promotion of good dental health (Dissanayake, 1991; Appelo and Postma, 2005). Studies (Patty, 1962; WHO, 1980; Moskowitz et al., 1986) have shown that concentration of Al and Ba and Pb at levels higher than the permissible level (Table 2) ion groundwater can cause serious health effect.

The Piper trilinear diagram in Figure 10 shows that the groundwater samples are mostly alkaline earth water types with about 80% of the samples falling within the Ca-Na-HCO_3 and Ca-Na-HCO_3-Cl water types while other pockets of local variations, including $CaHCO_3$, $NaHCO_3Cl$, $NaHCO_3$ and NaCl. Ca -Na-HCO_3 and Ca-Na-HCO_3-Cl water types jointly constitute less than 20% (Figure 5c). Generally, in these water types, $Na^{+}+K^{+}>Cl^{-}$ and $HCO_3^{-}>Ca^{2+}+Mg^{2+}$ (all in eq. concentrations), thereby resulting in excess HCO_3^{-} and Na^{+} (and K^{+}), thus creating an appreciable amount of $NaHCO_3$. Tijani (1994) noted that in exchange water; there is more HCO_3^{-} than ions of alkaline earth metals (Ca^{2+} and Mg^{2+}) in equivalent concentration. This is indicative of a cation exchange process, and this type of water is referred to as exchange water (Tijani 1994 citing Lohnert 1973). The excess bicarbonate ions then release alkali ions (usually Na^{+}) into solution by exchange reaction with cation exchanger such as clay minerals and other related minerals that form part of the aquifer materials thus enriching the water with $NaHCO_3$. The process as shown in eq. 1 (Tijani, 1994) is represented as;

$$Ca/Mg\ (CaCO_3)_2 + Na_2E \rightleftharpoons 2NaHCO_3 + Ca/MgE \quad \text{..........................eq.1}$$

Where E=Exchanger

Apart from the presence of cation exchanger in the form of clay minerals (the weathering product of the underlying rocks), the availability of adequate contact surface area and the long contact time between water and aquifer materials are also important for the above reaction to proceed. In Abeokuta area, the weathering profile provides the necessary conditions for the exchange reactions by containing clay minerals and this induced low permeability and allow for long contact time with percolating groundwater.

The groundwater from area underlain by porphyroblastic gneiss and the hornblende biotite gneiss (Table 4) are mostly dominated by Ca-Na-HCO_3-Cl and Ca-Na-HCO_3 water types. This is a clear reflection of the influence geology on the water types as these rocks have higher Ca^{2+} and Mg^{2+} in their composition relative to granites Table 3a. In addition, the $NaHCO_3Cl$, $NaHCO_3$ and NaCl are largely restricted to areas underlain by the granites. These rocks as shown by the chemistry of the underlying rocks (Table 3a and b) and expectedly in their weathering products are richer in Na^{+} and K^{+} relative to the gneisses, hence the restriction of Na^{+} (and K^{+}) rich groundwater to areas underlain by the granites. This indicates some influence of geology on the groundwater chemistry. The $CaHCO_3$, $NaHCO_3Cl$, $NaHCO_3$ and NaCl water types jointly constitute less than 20% of the groundwater in the study area. $CaHCO_3$ is alkaline earth water commonly found in Basement Complex of southwestern Nigeria, especially where there is limited mixing (Amadi, 1987) and low or negligible ionic contribution through anthropogenic sources. This water type is only found in few parts of Abeokuta area. NaHCO3Cl and NaHCO3 are also localised. The geochemical results and mineralogy of the rocks in Abeokuta area (Table 3) indicates that sodium/sodium bearing minerals are important constituents of the underlying rocks in the area. Several studies have reported the occurrence of NaHCO3 water type can result from water-rock interaction (Diop and Tijani, 2008; Tijani and Abimbola, 2003). The NaCl water type is an alkaline water type commonly found in locations close to the coast. However, it occurs in only one location (L16) in Abeokuta area, and it is localized as other nearby locations have different water type (L26 and 27). The occurrence of the water type at this location is localized related to localized anthropogenic influence. The NaHCO3Cl, NaHCO3 and NaCl are largely found in areas underlain by the granites (Table 4).

5. Conclusion

The study of occurrence, quality and geochemistry in parts of Abeokuta area of southwestern Nigeria, integrating geological, geophysical, geochemical characteristics of rocks and groundwater revealed the following:

Geophysical studies revealed the dominance of the H-curve type which constitutes more than 72% of the curve-type in Abeokuta area. Areas underlain by porphyroblastic gneiss and porphyritic granite have geo-electric parameters that favour high groundwater occurrence than areas underlain by either granite or hornblende gneiss. Hence, the groundwater potential of the areas underlain by the former rocks is higher compared with areas underlain by the latter. Most parts of the study area have low groundwater potential, suggesting the need for detailed groundwater exploration for location and construction of successful boreholes.

Table 3a. Results of Major oxides of the rock samples in Abeokuta Area

Analyte	Unit	MDL	Pegmatite	Porphyritic granite	Hornblende-Biotite Gneiss	Granite	Porphyroblastic Gneiss
SiO_2	%	0.01	74.36	72.35	54.51	73.08	66.17
Al_2O_3	%	0.01	14.12	14.29	17.05	12.83	13.79
Fe_2O_3	%	0.04	0.24	1.58	8.86	4.02	5.22
MgO	%	0.01	0.03	0.22	2.47	0.67	1.07
CaO	%	0.01	0.10	1.07	12.55	2.90	2.32
Na_2O	%	0.01	1.39	3.00	0.95	3.10	2.70
K_2O	%	0.01	9.33	6.67	0.20	1.52	4.26
TiO_2	%	0.01	<0.01	0.12	2.17	0.75	1.11
P_2O_5	%	0.01	0.01	0.12	0.47	0.25	0.45
LOI	%	-5.1	0.40	0.40	0.40	0.70	2.60
Sum	%	0.01	99.96	99.83	99.69	99.82	99.70

Table 3b. Summary of the result of the Trace Elements in the rock samples of Abeokuta Area

Elements	Range (ppm)	Elements	Range
Ni	Bdl – 29	Zr	7.2 – 532
Sc	Bdl – 42	Y	0.9 – 34.0
Ba	43 – 486	Mo	Bdl – 0.4
Be	Bdl – 4	Cu	1.5 – 13.2
Co	0.4 – 15.3	Rb	1.1 – 9.3
Cs	Bdl – 3.6	Zn	2- 107
Ga	13.5 – 24.5	Ni	0.6 – 5.4
Hf	0.4 – 14.4	As	Bdl -1.5
Nb	2.0 – 19.7	Cd	Bdl
Rb	3.8 – 306.3	Sb	Bdl – 0.2
Sn	Bdl – 3	Bi	Bdl
Sr	109.8 – 791.4	Ag	Bdl
Ta	0.1 – 1.4	Au	0.6 – 1.7
Th	1.3 – 84.5	Hg	Bdl
U	0.3 – 4.8	Tl	Bdl – 0.7
V	Bdl – 314	Se	Bdl
W	Bdl -0.8		

Bdl = Below detection limit.

Table 4. Percentages of groundwater facies based on underlying rock types/ well type in the study areas

Water types	Abeokuta (Rock types)			
	Hornblende Biotite Gneiss	Porphyroblastic Gneiss	Granite	Porphyritic Granite
$CaHCO_3$				5
$CaHCO_3Cl$		8		15
$CaNaHCO_3$	27	17	40	10
$CaNaHCO_3Cl$	64	67	40	45
$NaHCO_3$				5
$NaHCO_3Cl$	9	8	20	15
NaCl				5
	100	100	100	100

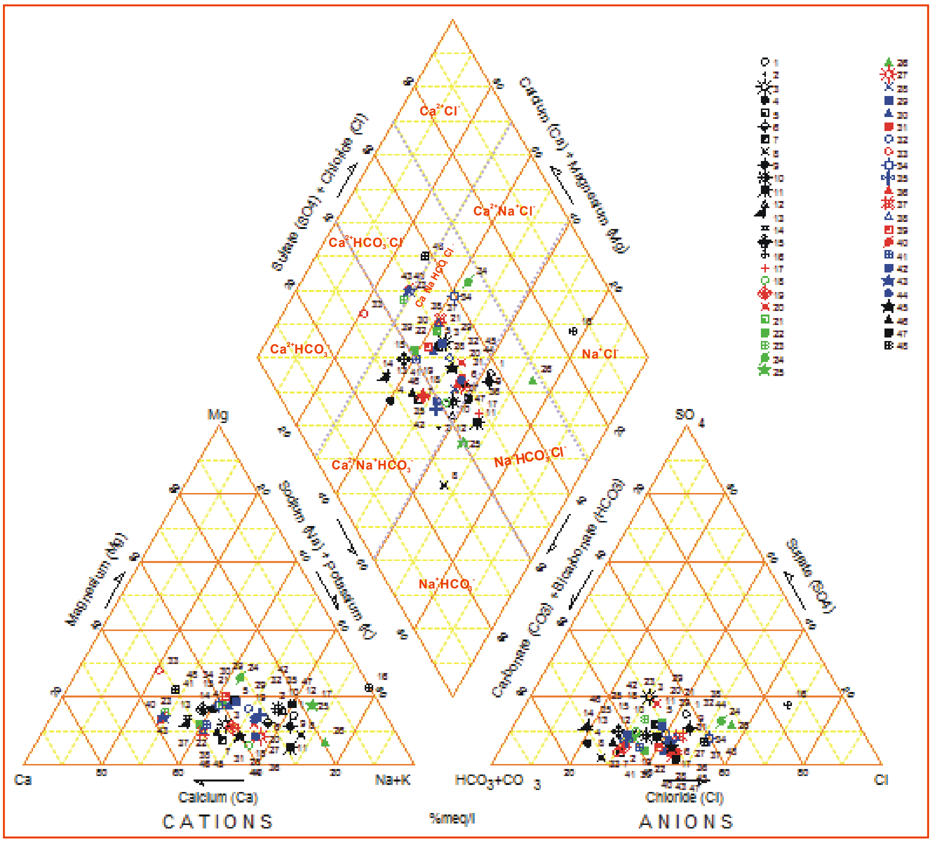

Figure 10. Piper Trilinear Diagram of Abeokuta area (after Piper, 1944)

The groundwater in the weathered/fractured aquifer in Abeokuta area is generally fresh, slightly acidic to alkaline and has higher TDS in areas close to R. Ogun. The main constituents of groundwater in orders of abundance are $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ and $HCO_3^- > Cl^- > SO_4^{2-}$ respectively for the cations and anions in Abeokuta area.

Nitrates in almost all part of the study area except for a few locations (16%) is within the range of nitrate in groundwater from natural sources. The groundwater is generally deficient in fluoride, and the groundwater in few areas has excess concentration of Al, Ba, Fe and Mn. The groundwater in Abeokuta environs is alkaline earth water having mostly Ca(Mg)-Na-HCO3 and Ca(Mg)-Na-HCO3-Cl water-type (90%) and with pockets of other water types (mostly alkaline) that include CaHCO3, NaHCO3Cl, NaHCO3 and NaCl. The groundwater character is partly influenced by localized pollution sources such as livestock waste, sewages, as well as by rock-water interaction.

From the foregoing, major ionic constituents, which have been the focus of most groundwater studies, especially in the southwestern part of the country are inadequate for evaluation of groundwater quality.

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