



Integrated Approach for Groundwater Assessment in Yetunde Brown, Ifako, Gbagada, Lagos State, Nigeria

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ABSTRACT: The poor quality of potable water sourced from boreholes and hand dug wells at Yetunde Brown, Gbagada, Lagos informed the integration of geophysical, physicochemical and Water Quality Index (WQI) to assess the condition of groundwater in the study area. Twenty-Five (25) Vertical Electrical Sounding (VES) data were acquired and complemented with water samples collected from three boreholes and two hand-dug wells within the neighborhood of the study area. The VES data were partially curve matched and inverted. Physicochemical parameters were measured in water samples. The results of the VES data revealed four to five geo-electric layers which correspond to the topsoil (with layer thickness and resistivity values from 0.6 to 1.3 m and 20.1 to 361.4 Ω m respectively), clay (with layer thickness and resistivity of 1.7 to 5.2 m and 2.8 to 22.1 Ω m), sandy clay (with layer thickness and resistivity values of 2.8 to 5.9 m and 12.4 to 56.8 Ω m) and clayey sand (with layer thickness and resistivity values of 23.8 to 31.8 m and 7.2 to 94.2 Ω m). The sand in VES 7, 9, 12-18 and 20 has resistivity values ranging from 151 to 331.5 Ω m. The depth to the identified aquifers fluctuates between 23.8 and 90.4 m. The measured iron, chloride and lead ions are above World Health Organization (WHO) recommendation for potable water in some water samples. WQI calculated reflected poor quality for two boreholes only, which could be due to the unconfined aquifers delineated in the second and fourth geo-electric layers making the water vulnerable to contamination. The study recommended that bore hole should be sunk at VES 7, 9, 12, 13, 18 and 20 at depth between 31.8 to 66.6 m for exploitation of good quality water.

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The availability and accessibility of potable and quality water resources is of major concern in Nigeria. According to World Health Organization (WHO) about 80% of all the diseases in human beings are caused by water (Mufid, 2012). Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of rural dwellers still depend majorly on untreated surface water. Ideally, water from rivers, springs, lakes and ponds are the easiest and most convenient way to meet the public demand for water but these sources are less than 0.01 percent of the world's total water and less than two percent of the world's fresh water (Ariyo and Banjo, 2008). They are spatially distributed and in most cases are highly polluted. On the other hand, groundwater accounts for about ninety-eight percent of the world's reasonably constant supply, which is not likely to dry up under natural conditions in crust to the surface sources. Though groundwater is significantly protected from surface pollutants, however, the need to ensure that the real conditions of the aquifer is understood and

delineated is highly desirable (Adiat *et al.*, 2012; Odukoya *et al.*, 2013 and Adeoti *et al.*, 2015). Groundwater investigation requires the use of integrated geophysical techniques for successful and comprehensive knowledge of its occurrence and status (Rosli *et al.*, 2012 and Sunmonu *et al.*, 2013). Several geophysical methods have been employed in order to address the problems of groundwater pollution, caused by both natural and anthropogenic activities. These include Time Domain Electromagnetic (TDEM), Electrical Resistivity, Seismic refraction, Very Low frequency electromagnetic and Borehole logging techniques (Oyedele *et al.*, 2007; Adeoti and Ishola 2008; Atakpo 2009; Adeoti *et al.*, 2015). The electrical resistivity method is one of the most used geophysical methods to delineate subsurface geological structures and aquifer units in most geological terrains. It is the most preferred method in groundwater contamination investigation because it is cheap, fast and provides good electrical contrast between the target of interest and the host material (Olorunfemi and Okhue, 1992;

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Sorensen *et al.*, 2005; Oyedele *et al.*, 2007; Adeoti and Ishola 2008; Atakpo 2009; Adeoti *et al.*, 2015; Adeoti *et al.*, 2016). Groundwater contamination could be caused by presence and increase in concentration of anions and cations (Cu^{2+} , Fe^{2+} , Zn^{2+} , NO_3^-) in water and the introduction of bacterial, viral and parasitic micro-organisms into water (Odukoya *et al.*, 2013). Drinking of water from polluted source by the local community without the adequate treatment in advance could cause serious health risk hazards. Hence, the need to carry out the comprehensive physicochemical analysis of water samples to determine the water treatment necessary before consumption (Amadi *et al.*, 2011; Sunmonu *et al.*, 2013 and Odukoya *et al.*, 2013). Water quality index (WQI) is essential because it is one of the most effective tools for the assessment and management of surface and groundwater. It provides a single number that expresses the overall quality of water at certain location and time based on several water quality parameters. The WQI is calculated from the point of view of suitability of the water for human consumption (Mufid, 2012).

Yetunde Brown Estate is a structured residential community that has been faced with the problem of poor water quality and the problem is taking toll on the health status of the residents. This therefore informed the use of electrical resistivity technique, physicochemical analysis and water quality index (WQI) to delineate the aquifer unit(s) and to assess the vulnerability of the groundwater to contamination in the study area.

MATERIALS AND METHOD

The Study Area: Yetunde Brown Estate is located at Gbagada, Lagos State, South-Western Nigeria. It lies within latitude N 6°33'52.9" to N 6°34'02.9" and longitude E 3°23'21.6" to E 3° 23'33.4". It is bounded by neighboring streets such as Soluyi, Kosofe, Oladunni and Ashafe-Tijani etc. The area falls within the extensive Dahomey Basin. Dahomey Basin is a combination of inland, coastal and offshore Basin that stretches from southwestern Ghana through Togo and the Republic of Benin to southwestern Nigeria. It is separated from the Niger Delta by Okitipupa ridge which is a subsurface basement (Fig.1). The Dahomey Basin is one of several sedimentary Basin whose thickness increases from North to South and from east to west. The littoral and lagoon deposit of recent sediment underlies the area. The coastal belt varies from about 8km near the Republic of Benin border to 24 km towards the eastern end of Lagos lagoon (Nton, 2001). The area consist also sediment of clay, unconsolidated sands and mud with a varying proportion of vegetable matter along the coastal areas

with alluvial deposits of coarse clayey unsorted sand with clay lenses and occasional pebble beds.

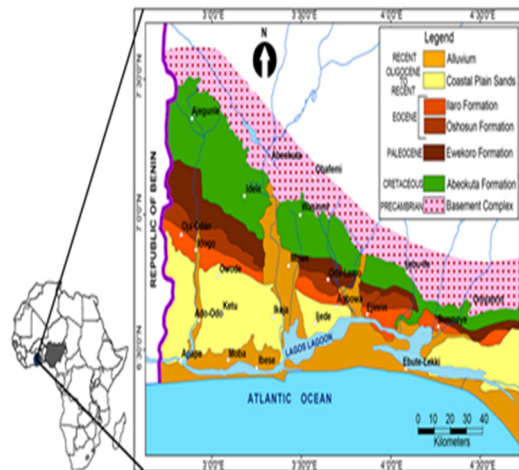


Fig 1: Geological Map of the Nigerian, part of the Dahomey Embayment (Folk, 1974)

Data Acquisition: Twenty Five (25) Vertical Electrical Sounding were acquired along five (5) traverses using Schlumberger electrode array (Fig. 2). The VES data was acquired using PASI Earth Resistivity meter, model 16-GL and five (5) water samples were taken at different locations within the study area and were georeferenced by Global Positioning System (GPS). The water samples collected using cleaned plastic bottles consist of three (3) boreholes (BH1, BH2 and BH3) and two (2) hand dug wells (W1 and W2). The water sample from BH3 served as the control (Fig. 2). The physicochemical parameters measured during the analysis were pH, electrical conductivity, temperature, turbidity, total dissolved solids (TDS), total suspended solid, total acidity, total alkalinity, dissolved oxygen, nitrate, sulphate, iron, lead, manganese, copper and chloride.

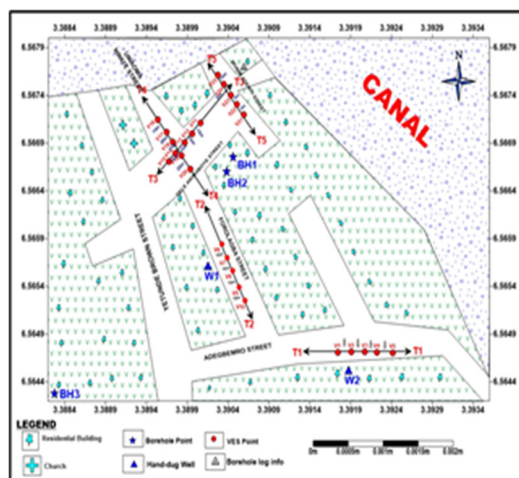


Fig 2: The Base Map of Study Area

Data Processing: The apparent resistivity data acquired were interpreted qualitatively and quantitatively. The apparent resistivity values were plotted against half of the current electrode spacing (AB/2) using transparent paper overlaid on log-log graph. The plotted field data curves were matched with standard and auxiliary curves to determine the true resistivity and thickness of successive layers. These estimated parameters were put into the WINRESIST software for inversion to produce true resistivity distribution. The model parameters were further used to generate geo-electric sections using AutoCAD software. For the water samples collected, the total dissolved solids (TDS) was measured with TDS meter, pH was determined by pH meter (Mettler Toledo), Turbidity was measured with Turbidimeter (Hach 2100 Q), cations (iron, lead and copper) were analyzed using Atomic Absorption Spectrophotometer while the anions (nitrate and chloride) were measured using the colorimeter method. The measured parameters were used to calculate the water quality index (WQI) for predicting water quality using the Equations (1-4) as demonstrated by Mufid (2012). The relative weight (RW) of the measured parameters were determined using equation (1), quality rating (Q_i) scale by Equation (2), product of RW and Q_i by Equation (3) and WQI using Equation (4). The WQI was calculated based on the suitability of groundwater for human consumption. The Correlation analysis was carried out based on the measured closeness between water quality parameters and WQI.

$$RW = \frac{SW}{\sum SW} \tag{1}$$

where:
 RW = Relative Weight,
 SW = Specific Weight of measured parameters,
 $\sum SW$ = Total Weight of measured parameters.

$$Q_i = (C_i / S_i) * 100 \tag{2}$$

where:
 C_i = Detected Concentration (mg/L),
 S_i = Safe Standard Concentration (mg/L),
 Q_i = Quality Rating

$$Sli = RW * Q_i \tag{3}$$

$$\text{Water Quality Index (WQI)} = \sum Sli \tag{4}$$

RESULTS AND DISCUSSION

Figures 3 and 4 are representative of the inverted resistivity curves generated. The qualitative interpretation revealed the presence of QH, QHA, QHK, QKH and HKH curve types in the study area. Figure 5 consists of VES 1-5 along traverse one (T1). The geo-electric section reveals five subsurface layers namely topsoil, clay/clayey sand, clay/peat, clayey sand, sandy clay and clayey sand/sand.

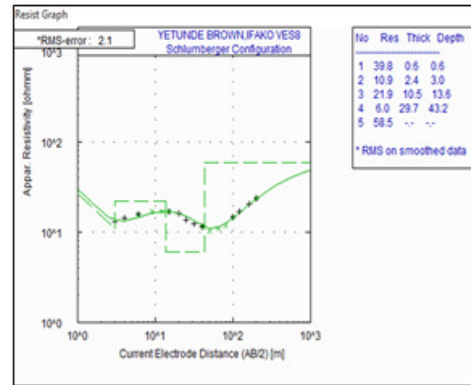


Fig 3: VES 8 curve (HKH)

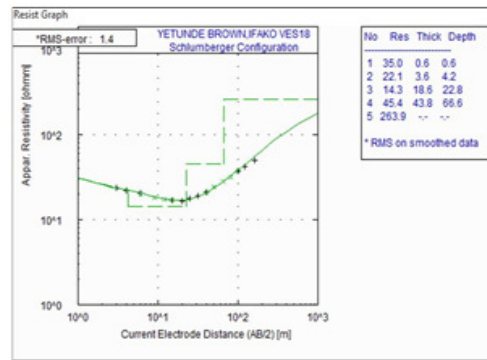


Fig 4: VES 18 curve (QHA)

The topsoil is characterized by resistivity values ranging from 27.2 to 361.4 Ω m and layer thickness of 0.6-1.3 m. The second layer denotes sandy clay with resistivity and thickness values that ranges between 13.6 to 56.8 Ω m and 2.8-5.0 m respectively. The third layer in VES (1, 2, 4 and 5) connotes clay/peat with resistivity and layer thickness values that ranges between 3.3 to 7.9 Ω m and 8.8- 15.5 m respectively. The fourth horizon along VES (1, 2 and 5) signifies clay/clayey sand with resistivity values ranging from 7.2 to 19.7 Ω m and layer thickness of 23.8-40.7 m while the clayey sand is replaced with clay/peat in VES 3 with resistivity and layer thickness value of 9.8 Ω m and 35.6 m respectively. But in VES 4, the fourth layer depicts clayey sand with resistivity value of 56.6 Ω m and layer thickness of 53.3 m. The fifth stratum in VES (1, 2, 3 and 5) is diagnostic of clayey sand/sand with resistivity values ranging from 26.5 to 60.2 Ω m but their layer thickness could not be determined because the current terminated within this horizon while the clayey sand /sand is replaced with clay/peat in VES 4 with resistivity value of 8.9 Ω m but the layer thickness could not be determined because the current terminated within this zone. Figure 6 comprises VES 6-10 along traverse two (T2) which has five geo-electric layers.

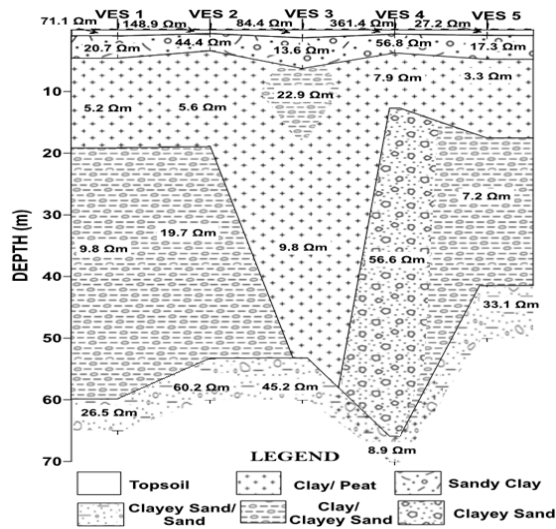


Fig 5: Geo-electric Section for VES 1, 2, 3, 4, and 5 along transverse one (T1)

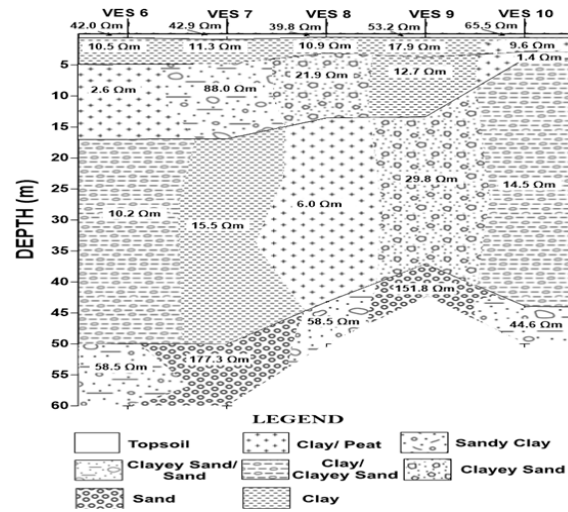


Fig 6: Geo-electric Section for VES 6, 7, 8, 9, and 10 along transverse two (T2)

These are representative of topsoil, clay/peat, clay/clayey sand, clayey sand and clayey sand/sand. The topsoil is characterized with resistivity values ranging from 39.8 to 65.5 Ωm and layer thickness of 0.6 - 0.9 m. The second identified layer in VES 6 - 10 denotes clay/peat with resistivity and thickness values that ranges between 9.6 to 17.9 Ωm and 2.4 - 4.4 m respectively. The third layer in VES (6, 9 and 10) connotes clay/peat with the range of resistivity and layer thickness values that ranges between 1.4 to 12.7 Ωm and 1.2 - 12.0 m respectively while the clay/peat is replaced with clayey sand/sand in VES 7 with resistivity and layer thickness value of 88.0 Ωm and 12.0 m respectively. In VES 8, the third horizon represents clayey sand with resistivity value of 21.9 Ωm and layer thickness of 10.5 m. The fourth horizon along VES (6 and 10) signifies clay/clayey sand with resistivity values ranging from 10.2 to 14.5 Ωm and layer thickness of 33.0 to 40.2 m. While the clay/clayey sand is replaced with clay/peat in VES (7 and 8) with resistivity and layer thickness that ranges between 6.0 to 15.5 Ωm and 29.7 to 33.2 m respectively. However, the fourth layer in VES 9 represents clayey sand having resistivity and layer thickness value of 29.8 Ωm and 23.6 m respectively. The fifth stratum along VES (6, 8 and 10) represents clayey sand/sand with resistivity values ranging from 44.6 to 58.5 Ωm but their layer thickness could not be determined because the current terminated within this horizon while the clayey sand/sand is replaced with sand in VES (7 and 9) with resistivity values ranging from 151.8 to 177.36 Ωm but their layer thickness could not be determined because current terminated within this zone. The sand sediments in these zones represent aquifer units where ground water could be tapped.

Figure 7 represents geo-electric section along traverse three (T3) generated from VES 11 - 15. The section shows five to six geo-electric layers corresponding to topsoil, clay/peat, clay/sandy clay, clayey sand, clayey sand/sand and sand. The topsoil is characterized with resistivity values ranging from 34.3 to 121.4 Ωm and layer thickness of 0.6 to 0.8 m. The second identified layer in VES 11 - 15 denotes clay with resistivity and thickness values that range between 11.9 to 17.5 Ωm and 2.8 to 3.5 m respectively. The third stratum in VES 11 and 14 connotes clay/peat with resistivity and layer thickness values that range between 3.7 to 8.6 Ωm and 1.8 to 7.1 m respectively. The clay/peat is replaced with clayey sand in VES 15 with resistivity and layer thickness value of 94.2 Ωm and 7.7 m respectively. The fourth horizon along VES 11 - 14 signifies clayey sand with resistivity values ranging from 19.0 to 45.6 Ωm and layer thickness of 18.6 to 38.4 m. The clayey sand is replaced with clay in VES 15 with resistivity and layer thickness value of 10.1 Ωm and 18.1 m respectively. The fifth stratum layer in VES 11 is diagnostic of clayey sand/sand with resistivity value of 53.8 Ωm but the layer thickness could not be determined because the current terminated within this horizon. While the clayey sand/sand is replaced with sand in VES (12 - 15) having resistivity values ranging from 189.3 to 239.2 Ωm but their layer thickness could not be determined due to current terminated within this region. The sand sediments in these zones represent aquifer units where groundwater could be tapped.

Figure 8 composes of VES 16 - 20 along traverse four (T4) which has five to six geo-electric sections.

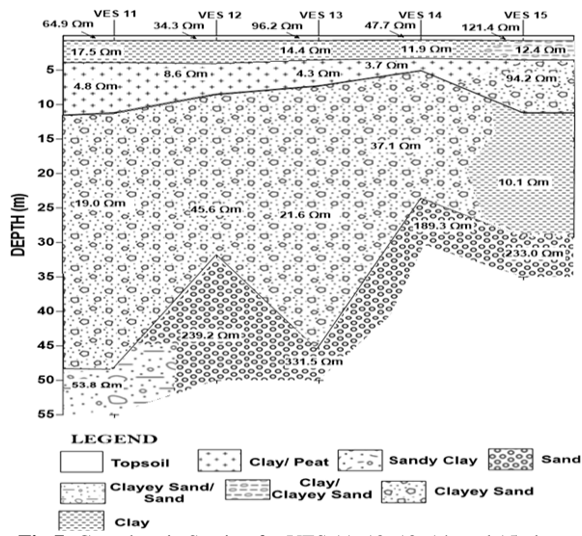


Fig 7: Geo-electric Section for VES 11, 12, 13, 14, and 15 along transverse three (T3)

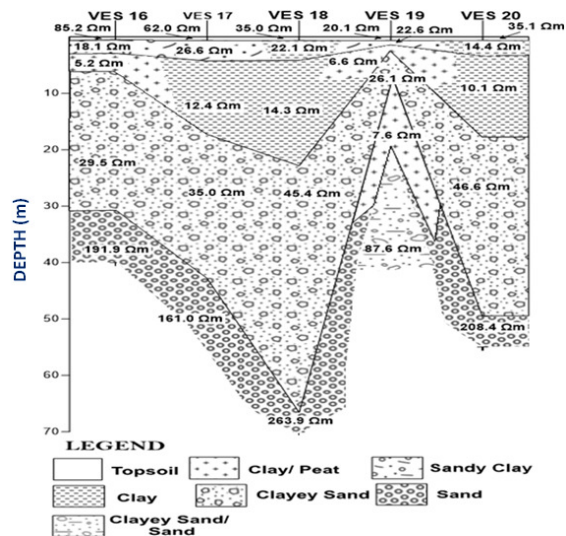


Fig 8: Geo-electric Section for VES 16, 17, 18, 19, and 20 along transverse four (T4)

The section corresponds to topsoil, clay/peat, sandy clay, clayey sand, clayey sand/sand and sand. The topsoil is characterized by resistivity values ranging from 20.1 to 85.2 Ωm and layer thickness of 0.5 - 0.7 m. The second layer in VES 16, 17 and 19 denotes sandy clay with resistivity and thickness values that ranges between 18.1 to 26.6 Ωm and 0.9 to 3.7 m respectively while the sandy clay is replaced with clay in VES 18 and 20 with resistivity and layer thickness values ranging from 14.4 to 22.1 Ωm and 2.5 to 3.6 m respectively. The third geo-electric layer in VES 16 - 20 connotes clay/peat with resistivity and layer thickness values that ranges between 5.2 to 14.3 Ωm and 1.0 to 18.6 m respectively. The fourth horizon is representative of clayey sand with resistivity values ranging from 26.1 to 46.6 Ωm and layer thickness of 4.7 to 43.8 m. The fifth stratum layer in VES 19 is diagnostic of clay/peat with resistivity value of 7.6 Ωm but the layer thickness of 12.0 m. The clay/peat is replaced with sand in VES 16, 17, 18 and 20 with resistivity values ranging from 189.3 to 239.2 Ωm but the layer thickness could not be determined because current terminated within this region. The sand in this zone represents an aquifer where ground water could be tapped. Though, some of the identified aquifers are not confined and could be vulnerable to contamination from nearby canal in the study area. The sixth layer in VES 19 represents clayey sand/sand with resistivity value of 87.6 Ωm but the layer thickness could not be determined because the probing current terminated within this zone. Figure 9 consists of VES 21 - 25 along traverse five (T5). The geo-electric section has five to six layers namely topsoil, clay/peat, clay/clayey sand, clayey sand, sandy clay, clayey sand/sand and sand.

The topsoil has resistivity values ranging from 81.1 to 126.0 Ωm and layer thickness of 0.5 - 0.7 m. The second identified layer denotes sandy clay with resistivity and thickness values that ranges between 16.4 to 34.8 Ωm and 1.9 to 3.1 m respectively. The third layer connotes clay/peat with resistivity and layer thickness values that ranges between 2.8 to 9.0 Ωm and 1.7 to 19.6 m respectively. The fourth horizon along VES 21 and 24 signifies clay/clayey sand with resistivity values ranging from 15.6 to 17.8 Ωm and layer thickness of 10.3 to 17.1 m while the clay/clayey sand is replaced with clayey sand in VES 22 with resistivity and layer thickness value of 22.7 Ωm and 40.0 m respectively. In VES 23, the fourth geo-electric layer is representative of clay/peat with resistivity value of 8.9 Ωm and layer thickness of 13.6 m. However, the fourth layer in VES 25 represent clayey sand/sand with resistivity and layer thickness value of 89.3 Ωm but the layer thickness could not be determined because current terminated within this region. The fifth substratum layer in VES 21 and 24 is diagnostic of clayey sand/sand with resistivity values ranging from 93.7 to 95.0 Ωm but their layer thickness could not be determined because the current terminated within this horizon while the clayey sand/sand is replaced with clay/peat in VES 22 having resistivity value of 5.6 Ωm but the layer thickness could not be determined because current terminated within this zone. In VES 23, the fifth horizon represents clayey sand with resistivity value of 30.1 Ωm but the layer thickness could not be determined because the probing current terminated within this zone. A summary of the physicochemical parameters of water samples analyzed is presented in Table 1 also the Relative Weight of the measured parameters is summarized in Table 2.

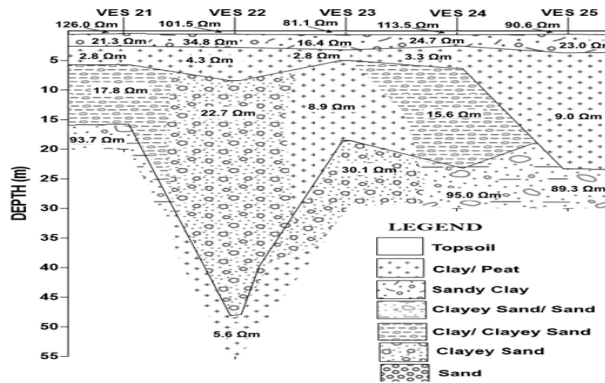


Fig 9: Geo-electric Section for VES 21, 22, 23, 24, and 25 along transverse five (T5)

The Quality rating (Q_i) of parameters analyzed is presented in Table 3 while Table 4 shows the product of Relative weight and Quality rating of water samples. Table 5 is the comparison of water quality Index of the collected water samples with WHO (2012). Table 6 presents the degree of a linear association between any two of the water quality parameters as measured by the simple correlation coefficient (r). The Correlation coefficient (r) values nearer to +1 or -1 shows perfect linear relationship between any chosen two variables (Mufid, 2012). This indicates the relationship between each pair of the water quality parameters (Table 6).

Table 1: Comparison of the Physicochemical parameters with WHO (2017) Standard

S/N	Test	BH1	BH2	W1	W2	BH3	WHO Standard (2017)
1.	pH	6.15	6.56	8.01	5.04	4.31	6.5-8.5
2.	Conductivity (μS/cm)	537	2601	1209	776	1000	1000
3.	Turbidity (FTU)	11.0	3.0	1.0	ND	ND	5
4.	Total Dissolved Solids (mg/L)	360	1540	810	520	670	500
5.	Total Solids (mg/L)	720	1870	1390	590	700	500
6.	Chloride (mg/L)	99.3	694.8	322.6	86.9	124.1	250
7.	Total Alkalinity (mg/L)	30.0	105.0	225.0	7.5	ND	200
8.	Total Acidity (mg/L)	7.7	9.4	10.2	3.4	34.9	56
9.	Dissolved Oxygen (mg/L)	7.5	6.6	6.7	9.2	8.6	>7.5
10.	Biological Oxygen Demand (mg/L)	24.8	49.6	12.9	19.8	30.7	40
11.	Nitrate (mg/L)	0.116	0.277	0.064	0.204	0.271	50
12.	Sulphate (mg/L)	6.6	267.7	62.0	29.2	2.6	250
13.	Copper (mg/L)	ND	ND	ND	ND	0.015	2.0
14.	Iron (mg/L)	0.12	ND	0.255	0.195	0.48	0.3
15.	Zinc (mg/L)	ND	0.045	ND	ND	0.285	3
16.	Lead (mg/L)	0.017	0.021	0.029	0.033	0.045	0.01
17.	Manganese (mg/L)	0.045	0.180	ND	0.090	0.225	0.4

Table 2: Specific Weight (SW) and Relative Weight (RW) of measured parameters

S/N	PARAMETERS	SW	RW = SW/ΣSW
1.	pH	4	0.089
2.	Total Dissolved Solids (mg/L)	3	0.067
3.	Total Solids (mg/L)	2	0.044
4.	Chloride (mg/L)	3	0.067
5.	Total Alkalinity (mg/L)	2	0.044
6.	Total Acidity (mg/L)	5	0.111
7.	Dissolved Oxygen (mg/L)	3	0.067
8.	Biological Oxygen Demand (mg/L)	4	0.089
9.	Nitrate (mg/L)	3	0.067
10.	Sulphate (mg/L)	2	0.044
11.	Copper (mg/L)	3	0.067
12.	Iron (mg/L)	4	0.089
13.	Zinc (mg/L)	1	0.022
14.	Lead (mg/L)	5	0.111
15.	Manganese (mg/L)	1	0.022
		ΣSW = 45	ΣRW = 1

Total Dissolved Solids (TDS): TDS is important in the assessment of the quality of groundwater, the measured value ranges between 360 and 1540 mg/L (Table 1) in the study area. This is suspected to be due to many anthropogenic activities from the dense residential area. Higher values of the TDS are usually attributed to application of agricultural fertilizer or discharge of certain industrial wastes, thus contributing the higher concentration of ions in the

groundwater (Rao, 1986). High concentration of TDS in groundwater is not advisable for a person who is suffering from kidney and heart diseases (Gupta *et al.*, 2004) to drink. Water containing high TDS solids may also cause laxative or constipation effects (Kumaraswamy, 1999).

Hydrogen-ion concentration (pH): The pH value varies from 4.31 to 8.01, indicating that the water is

mildly acidic in most of the study area except in W1 where the pH is 8.01 implying an alkaline nature of the groundwater at the location

Cations Concentration: The concentration of Cations such as Copper, Iron, Zinc, Lead and Manganese in the water samples are all within the permissible limits (Table 1). Copper was not detected in all the samples except in BH3 and occurred in trace amount. Copper is a metal that exists in the environment as a mineral in rocks and soil. It is commonly found at low levels in natural water bodies. However, where buried copper pipes corrode, they can release copper into groundwater to a level that can affect its quality and safety. Iron in groundwater supplies is a common problem. Its concentration level ranges from 0 to 50 mg/l, while WHO recommended level is < 0.3 mg/L. Iron in the water samples was not detected in BH2. It was found within the tolerable limit in other samples except in BH3 where its concentration is above the permissible limit (Table 1). If iron hydroxide deposits are produced by iron bacteria then they are also sticky and the problems of stain and blockage associated with it are many times worse. As rainwater infiltrates the

soil and underlying geologic formations, it dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for boreholes and wells (Hossain *et al.*, 2013). The concentration of Zinc in the water sample is only detected in BH2 and BH 3 below the allowable limit. Its high concentrations were not detected in BH1, W1 and W2. Zinc can be introduced into water naturally by erosion of minerals from rocks and soil, however since zinc ores are only slightly soluble in water. Zinc is only dissolved at relatively low concentrations. Older galvanized metal pipes and well cribbings that are coated with zinc may be dissolved by soft, acidic waters such as in BH1, BH2, BH3 and W2 (Table 1). Zinc is an essential nutrient for body growth and development, however drinking water containing high levels of zinc can lead to stomach cramps, nausea and vomiting. Water with a zinc concentration of more than 5 mg/L may start to become chalky in appearance with a detectable deterioration in taste. Because copper and zinc commonly occur in the soil profile and because of their diversified mobility, these two metals are sensitive indicators of pollution, especially in low-mineralized waters.

Table 3: Quality Rating (Q_i) of measured parameters

S/ N	PARAMETERS	RW	BH1 (Q_5)	BH2 (Q_4)	W1 (Q_3)	W2 (Q_2)	BH3 (Q_1)	WHO 2017 (S_i)
1.	pH	0.089	95	101	123	78	66	6.5-8.5
2.	Total Dissolved Solids (mg/L)	0.067	72	308	162	104	134	600
3.	Total Solids (mg/L)	0.044	144	374	278	118	140	500
4.	Chloride (mg/L)	0.067	39.72	277.9	129.04	34.76	49.64	250
5.	Total Alkalinity (mg/L)	0.044	15	52.5	112.5	3.75	ND	200
6.	Total Acidity (mg/L)	0.111	13.75	16.79	18.21	6.07	62.32	56
7.	Dissolved Oxygen (mg/L)	0.067	100	88	89.33	122.7	114.67	>7.5
8.	Biological Oxygen Demand (mg/L)	0.089	62	124	32.25	49.5	76.75	40
9.	Nitrate (mg/L)	0.067	0.23	0.55	0.13	0.41	0.542	50
10.	Sulphate (mg/L)	0.044	2.64	107.1	24.8	11.68	1.04	250
11.	Copper (mg/L)	0.067	ND	ND	ND	ND	0.75	2.0
12.	Iron (mg/L)	0.089	40	ND	85	65	160	0.3
13.	Zinc (mg/L)	0.022	ND	1.5	ND	ND	9.5	3
14.	Lead (mg/L)	0.111	170	210	290	330	450	0.01
15.	Manganese (mg/L)	0.022	11.25	45	ND	22.5	56.25	0.4

Table 4: WQI of the collected water samples

S/ N	PARAMETERS	BH1 (SI_5)	BH2 (SI_4)	W1 (SI_3)	W2 (SI_2)	BH3 (SI_1)
1.	pH	8.46	8.99	10.95	6.94	5.87
2.	Total Dissolved Solids (mg/L)	4.82	20.64	10.85	6.97	8.98
3.	Total Solids (mg/L)	6.34	16.46	12.23	5.19	6.16
4.	Chloride (mg/L)	2.66	18.62	8.65	2.34	3.33
5.	Total Alkalinity (mg/L)	0.66	2.31	4.95	0.17	ND
6.	Total Acidity(mg/L)	1.53	1.86	2.02	0.67	6.92
7.	Dissolved Oxygen (mg/L)	6.70	5.90	5.99	8.22	7.68
8.	Biological Oxygen Demand (mg/L)	5.52	11.04	2.87	4.41	6.83
9.	Nitrate (mg/L)	0.02	0.04	0.01	0.03	0.04
10.	Sulphate (mg/L)	0.12	4.71	1.09	0.51	0.05
11.	Copper (mg/L)	ND	ND	ND	ND	0.05
12.	Iron (mg/L)	18.87	ND	7.57	5.79	14.24
13.	Zinc (mg/L)	0.25	0.03	ND	ND	ND
14.	Lead (mg/L)	0.25	23.31	32.19	36.63	18.87
15.	Manganese (mg/L)	1.24	0.99	ND	0.50	0.25
WQI = $\sum SI_i$		111.55	114.90	99.37	78.37	59.5

Table 5: Comparison of WQI of the collected water samples with WHO (2012) Standard

WQI Value	Class	Water Quality	Water Sampled
<50	I	Excellent	---
50-100	II	Good Water	(CONTROL BH3, W1 and W2)
100-200	III	Poor Water	(BH1 AND BH2)
200-300	IV	Very Poor Water	---
>300	V	Unsuitable Water	---

Table 6: Correlation coefficient matrix of water quality parameters and WQI

	pH	TDS	TS	Cl	TA	TTAc	DO	BOD	NO ³⁻	SO ₄ ²⁻	Cu	Fe	Zn	Pb	Mn
pH	1														
TDS	0.204	1													
TS	0.202	0.999	1												
Cl	0.216	0.999	0.999	1											
TA	0.194	0.999	0.999	0.999	1										
TAc	0.240	0.997	0.996	0.999	0.997	1									
DO	0.962	0.291	0.290	0.296	0.282	0.312	1								
BOD	0.352	0.982	0.982	0.987	0.981	0.992	0.409	1							
NO₃-	0.186	0.999	0.999	0.998	0.999	0.995	0.277	0.978	1						
SO₄2-	0.193	0.999	0.999	0.999	0.999	0.996	0.280	0.981	0.999	1					
Cu	0.189	0.999	0.999	0.998	0.999	0.995	0.281	0.979	0.999	0.999711	1				
Fe	0.427	-0.57	-0.57	-0.54	-0.57	-0.51	0.228	-0.42	-0.59	-0.58121	-0.58	1			
Zn	0.205	0.999	0.998	0.999	0.999	0.998	0.286	0.986	0.998	0.998957	0.998	-0.548	1		
Pb	0.565	-0.65	-0.65	-0.64	-0.66	-0.61	0.414	-0.51	-0.67	-0.66603	-0.67	0.9136	-0.647	1	
Mn	0.559	-0.24	-0.24	-0.20	-0.24	-0.16	0.347	-0.06	-0.26	-0.24586	-0.25	0.9257	-0.207	0.776	1

TDS = Total dissolved solids, TS = Total solid; TA = Total alkalinity; TAc = Total acidity; DO = dissolved oxygen, BOD = biological oxygen demand;

The chemical form of the metal contaminant in soil and groundwater systems defines its solubility, mobility and toxicity (MOE, 2008). Lead enters groundwater through leaching from mining activities, through contact with plumbing, corrosion from pipes, solder, fixtures, faucets (brass), and fittings. Lead occurred above the permissible limits in the studied water samples from the study area with the highest value of 0.045 mg/L recorded in BH3 (Table 1). These elevated values of lead detected in the groundwater may not be unconnected with high anthropogenic activities from the dense residential area in the vicinity. Lead is harmful to adults. Adults exposed to lead can suffer from cardiovascular effects, increased blood pressure and incidence of hypertension (EPA, 2017). Manganese in the water samples was detected below tolerable limit (Table 1). Manganese in groundwater comes from rainfall, dissolution of manganese in minerals from surrounding rocks and leaching of manganese in percolating through soils. Greater concentrations of manganese are found in groundwater that are acidic (low pH) and are in a reduced (anaerobic) condition confirmed in Table 1.

Anions concentration: Nitrate concentrations in the water samples are within the WHO allowable limits in the study area (Table 1). Nitrate often gets into groundwater directly as the result of runoff of fertilizers containing nitrate. The highly low nitrate concentration in the water samples could be as a result of no agricultural practice that could impact the soil and groundwater with nitrate. Excess levels of nitrate in human diet can cause methemoglobinemia, or "blue

baby" disease (Feig, 1981). Sulphate in the groundwater samples ranges from 2.6 mg/L to 267.7 mg/L. The highest value was detected at BH2 (Table 1) at an elevated level above the allowable limit. High concentrations of sulfate in potable water can have a laxative effect when combined with calcium and magnesium, the two most common constituents of hardness (EPA, 1985).

Water Quality Index (WQI): The computed WQI values for the three boreholes (BH1- BH3) and two wells (W1 and W2) ranges between 59.5 and 111.55, with these WQI values it could be suggested that the ground water condition reflected poor to good quality water. Specifically, BH3, W1 and W2 reflected good quality water, while BH1 and BH2 reflected poor quality water (Table 5).

Conclusions: The VES results revealed four (4) to five (5) geo-electric layers which correspond to the topsoil, clay, sandy clay, clayey sand and sand. The physicochemical parameters such as chloride, iron and lead ions were found to be above WHO recommendation for drinking in some collected water samples. This agreed with the calculated WQI which reflected poor quality water from BH1 and BH2 only. This could be attributed to unconfined aquifers delineated by the VES in the second and fourth geo-electric layers which are vulnerable to contamination. Hence, the study recommends that borehole could be sunk at VES 7, 9, 12, 13, 15, 18 and 20 at depths

between 31.8 and 66.6 m for exploitation of good quality water.

REFERENCES

- Adeoti, L; Alile, O; Uchegbulam, O; Adegbola, RB (2012). Geoelectrical Investigation of the Groundwater Potential in Mowe, Ogun State, Nigeria. *Brit. J. Appl. Sci. Technol.* 2(1): 58-71.
- Adeoti, L; Bello, MA; Olatinsu, OB; Adiat, KAN (2015). Application of Geoelectrical and Chemical methods for groundwater assessment. A Case Study of Isheri- North, Ogun state, Nigeria. *Sci. Res. Ess.* 35(1): 24-38
- Adeoti, L; Ijezie, NT; Adegbola, RB; Ojo, AO; Afolabi. SO; Adesanya, OY (2016). Geoelectrical Investigation of Groundwater Potential At Riol Farm, Owode, Abeokuta, Ogun State. *J. Nig. Assoc. Math. Phys.* 34: 425 – 432
- Adeoti, L; Ishola, KS (2008). Geophysical and hydrogeological assessment of proposed refinery site in the lower plains of Niger Delta, Nigeria. *J. Sci., Technol. Environ.* 8 (2): 31-38.
- Adiat, KAN; Nawawi, MNM; Abdullah, K (2012). Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool- a case of predicting potential zones of sustainable groundwater resources. *J. Hydrol.* 440: 75-89.
- Amadi, A; Nwawulu, C; Unuevho, C; Okoye, N; Okunlola, I; Egharevba, N; Ako, T; Alkali, Y (2011). Evaluation of the Groundwater Potential in Pompo village, Gidan Kwano, Minna Using Vertical Electrical Resistivity Sounding. *J. Appl. Sci. Technol.* 1(3): 53-66
- Ariyo, SO; Banjo, AA (2008). Application of Electrical Resistivity Method for Groundwater Exploration in a Sedimentary Terrain: A Case Study of Ilaro-Remo, Southwestern Nigeria. *Continet. J. Earth Sci.* 3: 53-58
- Atakpo, EA (2009). Hydrogeological deductions from geoelectric survey in Uvwiamuge and Ekakpamre communities, Delta State, Nigeria. *Int. J. Phys. Sci.* 4(9): 477-485.
- EPA, (1999a). Health effects from exposure to high levels of sulfate in drinking water study. US Environmental Protection Agency. *Fed. Reg.* 50(219):46936
- Feig, S (1981). Methemoglobinemia. In: Nathan, DG; Oski, FA; Saunders, WB (ed). *Hematology of infancy and childhood Co., Philadelphia.*
- Folk, RL (1974). *Petrography of Sedimentary Rocks,* Hemphill Publishing Company, Austin, Texas, Pp 182
- Gupta, S; Kumar, A; Ojha, CK; Singh, GJ (2004). Chemical analysis of ground water of Sanganer area, Jaipur in Rajasthan. *J. Environ. Sci. Engr.* 46(1):74-78.
- Hossain, D; Isalm, MS; Sultana, N; Tusher, TR (2013). Assessment of Iron Contamination in Groundwater at Tangail Municipality, Banglesh. *J. Sci. Nat. Res.* 6(1): 117 -213
- Kumaraswamy, NJ (1999). Physico-Chemical analysis of groundwater of selected area in city (Tamilnadu), India. *J. Pollut. Res.* 10(1): 13-20.
- Mufid, A (2012). Application of Water Quality Index to Assess Suitability of Groundwater Quality for Drinking Purposes in Ratmao-Pathri Rao Watershed, Haridwar District, India. *Amer. J. Sci. Ind. Res.* 3(6): 395-402.
- Nton, M (2001). Sedimentological and Geochemical Studies of Rock Units in the Eastern Dahomey Basin, Southwestern Nigeria, Ph.D Thesis University of Ibadan. Pp 315
- Odukoya, AM; Folorunso, AF; Ayolabi, EA; Adeniran, EA (2013). Groundwater Quality and Identification of Hydro-geochemical Processes within University of Lagos, Nigeria. *J. Wat. Res. Protect.* 5: 930-940
- Olorunfemi, MO; Okhue, ET (1992). Hydrogeology and geology significant of Geoelectric survey at Ile-Ife, Nigeria. *J. Min. Geo.* 28(2): 221-229.
- Oyedele, KF; Meshida, EA; Akinrimisi, J (2007). Application of electrical resistivity method in coastal hydrogeological survey. *J. Appl. Sci. Technol.* 12 (2): 65-70.
- Rosli, S; Nawawi, MZM; Mohamad, ET (2012). Groundwater detection in alluvium using 2-D electrical resistivity tomography (ERT). *Elec. J. Geotech. Engr.* 17: 369-376.
- Rao, NS (1986). Hydrogeology and Hydrochemistry of Visakhapatanam Ph.D Thesis unpublished.
- Sorensen, KI; Auken, E; Christensen, N; Pellerin, L (2005). An Integrated Approach for

- Hydrogeophysical Investigations: New Technologies and a Case History In: Butler, DK (ed). Near-surface Geophysics SEG, Tulsa, USA, p. 585-597.
- Sunmonu, LA; Olafisoye, ER; Adagunodo, TA; Alagbe, OA (2013). Geophysical and hydro-physicochemical evaluation of hand-dug wells near a dumpsite in Oyo state, Nigeria. *Arch. Appl. Sci. Res.* 5 (6): 29-40.
- World Health Organization, (2012). Guidelines for Drinking Water Quality, WHO press, Geneva, Switzerland. Pp 150
- World Health Organization, (2017). Guidelines for Drinking Water Quality, WHO press, Geneva, Switzerland. Pp 155