Assessment of Groundwater Conditions Using Geophysical and Physicochemical Methods in Canal Estate, Okota, Lagos, Southwestern, Nigeria

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ABSTRACT

The dearth of potable water supply has made the residents of the Canal Estate result to providing alternative water for their daily activities. In view of this, the electrical resistivity (2D Electrical Resistivity Imaging (ERI), Vertical Electrical Sounding (VES) and physicochemical methods were used to investigate suitable aquifers that may provide adequately safe water supply for the residents of the area. Seven Wenner 2D ERI data and forty Schlumberger VES were acquired. Also, water samples were collected from existing boreholes and hand dug wells within the study area for laboratory analysis. Apparent resistivity values were calculated through forward modelling technique while VES data were partially curve matched. Five to six geoelectric layers corresponding to the topsoil, clay, sandy clay, clayey sand and sand were delineated. The low resistivity range (2 Ωm to 300 Ωm) of shallow sands is an indication of contaminated subsurface layers. In some cases, parts of the sands between 20 m to 50 m deep are observed to be polluted through percolation of contaminants from the surface. Physiochemical analysis of the water samples revealed values above or below WHO standard especially in the shallow seated sands. The Biological Oxygen Demand and Total Bacterial Count are well above the required WHO standard. In addition, the chloride, Iron (Fe), pH and Copper (Cu) contents are below WHO approved standard. This implies that the sand layer which constitute the aquifer units within the study area are polluted. Assessing aquifers with good water quality for domestic and industrial usage will require investigating deeper aquifers in the study area with dipole dipole or pole dipole array configuration.

1. Introduction

Nigeria, like most developing countries, is constrained financially, so, undertaking programs such as provision of adequate potable water to her citizens become difficult because many depend on pipe borne water for survival. This has made the people to resort to groundwater exploration as substitute to the ones provided for the communities by the government and its agencies. The over-exploitation of groundwater resources has put stress on the available groundwater resources (Adelusi, 2013; Al Maliki et al., 2020). Electrical resistivity method is among the most preferred geophysical methods in groundwater contamination studies and hydrogeological investigations (Carpenter et

al., 1990; Ogundana and Aladejana, 2014). These techniques are found very useful for mapping resistivity structure in complex subsurface geology (Griffiths and Basker, 1993; Kotra et al, 2016). The use of integrated hydro-chemical and geophysical methods is often recommended in ground water investigation (Kayabali et al., 1998; Al Maliki et al., 2020). Adeoti et al. (2010) used both 2D electrical imaging and VES to investigate saline water intrusion into freshwater aquifers. The investigation of sea water intrusion was also carried out by Gurunadha et al. (2010) and Chitea et al. (2011) using VES and ERT data. Arulprakasam et al., (2014) applied electrical resistivity technique for the demarcation of groundwater quality zones in parts of Vanur block, India. Hydrogeological assessment of groundwater resources was carried out in Southwest Nigeria with a view to highlighting the potential of the aquifers to provide potable water supply, Oloruntola and Adeyemi, 2014; Adeoti et al., 2015; Hassan et al., 2019).

Over exploitation of groundwater has led to the continued migration of contaminant plumes to the subsurface. In particular, the infiltration of saline waters or encroachment into fresh water aquifers (Kalimas and Gregorauskas, 2002; Rosli et al., 2012). The electrical resistivity method has been successfully employed in the delineation of subsurface geological sequence, geological structures/features of interest, aquifer units, types and depth extent in almost all geological terrains (Osazuwa and Chii, 2010; Adelusi, 2013). The quality of groundwater is a function of natural processes as well as anthropogenic activities (Badmus et al., 2001; Sharma and Bhattacharya, 2017). The majority of pathogenic micro-organisms that are found in water come from human and animal excrements. Thus, the presence of contaminants above World Health Organization (WHO) standard can cause different kinds of diseases: Typhoid fever, Paratyphoid fever, Dysenteries, Gastroenteritis, Infectious Hepatitis, cholera, Back pains, Pneumonia, Nasal congestion (Ojelabi et al., 2001). The focus of this study is on the assessment of the level of contamination of the groundwater by surface chemical contaminants. Resistivity and physicochemical methods were integrated to assess the groundwater potential of Canal Estate, Okota.

1.1 Geology and Location of the Study Area

The area being investigated lies in the Southwestern part of Nigeria and occur within the sedimentary terrain (Figure 1). According to Jones and Hockey (1964), and Nwajide (2013), the geology of Southwestern Nigeria reveals a sedimentary basin which has been classified into five major formations according to their geological formation age namely: the Littoral and the Lagoon deposits, Coastal Plain sands, the Ilaro formation, the Ewekoro formation and the Abeokuta formation overlying the crystalline basement complex with their ages ranging from Recent to Cretaceous (Nwajide, 2013). Four of these formations, excluding Ilaro, constitute aquifers in the Dahomey Basin, from which the geological section of Lagos was drawn. The Ilaro formation is composed predominantly of shaley clay (argillaceous sediments). Limestone forms the aquifer material in the Ewekoro formation while sands and gravels constitute the materials in aquifers of the recent sediments, Coastal plain sands and Abeokuta formations contain brackish water.
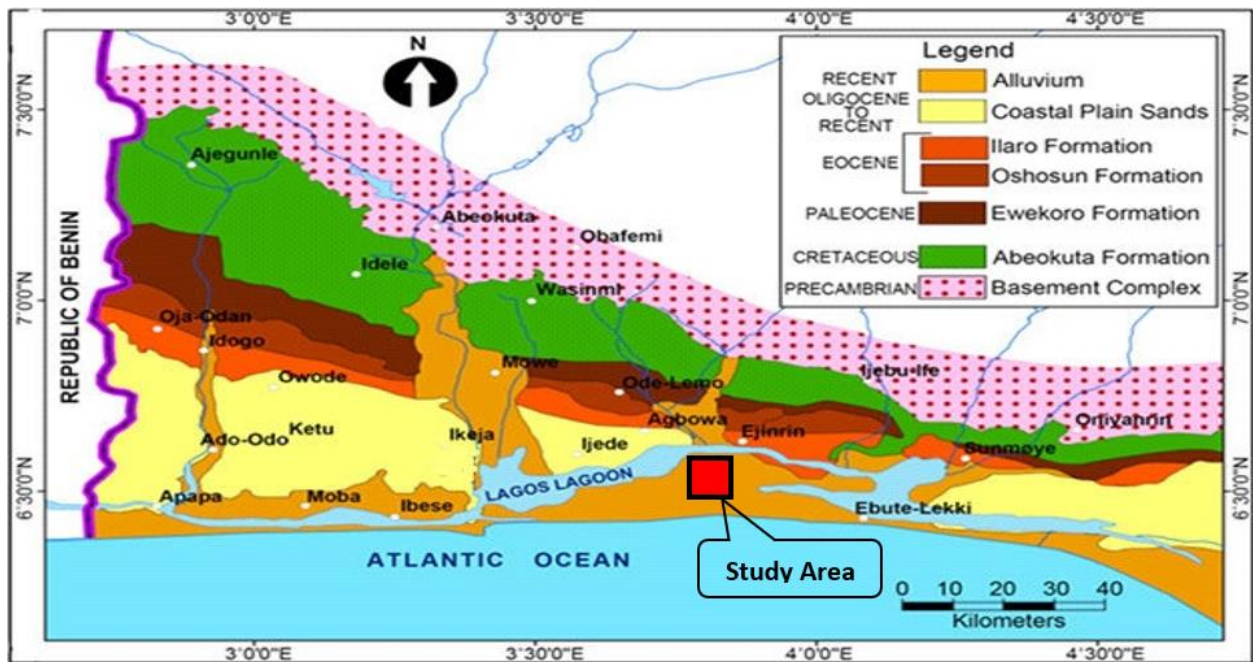
Figure 1: Geological Map of Lagos state and part of Ogun state showing the study area (Modified after Billman, 1976).

2. Methodology

2.1 Data Acquisition

The electrical resistivity survey was carried out along seven traverses using 2D electrical imaging and Vertical Electrical Sounding techniques. The Wenner array electrode configuration was used for the 2D resistivity imaging. Seven profiles were run with measurements made at 10 m interval in order to acquire better information. The base map of the study area is shown in Figure 2. The Schlumberger electrode configuration was used to acquire forty Vertical Electrical Sounding stations at different points along the seven traverses. Also, the current electrode spacing (AB) was varied from a minimum of 2.0 m to a maximum of 700.0 m at the VES locations. Some water samples were collected from hand dug Well (W) at 25 m deep and from Borehole (BH) at the depth of 30 m (Figure 2).

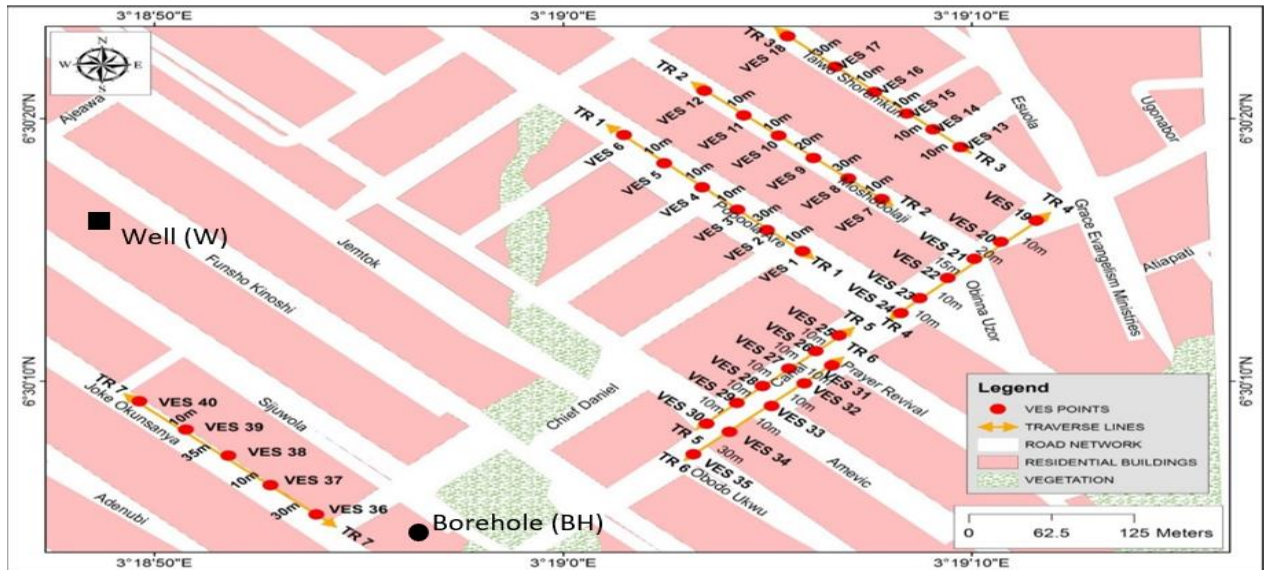*Corresponding author, e-mail: *allobioje@gmail.com*

Figure 2:   Base map of the study area.

2.2   Data Processing

The 2D electrical resistivity data set were inverted using the DIPROWIN software. The processing of the depth sounding curves was done by adopting the partial curve matching techniques. The technique involved the use of a standard two (2) layer master curve and four (4) auxiliary type curves (H, K, A and Q). The apparent resistivity values obtained were plotted against the current electrode separation for each VES point using a log-log graph. The preliminary interpretation of the resistivity curves using partial curve matching technique to obtain the layer resistivity and layer thickness was used as an initial model for a computer iterative software known as WINRESIST. The geoelectric sections were generated by AUTOCAD software where four or more interpreted VES results along a profile were combined.

2.3   Analysis of Water Samples

The pH value was measured by the use of a pH meter while the Total Dissolves Solids was determined using a TDS meter. The anions (nitrate, chloride and phosphate) were measured with the use of colorimeter method, while the cations (iron, lead and copper) were analyzed using Atomic Absorption Spectrophotometer. The result of the laboratory analysis of the water

samples were compared with the WHO standards (2009). This standard was used as a guide for the classification of physical and chemical parameters of the collected water samples in the study area.

3. Results and Discussion
3.1 2D Resistivity structures

The results of the 2D resistivity profiles are shown in Figure 3(a – g). The result shows the 2D resistivity distribution of the subsurface layers in Canal Estate, Okota. The VES locations on the 2D resistivity profiles are indicated by arrows. Figure 3a is the resistivity profile for Traverse one with VES 1 to VES 6 located at respective lateral distances of 80 m, 90 m, 110 m, 120 m, 130 m and 140 m. The VES 7 to VES 12 are on Traverse two (Figure 3b), VES 13 to VES 18 are situated on Traverse three (Figure 3c) while VES 19 to VES 40 are on Traverse four, Traverse five, Traverse six and Traverse seven as shown in the respective Figures 3d, 3e, 3f and 3g. These profiles are 200 m long with 50 m depth of investigation.

3.2   VES Geoelectric sections

The geoelectric sections for the VES points are presented as AA', BB', CC', DD', EE' FF' and GG' in Figures 4a, 4b, 4c, 4d, 4e, 4f and 4g

respectively. These are one dimensional information of the subsurface structure which helps to correlate information from the 2D resistivity results.
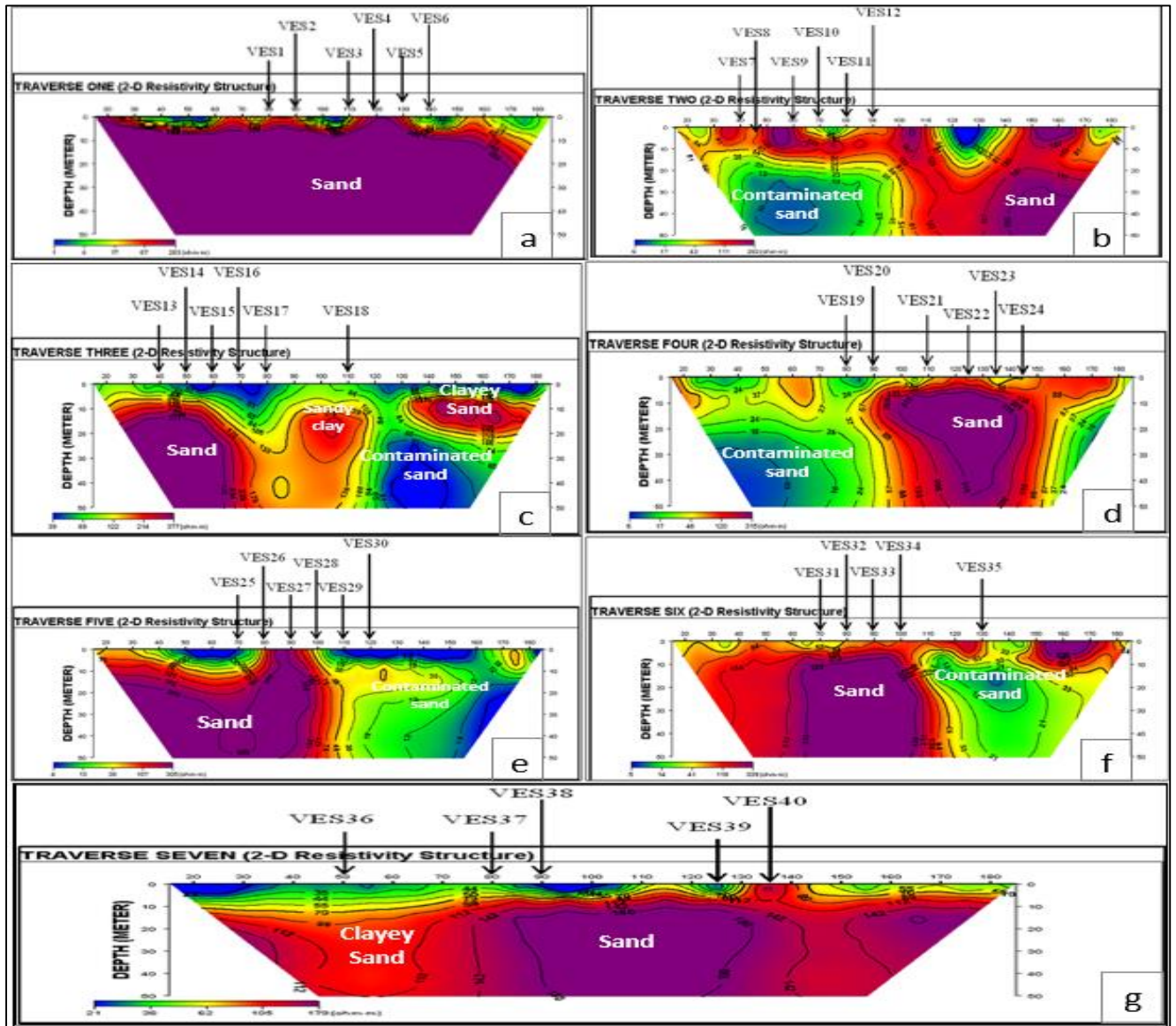

Figure 3:   Interpreted 2D resistivity sections along Traverses one to seven showing VES points.
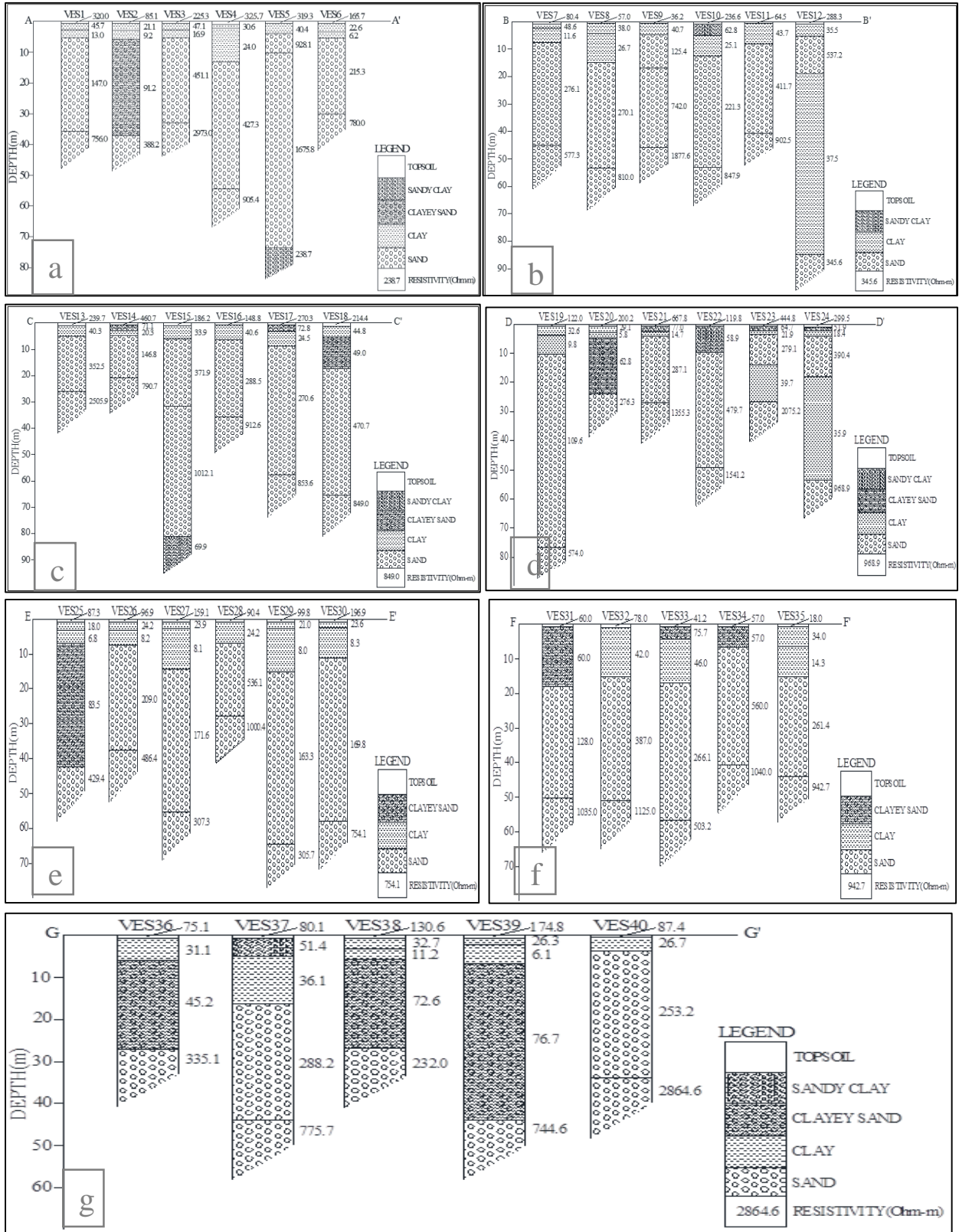
Figure 4. Geoelectric sections of Traverses one to seven

3.3. Integration of 2D resistivity structures and VES Geoelectric sections

In the 2D resistivity section of traverse one (Figure 3a), two distinct subsurface zones are observed. The first zone has resistivity structures with depths of about 8 m from the surface. This part reveals resistivity values which range from 1 Ωm to about 40 Ωm across the profile. These values are indicative of clay, sandy clay and contaminated sand due to its low resistivity values between 1 Ωm and 40 Ωm. At depth over 8 m, the resistivity values range from 40 Ωm to about 264 Ωm across the profile, it signifies the presence of clayey sand and sand. The geoelectric section (AA') with VES points 1 to 6 (Figure 4a) shows similar resistivity structures at below 10 m from the surface. Sand and clayey sand predominately occupy the subsurface at depth more than 10 m. This observation shows significant correlation between the 2D and VES techniques. The resistivity structure in Traverse two (Figure 3b) reveals probable large aquifer concentration (140 Ωm to 280 Ωm) at depth of 10 m to 50 m with lateral distance of 110 to 170 m. Furthermore, the VES points 7, 8, 9, 10, 11 and 12 (BB') in Figure 4b indicate the presence of sand at depth between 10 m and 50 m. The low resistivity values (10 Ωm to 50 Ωm) observed at lateral distance of 30 m to 90 m are possible indication of the presence of contaminants due to its low resistivity value range.

In Figure 3c, the shallow surface is mainly characterized by clay/contaminant/pollutant at depth of less than 10 m. Beyond this depth are indications of the presence of clay, sandy clay, clayey sand and sand. The VES points 13, 14, 15, 16, 17 and 18 (CC') as shown in Figure 4c support the presence of sand at depths above 10 m. The pattern of resistivity structure also indicates possible contaminant seepage at lateral distance between 120 m to 170 m and depth above 20 m. Traverse four in Figure 3d also reveal a possible effect of contaminant in the aquifer especially between lateral distance 20 m and 90 m due to the observed low resistivity between 6 Ωm and about 20 Ωm. At this distance, the shallow subsurface of up to 10 m shows the presence of clay or contaminant which may have percolated into the deep aquifer. VES points 19, 20, 21, 22, 23 and 24 (DD') in Figure 4d indicates that the average depth range of the aquifer is about 10 m from the surface with a thickness of about 40 m.

The shallow layer of less than 10 m in Figure 3e reveals low resistivity (4 Ωm to about 20 Ωm) due to presence of contaminant/clay. Deeper layers on the right side of traverse five (Figure 3e) show contaminated sand through seepage. Figure 4e also support the presence of contaminated sand as depicted in VES 29 and VES 30. Similar resistivity pattern is observed in Traverse six (Figure 3f) which runs parallel to Traverse five. The right side reveals contaminated sand due to contaminants that percolated from the surface. Figure 4f further shows that the shallow subsurface mainly contain clay and sandy clay up to about 20 m from the surface. In the case of traverse seven (Figure 3g) which is at a significant distance from the first six traverses, clay and sandy clay are observed to dominate the first 10 m from the surface. Deeper into the subsurface revealed the presence of clayey sand and sand (Figure 4g) with little or no significant contamination.

3.4   Chemical Analysis

The result of the laboratory analysis carried out on the water samples are presented in Table 1.

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Table 1: Physicochemical and Microbiological characterization of the water samples and regulatory limits for potable water from Well (W) and Borehole (BH).

Parameter	Clear Water (BH)	Reddish Brown Water (W)	WHO Limit	Parameter	Clear Water (BH)	Reddish Brown Water (W)	WHO Limit
pH	4.74	4.89	6.5-8.5	Nitrate (mg/L)	4.26	9.20	10
Turbidity (NTU)	2	17	5	Total Dissolved Solids (mg/L)	380	960	500
Total Acidity (mg/L)	90.1	424	56	Ni (mg/L)	<0.01	<0.01	0.02
Chloride (mg/L)	5.6	45	250	Pb (mg/L)	<0.01	<0.01	0.1
Mineral Oil (mg/L)	Nil	Nil	0.003	Cr (mg/L)	<0.01	<0.01	0.1
Dissolved Oxygen (mg O_2/L)	8.9	7.1	>7.5	Total bacterial count	2.2×10^3	5.6×10^3	100
Biological Oxygen Demand (mg O_2/L)	85.3	242	0	Total faecal coliform	Nil	Nil	10*
Chemical Oxygen Demand (mg O_2/L)	154	533	5	Cu (mg/L)	< 0.01	< 0.01	3.0
Sulphate (mg/L)	3.50	40.1		Fe (mg/L)	< 0.01	< 0.01	0.3

The chemical analysis of water samples show that pH varies from 4.89 to 4.74, total acidity of Well and Borehole varies from 90.1 to 424 mg/L showing that the water is acidic and has a low pH value. The total dissolved solids vary from 380 to 960 mg/L which is either very low (BH) or very high (W) of the WHO standard (2009). Chemical oxygen demand ranges between 154 to 533 mg/L (O_2) and biological oxygen demand 85.3 to 242 are both well above the WHO limit. The ionic concentration for chloride, nitrate ion, iron, copper and lead ion had values less than 0.01 mg/L. The pH, total acidity, total dissolved solids, dissolved oxygen, biological and chemical oxygen demand and total bacteria are not within acceptable limits especially for the reddish-brown water. These values, however, do not fall within the WHO standard for drinking water. These make

them unsafe for human consumption. However, the clear water had some satisfactory results, for example, acceptable turbidity, dissolved oxygen, total dissolved solids and faecal coliform count.

Conclusion

Geophysical method of investigation involving Vertical Electrical Resistivity Sounding and 2D Resistivity methods have been integrated with physicochemical analysis to assess groundwater potential and quality. The results revealed five to six geoelectric layers which corresponded to the topsoil, clay, sandy clay, clayey sand and sand. The 2D method further delineated the extent of contamination in the sand layers. The resistivity values of some layers especially the shallow seated sands ranged from 109.6 to 1675.8 Ωm in VES 1, 3 – 10,

12 – 24, 26 – 35, 37 and 40. Furthermore, deeply buried sands in VES 1 – 17, 19 – 23 and 25 – 40 has resistivity values of between 345 to 2975 Ωm. This difference in resistivity values is an indication of the presence of high level of pollutants in the shallow seated sands causing reduction in the resistivity. Physicochemical analysis of the water samples from Well and Borehole support the presence of contaminants. Parameters such as Biological Oxygen Demand and Total Bacterial Count showed values that are above the required WHO limit. Also, other parameter like chloride, Iron (Fe), pH and Copper (Cu) contents are below WHO approved standard. This study revealed that some of the deep sands were moderately polluted when compared to the shallow sands. The clear water (BH) should be subjected to liming in order to precipitate the acid cations responsible for its acidity and passed through ultrafiltration to remove the precipitated metals and bacteria. The water should go through carbon adsorption bed or subjected to ultraviolet oxidation to remove oxygen-demanding materials responsible for the unacceptable biological oxygen demand and chemical oxygen demand levels. It is therefore important to carry out further studies using wider spread in order to identify deeper sands units (aquifers) with no contaminants.

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