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RESEARCH ARTICLE

DELINEATION OF CONCENTRATION OF FERRUGINOUS MINERALS IN AQUIFERS IN YENAGOA, BAYELSA STATE, NIGERIA, USING GEOELECTRIC VERTICAL ELECTRICAL SOUNDING (VES) AND PHYSICOCHEMICAL TECHNIQUES

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ABSTRACT

A total of sixteen Vertical Electrical Sounding (VES) surveys and five physicochemical analyses were-carried out in selected locations within the Yenagoa Metropolis, in Bayelsa State, Nigeria, to delineate the concentration of ferruginous minerals in freshwater aquifers in the area. For the geophysical survey, the Schlumberger electrode configuration was employed. The resulting data obtained was processed and interpreted using Excel suite, IPI2WIN resistivity, Surfer-11 and Rockworks software. The results revealed four to six geologic layers across the area, and were used to generate geoelectric maps which showed that in most part of the study area, there were uneven distributions of shallow aquifers (4 – 10m), and uneven layers of clay and sandy-silt at varying depths up to 20m. The physicochemical analysis of raw water samples collected from five boreholes located in close proximity to the VES sounding locations were analysed for physical and chemical parameters. Physical parameters tested include colour, conductivity, turbidity, and temperature. Chemical parameters analysed are pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS) Alkalinity, Total Iron, Carbonate, Chloride, Sulphate, and heavy metals such as copper, chromium, nickel, cadmium, manganese, zinc and lead. The pH was determined using a Mettler Toledo (GmbH 8603 Schwerzenbach) pH meter by direct measurement. An analogue mercury thermometer was used for temperature measurements and a Hach 2100A turbidimeter for turbidity determination. Also, the concentrations of Zinc, Lead, and Copper in the water samples were obtained using the flame atomic absorption spectrophotometer. It was observed that the values SO_4^{2-} , Cl^-, Na^{2+}, Mg^{2+}, Ca^{2+}, F^- have values below World Health Organization (WHO) standard in all boreholes tested while Mn^{2+}, NH_3, $PO^{3-}$and Fe^{2+}, K^+, and Cu^{2+} have values above WHO standard in some boreholes. The pH values all showed that the water was slightly basic as the values all exceeded the neutral limit 7, with only station showing slightly elevated pH value 9, suggesting the presence of iron bacteria. F^-, K^+, Fe^{2+} and Mn^{2+} have values that exceeded the WHO standard. The results from Physicochemical-and geophysical analysis suggest that at depths of 20 – 45m, the concentration of ferruginous minerals is high especially towards the north eastern section of the study area and so drilling should be made to approximate depths of 50 – 80m for minimal iron contamination in the aquifers.

KEYWORDS

Groundwater, Geoelectric, Aquifer, Physicochemical, Ferruginous, Yenagoa, Nigeria.

1. INTRODUCTION

The importance of water as a useful natural resource goes beyond the fact of being essential for the survival of mankind but also for the survival of the natural environment. The availability and quality of water have played a key role in the socio-economic development of Bayelsa state and Nigeria at large. However, an increase in the demand for water has stimulated the development of groundwater resources and its extraction (Afuwai, 2013). As available freshwater resources dwindle in many regions, with increased urbanization also taking place along the coastline communities which has resulted in the deterioration of groundwater quality in the coastal areas such as Bayelsa State caused by natural means such as saltwater intrusion or by anthropogenic interference (Amadi, 2010; Amadi et al. 2012). Further withdrawals are predicted to increase by 50 percent by 2025 in developing countries, and 18 percent in developed countries (UN-WWAP, 2006). To this end, therefore, groundwater happens to be a more reliable source of fresh water for over half of the world population as it accounts for over 80% of the available freshwater on earth (Alabi et al. 2010).

The state of the hydrological properties, its water quality, and ecosystems within which water is found are major factors contributing to man's well-being (UN-WWAP, 2006). Therefore, it is necessary that the quality of drinking water should be checked at regular time interval, because due to use of contaminated drinking water, human population suffers from

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varying of water borne diseases (Gebreyohannes et al. 2015). Also, physicochemical and laboratory assessment of several water sources have raised health concerns due to the detection of high concentrations of dissolved minerals and other contaminants in (aquifers) groundwater bodies has become increasingly worrisome to global water quality standards. Previous studies have shown that groundwater is the subsurface transporting agent for dissolved chemicals which includes certain contaminants. Materials dissolved from buried wastes may be transported from the burial or disposal site by groundwater flow into aquifers in the locality, the result of such being that the quality of water from wells is impacted by the contaminated groundwater.

Due to the fact that groundwater moves slowly through underground mediums and by the action of natural flushing of aquifers, when areas are contaminated, they commonly remain so for decades or longer. The presence of these dissolved minerals in groundwater is a result of weathering and interaction with the geologic formation which may affect human health (Freeze and Cherry 1979; Domenico and Schwartz 1990; Kortatsi, 2007; Aghazadeh and Mogaddam 2010). The chemistry of the groundwater water is influenced by a variety of factors which include chemistry of recharging precipitation waters, weathering of the underlying rock, decay of organic matter, and a wide range of anthropogenic activities (Banahene, 2015). As this interaction continues, certain mineral constituents are dissolved and absorbed into the flow channel. Edet *et al* [12] noted that natural water quality problems have also been caused in relation to dissolution of evaporate minerals in the Benue Basin (Edet et al. 2011; Ekwere and Ukpong, 1994; Uma, 1998; Tijani et al. 2002).

Groundwater in the preferred source of potable water in the Bayelsa state, due to the fact that it is less prone to contamination as a result of its natural filtration (Tariwari et al. 2005). The Niger Delta region is blessed with large quantity of groundwater from shallow aquifer, but the region is still challenged by water inadequacy due to the commercialization of available potable water, making it unavailable to indigent people. This is a major issue as most groundwater aquifers found in Bayelsa state also contain high concentration of dissolved iron and other heavy metals. The iron dissolved in groundwater is in the reduced iron II form. This form is soluble and is usually harmless. However, when iron II is oxidized by exposure to air it forms Fe^{3+} ion and precipitate a rust colour ferric hydroxide also by the action of iron related bacteria. Iron III forms insoluble hydroxides in water (Ihuoma et al. 2018). If the iron hydroxide deposits are produced by iron bacteria then they are also sticky and the problems of stain and blockage are many times worse. When ferric or ferrous iron is present in water the effects can be seen, smelled, tasted and felt. Iron in water stains laundry, drink ware, dishes, toilets, tubs, sinks, and fixtures by leaving yellow, red, and brown spots, it reduces water flow from the borehole; blocking most pipes. Although iron is an essential element for human nutrition and metabolism, in high concentration, it may have a toxic effect like hemochromatosis in tissues which causes arthritis (Tambekar et al. 2013).

Inhabitants in most towns have individual boreholes that are sited without prerequisite geophysical and physicochemical tests. This has resulted in boreholes that have failed over time due to the borehole not reaching the best aquifer level. Also, we find out that the water from these boreholes tends to be brownish as a result of significant iron content in it (Okiongbo and Ogobiri 2011). The study of groundwater occurrence and quality pollution in Yenagoa metropolis is one way of understanding and mitigating the water resource problem facing the people of the area. The overburdened issue of water contamination due to geogenic and man-made factors in the region has raised concern amongst researchers, causing them to study the region in a bid to better understand and proffer solutions to these water challenges. This study, therefore, focuses on the need for accurate characterization of the subsurface for a better understanding of the groundwater architecture and how it is affected by the iron concentration of the area to aid plan for the future development of boreholes and wells in this region.

2. GEOLOGY AND HYDROGEOLOGIC SETTING OF THE STUDY AREA

Bayelsa State is geographically located within latitude 4°15′ North and latitude 5°23′ North. It is also within longitudes 5°22′ East and 6°45′ East (Figure 1). The state is bounded by Delta State on the north, Rivers State on the east and the Atlantic Ocean on the western and southern parts. The study areas encompassing 16 VES locations in Yenagoa local government area, Bayelsa state and are located between latitude 4.888235" and longitude 6.248924" to 6.336973 E".

The geology of the area is underlain by the Coastal Plain sands, which in this area is overlain by soft-firm silty clay sediments belonging to the Pleistocene Formation (Short and Stauble, 1967). The Niger delta region essentially illustrates the influence of river movements from several distances inland as it drives towards the oceans. The Niger Delta has three distinct lithological formation, the Akata formation, Agbada formation and the Benin formation. The Akata formation at the base of the basin consist of Marine shale deposit, it is followed unevenly by the Agbada formation which consists of alternate Layers of Sand Stone and Shale. The more recent Benin formation at the top of the basin consists of sands, clay, Peat and some Granular materials. The Coastal Plain slopes gradually from an elevation of 240m to 12m above mean sea level and is largely characterized by mangrove forest. The aquifer has a south west gradient towards the Delta and is thickened seawards in the same direction of ground water movement. The Study area is situated in the Coastal Plain region, quaternary in Age. The Zone is made of Coarse to Medium sand, with Silty and Clay lenses. Within the Project area, groundwater is abstracted from the Benin formation, mainly in its upper section (< 300m).

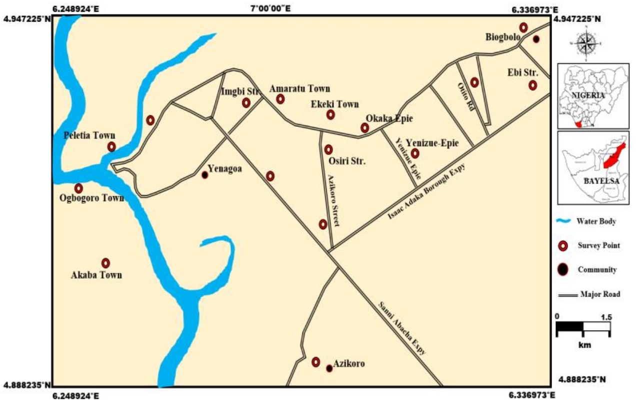

Figure 1: Map of Study Area showing VES Locations

The aquifer at shallow depth (> 10m) are unconfined while the deeper aquifers are confined and isolated from the ground surface and the natural recharge comes Northern high Coastal Plain. The Upper unconfined aquifer varies from 15m to nearly 100m. The middle semi-confined aquifer consists of medium to coarse grained sands with clay lenses and fine clayey sands (100m-200m). The Lower Aquifer extends from 200m - 300m in depth.

The study area, experiences an annual rainfall of 2500mm, while the average specific yield of the aquifer in these areas is 10,500liter/hr./m and the Transmissivity is >100m2/day (Offidile, 2013). Okiongbo *et al*. stated Transmissivity values range, from 1634.0 m2/day to 5292.0 m2/day within most parts of Yenagoa and the neighbouring Sagbama LGA (Okiongbo, 2012). These values are typical of an unconsolidated fine-medium-coarse sand. The study area also witnesses massive flooding and inundation of coastal aquifers by saline water especially low-lying areas and reclaimed wetlands (Idu, 2015). Moreover, Bayelsa State where the study area is situated, lies at the southernmost part of Nigeria, at the core of the Niger Delta region and is peculiarly described as a moist area. This peculiarity is fuelled by interconnected waterways, hydrocarbon and natural gas potentials amongst other resources. Bayelsa environment is delicate and fragile with relatively rich vegetation. Due to diurnal fluctuation of the tides, these area experiences lots of rainfall which causes flash flooding most of the time. This episodic natural events in this part of the Delta, account for the difficulty of living in this very aquatic terrain. The general topography of Bayelsa State is consistent with a coastal environment as it slopes gently in a north-south direction towards the Oceans. Bayelsa can be described as a lowland or flat monotonous Land form region (Ofomola, 2015). The area is benchmarked by tidal flats, beaches, beach ridge barriers and seasonal flood plains. It is also predominated by lagoons and cliffs. Composed of horizontal structure of low relief formed from sediment materials deposited over millions of years.

Bayelsa State in which the study area is a part consist of two broad morphologic regions identifiable as the older coastal sands of about cretaceous age. These make up the higher land and the relatively more recent Deltaic plain sand associated with the Sombreio-Warri plain. These deposits are the outcome of a transgressive phase occurred 30,000-10,000 years before present. The deposits of the modern Niger Delta in the state overlie older sediments which range in age from the cretaceous to early quaternary. Four morphological units are recognized in the subaerial Niger Delta namely; the outer barrier island complexes, the vegetated tidal flats, the lower flood plain, the narrow upper flood plain between Onitsha and the bifurcation of the Niger.

The climate of Bayelsa State has been identified as a humid semi-hot equatorial climate. Weather conditions over the state are brought about by moist tropical maritime air mass and the dry and dust laden tropical continental mass. The generally acknowledged seasons within the state are the wet/ rainy seasons (March to late October) and the dry/ harmattan season (November to Early March). The mass of moist air is predominant during the rainy months which increase the average humidity of the area. The mean annual rainfall ranges from 2,000 to 4,000mm and spreads over 8-10 months of the year between the months of March and November. The rainfall index shows that although the state experiences high rainfall, it reduces northwards away from the coast, with areas like Akassa town recording the highest rainfall in Nigeria.

The relative humidity due mainly to high precipitation causes the moisture content of the atmosphere to remain comparatively uniform over the state during most part of the year. The months of June and October is said to record a monthly mean of over 80% (Alagoa, 1999). During the dry season moisture content records a low value of 65%, while in May it rises to 78%. The reduction in moisture content is caused by the prevailing North-East trade winds (harmattan wind) which are dry, cold and dust laden. Temperature in Bayelsa State is fairly constant throughout the year over the entire state with a maximum of 30^0C because of its latitudinal location in the equatorial belt. Highest temperature is normally recorded between February and March each year. While the lowest values occur during June and July the peak of the rainy season. Temperature decreases from its peak 30^0C in September to 25^0C in November at the onset of the north-east trade wind.

3. THEORY OF ELECTRICAL RESISTIVITY METHOD

The electrical resistivity method is a non-invasive geophysical method which simply works by applying Ohm's principle in its operation.

$$V = IR \qquad (1)$$

where V (volts) is the potential difference between two points in a conductor; I (amperes) is the current flow; R (ohms) is the constant of proportionality called resistance. In Ohmic materials the resistance of the conducting object is found to be directly proportional to the length, L of the object and inversely proportional to its cross-sectional area A. The constant of proportionality, in this case, is called resistivity, of the conductor). The resistivity of an object is mathematically expressed as:

$$R = \rho\ (l/A) * (V/I) \qquad (2)$$

where ρ is the resistivity which is an intrinsic property of the material; A = Cross- sectional Area of material; V = Voltage; I = Current; *l* = length of material. Thus Conductivity (σ), is the inverse of resistivity and is measured in milliSiemen per meter (mS/m):

$$J = \sigma E \qquad (3)$$

where σ is the conductivity of the material; E = Electric field.

$$\rho = \frac{1}{\sigma} \qquad (4)$$

The apparent resistivity (ρ_a) obtained from earth measurements does not vividly represent the true resistivity of the subsurface and may not directly be related to the real value of resistivity in a heterogeneous earth. In reality, its value may be larger or smaller than the actual resistivity, or in rare cases, it may be identical with one of the true resistivity values in a heterogeneous earth (Tipler and Kyker, 1982). Therefore, to obtain the true resistivity of any point in the ground, the apparent resistivity value obtained which describes (ΔV/I) measured is multiplied with the appropriate geometrical factor K. In a Schlumberger sounding spread (Figure 2), the voltage electrodes are usually kept small and fixed while only the C1C2 spacing is changed. By convention A, B, M and N in the formula below is equal to C1, C2, P1 and P2 respectively.

The apparent resistivity $$\rho_a = \left[\frac{(AB)^2 - (MN)^2}{MN}\right]\left(\frac{\Delta V}{I}\right) \qquad (5)$$

where Geometric factor, K = $$\pi\left[\frac{(AB)^2 - (MN)^2}{MN}\right] \qquad (6)$$

$$\rho_a = K\left(\frac{\Delta V}{I}\right) \qquad (7)$$

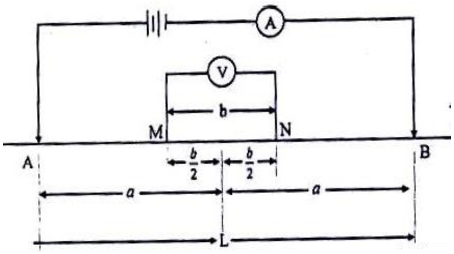

Figure 2: Schematic Diagram of Schlumberger Array

4. STANDARD OF PHYSICOCHEMICAL PARAMETERS QUALITY FOR DRINKING WATER

Water content have different types of floating, dissolved, suspended and microbiological as well as bacteriological impurities. That is why some physical test should be performed for testing of physical appearance, for example temperature, colour, odour, pH, turbidity, total dissolved solids (TDS), and the chemical tests should be perform for dissolved oxygen, alkalinity, hardness and other characters (Navneet et al. 2010). However to obtaining more and more quality and purity water, it should be tested for its trace metal, heavy metal contents and organic (pesticide residue). Based on these it is important that drinking water should pass these entire (parameters listed above) tests and it should content required amount of mineral level before it can be considered for whatever purpose (Patil et al. 2012; Poonkothai and Paryatham, 2012). Only in the developed countries all these criteria's are strictly monitored. Due to very low concentration of heavy metal and organic pesticide impurities present in water it need highly sophisticated analytical instruments and well trained manpower (Gupta et al. 2009).

4.1 Temperature

The water temperature in an established system controls the rate of all chemical reactions, and affects fish growth, reproduction and immunity. Drastic temperature changes can be fatal to microorganisms and all the aquatic lives (Basavaraja et al. 2011).

4.2 pH

Measurement is one of the most important measurements in determining the corrosive nature of water. Lower the pH value higher is the corrosive nature of water. The pH was positively correlated with electrical conductance and total alkalinity. The reduced rate of photosynthetic activity the assimilation of carbon dioxide and bicarbonates which are ultimately responsible for increase in pH, the low oxygen values coincided with high temperature during the summer month (Manjare et al. 2010). Various factors bring about changes the pH of water. The higher pH values observed suggests that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physicochemical condition (Smith and Hollibaugh, 1997).

4.3 Electrical Conductivity (EC)

Conductivity shows significant correlation with ten parameters such as

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temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand, chloride and iron concentration of water they suggest that the underground drinking water quality can be checked effectively by controlling conductivity of water and this may also be applied to water quality management of other study areas. It is measured with the help of EC meter which measures the resistance offered by the water between two Platonized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution.

4.4 Carbon Dioxide

Is the end product of all organic carbon degradation in almost all aquatic environments and its variation is often a measure of net ecosystem metabolism. Therefore, in aquatic biogeochemical studies, it is desirable to physicochemical parameters for testing of water measure parameters that define the carbon dioxide system (Premlata, 2009). CO_2 is also the most important greenhouse gas on Earth (Saravanakumar and Ranjith, 2011). Its fluxes across the air-water or sediment-water interface are among the most important concerns in global change studies and are often a measure of the net ecosystem production and metabolism of the aquatic system (Sawane et al. 2006). There are various readily measurable parameters of aquatic carbon dioxide system: such as pH (pCO_2), total dissolved inorganic carbon (DIC) and total alkalinity (TA). Surface water pCO_2 can be measured by photometric method and DIC CO_2 is measured by coulometer or by an infrared CO_2 analyser (Wang et al. 2002). Total Alkalinity CO_2 is determined by HCl titration of the water sample to the CO2 equivalence point.

4.5 Alkalinity

They are composed primarily of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-), alkalinity acts as a stabilizer for pH. Alkalinity, pH and hardness affect the toxicity of many substances in the water. It is determined by simple dilution of HCl titration in presence of phenolphthalein and methyl orange indicators (Agarwal & Manish, 2011). Hydroxyl alkalinity (causticity) in boiler water is necessary to protect the boiler against corrosion. Too high a causticity causes other operating problems, such as foaming. Excessively high causticity levels can result in a type of caustic attack of the boiler called "embrittlement".

4.6 Dissolved Oxygen (DO)

Is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, and stratification. The high DO in summer based on an increase in temperature and duration of bright sunlight has influence on the percentage of soluble gases present in the water (O_2 & CO_2). During summer the long days and intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO_2 and giving off oxygen (Sharma et al. 2005). This possibly accounts for the greater qualities of O_2 recorded during summer. The difference in the initial and final DO (dissolved oxygen) gives the amount of oxygen consumed by the bacteria during this period. This procedure needs special container or bottles which seal the inside environment from atmospheric oxygen (Aftab et al. 2005).

4.7 Carbonate

Whenever the pH touches 8.3, the presence of carbonates is indicated. It is measured by titration with standardized hydrochloric acid using phenolphthalein as indicator [41]. Below pH 8.3, the carbonates are converted into equivalent amount of bicarbonates. The titration can also be done pH metrically or potentiometrically.

4.8 Bicarbonate

Is also measured by titration with standardized hydrochloric acid using methyl orange as indicator (Singhal et al. 2005). Methyl orange turns yellow below pH 4.0. At this pH, the carbonic acid decomposes to give carbon dioxide and water.

4.9 Biochemical Oxygen Demand (BOD)

Is a measurement of organic material contamination in water, specified in mg/L. BOD is the amount of dissolved oxygen required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials (e.g., iron, sulphites).

4.10 Chemical Oxygen Demand (COD)

Is another measurement of organic material contamination in water specified in mg/L. COD is the amount of dissolved oxygen required to cause chemical oxidation of the organic material in water. Both BOD and COD are key indicators of the environmental health of a surface water supply. They are commonly used in waste water treatment but rarely in general water treatment.

4.11 Sulphate

Is measured by nephelometric method in which the concentration of turbidity is measured against the known concentration of synthetically prepared sulphate solution. Barium chloride is used for producing turbidity due to barium sulphate and a mixture of organic substance (Glycerol or Gum acetia) and sodium chloride is used to prevent the settling of turbidity (Adnan et al. 2010).

4.12 Ammonia

Is measured spectroscopically at 425 nm radiation with a colour complex of Nessler's reagent. The conditions of the reaction are alkaline and cause severe interference from hardness in water.

4.13 Calcium

Is measured by complexometric titration with standard solution of ETDA using Patton's and Reeder's indicator under the pH conditions of more than 12.0. These conditions are achieved by adding a fixed volume of 4N Sodium Hydroxide. The volume of titre (EDTA solution) against the known volume of sample gives the concentration of calcium in the sample.

4.14 Magnesium

Is also measured by complexometric titration with standard solution of EDTA using Eriochrome black T as indicator under the buffer conditions of pH 10.0. The buffer solution is made from Ammonium Chloride and Ammonium Hydroxide. The solution resists the pH variations during titration.

4.15 Sodium

Could be measured with the help of flame photometer. The instrument is standardized with the known concentration of sodium ion (1 to 100 mg/litre). The samples having higher concentration are suitably diluted with distilled water and the dilution factor is applied to the observed values.

4.16 Potassium Physicochemical parameters for testing of water

This could be measured also with the help of flame photometer. The instrument is standardized with known concentration of potassium solution, in the range of 1 mg to 5 mg/litre. The sample having higher concentration is suitably diluted with distilled water and the dilution factor is applied to the observed values.

4.17 Chloride

Is measured by titrating a known volume of sample with standardized silver nitrate solution using potassium chromate solution in water or eosin and fluorescent solution in alcohol as indicator. The latter indicator is an adsorption indicator while the former makes a red colour compound with silver as soon as the chlorides are precipitated from solution.

4.18 Silicates & Phosphate

They could also be measured spectroscopically. The yellow colour is developed from the action of phosphates and silicates on molybdate ion under strong acidic conditions. The intensity of colour is directly proportional to the concentration of phosphate and silicates in the sample (WHO, 2004).

5. MATERIALS AND METHODS

5.1 Geo-Electrical Resistivity Survey

A total of sixteen VES soundings and five boreholes were utilized to achieve the aim of this work. The geoelectric survey data was obtained by employing the Schlumberger electrode configuration using the standard equipment; an ABEM SAS 300B Terrameter, four steel electrodes (current and potentials), Rechargeable (DC) battery source, Measuring Tapes, Cables, Hammer, GAMIN Etex (GPS), and Recording Sheets. At each sounding location, the respective coordinates and elevations were measured using the hand-held GAMIN Etex (GPS). The VES sounding locations are: VES 1 (Akaba Town), VES 2 (Obogoro Town), VES 3 (Peletia Town) VES 4 (Mbiama/Yenagoa Road), VES 5 (Imbgi Town), VES 6 (Amaratu), VES 7 (Ekeki Town) VES 8 (Okaka- Epie) VES 9 (Osiri Street) VES 10 (Sani -Abacha Exp.), VES 11 (Azikoro 1) VES 12 (Azikoro Town), VES13 (Yenzue-Epie), VES 14 (Otiotio Road), VES 15 (Ebi Street), VES 16 (Biogbolo Town).

The sixteen VES sounding locations were identified and georeferenced using the GAMIN Etex (GPS) while the Total Station Survey equipment. The field array type adopted was the Schlumberger array. The ABEM Terrameter (SAS) 300 model was used as the signal averaging system for data acquisition. Spatial considerations and amount of manpower to operate equipment advised the employment of this array. Also, the configuration is favourable at delineating small variations/ intervals of soil horizons. In the Schlumberger electrode arrangement (Figure 2), the central electrodes (MN) or (P1, P2) are kept relatively close together when compared to the separation of the outside current electrodes (AB). The distance between C1 and P1 is equal to the distance between C2 and P2. In a VES using the Schlumberger array, the effective depth of penetration is generally 20–40% that of the outer electrode spacing (C1, C2), dependent on the earth resistivity structure. Thus, the potential electrode spacing will be occasionally extended but not more than one-fifth of the distance between the current electrodes C1 and C2 half spacing (a). As the current electrodes are expanded, it penetrates deeper and at a stage the signals on the Terrameter becomes weak. The current electrode spread ranged from the minimum spacing of 200 - 400m maximum spacing. The result from the VES soundings obtained were used to compute the apparent resistivity. The apparent resistivity values were arranged in an excel spreadsheet environment and later loaded into IP12WIN resistivity analysis software to generate the desired results of number of layers, depth and layer thickness at each sounding location.

5.2 Physicochemical Analysis

For the water samples, sample tubes (100ml sterilized polyethylene bottles) were used to collected samples and the physical parameters (temperature, pH, colour, electrical conductivities were tested. The obtained samples were handled with care and transported to the laboratory for further analyses. Chemical parameters analysed are pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS) Alkalinity, Iron, Carbonate, Chloride, Sulphate, and heavy metals such as copper, chromium, nickel, cadmium, manganese, zinc and lead. The pH was determined using a Mettler Toledo (GmbH 8603 Schwerzenbach) pH meter by direct measurement, an analogue mercury thermometer was used in making temperature measurements and a Hach 2100A turbidimeter was used for turbidity determination.

6. RESULTS AND DISCUSSION

The results of the work are presented in Figures 3 – 7 and in Tables 1 – 3.

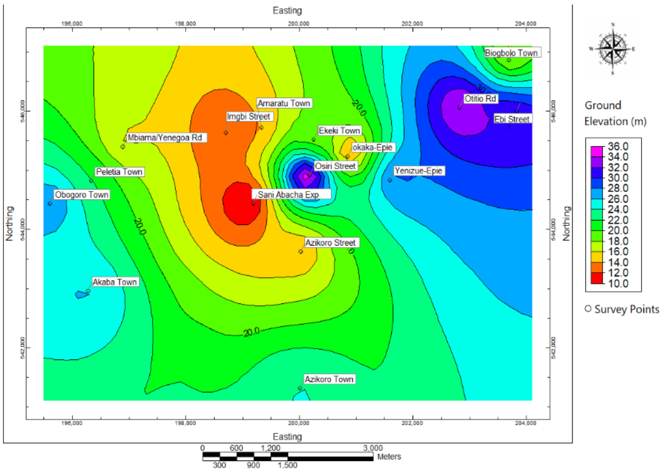

Figure 3: Elevation Map of Study Area

Table 1: VES Points showing the measured Parameters

VES No.	Coordinates		Location	Layer Resistivity						Layer Thickness (m)					Curve Type	Error (%)	Elevation (m)
	Northing	Easting		ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	h_1	h_2	h_3	h_4	h			
1	542962	196275	Akaba Town	40.42	62.3	872.9	13.75	-	-	0.6	2.021	9.759	-	-	AK	1.65	26
2	544439	195604	Obogoro Town	35.6	117	39.3	2215	155	-	0.35	8.51	14.636	13	-	KHK	2.59	27
3	544812	196330	Peletia Town	81.9	751	129	332	0.261	-	1.02	7.88	12.3	34.7	-	KHK	7.51	22
4	545398	196888	Mbiama/Yenagoa	8.86	157	885	82.1	-	-	0.418	2.51	150	-	-	AK	3.37	16
5	545636	198702	Imgbi Town	83.3	285	45.6	809	23.6	-	0.463	0.568	5.89	6.15	-	KHK	3.58	12
6	545722	199331	Amaratu Town	47.7	114	722	104	18.4	-	0.256	2.42	2.01	75.2	-	AKQ	4.25	14
7	545517	200253	Ekeki Town	27.1	157	1226	9.23	-	-	0.647	9.09	16.7			AK	5.85	19
8	545234	200852	Okaka-Epie	34	864	39.9	259	-	-	0.777	5.5	33.1	-	-	KH	4.4	14
9	544919	200186	Osiri Street	43.1	14550	228	2436	1688	408	0.432	0.379	4.08	10.5	6	KHKQ	3.44	35
10	544433	199186	Sani-Abacha Exp	96.7	14	3422	185	2.64	-	0.515	0.656	3.15	147	-	HKQ	5.09	10
11	543627	200023	Azikoro Street	15.42	535.9	1.622	-	-	-	2.834	14.65	-	-	-	K	1.65	15
12	541318	200010	Azikoro Town	12.1	3.84	203	32.5	-	-	1.3	1.32	101	-	-	HK	3.78	24
13	544837	201594	Yenzue-Epie	84	3219	333	63.5	-	-	0.788	2.44	16	-	-	KQ	7.28	28
14	546056	202822	Otiotio Road	60	1698	674	209	1.51	-	0.567	2.84	3.86	26	-	HQQ	6.63	34
15	545997	203822	Ebi Street	364	1094	300	153	117	-	0.52	0.699	4.91	15.8	-	HQQ	2.26	32
16	546865	203688	Biogbolo Town	65.1	24.1	830	56.5	0.474	-	0.735	0.789	8.69	63.7	-	HKQ	4.05	18

Table 2: Physicochemical Water Sample Analysis Results

Source	Borehole Water (Raw)		Borehole Water (Raw)		Borehole Water (Raw)	
Location	**Swali Market, Yenagoa**		**Ekeki Park**		**Epie National High School, Kpansia**	
Date	8th August, 2015		7th August, 2015		8th August, 2015	
Quantity	4 Litres		4 Litres		4 Litres	
Test Performed	**RESULT**	**LIMIT**	**RESULT**	**LIMIT**	**RESULT**	**LIMIT**
General Appearance	Cloudy	Clear	Cloudy	Clear	Cloudy	Clear
Odour	Objectionable	Unobjectionable	Objectionable	Unobjectionable	Objectionable	Unobjectionable
Taste	Objectionable	Unobjectionable	Objectionable	Unobjectionable	Objectionable	Unobjectionable
Colour, HU	25	<15	25	<15	38	<15
Turbidity, NTU	21	5	25	5	25	5
Conductivity, µs/cm	50	180	50	180	80	180
Total Dissolved Solids mg/L	690	500	552	500	1104	500
Ph	8.0	6.5 – 7.5	9.0	6.5 – 7.5	8.5	6.5 – 7.5
Hardness, $MgCO_3$ mg/L	30	30	32.1	30	32.1	30
Hardness, $CaCO_3$ mg/L	70	70	74.9	70	74.9	70
Total Hardness Mg/$CaCO_3$ mg/L	100	100	107	100	107	100
Nitrite, mg/L	1.22	1.0	1.29	1.0	1.29	1.0
Nitrate, mg/L	0.71	0	0.85	0	1.0	0
Iron, mg/L	2.65	0.3	2.88	0.3	3.30	0.3
Sulphate, mg/L	105	200	150	200	170	200
Manganese, mg/L	1.8	0.1	1.7	0.1	1.9	0.1
Copper, mg/L	0.00	0.02	0.01	0.02	0.00	0.02
Silica, mg/L	39.1	40	40.6	40	46.4	40
Phosphate, mg/L	2.1	0.05	2.5	0.05	2.7	0.05
Lead, mg/L	0.01	0.02	0.00	0.02	0.00	0.02
Ammonia, mg/L	9.2	0.02	10.4	0.02	11.9	0.02
Chloride, mg/L	191	250	200	250	205	250
Nickel, mg/L	0.00	0.1	0.00	0.1	0.00	0.1
Mercury, mg/L	0.00	0.001	0.00	0.001	0.00	0.001
Zinc, mg/L	2.9	5.0	3.6	5.0	4.1	5.0
Fluorides, mg/L	1.2	1.5	1.5	1.5	1.2	1.5
Sodium, mg/L	151	200	150	200	156	200
Cyanide,mg/L	0.00	0.1	0.00	0.1	0.00	0.1
Aluminium, mg/L	0.00	0.2	0.00	0.2	0.00	0.2

Table 3: Physicochemical Water Sample Analysis Results Cont'd

Source	Borehole Water (Raw)		Borehole Water (Raw)	
Location	**Akaba Community**		**Peletia**	
Quantity	4 Litres		4 Litres	
Test Performed	**RESULT**	**WHO**	**RESULT**	**WHO**
General Appearance	Cloudy	Clear	Cloudy	Clear
Odour	Objectionable	Unobjectionable	Objectionable	Unobjectionable
Taste	Objectionable	Unobjectionable	Objectionable	Unobjectionable
Colour, HU	20	<15	25	<15
Turbidity, NTU	21	5	25	5
Conductivity, µs/cm	74	180	80	180
Total Dissolved Solids mg/L	690	500	552	500
pH	8.15	6.5 – 7.5	8.4	6.5 – 7.5
Hardness, $MgCO_3$ mg/L	31	30	31.1	30
Hardness, $CaCO_3$ mg/L	69	70	76.9	70
Total Hardness Mg/$CaCO_3$ mg/L	100	100	108	100
Nitrite, mg/L	1.12	1.0	1.26	1.0
Nitrate, mg/L	0.75	0	0.80	0
Iron, mg/L	1.1	0.3	2.0	0.3
Sulphate, mg/L	115	200	143	200
Manganese, mg/L	1.1	0.1	1.8	0.1
Copper, mg/L	0.00	0.02	0.01	0.02
Silica, mg/L	39.1	40	40.6	40
Phosphate, mg/L	1.7	0.05	2.3	0.05
Lead, mg/L	0.01	0.02	0.00	0.02

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Ammonia, mg/L	7.2	0.02	11.4	0.02
Chloride, mg/L	191	250	200	250
Nickel, mg/L	0.00	0.1	0.00	0.1
Mercury, mg/L	0.00	0.001	0.00	0.001
Zinc, mg/L	2.9	5.0	3.2	5.0
Fluorides, mg/L	1.2	1.5	1.5	1.5
Sodium, mg/L	164	200	148	200
Cyanide, mg/L	0.00	0.1	0.00	0.1
Aluminium, mg/L	0.00	0.2	0.00	0.2

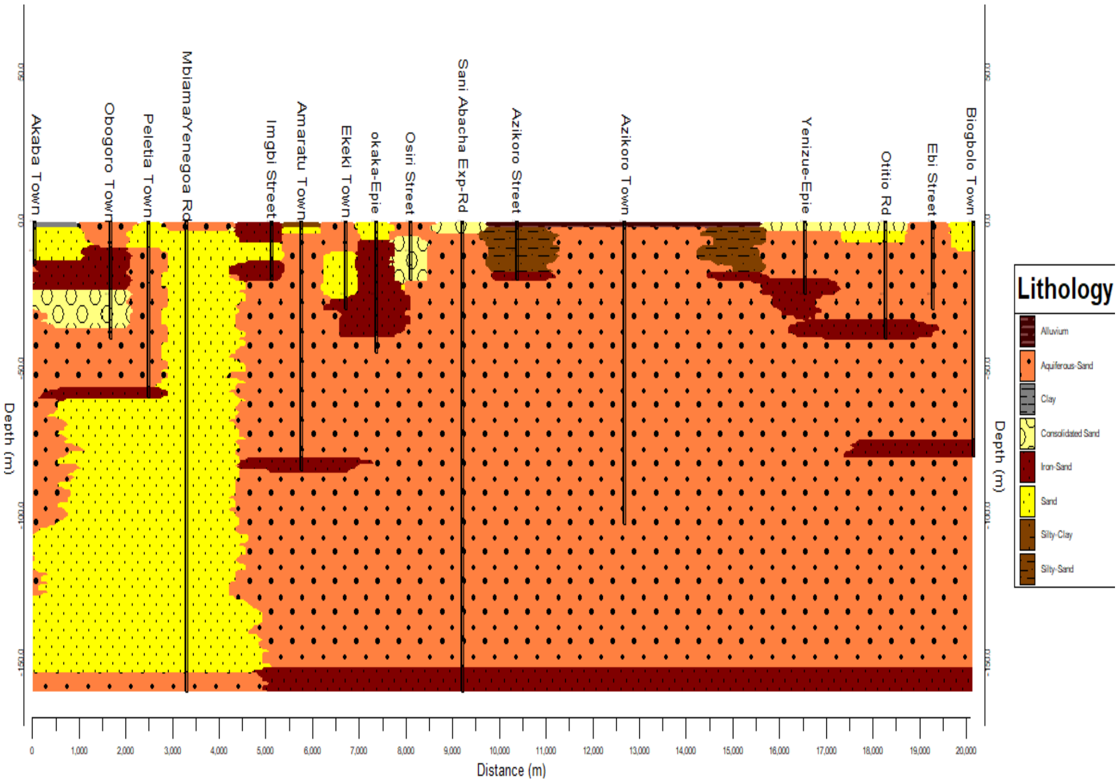


Figure 4: Geoelectric Section across the Study Area

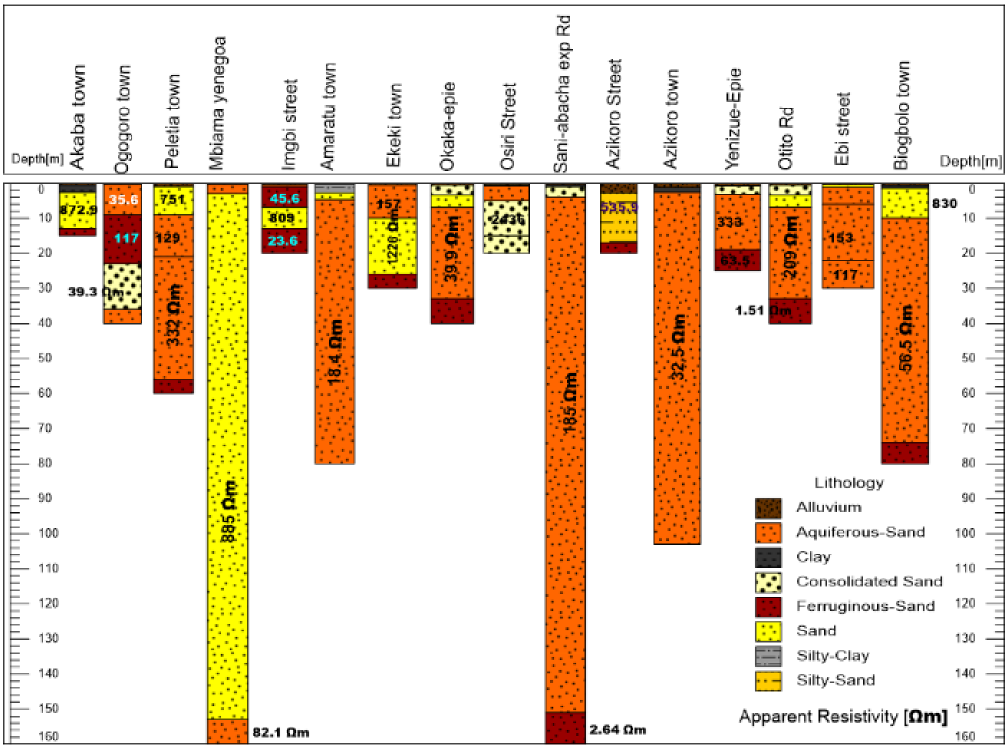
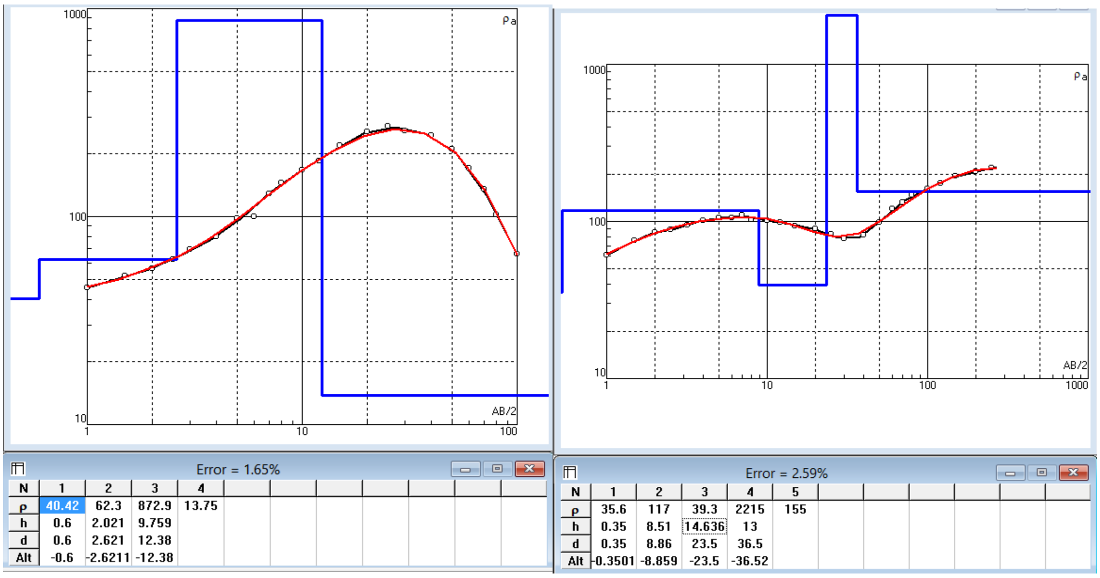


Figure 5: Geoelectric Section showing individual Station Lithology



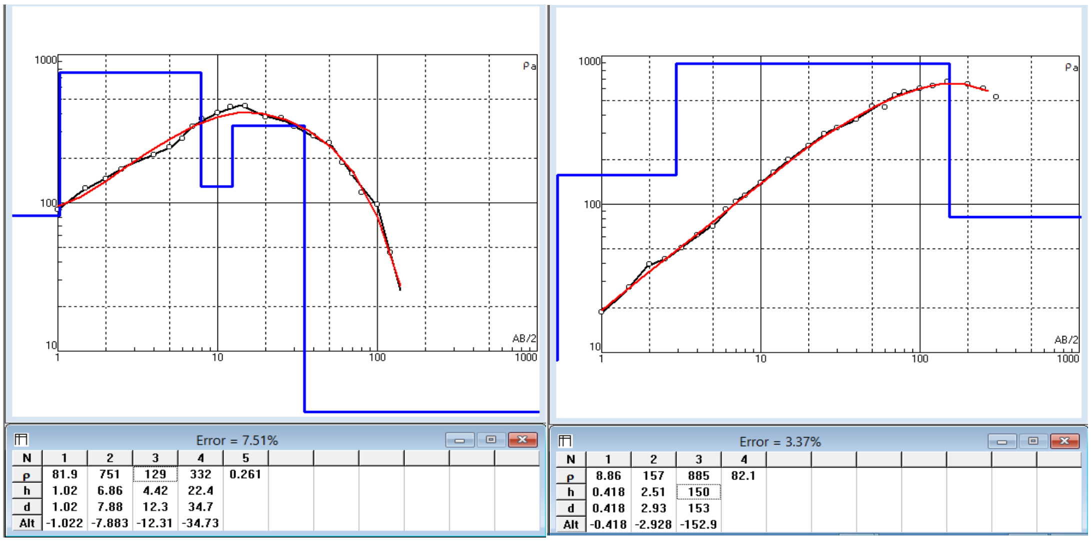
Error = 1.65%

N	1	2	3	4
ρ	40.42	62.3	872.9	13.75
h	0.6	2.021	9.759	
d	0.6	2.621	12.38	
Alt	-0.6	-2.6211	-12.38	

Error = 2.59%

N	1	2	3	4	5
ρ	35.6	117	39.3	2215	155
h	0.35	8.51	14.636	13	
d	0.35	8.86	23.5	36.5	
Alt	-0.3501	-8.859	-23.5	-36.52	

VES 1 **VES 2**



Error = 7.51%

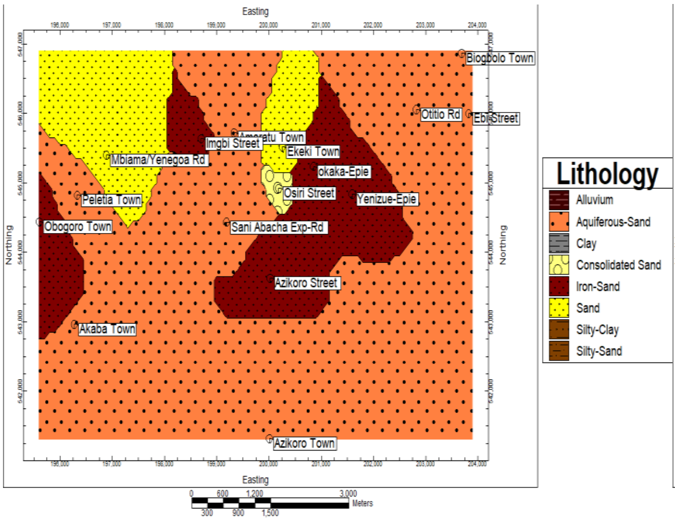
N	1	2	3	4	5
ρ	81.9	751	129	332	0.261
h	1.02	6.86	4.42	22.4	
d	1.02	7.88	12.3	34.7	
Alt	-1.022	-7.883	-12.31	-34.73	

Error = 3.37%

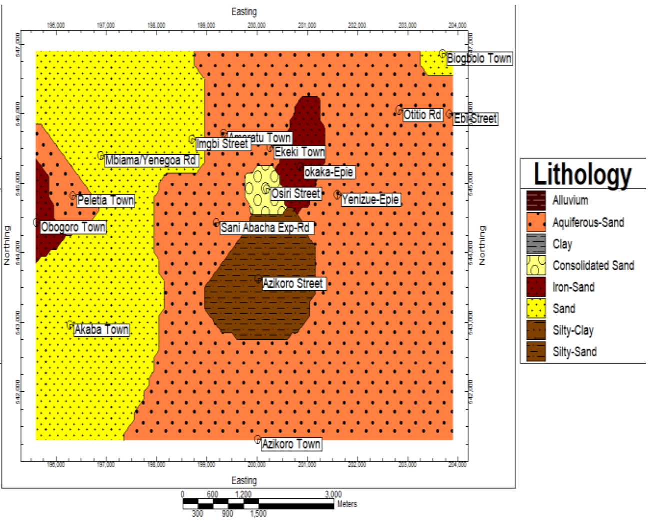
N	1	2	3	4
ρ	8.86	157	885	82.1
h	0.418	2.51	150	
d	0.418	2.93	153	
Alt	-0.418	-2.928	-152.9	

VES 3 **VES 4**

Figure 6: Four examples out of 16 of Stations of Interpreted Resistivity Curves



Lithology Map at 10m across the Study Area



Lithology Map at 20m across the Study Area

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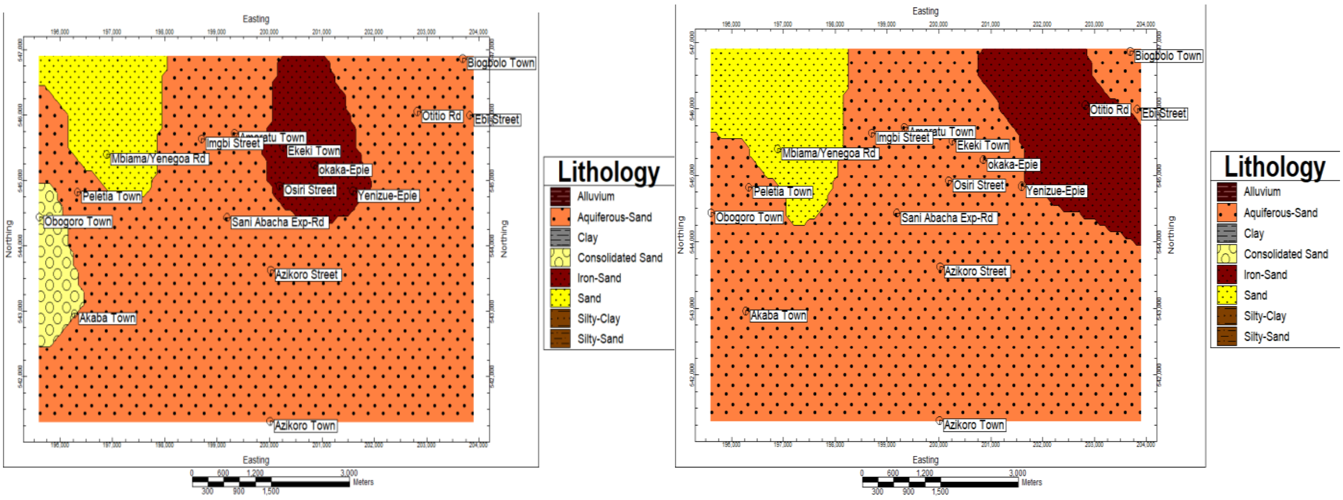
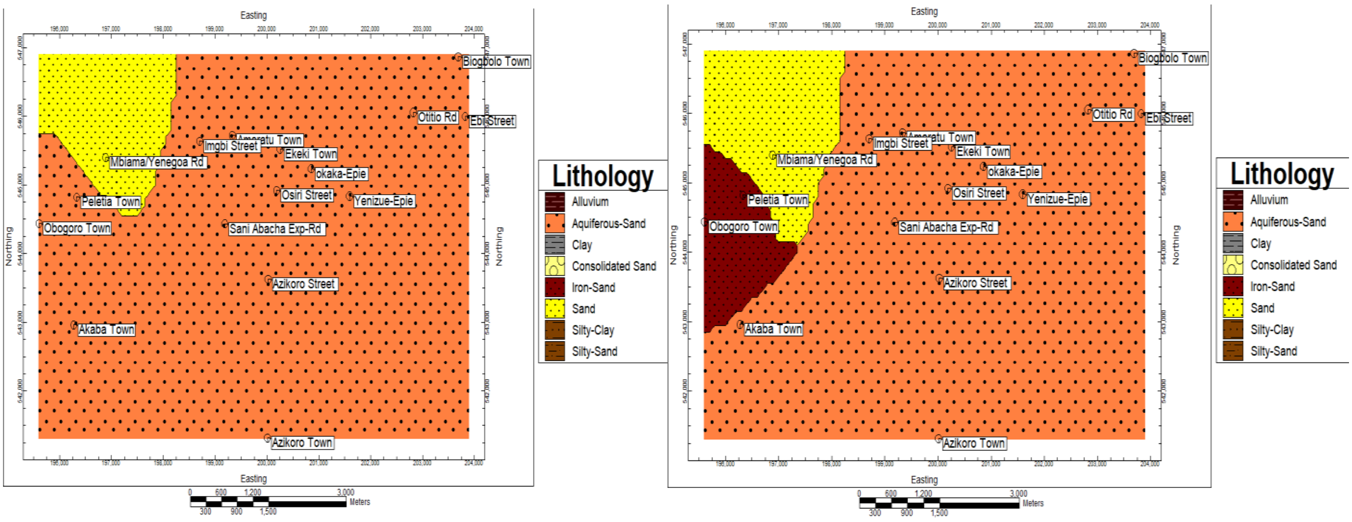


Lithology Map at 30m across the Study Area

Lithology Map at 40m across the Study Area



Lithology Map at 50m across the study area

Lithology Map at 60m across the study area

Figure 7: Lithology Maps across the Study Area

6.2 Discussion

6.2.1 Geoelectric Survey

Results obtained from the geoelectric data was used to model geoelectric curves and determine the releveant geoelectric parameters. These parameters were used to produce lithology maps which showed an inhomogeneous distribution of various earth materials across the study area. Isopach (Aqufer thickness) maps and iso-resistivity maps were also produced showing variation in resistivity across the study area. The elevation varies between 10m and 35m with an average of 21.6m (Table 1; Figure 3). Greatest in the upland recharge areas where groundwater levels are deepest. Groundwater-levels at lower elevations are near valley bottoms, which are groundwater discharge areas.

6.2.2 VES Sounding at Akaba, Obogoro, Peletia and Mbiama/Yenagoa road

The results of the VES models at Akaba, Obogoro, Peletia and Mbiama/Yenagoa road are discussed in this section. These locations are at the western axis of the study area, Akaba town and Mbiama /Yenagoa curves produced an AK type with their models revealing three geoelectric layers having considerably low resistivities at the first layer (40.42Ωm and 8.86 Ωm). The possible aquiferous layer from both models is the third layer having resistivity values of 872.9Ωm and 885Ωm respectively and layer thicknesses of 9.76m and 150m respectively. At Obogoro and Paletia Towns, the curve type observed was a KHK curve with their models revealing four geoelectric layers each. At both sites, there lower resistivities were noticed at the first layer (35.6Ωm and 81.9Ωm) and third layer (39.3Ωm and 129Ωm). The aquiferous layer from both models lies at the fourth layer having resistivity values of 2215Ωm and 332Ωm respectively and layer thicknesses of 13m and 34.7m respectively.

6.2.3 VES Sounding at Imgbi, Amaratu, Ekeki and Okaka-Epie Towns

In this section, results of the VES models at Imgbi, Amaratu, Ekeki and Okaka-Epie Towns are discussed. These locations are at the central axis of the study area map. At Imgbi town, the model curve type identified is a KHK curve while the model obtained at Amaratu town is an AKQ curve type. In both locations, four geoelectric layers were identified at each location with the first lateritic layers having resistivity values of 83.3 Ωm and 47.7 Ωm respectively and thickness of 0.463 and 0.256m. The second layer at both locations have resistivity values of 285 Ωm and 114 Ωm with thickness 0.568m and 2.42m respectively, both suggesting a thin lens of clay/fine sand deposit. The third layer at Imgbi identified as a low resistivity layer has a resistivity signature of 45.6 Ωm and a thickness of 5.89m suggesting the presence of conductive materials. The aquiferous layer present is the fourth layer, characterized by fine sandy materials at a resistivity range of 809 Ωm with a thickness of 6.15m. The third layer at Amaratu suggests a fairly viable aquiferous layer possibly medium coarse sand, with a resistivity signature of 722 Ωm at a shallow depth of 2.42m. The resistivities at the third and fourth layers decrease with depth, suggesting an interface of a freshwater zone and a contaminated region. The second layer has the best prospect of an aquiferous layer; however, it lacks the required thickness to show any viable amount for domestic extraction. The fourth layer therefore represents the true aquiferous zone in the location with a resistivity value of 104 Ωm and thickness of 75.2m.

At Ekeki town and Okaka-Epie town, the observed model curve type is an AK curve with three geoelectric layers each. The resistivity values detected at the top geoelectric layers were considerably low compared to the resistivity signatures of the second layers. At both locations, the first geoelectric layer has resistivity values (27.1 Ωm and 34 Ωm) with layer thickness of (0.647m and 0.777m). The second layer has resistivity values (157 Ωm and 864 Ωm) with individual layer thickness of (9.09m and 5.5m). The third geoelectric layer which also showed high resistivity value of 1226 suggest the presence of a sandy-clay formation with a thickness of 167m in the Ekeki axis. However, the result at Okaki-Epie showed a decrease in the resistivity value to 39.9 Ωm and a thickness of 33.1m suggesting the presence of a contaminant or most likely high deposits of conductive minerals (iron) in the aquifer. The second layer tends to be a favorable aquiferous layer in at Ekeki while the third layer represents the water bearing formation at Okaka- Epie.

6.2.4 VES Sounding at Osiri Street, Sani-Abacha Expressway, Azikoro Street and Azikoro Town

The geoelectric information obtained from Osiri Street delineated the presence of six geoelectric layers producing a KHKQ curve type. The layers were unevenly identified to have high resistivity signatures at shallow depths less than 10m. The first geoelectric layer had the lowest resistivity at 43.1 Ωm with a thickness of 0.432m possibly due to near-surface conductive materials present. The second layer however showed a sharp increase in resistivity (14550 Ωm) with a shallow thickness of 0.479m, this may be due to the presence of clay-rich consolidated sands. The third layer (identifiably the shallow aquiferous layer) had a resistivity 228 Ωm and a thickness of 4.08m. The fourth and fifth layers also exhibit high resistivity values of (2436Ωm and 1688Ωm) with thicknesses of 10.5m and 6m respectively. The sixth layer has a resistivity of 408 Ωm with an unknown depth.

At the Sani-Abacha Express road sounding, the inferred subsurface revealed five geoelectric layers with the top lateritic soil having a resistivity of 96.7 Ωm at a near surface thickness of 0.515m. This layer is followed successively by a thin layer of fairly consolidated sand likely contaminated by leachate infiltration has a resistivity of 14 Ωm and a thickness of 0.656m. The third layer has a resistivity of 3422 Ωm and a thickness of 3.15m, the identified aquiferous layer is the fourth layer having a resistivity signature of 185 Ωm and a thickness of 147m. The fifth layer identified as a highly contaminated layer has a resistivity of 2.64 with an undefined thickness.

At Azikoro Town and Azikoro Street, two curve types were identified, HK at Azikoro Town and k at Azikoro Street. At Azikoro Town, four geoelectric layers were identified. The first layer composed of the alluvium has a resistivity value of 12.1 Ωm with a near surface thickness of 1.3m, the second layer is arguably composed of conductive/ contaminant matter, which may explain the low resistivity value of 3.84 Ωm noticed with a thickness of 1.32m. the third layer, identified as the aquiferous layer in the sounding location has a resistivity value of 203 Ωm and layer thickness of 101m, the fourth layer, gave an outstanding 1.51 Ωm as its resistivity signature at an uncertain thickness indicating the presence of clay or high iron deposit as the location falls within the iron rich zone identified by Ujile (Ujile, 2013).

The first layer resistivity value is 1028Ωm with a depth of 0.5m is interpreted as Topsoil; the second layer resistivity value is 1604Ωm with a depth of 15m is laterite. The third layer resistivity value is 7127Ωm with depth to infinity is interpreted as laterite, This VES point shows no striking potential for underground water.

6.2.5 VES Sounding at Yenzue-Epie, Otiotio Road, Ebi Street and Biogbolo Town

The results of the VES models at Yenzue-Epie, Otiotio Road, Ebi Street and Biogbolo Town show curve types of KQ, HQQ and HKQ with 4 to five distinctive geoelectric layers. These locations are at the North-eastern axis of the study area, Otiotio Road and Ebi Street curves both produced an HQQ type with their models revealing five geoelectric layers with the top layer, presumably lateritic sand and silty clay having low resistivity values at (60 Ωm and 364 Ωm) respectively with thicknesses of 0.567m and 0.52m. The possible aquiferous layer at Otiotio Road and Ebi Street is the third layer having resistivity values of 674Ωm and 300Ωm respectively and layer thicknesses of 3.86m and 4.91m respectively, however the fourth and fifth layers at the Ebi Street result indicate plausible aquifers with excellent thickness that may be contaminated by conductive minerals as the resistivity signatures are lower at these layers.

At Yenzue-Epie and Biobgolo Towns, the curve types observed are KQ and HKQ curves respectively with their models revealing four geoelectric layers at Yenzue-Epie and five layers at Biogbolo Town. At Yenzue-Epie, the top alluvium has a resistivity value at 84 Ωm indicating the presence of conductive materials at the near subsurface with a thickness of 0.788m. This layer is followed by a layer of consolidated sandstone registering a resistivity value of 3219 Ωm with a thickness of 2.44m. The third layer was identified as the aquiferous layer, registering a resistivity of 333 Ωm and a thickness of 16m. The forth layer thickness is undefined and shows a drop in resistivity suggesting the presence of high conductive materials at that depth. At Biogbolo Town, the first two layers show considerably low resistivities of 65.1 Ωm and 24.1Ωm at a total thickness of 1.524m. The third geoelectric layer which is composed of fine sandy layer in the sounding area has a resistivity value of 830Ωm with a thickness of 8.69m. This layer is followed by a thick aquiferous layer of thickness 63.7m with a resistivity value of 56.5Ωm. This low resistivity may be due to the presence of contaminants at low concentration within the aquifer. The fifth layer is identified as a low resistivity layer, presumably due to contamination or presence of high iron concentration in the first layer (35.6Ωm and 81.9Ωm) and third layer (39.3Ωm and 129Ωm). The aquiferous layer identified from both models lies at the fourth layer having resistivity values of 2215Ωm and 332Ωm and layer thicknesses of 13m and 34.7m respectively.

6.2.6 Physicochemical Analysis

The results of the physicochemical parameters measured are shown in Table 4.3. The physical parameters are; pH, electrical conductivity, temperature while the hydrochemical parameters are; Na+, K+, Mg+, Ca+, Fe^{2+}, Cl^-, SO_4^{2-} , CO_3^{2-}, Mn^{2+} and the results compared with WHO [43] standard. It was observed to be below detectable limit (BDL) in all the boreholes analysed. For the physical parameters it was observed that the general appearance of all five samples was cloudy and had an undesired taste and smell. The pH values ranged from 8.0 to 9.0. When compared with the WHO [43] accepted standard, it is observed that all the boreholes have pH values within the range of the WHO [43] standard of 6.5-8.5. Results from all five samples had pH values greater than 7 (neutral level) which indicates that the water in these boreholes are basic with the sample for Ekeki having the highest at 9.0. The results show that there is a relationship between the pH and iron values as it displays that the iron concentration tends to increase with higher pH values [43]. This may be due to leachate infiltration into the aquiferous regions [32].

The concentration of Na+, Ca+, SO_2^-, Mg^{2+}, and Cl are below the WHO [343] standard. While the values of Mn^{2+}, Fe^{2+}, K+, F and HN_2 were high in all five borehole samples, all exceeding the WHO [43] approved limit. These high concentrations may be due to the leaching of contaminants into the groundwater resources, the presence of earth minerals in high concentration and oxidation of ions within the aquifer. The total hardness of the water detectable by the concentration of $Mg/CaCO_3$ in the samples ranged from 100 to 107 mg/L across the boreholes which suggests that there may be temporary hardness witnessed in boreholes in around Ekeki and Kpansia while the sample at Swali was within the WHO [43] approved standard. It was also noticed that the concentration of Na+ low ranging from 150 to 156 mg/L which may suggest that the ion exchange/ reaction rate present in the soil may be low.

7. CONCLUSION

From the study, results of the geoelectric survey and the subsequent geologic maps obtained showed that in most part of the study area, there were uneven distribution of shallow aquifers (4 – 10m), this was followed unevenly by layers of clay and sandy-silt at varying depths up to 20m.2-D geoelectric profile from the study areas show the vertical and horizontal spread of the layers with identified resistivity, depth, thickness and material. From the profile, areas of low resistivity materials (clay/ferruginous sand) were clearly identified and interpreted as zones of high iron contamination or zones of leachate infiltration.

From the physicochemical investigation, it was observed that the values $SO4^{2-}$, Cl^-, Na^{2+}, Mg^{2+}, Ca^{2+}, F^- are below WHO [30] standard in all boreholes tested while Mn^{2+},NH_3, $PO^{3-}$and Fe^{2+}, K^+, and Cu^{2+} have values above WHO [30] standard in some boreholes. The pH values shown in table 3.2a and 3.2b, all showed that the water was slightly basic as the values all exceeded the neutral limit 7, but were within the WHO [30] limit (6.5 – 8.5) with only Ekeki showing slightly elevated pH value 9, which suggest the presence of iron bacteria. The pH range was within WHO [43] standard. F^-, K^+, Fe^{2+} and Mn^{2+} have values that exceeded the WHO [43] standard in some boreholes while SO_4^{2-}, Cl^-, Na^{2+}, Ca^{2+}, Mg^{2+} and Cu^{2+} have values below WHO [43] standard in all the boreholes. The chemical parameters above the WHO [43] standard indicates the dissolution of leachate bearing these mineral ions into the subsurface aquifer while those below indicates low concentration of these minerals. The results from boreholes and geophysical analysis suggest that at depths of 20 – 45m the concentration of ferruginous minerals is high especially towards the north eastern section of the study area as seen in Fig. 7.

8. RECOMMENDATIONS

The results obtained from this study have shown that for a more efficient understanding of the impact of ferruginous minerals on aquifer resources in the study area, an integrated approach is needed to infer on a wide array of variables that control the occurrence of these waters and its chemical properties. This study therefore suggests that;

1. There should be proper geophysical investigation prior to setting boreholes in order to properly map-out the lithologic sequence of the area.
2. All newly drilled wells/ boreholes must be subjected to routine physicochemical tests, advisably before and after casing. This test should be repeated at bi-annual intervals to help monitor contaminant movement into aquifers.
3. Deeper borehole drilling is recommended where the depth of well casing should be above 50m in most parts of the study area, with regions around Kpansia and its surrounding having wells as deep as 55 – 70 m.
4. It is also advised that soil tests be carried out to determine the occurrence and effect of leachate on the soil.
5. We suggest that further research should be carried out on a larger scale to monitor the occurrence and distribution of ferruginous minerals in other areas of the state, which may serve as a guide to drillers and water resource planners.
6. Also, it is necessary that since most viable aquifers in the study area are unconfined and characterized by possible leachate contamination due to infiltration and percolation of man-made leachate and other natural factors, caution be taken to mitigate the spread of water borne diseases especially since most boreholes in the area are public ones. This can be made possible through constant monitoring by relevant Government agencies.

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