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Environmental Risk Assessment of Subsurface Corrosion Severity as Aids to Pollution Level of Proliferated Petrol Stations in Abeokuta Metropolis Using Geophysical Technique

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Abstract: *Twenty (20) Vertical Electrical Sounding (VES) Method of Geophysical Investigation was carried out in Abeokuta, South-West Nigeria adopting the Schlumberger configuration with maximum electrode separation (AB/2) of 100 m and minimum of 32m with a linear electrodes array (AMNB) in order to delineate the subsurface geologic layers and determine both their corrosion severity and overburden Protective capacity rating (OPCR) as aids to evaluating the vulnerability and pollution level in groundwater system of the study area. The acquired data were interpreted with WinRESIST software with identified curve types; KH and HKH curves among others are in many instances indicative of fracturing which serve as favourable zones for groundwater abstraction. The VES data interpretation delineated four (4) major lithological units in the order of the lateritic topsoil, weathered material, fractured basement/fresh bedrock with delineated low resistivity water absorbing, clayey, linear fracture zones at varying depths. It was concluded that the very low resistivity of the area investigated indicates that the subsurface structure is highly corrosive. Depths of burial of the storage tanks varied from the maximum depth of 5.0m to the minimum depth of 4.0m with an average depth of 4.7m while the overburden thickness to the aquiferous zone in the study area as determined from the electrical resistivity inversion ranged from the maximum depth of 22.4m (VES5) to the minimum thickness of 3.3m (VES19) with an average thickness of 4.7m. This investigation revealed that 10% of the locations comprising VES17 and VES19 are extremely corrosive; 10% are highly corrosive; 35% are corrosive; 25% are moderately corrosive; 5% are mildly corrosive and 15% are non-corrosive.*

No VES location exhibited Very Good to Excellent OPCR while only 5% exhibited Good OPCR. 65% of the stations fell within Moderate OPCR; this is due to their relatively high overburden thickness compared to other locations.

Keywords: corrosion severity, proliferation, vulnerability status, lethal effects, clay sections

INTRODUCTION

It is a well-known fact that Petroleum and its derivatives dominate the Nigerian economy, accounting for almost 98% of exports, above 80% of government revenue, and 70% of government spending (Akpotor, 2019). Corrosion is the degradation of a material by an electrochemical reaction with its environment (Jerome *et al.*, 2015). An anode, a cathode, an electrolyte, and a metallic path are the four components that make up the corrosion cell (Ahmad, 2006). Proliferation of petrol stations without adequate corrosion preventives to the underground storage tanks (USTs) and safety measures threatens total environment in some parts of the globe. Groundwater quality and overall sustainability has been of great challenge in such locations most especially where the inhabitants depend on shallow groundwater system for their water needs. Surface and subsurface environmental hazards particularly to the groundwater system take a gradual process. Due to this outcome, governmental authorities at different tiers, stakeholders in oil and gas industries and even researchers in less advanced societies often ignore the situation and future consequences for the ignorant citizens to live with. Universal guidelines, monitoring procedures and standard regulations for sitting and establishing petrol stations exist without special consideration to water table variation of the area. The exigencies of the latent issues of environmental safety and sustainability saddled the researchers to creating necessary awareness on the condition, so as to proffering remediating measures and solutions accordingly in the affected areas (Okwudili et al., 2021). Establishment of Petrol stations became a booming business suddenly in Nigeria in the late 90's due to the high demand for petroleum products in the societies. There is an indiscriminate sitting and establishment of all manners and questionable standards of petrol stations by individuals with varying business drives predominantly not complying with the existing guidelines and regulations. Proliferation of petroleum stations all over the world has been reported to have serious environmental implications that demand for regular monitoring and risk assessment. It is quite saddening that such monitoring, inspection and risk assessment needed for assurance of environmental safety not strictly and reportedly carried out in this part of Nigeria. Petrol stations are places of storage for petroleum products namely petrol, gasoline, kerosene and often cooking gas. Aside from the availability of aforementioned products in urban and rural settings, they equally possess the potentials to cause accidents and environmental hazards; fire disaster, air pollution, soil contamination, and groundwater pollution with consequent virulent and debilitating threats to human lives, properties and entire ecosystem if not properly situated and handled (Lacey and Singh, 2011). Proliferation of petrol stations is often the product of human greed over petroleum products which include hoarding, artificial scarcity and overall profiteering strategies. In past years, there were few petrol stations because investors were not really making much profit but due to human factors, fuel hoarding and creation of artificial scarcity, current investors and marketers now found petrol stations business as gold-mine where to amass outrageous wealth without proper consideration to the accompanied safety measures (Okwudili *et al.*, 2021).

Considering the high risks and dangers associated with petroleum products as greatly flammable, its production, transportation, offloading, storage and sale points should not be taken for granted like other products. More than 2.3 million lives and properties worth more than 4.5 billion lives were lost to fire outbreaks associated with petroleum products mishandling (WHO, 2004). A petrol station can be operated only upon obtaining the so-called administrative decision. Every liquid fuel base and station has to be equipped not just with the required devices and systems preventing penetration of petroleum products into the soil, surface water and groundwater but also with measuring system that permit monitoring and adequate warning of potential hazards (Okwudili *et al.*, 2021). In Nigeria, the utilization of license issuance to all petrol stations has been through the Department of Petroleum Resources (DPR) in order to save both the people and the environment from pollution. The principal environmental concern at fuel stations are the location of the station, the possibility of leakage due to corrosion of the buried storage tanks, the safety of the people and protection of the environment since petrol and other motor fuels are primarily hazardous. The primary aim of this study is to commence investigation and monitoring for early detection of leaks from petrol stations within Abeokuta metropolis which is quite applicable anywhere across the globe especially identifiable locations where water table is close to the surface. Petrol gives off vapours which when mixed with air at ambient temperature can explode and burn if ignited causing loss of lives and damages to the environment. They can contaminate soil, surface water and groundwater and they are highly injurious on exposure to aquatic system
Direct Losses and Indirect Losses are two categories of Losses due to corrosion. Direct Losses losses that can be accounted for using quantitative measures, such as replacement cost, protection cost, and corrosion inhibition while Indirect Losses are those losses that cannot be evaluated quantitatively, such as loss of products to spill and fire, loss of revenue due to downtime, loss of efficiency of equipment, contamination of products, environmental pollution, over-design to make allowance for metal loss, and delays that may arise from lawsuits and ill-will. Although most studies have focused on the direct costs of corrosion, it is agreed that the indirect impact of corrosion is significantly greater (Fayomi *et al.,* 2019). The global cost of corrosion is projected to be US$2.5 trillion, which is equivalent to 3.4% of the global Gross Domestic Product (GDP). The projection is to enhance the implementing available corrosion control measures saving between 15% and 35% of the cost of corrosion of which the outcome of this study will go a long way in contributing to this effect (Amadi *et al.,* 2022).

Geophysical methods have been implemented on a wide range of applications ranging from groundwater explorations and contaminant plumes detections; road, dams and dikes constructions to environmental studies; since the last decade, the involvement of applied geophysical techniques in civil and environment engineering has become a promising approach (Luma and Jadi, 2000, Othman, 2005). At present, standard engineering practices require investigation of the subsurface at engineering construction sites. In baseline studies for underground buried structures like storage tanks, for example, issues relating to the corrosivity of the subsurface host soil, alongside possible effects on in an environment are investigated (Agunloye, 1984). Soil corrosion is a complex phenomenon with multitude variables. Several chemical actions and reactions occur between the laid pipes or storage tanks and their immediate environment, the host soil. Unfortunately, site engineers sometimes fail to integrate pre-development geophysical investigations in their schedule tasks for cost and other logistic considerations despite their necessity (Olorunfemi *et al.,* 2000, Olorunfemi *et al.,* 2004). One of the simplest measurable and empirical classifications is based on soil resistivity. Basic knowledge of the resistivity of the surrounding soil gives an indication of the corrosiveness of the stratum. Sandy soil is high up on the resistivity scale due to their limited water storage capacity and high porosity. Hence, it is considered the least corrosive. On the other hand, Clay soils especially those contaminated with saline water are on the opposite end of the resistivity spectrum (Ozegin *et al.,* 2011). Thus, it is desirable to investigate and estimate the corrosivity of the subsurface structure at Abeokuta Metropolis with a view to delineating the subsurface geologic layers and determine their corrosion severity. The area was consequently investigated using the electrical resistivity by applying Schlumberger configurations to ascertain the resistivities of the geologic layers and their corrosive severity. Many of the fuel stations in Abeokuta metropolis were established without proper environmental plans with no cathodic protection to stop corrosion and leakages over extent period. Though, the underground storage tanks (USTs) in these stations are subjected to leak proof test because they are not adequately protected against corrosion because the applied corrosion control measures are not likely to sustain the thanks beyond 15 to 20 years as many of the fuel station's USTs may develop leakages at different parts thereby invading the near subsurface with unprecedented pollution impacts on the near-surface aquiferous zone being the major source of domestic water system in the area (EBRD, 2009; Ishola *et al.,* 2016). This challenge is not portrayed as only an existing one but serves as a major concerns not only the affected locations but entire ecosystem because when petrol is released into the environment, it generates numerous health implications such as contamination of soil, surface water and groundwater system (DEFRA, 2000). Extremely high number and dense spacing of fuel stations is in complete disregard to an area's richness in surface water and groundwater resources and their significance for water supply where the geologic condition like rock types and texture and subsurface weathered nature leads to a high vulnerability of the water resources to pollution (Abdulrazak and Kobeissi, 2010; DPR, 2010).

STUDY AREA

Location and Accessibility

The study area is within Abeokuta metropolis, the capital of Ogun State, the prominent urban settlement of the state. It is located on the east bank of the river Ogun in Southwestern Nigeria and covering a total area of about 879 km^2. Ogun state is bounded in the west by Benin Republic, in the south by Lagos, in the north by Oyo and Osun, and in the east by Ondo state (Fig. 2.1). Abeokuta is in the sub-humid tropical region of Southwestern Nigeria; it lies between latitude $7^{0}10^{1}$ N to $7^{0}07^{1}$N and longitude $3^{0}23^{1}$E to $3^{0}20^{1}$E with a population of 605,451 (projected from 1991 Census of 374,043 at 3.5 growth rate). Its geographical location makes it easily accessible through Abeokuta-Ibadan road and from Lagos, the industrial capital of Nigeria and Nation's major seaport (Akanni, 1992; Ishola *et al.,* 2016a; Ishola *et al.,* 2016b) seen in Fig. 2.2.

Physiography and Geology of the Study Area

The topography of the area has an elevation ranging from 100 to 400m above sea level. The relief is generally low with the gradient in the north-south direction (Ishola *et al.,* 2016). The Ogun river takes its source from the Iganran hills at elevation of about 530m above mean sea level and flows directly southwards over a distance of about 480km, before it discharges into the Lagos Lagoon (Ishola *et al.,* 2016b).

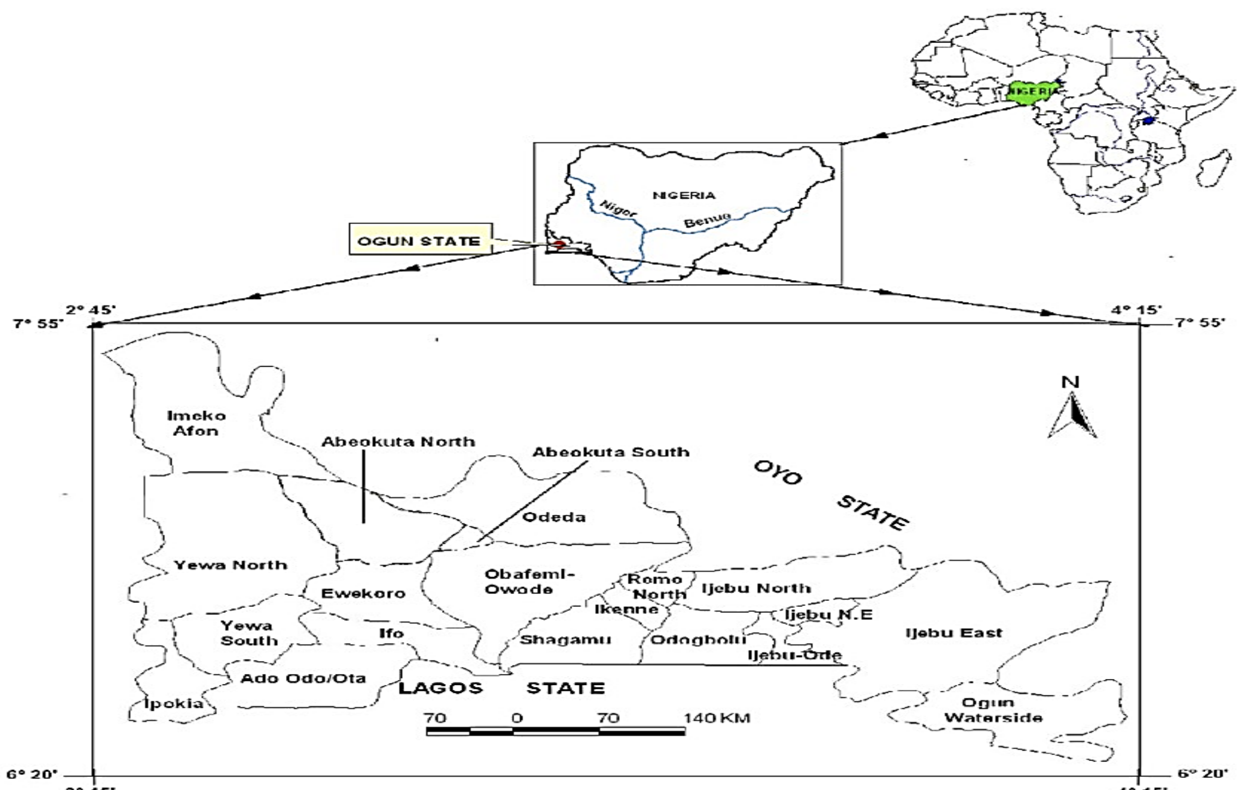

Figure. 1.1: Location Map of Abeokuta and its environs showing the major localities with intersected Maps of Africa and Nigeria (Ishola *et al.*, 2016b)

The study area is characterized of a tropical climate with alternating wet and dry seasons. The wet season which is cloudy, spans between middle of March and early November with double maxima of rainfall whose peaks occur in June and September. It is associated with the southwest monsoon wind from the Atlantic Ocean. The dry season is partly cloudy and it is associated with the northeast trade wind from the Sahara desert (Onakomaiya and Jegede, 1992). It lasts from November to early March with the month of December and January being relatively very dry. The average annual temperature and rainfall is about 33°C and 1260mm respectively. The vegetation of the study area shows that it lies in the Southwest tropical rainforest of Nigeria with many light forests, dispersed trees and scrubs (Ishola *et al.,* 2016b).

The study area is located within the southwestern part of the Basement Complex of Nigeria. These rocks are of Precambrian age and they extend from the North-Eastern part of Ogun State to which the study area belongs running South-West and dipping towards the coast (Ishola *et al.*, 2016). They belong to the youngest of the three major provinces of the West African Craton recognized by Hurley and Rank (Ishola *et al.*, 2016a). The rejuvenation of the rocks occurred during the pan-African orogeny about six hundred million years ago. The sedimentary rocks segment of Ogun State is approximately three-quarters of the surface Area of the state and the basement complex rocks make up the remaining one-quarter of the surface area of the State.

The basement complex metamorphic rocks are characterized by various folds, structures of various degree of complexity, faults, foliation and many more. These structural features have a predominant NNE-SSW orientation which is particularly strong within the low grade metamorphic. Gneiss, schists, quartzites, and amphiboles are the common metamorphic rocks encountered with various rock types ranging from granite, granitic gneiss and pegmatite. The individual rock has various hydrogeologic characteristics and belongs to the stable plate which was not subjected to intense tectonics in the past (Ishola *et al.*, 2016a). Therefore, the underground faulting system is minimal and this has contributed to the problem of underground water occurrence in the area. The northern side of Abeokuta like Lafenwa side is characterized by pegmatite underlain by granite and therefore has good hydrogeological history. To the North east of Abeokuta North LGA lies Odeda study area which comprises of folded gneiss, schists, quartzites, older granites, and amphibolites/mica schists (Ishola *et al.*, 2016a) with equally good hydrogeological history. The western part is characterized by granite gneiss, granite and migmatites which is less porous and various quartzite intrusions enters into the transition zones with sedimentary basin (Key, 1992). Ayoade (2003) described hydrogeology as the scientific study of groundwater with emphasis on the geology and its occurrence, movement and chemical characteristics of groundwater. According to Houston (1995), the bedrock over much of Africa is of Precambrian formations, which are dominated by relatively impermeable crystalline rocks such as granites, schists, gneiss and quartzites. It was often necessary to drill 60-80m deep with wells often yielding less than $2m^3$/day (Ishola *et al.*, 2016a). According to Farquharson and Bullock (1992), the basement aquifers occur within the weathered residue overburden (the regolith) and the fractured bedrock. Development of the regolith components is by wells and shallow boreholes which are liable to be drilled by lightweight percussion rigs. Viable aquifers wholly within the fractured bedrock occur because of the typically low storativity of fracture systems that is less than 1%. The development of bedrock components requires interaction with storage available in overlying adjacent saturated regolith or other suitable formations such as alluvium (Ishola *et al.*, 2016a; Ishola *et al.*, 2016b).

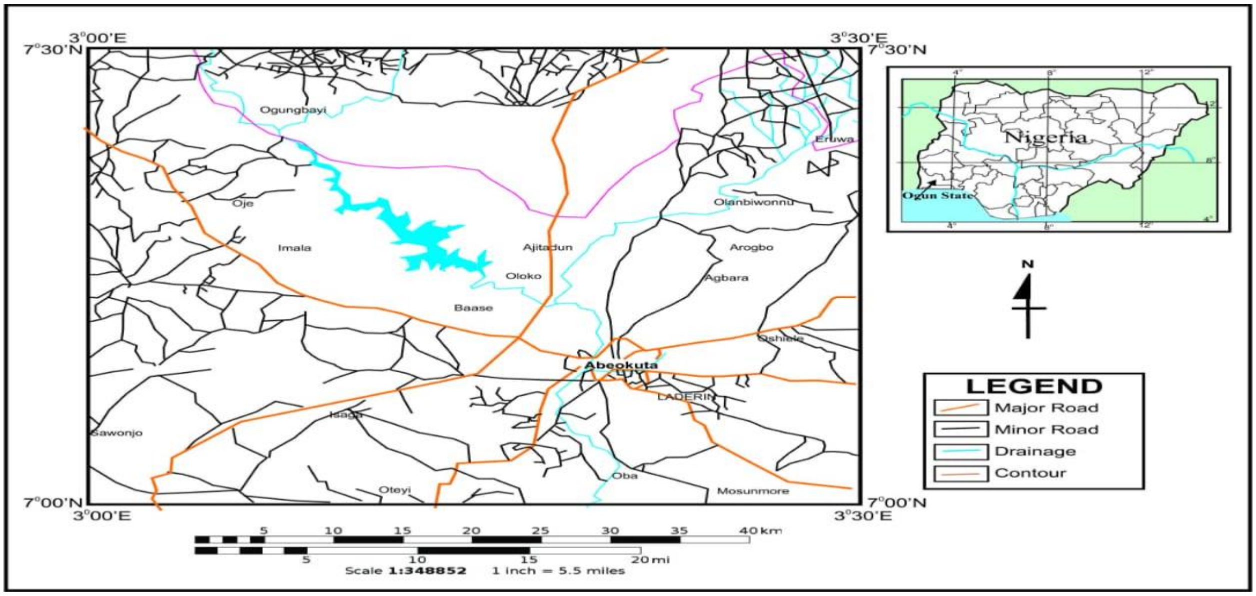

Fig. 2.2: Accessibility Map of the Study Area (Ishola et al., 2016a).

Gneiss-migmatite complex is the most widespread rock group in the study area, and it comprises gneisses (the most widespread rock types), quartzites, calc-silicate rocks, biotite-hornblende schists and amphibolites (Obaje, 2009; Fig. 2.3.). The older granites occur in and around Abeokuta, and they are Late Precambrian to early Proterozoic in age with magmatic origin (Obaje, 2009).

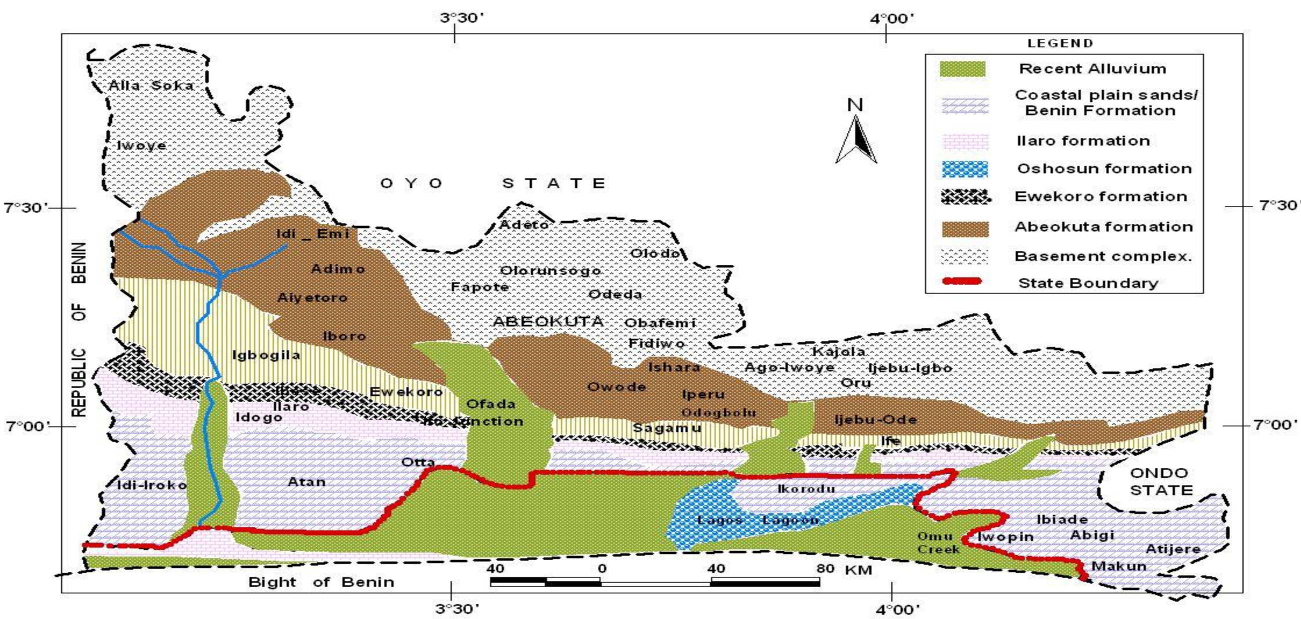

Fig.1: Map of Ogun State Showing the Basement Geology of the Study Area (Modified after Kehinde-Phillips (1990), Obiora and Onwuka (2005)

MATERIALS AND METHODS

Theoretical Background of Geoelectric Parameter Evaluation

The primary aim of electrical resistivity surveys is to evaluate the subsurface resistivity by making corresponding measurements on the surface where true resistivity of the subsurface can be estimated from the measurements made (Sharma, 1997; Okolie et al., 2010; Ishola *et al*., 2016a). The subsurface resistivity distribution is related to various geological conditions such as the mineral and fluid content, density, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2). Generally, there are two approaches for the resistivity surveying as displayed in Fig. 4 (Ishola *et al*., 2016a; Ishola *et al*., 2016b).

- the variation of resistivity with depth measured by vertical electrical sounding (VES)
- the lateral variation in the electrical properties of rocks measured by horizontal profiling

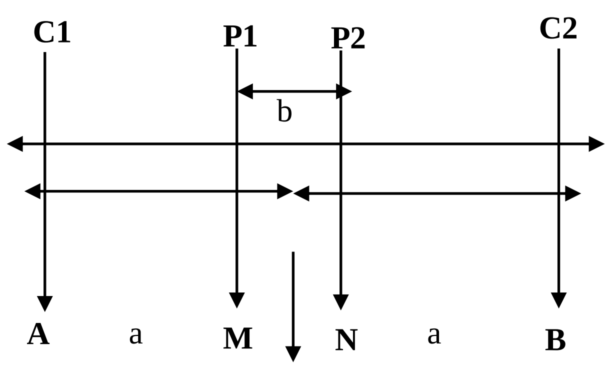

Fig. 2: Field illustration showing Schlumberger arrays (Ishola *et al*., 2016a)**.**

There exists a vertical variation in resistivity with depth in a heterogeneous subsurface where the apparent resistivity rather than the true resistivity is measured. The flow of current in such a medium is controlled by its density, porosity and salinity of the fluid contents. The apparent resistivity ρ can be expressed as:

$$\rho = \frac{2\pi\Delta V}{I}\left(\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{BN}\right)^{-1} \qquad 1$$

G is the geometric factor which depends on the electrode configuration while R corresponds to the resistivity of the space between potential electrodes. The schlumberger configuration was given by r = AN− AM = BM+ BN and

$$G = \left[\left(\frac{\pi}{2r}\right)\frac{L}{R}\right]^{-1} \qquad 2$$

It is pertinent to examine the subsurface flow of electric current under the control of external potential since it enabled the understanding of a a major characteristic of direct current methods which is depth of investigation. We have by the ohm's law (Telford *et al.*, 1990; Ishola *et al.*, 2016a).

$$J = -\frac{1}{\rho}\nabla V \quad 3$$

Where I and V are the current density and potential difference respectively; for two grounded electrodes (Fig. 2). We have

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$ 4 (Telford *et al.*, 1990; Ishola *et al.*, 2016a)

Thus, the horizontal component J_x for the two electrode system is

$$J_x = \frac{-1}{\rho}\frac{I\rho}{2\pi}\left(\frac{\partial}{\partial r}\right)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad 5$$

$$J_x = \frac{I}{2\pi}\left(\frac{x}{r_1} - \frac{x-L}{r_2}\right) \quad \text{Furthermore } r^2 = x^2 + y^2 + z^2$$

$$J_x = \frac{I}{2\pi}\left(\frac{x}{{r_1}^3} - \frac{x-L}{{r_2}^3}\right) \quad 6$$

Assuming to be in the median plane, then $r_1 = r_2 = r$ and x = $\frac{L}{2}$, what allows us to write

$$J_x = \frac{I}{2\pi}\left(\frac{x}{{r_1}^2} - \frac{x-L}{{r_2}^2}\right) \quad 7$$

The highlights in the above equation revealed the fact that current density at vertical x position depends on the depth z and the spacing electrode injection. The phenomenon can be seen considering the current J (and not J). Integrating elementary current, δI_x would yield to the expression of the current function flowing by one part of the plane given by Telford *et al.*, 1990 and Ishola *et al.*, 2016a.

$$\delta I_x = I_x \partial_y \partial_z = \frac{I}{2\pi}\frac{L}{[(\frac{L}{2})^2 + y^2 + z^2\ ]^{\frac{3}{2}}}\partial_y \partial_z \quad 8$$

$$\text{So, } \frac{I_x}{I} = \frac{L}{2\pi}\int_{Z_1}^{Z_2}\partial_z \int_{-\infty}^{+\infty}\frac{\partial_y}{[(\frac{L}{2})^2 + y^2 + z^2\ ]}\}$$

$$= \frac{2}{\pi}\{\tan^{-1}\frac{2Z_1}{L} - \tan^{-1}\frac{2Z_1}{L}\}$$

When L = $2z_1$ and $z_2 = \infty$

$$\frac{I_x}{I} = 1 - \frac{2}{\pi}\tan^{-1} 1$$

$$= 1 - \frac{2\pi}{\pi 4} = 0.5 \quad 9$$

The above relationship revealed that almost half of the injected current propagating in the direction x (I_x/I ≈ 0.5) investigates a depth lower than half of electrodes separation.

Data Acquisition and Interpretation

The Terrameter model SAS 300B was used to acquire twenty (20) VES soundings in Abeokuta metropolis within Ogun State South-West Nigeria adopting the Schlumberger configuration, and maximum electrode separation (AB/2) of 100 m and minimum of 32m with a linear electrodes array (AMNB) shown in Figure 4. Potential electrodes M and N are kept fixed at the centre of the array while current electrodes A and B are moved outward symmetrically (Telford, 1990). The ground injection of current through current electrodes A and B enabled the measurement of the potential drop between potential probes M and N. The current penetrates deeply into the ground as the electrode A and B spacing increases. The orientation of the traverse is in the north-south direction so as to align with lithologic unit, most rocks lies in this location. This helps to prevent the occurrence of having data that are anisotropic in nature. The qualitative interpretation was achieved by plotting the Resistivity data on the log-log paper which relate the resistivity data to the geology of the study area while quantitative interpretation referred to a curve matching and computer assisted program called iteration. The I-D forward modeling (1DF) for the VES interpretation called WinRESIST version 1. 0 program that provides a way for the user to interactively model vertical electrical sounding data by changing the geologic conditions and parameter that control earth resistivity responses (Pirttijärvi, 2009). This provided a comparison of real resistivity data to synthetic data in other to make geologic interference from the features observed in the real data. The user iteratively changes the model to facilitate a sufficient match with the real data so that the model is a possible representation of the geologic condition that produced the real resistivity data. The interpretation of twenty (20) vertical electric sounding conducted in the study area indicated four (4) identified lithological layers with the subsurface geological constituents comprising of Topsoil, Clay, Weathered basement and Fresh Basement based on their corresponding resistivity values obtained during the interpretation and local geology of the study area. The summary of the lithological parameter which includes thickness, depth, resistivity, and curve type were obtained from the screen graphic by eliminating the generation of anomalous layers caused by noise in the field data as displayed in Fig. 4.1.

Estimation of Geoelectric Parameters using Dar-Zarouk Parameters

Anisotropy coefficient is a standard geoelectrical parameter used in measuring the inhomogeneity of a given medium (Olorunfemi *et al.*, 1999). In stratified conductors, identifiable parameters are very important in understanding interpretation of the geoelectrical model of stratified conductors. Combinations of the thickness and resistivity of each identified geoelectrical layer is related to these parameters (Olayinka, 1996 and Ishola, 2019). The integration of the thickness and resistivity of the geoelectric layers into single variables; the Dar-Zarouk parameters of Transverse unit resistance (R) and Longitudinal unit conductance (S), can be adopted in the course of assessing aquifer properties such as hydraulic conductivity (K), transmissivity (T) as well as the protective capacity (*Pc*) of the overburden rock materials in the course of geo-electrical section with a unit crossectional area. Its increase linearly follows the increase in groundwater yield.

For a geologic layer that is not only horizontal but also homogenous and isotropic, the Dar-Zarouk parameters of transverse unit resistance and longitudinal unit conductance can be mathematically derived as follows:

$$H = \sum_{i=1}^{n} h_i \quad \ldots\ldots 10$$

The longitudinal conductance 'S' is given as

$$S_I = \sum_{i=1}^{n} h_{i/\rho_i} \quad \ldots\ldots 11$$

the addition of thickness gives H while the transverse unit resistance is given as'R'

$$R_i = \sum_{i=1}^{n} h_i p_i \quad \ldots\ldots 12$$

From equation (1) and (3) the longitudinal resistivity is

$$\rho_l = H/S = \sum h_i / \sum h_i / p_i \quad \ldots\ldots 13$$

Where $H = \sum_{i=1}^{n} h_i$ and $S_i = \sum_{i=1}^{n} h_{i/\rho_i}$

From equation (10) and (12) the transverse resistance is

$$\rho_t = R/H = \sum h_i p_i / \sum h_i \ldots\ldots 14$$

Where T = $\sum \rho_i h_i$

H = $\sum_{i=1}^{n} h_i$

The Anisotropic coefficient (⋋) = $\sqrt{\rho_t/\rho_l}$

$$(\lambda) = \sqrt{\frac{T}{H} \cdot \frac{S}{H}} \ldots\ldots 15$$

T and S are represented as Dar-Zarrouk parameters.

For an isotropic medium we have $\rho_t = \rho_l$ such that $\lambda = 1$ while for an anisotropic medium we have $\rho_t > \rho_l$ such that $\lambda > 1$

Equation (15) is principally used for sedimentary rocks but can also adopt for basement complex rocks that exhibit layered structured (Olayinka (1996; Ishola *et al.*, 2016a; Ishola *et al.*, 2016b). The reflection coefficient between the sub-basement and basement layer was calculated which is an indication that the fracture within the bedrocks are filled with water.

$$K_n = \frac{\rho_n - \rho_n - 1}{\rho_n + \rho_n - 1} \ldots\ldots 16$$

Where Kn is the reflection coefficient

n is the no of layers

ρ_n *is the layer resistivity of the* nth layer

$\rho_n - 1$ is the layer resistivity overlying the nth layer.

The layer resistivity and thickness of the ith layer are respectively given as ρ_i and h_i are. The aquifer transmissivity (T) can therefore be expressed as the hydraulic conductivity (k) multiplied by the layer thickness (h),

$$T = Kh \ldots\ldots 17$$

For pure saturated aquifers whose natural fluid properties are fairly constant (that is, no significant effect on the general subsurface water quality by surface contaminant loads), the hydraulic conductivity is therefore proportional to the aquifer resistivity. This implies that, the aquifer hydraulic conductivity K can be approximated to the true resistivity of the aquifer derived from geoelectric investigation even in the absence of a pumping test data (Olorunfemi and Okhue, 1992; Hubbard and Robin, 2002; Ishola *et al.*, 2016b). Therefore,

$$T = Kh = \rho h \ldots\ldots 18$$

But the transverse resistance (R) represents the product of the resistivity to its thickness which is numerically equal to the transmissivity (T) as given in equation 10.

$$T = R = \sum h_i p_i \ldots\ldots 19$$

The aquifer protective capacity characterization is based on the values of the longitudinal unit conductance of the overburden rock units. The longitudinal conductance (S) serves as a measure of the impermeability of a confining layer which principally comprises of clayey/shaly overburden. Such layers are characterized by low hydraulic conductivity (k) and low resistivity. Protective capacity (P_C) of the overburden layers is proportional to its longitudinal conductance (S) (Olayinka and Yaramanci, 2008; Ishola, 2019).

$$P_{OC} = S = \sum_{i=1}^{n} h_{i/\rho_o} \ldots\ldots (20)$$

(Olayinka and Yaramanci, 2008; Oborie and Nwankoala, 2012; Ishola et al., 2024).

RESULTS AND DISCUSSION

Preliminary Site Investigation

It was gathered some of the filling stations were closed to residential buildings, workshops, hospitals and schools (Table 4.1). There a high level of risks during dry season due to flood and road failure since many of the trucks carrying fuel brake down during this period and cause oil leakages that got washed by rain into nearby tributary of Ogun river thereby contaminating both surface and groundwater in the area with most of them not properly situated while private structural development encroached into some of the petrol stations judging by the varying environmental conditions around them (Table 4.1). In each of the petrol stations were found pressure release pipes corresponding to the number of USTs in the station. A pressure release pipe of about 6cm diameter is usually mounted at the extremes of every USTs for the purpose of releasing pressured gas into the atmosphere thereby controlling the gas tank pressure with the atmospheric thereby safeguarding the location from explosion.

Geophysical Implications

Geoelectric Parameters and Environmental Conditions of Underground Storage Tanks of Abeokuta Petrol Stations

Four curve types namely HA, KH, HK, and AK were obtained in the study area (Table 4.1). The KH and HKH curves in many instances are indicative of fracturing which serve as favourable zones for groundwater abstraction (Ishola *et al.*, 2024). The plotted curve types and the associated geoelectric parameters obtained for all (20) the sounded locations are displayed in Fig. 4.1a to 4.1h. Geoelectric section is a vertical display of the subsurface layer in which the apparent resistivity values are plotted against the layer thickness. The geoelectric section shows the respective layer resistivity in against their corresponding layer thickness. The VES data interpretation delineates four (4) major lithological units n the study area namely; the lateritic top soil, the weathered material, fractured basement and fresh bedrock. In the attempt to correlate the geoelectric sequence across the study area, geoelectric sections were taken across three directions as displayed in Fig. 4.2a, 4.2b and 4.2c respectively.

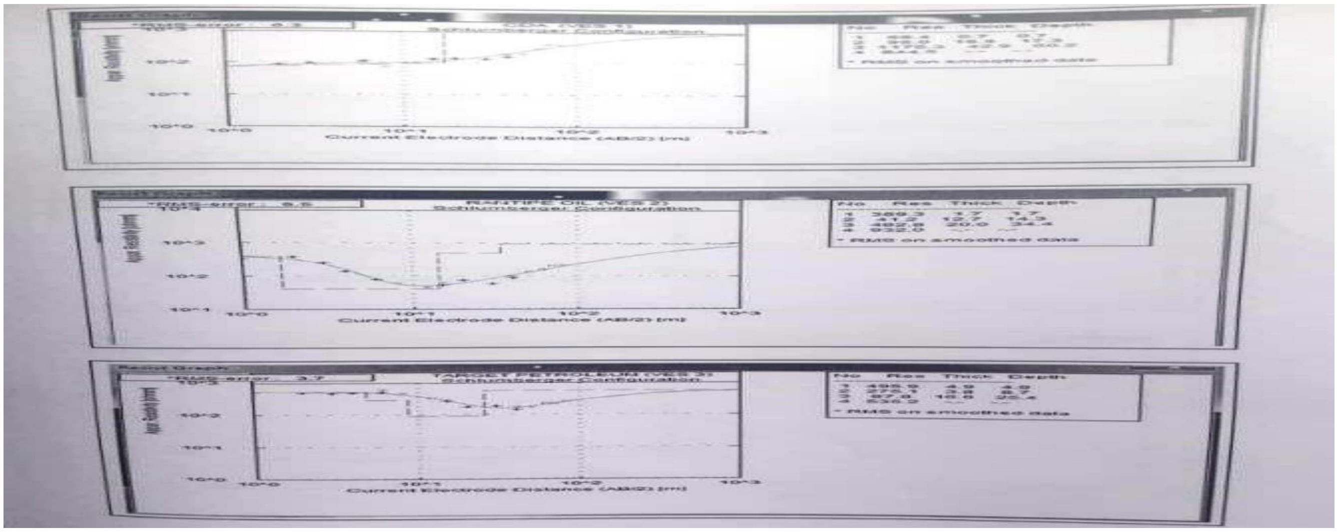

Figure. 4.1a: Typical curve types and associated Geoelectric parameters generated across VES1, VES2 and VES3 in the investigated area

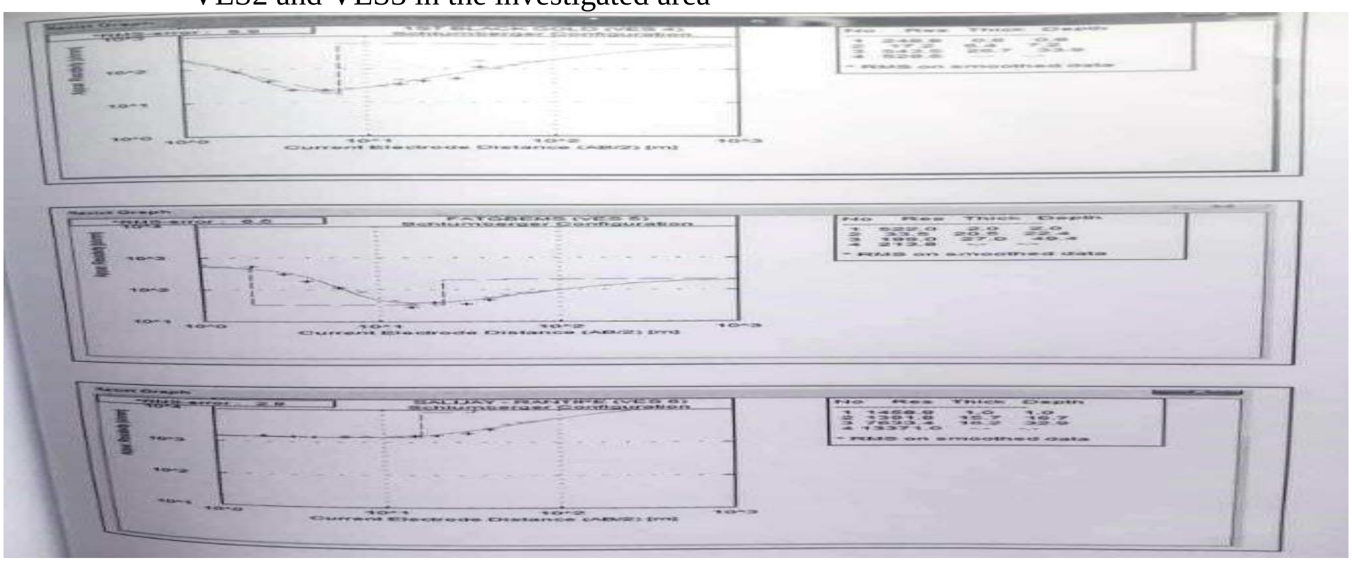

Figure. 4.1b: Typical curve types and associated Geoelectric parameters generated across VES4, VES5 and VES6 in the investigated area

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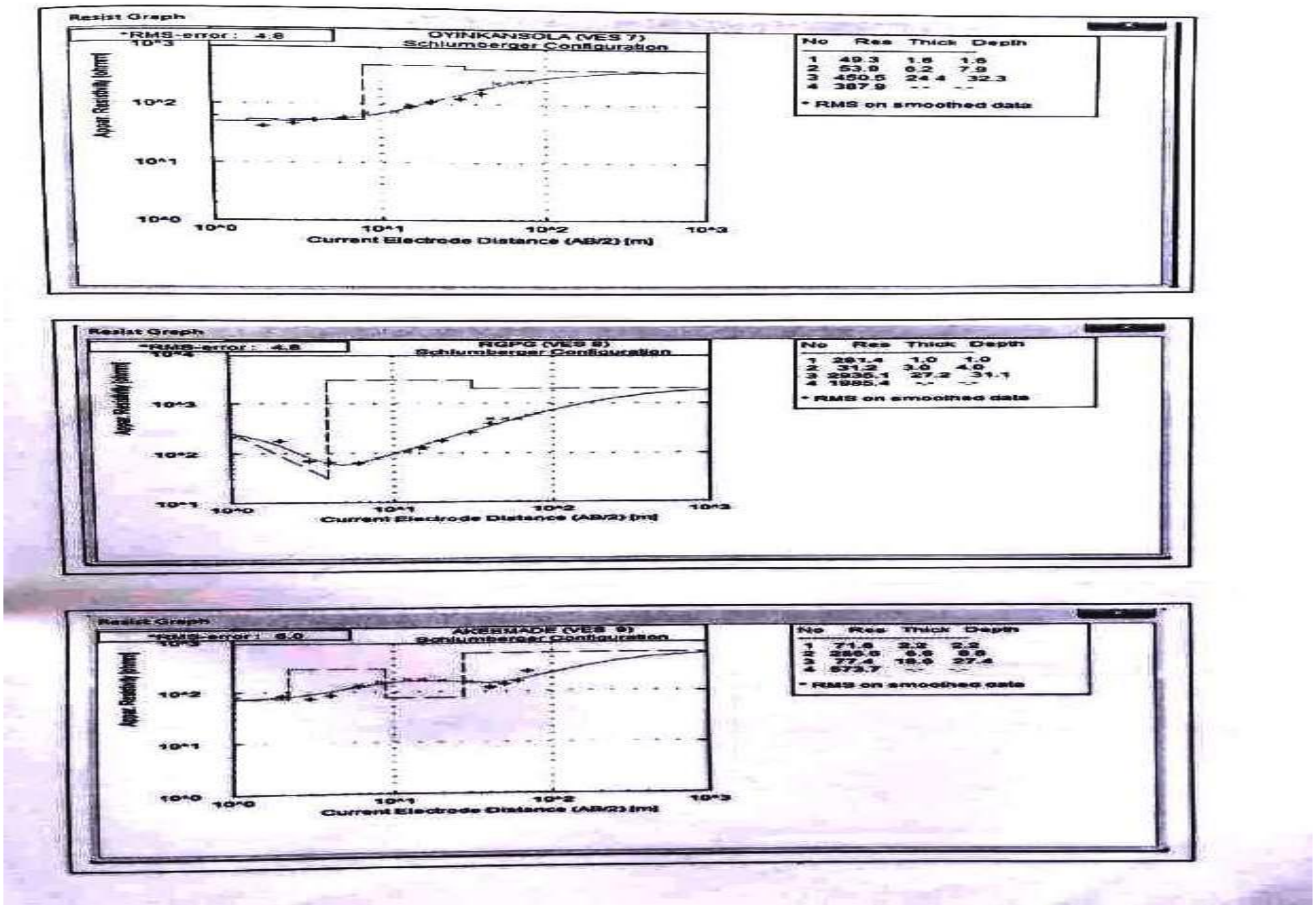

Figure. 4.1c: Typical curve types and associated Geoelectric parameters generated across VES7, VES8 and VES9 in the investigated area.

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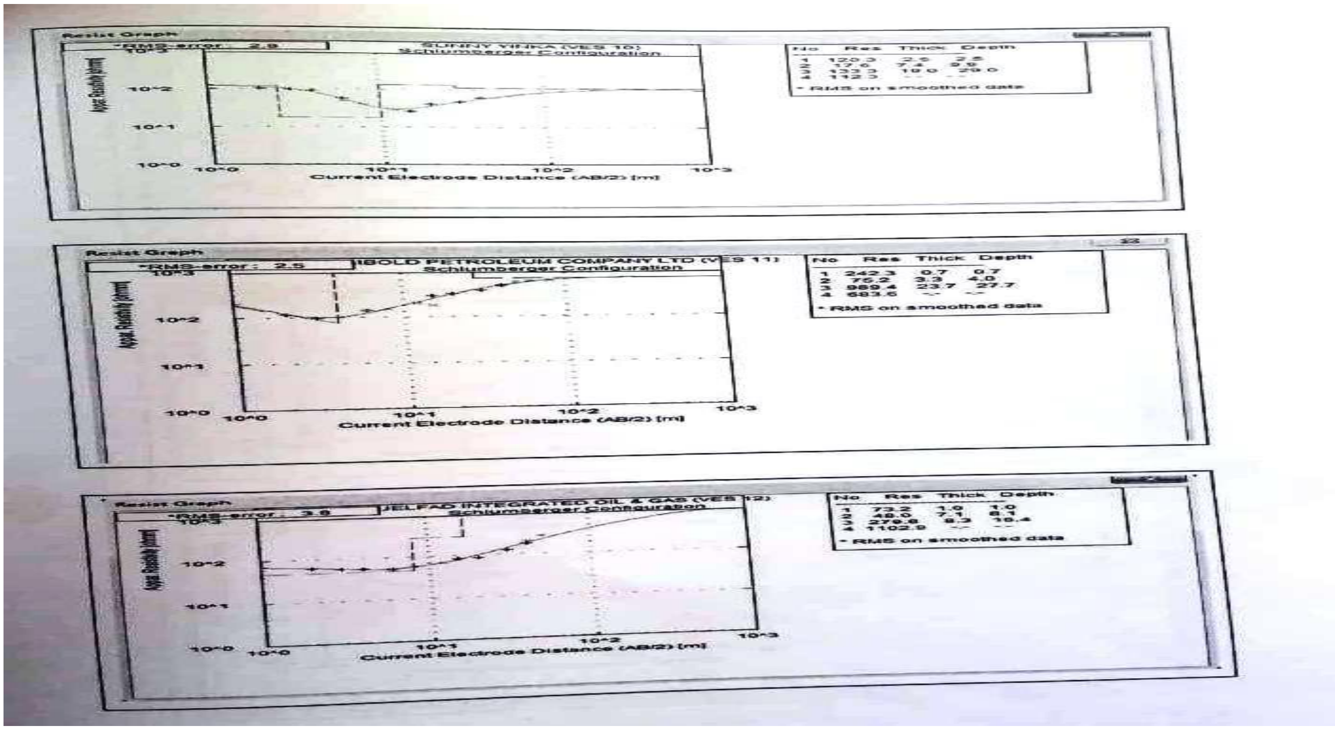

Figure. 4.1d: Typical curve types and associated Geoelectric parameters generated across VES10, VES11 and VES12 in the investigated area

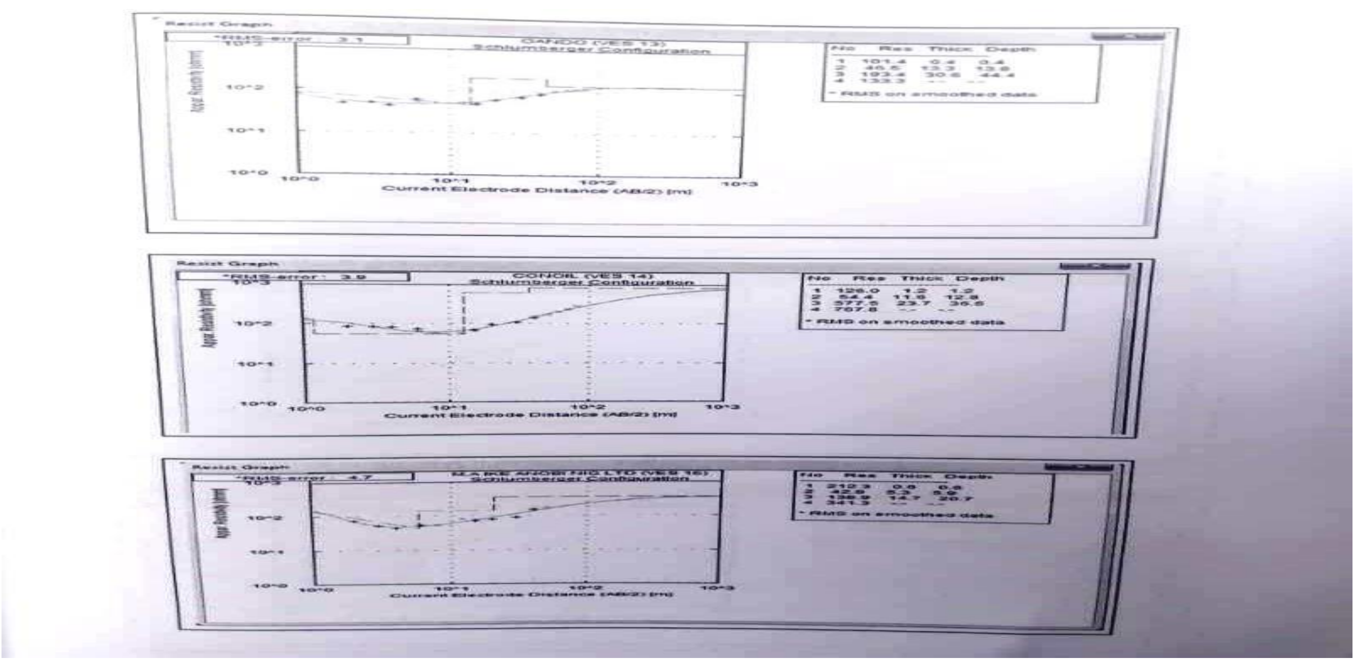

Figure. 4.1e: Typical curve types and associated Geoelectric parameters generated across VES13, VES14 and VES15 in the investigated area

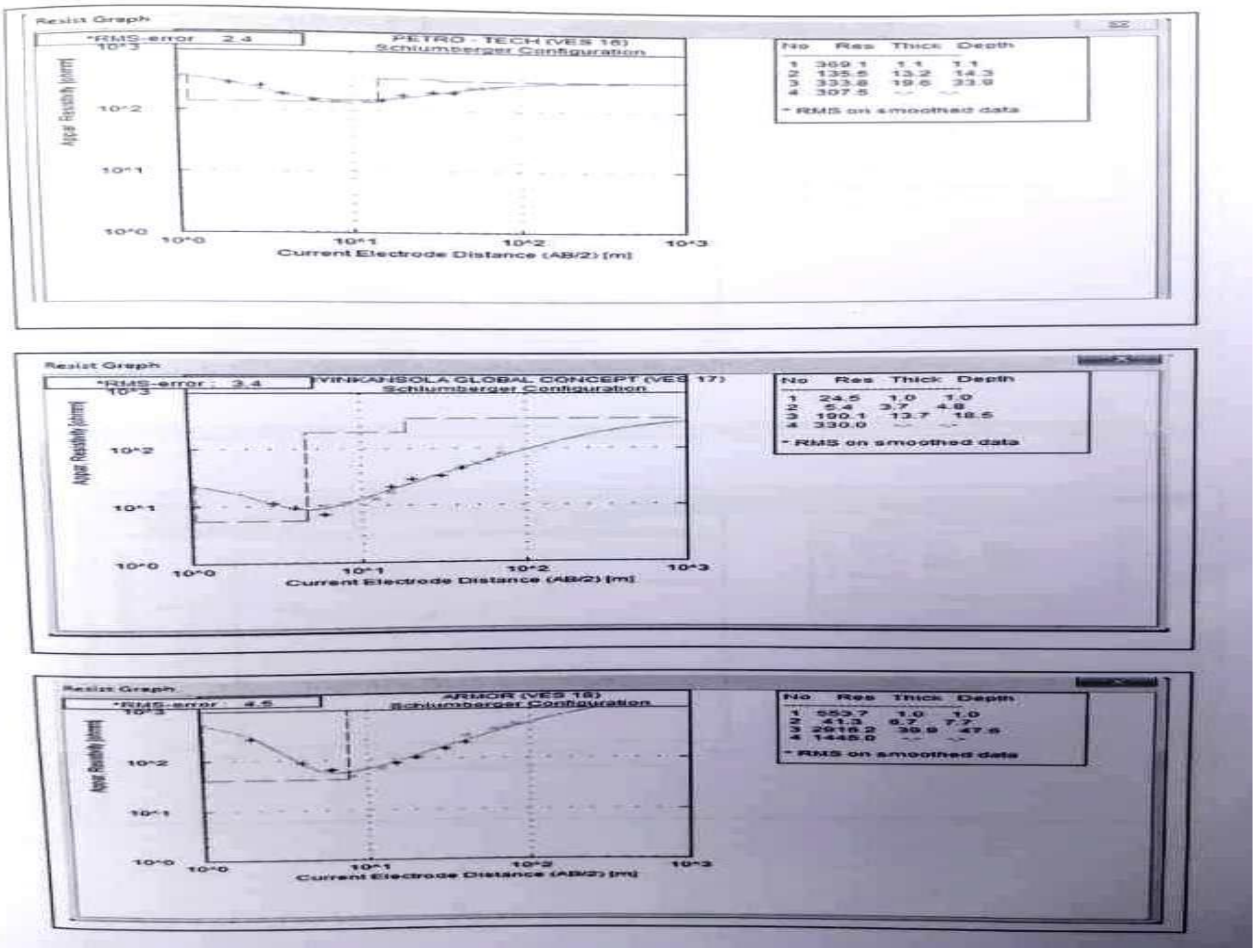

Figure. 4.1f: Typical curve types and associated Geoelectric parameters generated across VES16, VES17 and VES18 in the investigated area

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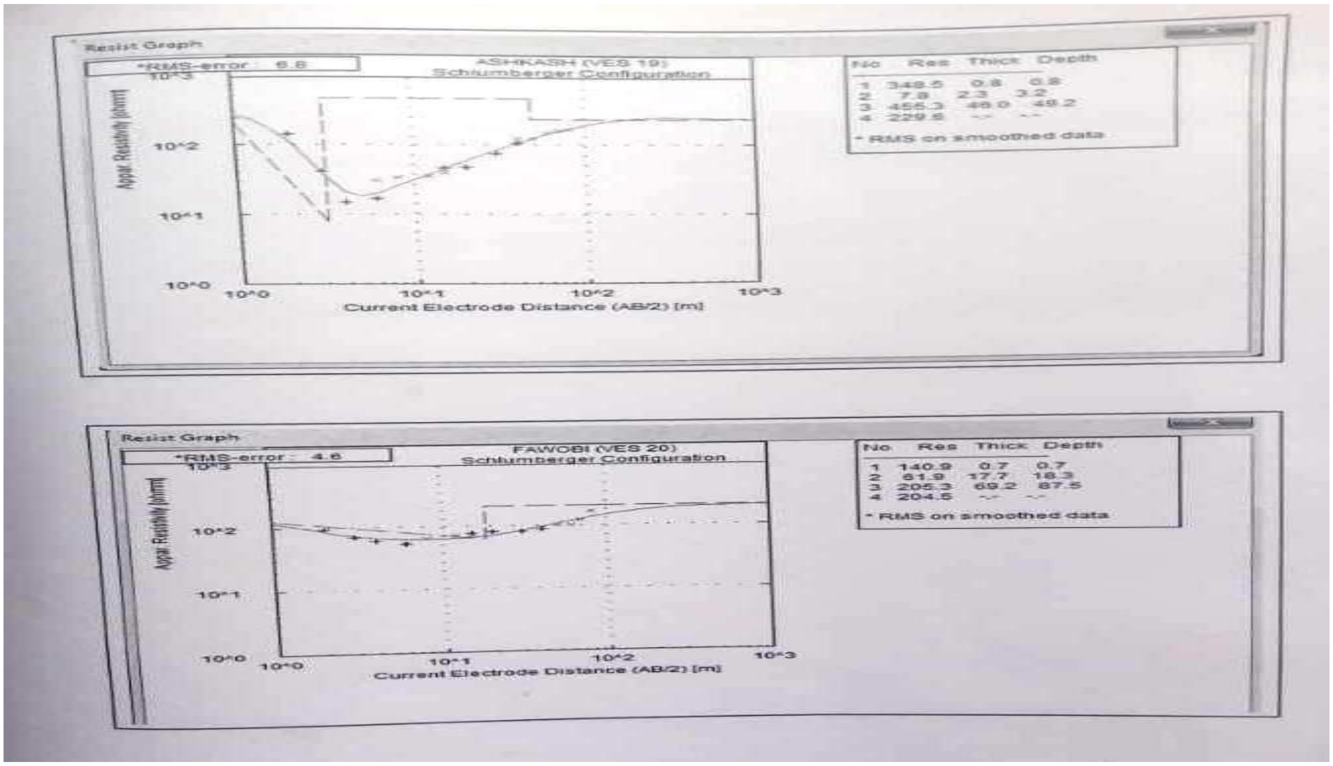

Figure. 4.1g: Typical curve types and associated Geoelectric parameters generated across VES19 and VES20 in the investigated area

The result of the geoelectric section taken along AA−AA' direction in the study area is displayed in Fig. 4.1. It comprises of VES stations in VES5, VES9 and VES14. Three major geoelectric units delineated were lateritic topsoil, conglomerate/weathered material, fractured/fresh basement with their resistivity values ranging from 71.6 Ωm to 522.0Ωm and corresponding thickness values ranging from 1.2m to 2.2m. The conglomerate/weathered material layer resistivity values range from 33.5 Ωm to 286.6 Ωm and the thickness values range from 6.6m to 20.5m. The basement has resistivity values ranging from 77.4 Ωm to 577.5 Ωm while Depth to bedrock values ranged from 18.6m to 27.0m across the section. Previous studies have revealed that the unconsolidated overburden could constitute potential aquifer if significantly thick (Ishola *et al.*, 2016). The overburden thickness at VES5 (Fatgbems Petrol Station) and VES9 (Akeemade Petrol Station) are relatively thick with thickness values of 22.4m and 27.4m respectively. The aquifer delineated at VES9 could be protected from contamination from surface run-off or any biodegraded pollutant from the direct overlying layer of sandy formation (Fig. 4.2a).

The result of the geoelectric section taken along BB−BB' Northeast-Southwest direction of the investigated area is displayed in Fig. 4.2b. It comprises of VES1, VES6 and VES17. The geoelectric units delineated were topsoil, weathered layer, and fractured/fresh basement. The topsoil has resistivity values ranging from 24.5 Ωm to 1458.9 Ωm and thickness values ranging from 0.7m to 1.0m. The conglomerate/weathered material layer resistivity values ranged from

5.4 Ωm to 1391.8Ωm and corresponding thickness values ranging from 4.8m to 17.3m. The basement has resistivity values ranged from 190.1Ωm to 1391.8Ωm with the corresponding thickness values which ranged from 13.7m to 42.8m across this section.

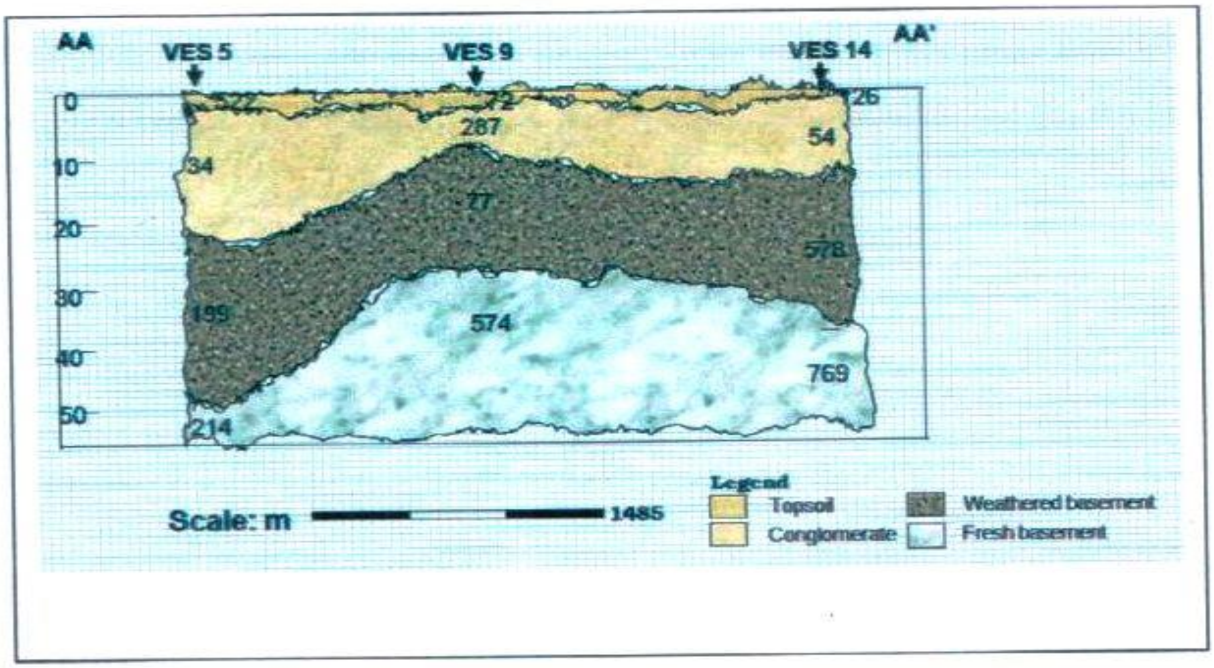

Figure. 4.2a: Geoelectric Section showing the Layer Resistivity and Inferred Lithology along AA-AA' Direction of the Study Area

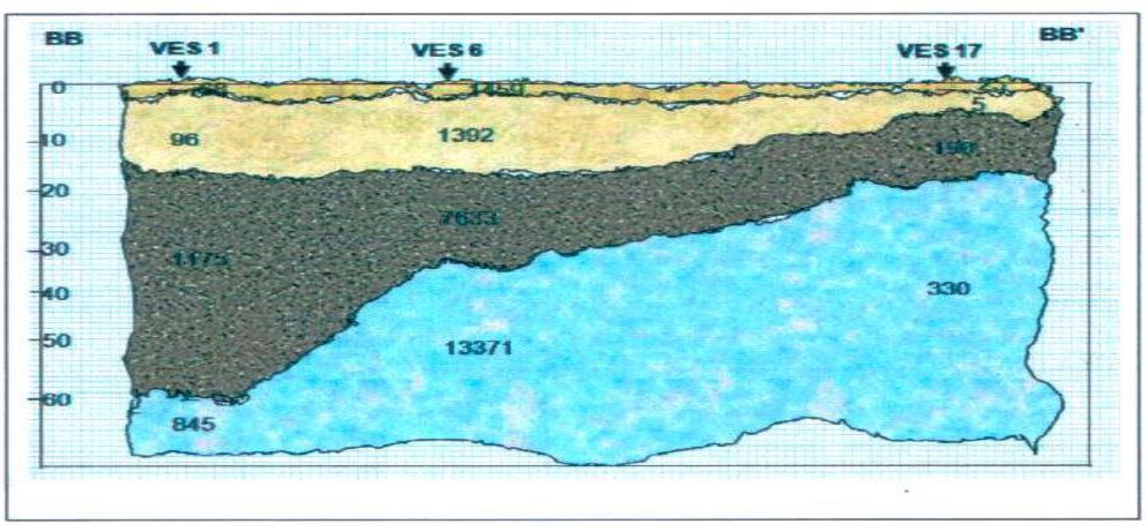

Figure 4.2b: Geoelectric Section showing the Layer Resistivity and Inferred Lithology along BB-BB' Direction of the Study Area

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The result of the geoelectric section taken along CC−CC' East-Southwest direction of the investigated area is displayed in Fig. 4.2c. This section comprises of VES19, VES18, VES17 and VES8. The lithologic units delineated were classified as topsoil, conglomerate/weathered basement, and fractured/fresh basement. The topsoil has resistivity values ranging from 24.5 Ωm to 553.7Ωm with the thickness values ranging from 0.8m to 1.0m. The second layer of conglomerate/weathered material layer possessed resistivity values that ranged from 5.4 Ωm to 41.3Ωm with corresponding thickness values ranging from 3.0m to 7.7m. The third layer has resistivity values that ranged from 190.1Ωm to 2935.1Ωm while the thickness values ranged from 18.5m to 49.2m. The last layer is composed of fresh basement with resistivity values that ranged from 229.6Ωm to 1985.4Ωm. Due to thinness or low overburden thickness values of these areas (< 5m) across the traverse line, it is therefore inferred that these areas are prone to contaminant seepages because of the protective formation materials overlying the underground water along the investigated axis.

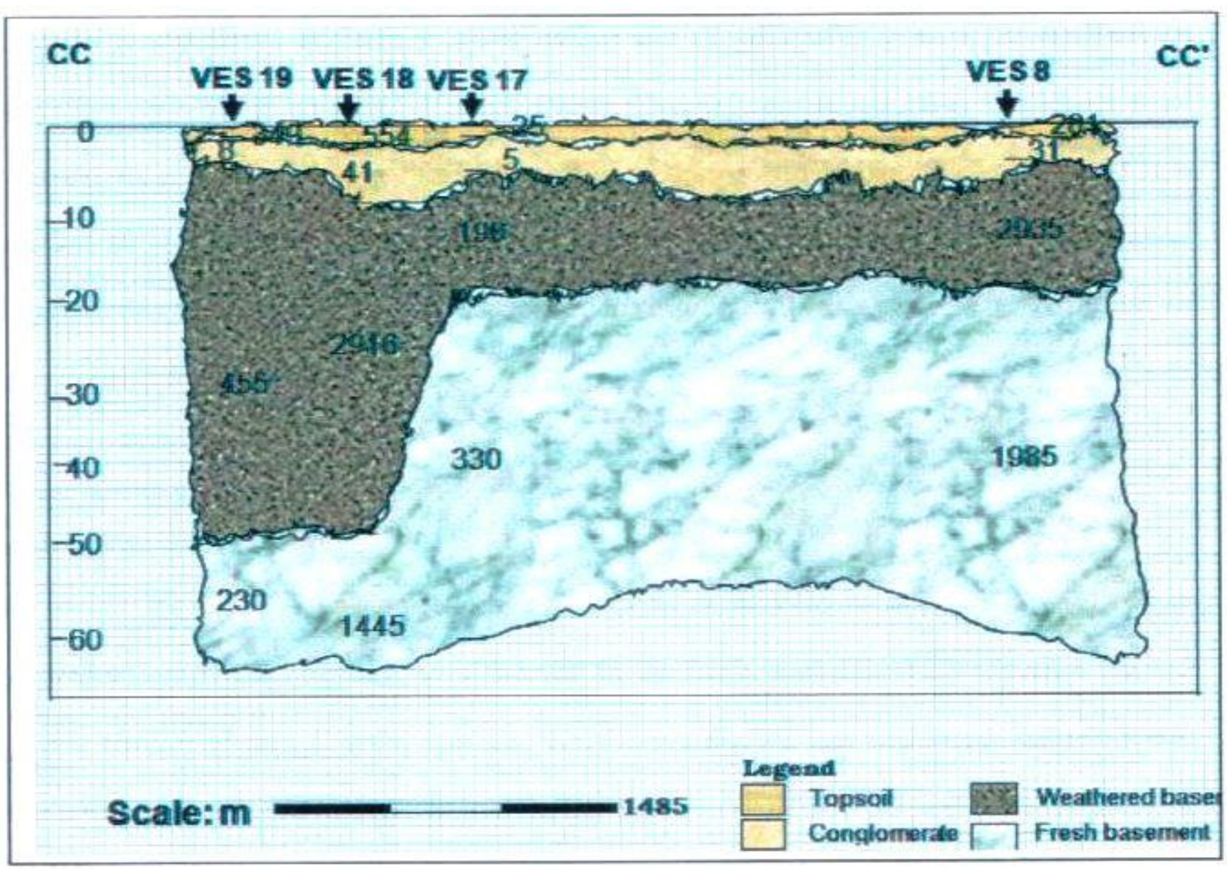

Figure 4.2b: Geoelectric Section showing the Layer Resistivity and Inferred Lithology along CC-CC' Direction of the Study Area

The resistivity values obtained from the first layer at all the sounded VES locations were utilized in the evaluation of the corrosion severity of the subsurface soil in the study area (Table). Previous studies carried out in a similar geological terrain had earlier revealed that resistivity values of the weathered layer can be utilized in evaluating the extent of corrosivity of the invaded soil (Oladapo *et al.*, 2004). This is because burial of utilities and underground storage tanks are often restricted to shallow depth. Areas that were considered to be of high corrosivity were generally characterized by low resistivity and high moisture content with comparable resistivity standard of ρ <150 Ωm. These delineated areas are vulnerable to leakages and consequential pollution and should be taken into consideration in the burial of utilities and underground storage tanks so as to safeguard the groundwater in the area from getting contaminated. These identified areas of high corrosivity are around the Northeast portion (Obantoko axis towards Abiola way) and Southwest (Adigbe area) of the study area (table). Also, The resistivity values obtained from the second layer at all the sounded VES locations were equally utilized in the evaluation of the corrosion severity of the subsurface soil in the study area to know the extent of protection of the underlying aquifers in the study area (Table 4.1 and 4.2); the areas of high corrosivity were equally delineated within the Northeast flank around Obantoko axis towards the central portion of the study area

Table 4.1: Geoelectric Parameters and Environmental Conditions around Abeokuta Petrol Stations

Zones	Name and Locations of Petrol Station	Ves Points	Layer No	Res (Ωm)	Inferred Lithology	Thick Ness (m)	Depth (m)	Curve Types	Coord Inates (UTM)	Environmental Condition around the Petrol Stations
	CDA P.S	VES1	1	68.4	LT	0.7	0.7	AA	N=793358 E=543151	3.2m Close to residential building/1.6m close to auto-mobile/1.2m close to workshop/3.3m behind school
Abiola way/ Obantoko Axis			2	96.0	CLY	16.6	17.3			
			3	117.5	W.B	42.8	60.2			
			4	844.5	FB	–	–			
	RANTIPE P.S OBANTOKO	VES2	1	389.3	LT	1.7	1.7	HA	N=793327 E=542998	1.5m Close to residential building/5.9m close to Hotel/ 1.8m close to auto-mobile workshop
			2	41.2	CLY	12.7	14.3			
			3	482.8	W.B	20.0	34.4			
			4	932	FB	–	–			
	TARGET P.S OBANTOKO	VES3	1	495.9	L.T	4.9	4.9	QH	N=793297 E=542815	2.5m Close to residential building/1.2m close to automobile workshop/3m behind school
			2	275.1	CLY	3.8	8.7			
			3	87.0	W.B	16.6	25.4			
			4	535.2	W.B	–	–			
	1ST BLACK GOLD P.S OBANTOKO	VES4	1	248.8	L.T	0.8	0.8	HK	N=793204 E=542692	3.6m Close to residential building
			2	17.2	CLY	6.4	7.2			

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			3	543.5	W.B	26.7	33.9			
			4	529.6	W.B	–	–			
	FATGBEMS P.S ASERO	VES5	1	248.8	L.T	0.8	0.8	HK	N=793215 E=542697	1.7m Close to Hospital
			2	17.2	CLY	6.4	7.2			
			3	543	W.B	26.7	33.9			
			4	529.6	W.B	–	–			
	SALIJAY RANTIPE P.S ABIOLA WAY	VES6	1	1458.9	L.T	1.0	1.0	HK	N=791667 E=540915	2.4m Close to Residential Building and 6.7m close to School
			2	1391.8	H.P	15.7	16.7			
			3	7633.4	F.B	16.2	32.9			
			4	18371	F.BR	–	–			
Lantoro/Adatan Axis	**OYINKANS OLA P.S** OKE-YIDI LANTORO	VES7	1	49.3	L.T	1.6	1.6	HK	N=791268 E=540608	1.9m Close to Residential Building and 1.7m to Borehole
			2	53.9	CLY	6.2	7.9			
			3	450.5	F.BM	24.4	32.3			
			4	387.9	F.BM	–	–			
	RGPG P.S OYESHIKU LANTORO	VES8	1	281.4	L.T	1.0	1.0	HK	N=792035 E=539534	4.3m Close to Residential Building
			2	31.2	CLY	3.0	4.0			
			3	2935.4	F.B	27.2	31.1			
			4	1985.4	F.BM	–	–			
	AKEEMAD E PS ISALE-ABETU	VES9	1	71.6	L.T	2.2	2.2	KH	N=792158 E=539534	2.5m Close to Residential Building/3.6m beside school
			2	286.6	C.G	6.6	8.8			
			3	77.4	CLY	18.6	27.4			
			4	573.7	F.B	–	–			
	SUNNY-YINKA P.S KUGBA	VES10	1	120.3	L.T	2.5	2.5	HK	N=792925 E=539318	1.7m Close to Residential Building
			2	17.6	CLY	7.4	9.9			
			3	133.3	C.G	19.0	29.0			
			4	112.3	W.B	–	–			
	DAMBOLD P.S OKE-EFON	VES11	1	242.3	L.T	0.7	0.7	HK	N=793540 E=539164	2.4m Close to Residential Building
			2	75.2	CLY	3.3	4.0			
			3	989.4	F.B	23.7	27.7			
			4	683.6	F.BM	–	–			

	JETFAD P.S LAFIAJI	VES12	1	73.2	L.T	1.0	1.0	HA	N=793724 E=538612	3.3m Close to Residential Building
			2	48.0	CLY	7.1	8.1			
			3	279.8	W.B	8.3	16.4			
			4	1102.9	F.B	–	–			
Lafenwa Axis	**OANDO P.S** LAFENWA	VES13	1	107	L.T	0.4	0.4	HK	N=791940 E=536129	2.8m Close to Residential Building
			2	46.5	CLY	13.3	13.8			
			3	193.4	W.B	30.6	44.4			
			4	133.3	F.BM	–	–			
	CONOIL P.S LAFENWA	VES14	1	126.0	L.T	1.2	1.2	HA	N=790927 E=535947	1.4m Close to Residential Building
			2	54.4	C.G	11.6	12.8			
			3	577.5	W.B	23.7	36.5			
			4	767.8	F.B	–	–			
nwa Axis	**M.A IKE ANOBI P.S** OKE-AGBEDE LAFENWA	VES15	1	212.3	L.T	0.6	0.6	HA	N=791295 E=535700	2.7m Close to Residential Building
			2	42.9	CLY	5.3	5.9			
			3	138.9	W.B	14.7	20.7			
			4	341.3	F.B	–	–			
Onikolobo/Adigbe Axis	**PETROTEC P.S** ORI-APATA	VES16	1	369.1	L.T	1.1	1.1	HK	N=788992 E=535488	5.8m Close to Residential Building
			2	135.5	C.G	13.2	14.3			
			3	333.8	W.B	19.6	33.9			
			4	307.5	F.BM	–	–			
	OYINKANSOLA P.S ONIKOLOBO	VES17	1	24.5	L.T	1.0	1.0	HA	N=788287 E=535734	3.5m Close to Residential Building
			2	5.4	CLY	3.7	4.8			
			3	190.1	W.B	13.7	18.5			
			4	330.0	F.B	–	–			
	ARMOUR P.S ADIGBE	VES18	1	553.7	L.T	1.0	1.0	HK	N=787549 E=535734	2.6 Close to Residential Building/7m to School
			2	41.3	CLY	2.3	3.2			
			3	2916.2	F.B	46.0	49.2			
			4	1445.0	F.BM	–	–			
	ASHKASH P.S ADIGBE	VES19	1	348.5	L.T	1.0	1.0	HK	N=786750 E=535060	1.8m Close to Residential Building/3.6m

										close to Police Station
			2	7.8	CLY	2.3	3.3			
			3	455.3	W.B	46.0	49.2			
			4	1445.0	F.B	−	−			
	FOWOBI P.S ONIKOLOBO	VES20	1	140.9	L.T	0.7	0.7	HK	N=787090 E=537054	5.8m Close to Residential Building/2.3m to administrative Office
			2	61.9	C.G	17.7	18.3			
			3	205.3	W.B	69.2	87.5			
			4	204.5	F.BM	−	−			

KEY

P.S = Petrol Station
L.T = Lateritic Topsoil
CLY = Clay
W.B = Weathered Basement
F.B = Fresh Basement
F.BR = Fresh Bedrock
C.G = Conglomerate
H.P = Hard Pan
F.BM = Fractured Basement

Subsurface Resistivities as Aid to Determination of Corrosion Severity

Subsurface soil resistivity is perhaps the most essential factor in determining corrosion severity as well as subsurface pollution emanating from leakages from underground storage tanks because it gives an indication of the concentration of soil electrolytes which is highly crucial to corrosion process. Low resistivity soils would promote corrosion; in otherwords, the higher the rate of corrosion, the lower the resistivity of the subsurface soil (Kingdom and Abam, 2021). According to Amadi *et al.*, 2023, there is a high connection between soil corrosivity and soil resistivity with their suggested finding revealing soil resistivities less than 10Ωm, 10 Ωm to 30 Ωm, 30Ωm to 50 Ωm, 50Ωm to 100 Ωm, 100 Ωm to 200 Ωm and greater than 200 Ωm should be regarded as extremely corrosive, highly corrosive, corrosive, moderately corrosive, mildly corrosive and essentially non corrosive respectively (Reberge, 1999; Villanueva-Balsera *et al.*, 2018). Resistivity has been considered the most important variable that can be used as tool for investigating subsurface corrosivity because of the significant correlation that exist between corrosion and conductivity as highly resistive subsurface layer tend to retard ionic currents which are linked to corrosion reactions (Villanueva-Balsera *et al.*, 2018). Corrosion risk can be calculated using pH values to estimate the degree of corrosivity of the soil. Subsurface layers with any of the following namely low resistivity, low pH, and high chloride and sulphate concentrations are typically the most corrosive. At low pH, clayey soils have low resistivity and high corrosivity and those contaminated with crude oil and saline water are extremely corrosive at pH values less than 5.5 (Irunkwor and Ngerebara, 2018). Subsurface resistivity measurement can be utilized as early indicator of the potential for corrosion growth rate; it serves as a function of soil moisture and ionic soluble salt concentrations, it is therefore regarded as the most comprehensive indication of soil corrosivity. Without the need for extensive subsurface sampling programs, subsurface resistivity can be used to measure and map subsurface parameters (Sing *et al.*, 2013). It has also been debated that soil resistivity is one of the most crucial design factors when taking into professional consideration on the installation of cathodic protection for underground pipelines (Alhabobi and Albayati, 2016).

In this study, while evaluating the subsurface environmental corrosivity towards underground structures like storage tank is a critical factor where the data is a reflection of in-situ resistivity conditions for the purpose of inferring the degree of corrosivity as well as consequent determination of pollution level around proliferated petrol stations in Abeokuta metropolis, South-West Nigeria whose results can be used as a reference as displayed in Table 4.2. The variation of resistivity values most specifically the second layer at all VES locations were utilized in the evaluation of corrosion severity and pollution level in order to determine the vulnerability of the aquiferous zones in this area to pollution emanating from the buried underground storage tanks (Fig. 4.3). This investigation using the classification standard of Reberge, 1999 and Villanueva-Balsera et al., 2018 revealed that 10% of the locations comprising VES17 and VES19 are extremely corrosive; 10% (VES4 and VES10) are highly corrosive; 35% (VES2, VES5, VES8, VES12, VES13, VES15 and VES18) are corrosive; 25% (VES1, VES7, VES11, VES14 and VES20) are moderately corrosive; 5% (only VES1) are mildly corrosive and 15% (VES3, VES6 and VES9) are non corrosive (Table 4.2).

Table 4.2: Subsurface Corrosion Severity and Pollution Level around Proliferated Petrol Stations in Abeokuta Metropolis

VES Stations	Corrosivity 1st Layer (Ωm)	Corrosivity 1st Layer (Ωm)	Overburden Thickness (m)	Corrosion Severity	Longitudinal Conductance (Ω/m)	Depth of Burial of USTs (m)	Pollution Level
VES1	68.4	96.0	17.3	Moderately Corrosive	0.54741	5.0	Vulnerable
VES2	389.3	41.2	14.3	Corrosive	0.35404	4.5	Vunerable
VES3	495.9	275.1	8.7	Non-Corrosive	0.21450	5.0	Vulnerable
VES4	248.8	17.2	7.2	Highly Corrosive	0.42443	5.0	Highly Vulnerable
VES5	522.0	33.5	22.4	Corrosive	0.42448	5.0	Vulnerable
VES6	1458.9	1391.8	16.7	Non-Corrosive	0.01409	5.0	Vulnerable
VES7	49.3	53.9	7.9	Moderately Corrosive	0.20164	4.5	Vulnerable
VES8	281.4	31.2	4.0	Corrosive	0.10897	4.0	Polluted
VES9	71.6	286.6	8.8	Non-Corrosive	0.29427	4.5	Highly Vulnerable
VES10	120.3	17.6	9.9	Highly Corrosive	0.58377	5.0	Highly Vulnerable
VES11	242.3	75.2	4.0	Moderately Corrosive	0.07073	4.0	Polluted
VES12	73.2	48.0	8.1	Corrosive	0.19124	5.0	Highly Vulnerable
VES13	107.4	46.5	13.8	Corrosive	0.44798	5.0	Vulnerable

VES14	126.0	54.4	12.8	Moderately Corrosive	0.26380	5.0	Vulnerable
VES15	212.3	42.9	5.9	Corrosive	0.23220	4.5	Highly Vulnerable
VES16	369.1	135.5	14.3	Corrosive	0.15912	5.0	Highly Vulnerable
VES17	24.5	5.4	4.8	Extremely Corrosive	0.79807	4.5	Vulnerable
VES18	553.7	41.3	7.7	Corrosive	0.17772	4.5	Vulnerable
VES19	348.5	7.8	3.3	Extremely Corrosive	0.39877	4.0	Polluted
VES20	140.9	61.9	18.3	Moderately Corrosive	0.62798	5.0	Vulnerable

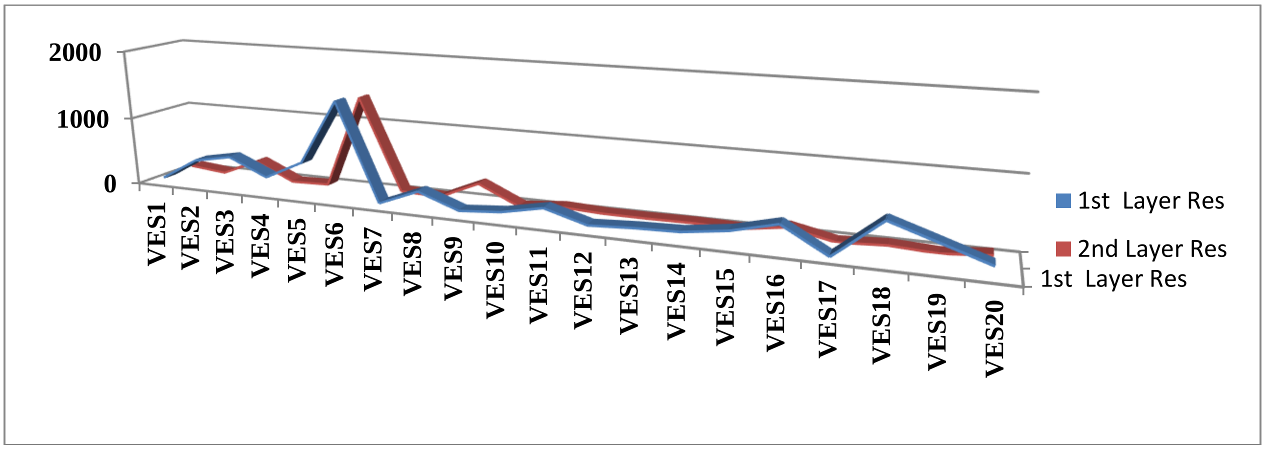

Fig 4.3: Variation of First and Second Subsurface Layer Resistivity in the Study area

Overburden Protective Capacity and Ecotoxicological Risk of Invading Petroleum Products

Overburden protective capacity in all VES stations of the study area is considered to be of economic importance so that when utilities are to be installed, it would go a long way in identifying locations that are adequately protected from invading pollution. The calculated longitudinal conductance values as displayed in Table 4.2 can be utilized in evaluating the protective capacity in an area. This is because the earth medium acts as a natural filter to invading fluids and contaminant seepages; its ability to retard and filter percolating fluid is a measure of its protective capacity (Olorunfemi *et al.*, 1998; Ishola *et al.*, 2023). The classification of Oladapo et al., 2004 and Ishola et al., 2024 was therefore adopted not only to suite a crystalline basement complex environment but also to evaluate the protective capacity of the overburden overlying the aquifer in the area as being proportional to the hydraulic conductivity. The modification involved the derivation of the protective capacity rating due to the subsurface geologic variation and geoelectric complexity characterizing the basement rocks and associated constituents. Table 4.3 below revealed the outcome of the subsurface condition of the study area in terms of the Overburden Protective Capacity Rating (OPCR) and Corrosion Severity. No VES location exhibited Very Good to Excellent OPCR while 5% (VES17 only) exhibited Good OPCR. 65% of the investigated stations which comprises of VES1, VES2, VES3, VES4, VES5, VES7, VES9, VES10, VES13, VES14, VES15, VES19 and VES20 falls within Moderate OPCR (Table 4.2); this is due to their

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relatively high overburden thickness compared to other locations. 20% of the entire investigated locations which comprises of VES8, VES12, VES16 and VES18 were found within the Weak OPCR while 10% were of Poor OPCR.

It was observed that despite VES16, VES6, VES3 were found within Poor to Moderate OPCR, the severity of their corrosion were Mildly Corrosive to Non-Corrosive which poses less hazard at the subsurface based on their present state but serves as potential future dangers to the people occupying the surrounding buildings who harness groundwater as their major source of water consumption. VES19, VES17, VES15, VES13, VES10, and VES4 though exhibited Good to Moderate OPCR. Based on classification, corrosive severity in this locations are Extremely and Highly corrosive while VES8, VES12 and VES18 were within a Weak OPCR and equally possesses corrosive severity; these areas are highly polluted as the aquiferous zones within the locations were susceptible to contaminant seepages emanating from the storage tank leakages with unprecedented lethal effects on human and biological populations that consume such water in the area.

Table 4.3: Overburden Protective Capacity Rating versus Corrosion Severity around Proliferated Petrol Stations in Abeokuta Metropolis

Reberge, 1999 and Villanueva-Balsera et al., 2018					Oladapo et al., 2004; Ishola et al., 2024).			
Subsurface Layer Resistivity(Ωm)	**Percen tage (%)**	**VES Stations**	**Corrosion Severity**		**Longitudinal Conductance**	**Percentage (%)**	**VES Stations**	**Overburden Protective Capacity Rating**
< 10	10	VES17, VES19	Extremely Corrosive		> 10	0	NIL	Excellent
10 – 30	10	VES4, VES10	Highly Corrosive		5 − 10	0	NIL	Very Good
30 − 50	35	VES2, VES5, VES8, VES12, VES13, VES15 and VES18	Corrosive		0.7 – 4.9	5	17	Good
50 − 100	25	VES1, VES7, VES11, VES14, and VES20	Moderately Corrosive		0.2 – 0.69	65	VES1, VES2, VES3, VES4, VES5, VES7, VES9, VES10, VES13,VES14, VES15, VES19 and VES20	Moderate
100 − 200	5	VES16	Mildly Corrosive		0.1 − 0.19	20	VES8, VES12, VES16 and VES18	Weak
>200	15	VES3, VES6 and VES9	Non-Corrosive		< 0.1	10	VES6 and VES11	Poor

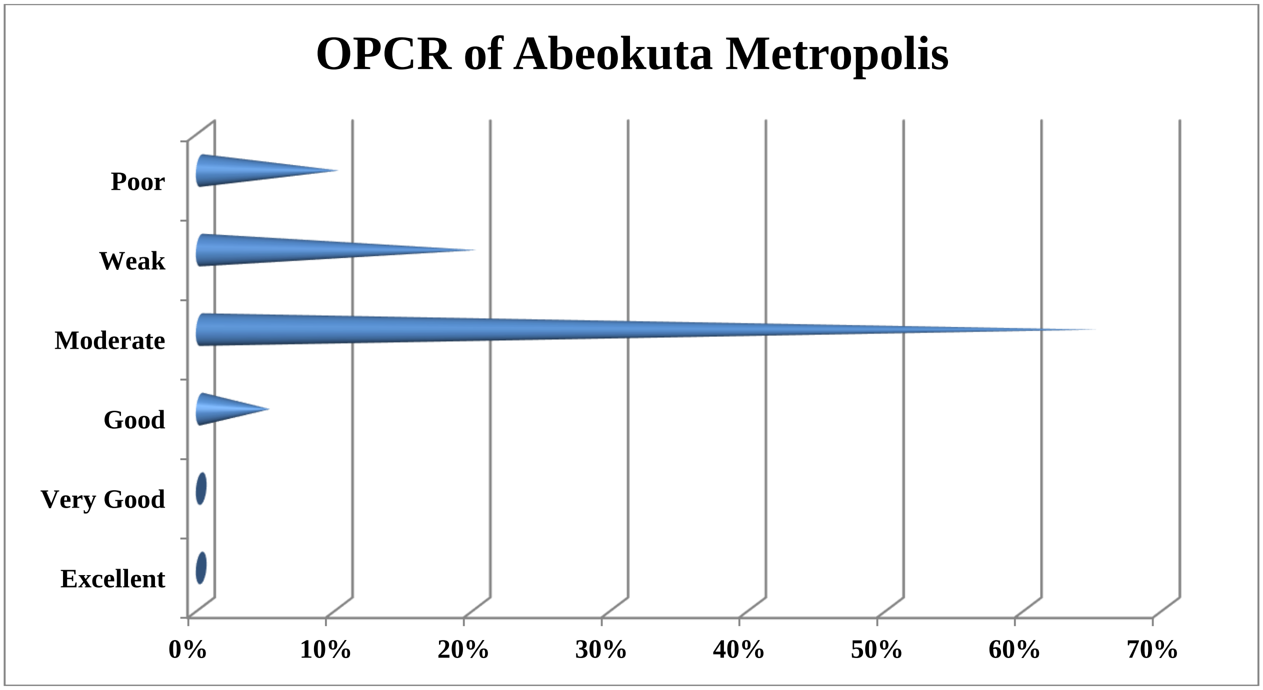

Fig 4.4: Overburden Protective Capacity Rating in Abeokuta Metropolis

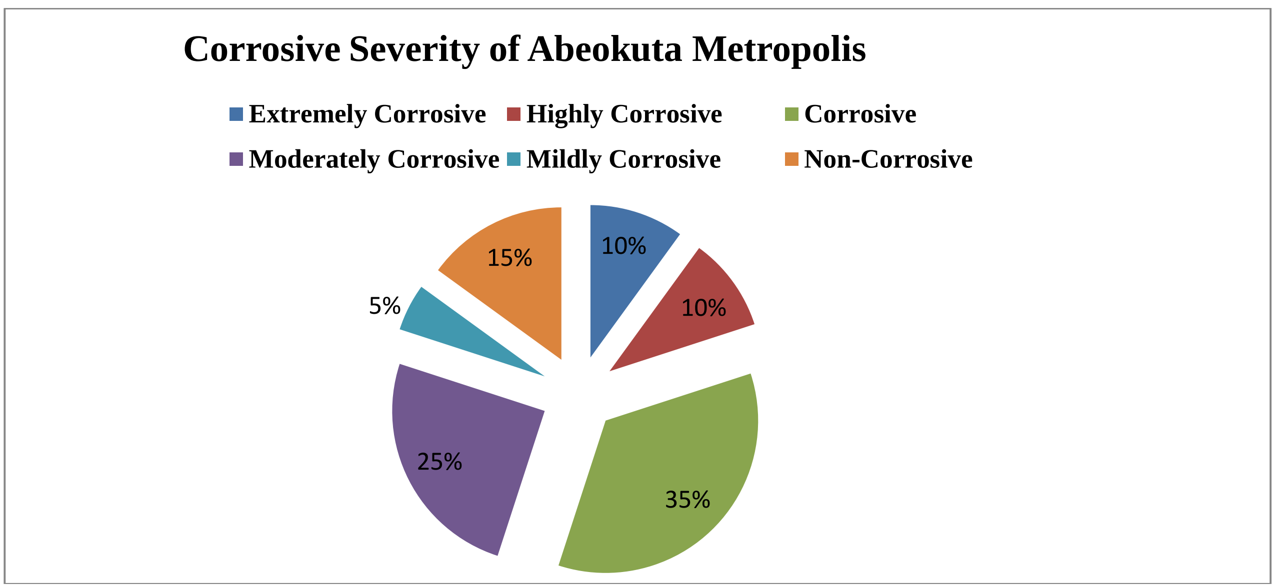

Fig 4.5: Corrosive Severity in Abeokuta Metropolis

Since service petrol stations offer fuel bases and create risks of soil contamination as a result of surface fuel tank leakages, petrol oil spillages and underground storage tank leakages. The migration of these contaminants in the subsurface depends on a variety of factors which include; the concentration of petroleum products, climates and soil parameters namely soil type, sportive capacity, pH, solid and liquid contents and air phase. In the case of wet soil dominated with high temperatures, it will give rise to high occurrence of biodegradation of petroleum related pollutants, evaporation and mineralization. Since subsurface sediments act as sinks for pollutants, environmental contaminants have been known to have direct toxic effects when released into the groundwater system and aquatic environment (Forstener *et al.*, 1998; Fleeger *et al.*, 2003; Ishola *et al.*, 2016). Also, the accumulated heavy metals and organic pollutants in sediments could be released back into groundwater system because of the direct link between surface water, groundwater and sediments with deleterious and virulent implications on human health. At low temperatures, biodegradation process will run at a slower rate and the reduction in the concentration of pollutants will be primarily due to the processes of diffusion and soaking. The Nigerian Standards developed by the Federal Environmental Management Agency (FEMA) specified the admissible soil concentrations for crude oil derivative substances relate these values to the soil profile (FEPA, 1991; Umeroh et al., 2016). Thus, some asphalts, tars, waxes, and oils accumulate on the soil surface but poorly water soluble aliphatic hydrocarbons move to the depth of the soil profile and form a layer which encloses the grains of sand. Aromatic hydrocarbons that are characterized by comparatively higher water solubility migrate towards precipitation and subsurface with unprecedented impacts on the groundwater system. Of the aromatic hydrocarbons that are present in the petroleum products, benzene, toluene, and xylenecare are classified as most toxic petroleum components.

CONCLUSION

Environmental risk assessment of the subsurface environment was carried out around proliferated petrol stations in Abeokuta metropolis using vertical electrical sounding method of geophysical investigation in order to determine overburden protective capacity of the aquiferous zones and corrosion severity which serves as aids for the overall rating of the pollution level of the study area. The investigation has revealed that the main aquiferous units are situated at the North-East and South-West section of the study area. The outcome of this subsurface geophysical investigation in terms of the Overburden Protective Capacity Rating (OPCR) and Corrosion Severity revealed that not even a single VES location exhibited Very Good to Excellent OPCR while only 5% (VES17 only) exhibited Good OPCR while 65% of the investigated stations which comprises of VES1, VES2, VES3, VES4, VES5, VES7, VES9, VES10, VES13, VES14, VES15, VES19 and VES20 fell within Moderate OPCR (Table 4.2); this is due to their relatively high overburden thickness compared to other locations. 20% of the entire investigated locations which comprises of VES8, VES12, VES16 and VES18 were found within the Weak OPCR while 10% were of Poor OPCR.

It worthy of notes that despite VES16, VES6, and VES3 were found within Poor to Moderate OPCR, the severity of their corrosion were equally Mildly Corrosive to Non-Corrosive; though this seemed less hazardous based on their present state but could serve as potential future dangers to the occupants in the surrounding buildings within the affected vicinity who harness groundwater as their major source of water consumption. Also, VES19, VES17, VES15, VES13, VES10, and

VES4 though exhibited Good to Moderate OPCR with their corrosive severity being in the range of Extremely and Highly corrosive while VES8, VES12 and VES18 were within a Weak OPCR and equally possesses corrosive severity; these areas are highly polluted as the aquiferous zones within the locations were susceptible to contaminant seepages emanating from the storage tank leakages with unprecedented lethal effects on human and biological populations that consume such water in the area (Joseph, 2005; USEPA, 2010). The aforementioned areas exhibiting some corrosive tendencies were situated at the South-East and North-West portions while other flanks were being slightly affected. These affected sections of the area are underlain by materials of weak to poor protective capacity and were therefore vulnerable to pollution from the contaminant seepages emanating from the underground buried storage tanks; the shallow depth of burial of the underground storage tanks varied from the maximum depth of 5.0m to the minimum depth of 4.0m with an average depth of 4.7m while the overburden thickness to the aquiferous zone in the study area ranges from the maximum depth of 22.4m (VES5) to the minimum thickness of 3.3m (VES19) with an average thickness of 4.7m. The North-Eastern portion, the Southwestern portion and the Central portion of the study area were underlain by materials of moderate to good protective capacity. These study areas coincide with zones of appreciable overburden thickness with clay columns thick enough to protect the groundwater in the area. The results of this study have shown that certain environmental factors surrounding the subsurface like corrosivity and protective capacity should never be ignored at planning stages of petrol stations and where utilities are to be installed around residential buildings.

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