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Geoelectric investigation and physicochemical analysis of parts of Niger Delta, Nigeria, for groundwater quality assessment

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Abstract

Geoelectrical methods integrated with physicochemical analyses of borehole samples were employed to determine groundwater contamination levels in the area. Vertical electrical sounding (VES) and 2D resistivity techniques were conducted along the area's four transverses. The field data were processed using the RES2DINV and IPI2WIN software. Groundwater samples were collected from three boreholes in the area and one borehole outside the mechanic village area as a control. The results of the VES indicated that at depths beyond 18 m, resistivity greater than 200 Ωm suggested that fresh gasoline oil spills increased the electrical resistivity of the groundwater. Additionally, at depths beyond 2 m, with a resistivity range of less than 85 Ωm, biodegraded hydrocarbon spills in the auto mechanic village were evident, making the groundwater less electrically resistive. The 2D resistivity results showed two types of anomalies: high and low resistivity zones. The high resistivity zones indicate uncontaminated areas, while the low resistivity zones indicate contaminated areas. The physicochemical analyses and heavy metal groundwater samples revealed that gasoline oil infiltrated the subsoil down to the water table as a free-phase hydrocarbon. The depths of the water table and aquifer extended beyond 10 and 36 m, exhibiting high resistivity ranges greater than 287.7 and 548.6 Ωm, respectively. In conclusion, the gasoline oil spills saturate the unsaturated zone and subsequently leach into the groundwater aquifer at depths beyond 18 m, showing a high resistivity range greater than 350 Ωm.

Keywords: Physicochemical, RES2DINV, IPI2WIN, Geoelectrical, Pseudo section, Lateritic Sand

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1 Introduction

The importance of groundwater cannot be overstated, making it an essential natural resource for various domestic and industrial applications (Longe and Balogun, 2010; Uguru et al., 2020a). Currently, the quality of groundwater is compromised due to rising levels of urbanization and industrialization (Ekeleme et al., 2015). A significant issue is the contamination of soil and water caused by industrial and human activities. Groundwater sources are a vital component of global freshwater reserves, providing the primary supply for domestic, agricultural, and industrial water needs (Chilton, 1996). In the Niger Delta, water resources are plentiful. Still, their quality is unsuitable for human consumption due to large-scale industrial and human actions, such as the arbitrary discharge of heavy metals, petroleum, and its derivatives into the environment by mechanic workshops. Numerous researchers, including Therese et al. (2007), Adelekan et al. (2011), Adewoyin et al. (2013), Ebong et al. (2017), Nebo et al. (2018), and Muze et al. (2020), have studied the impact of auto mechanic workshops on groundwater quality within their immediate surroundings.

Nevertheless, the population of automobile workshops in Nigeria is increasing due to the significant influx of used vehicles and old vehicle engines from developed countries (Oloruntoba and Ogunbunmi, 2020). Artisans in the auto repair industry frequently dispose of used engine oils, lubricating oils, and other solvents containing petroleum hydrocarbons (PHs) by dumping or spilling them in their workshops (Wang et al., 2000). The main tasks performed by these artisans include vehicle maintenance, painting, panel beating, and fabrication. These shops discharge waste products such as engine oil, transmission oil, brake fluid, damaged tires, battery electrolytes, wire carbide, and spent batteries into the surrounding environment. The spent oils and solvents generated in auto-repair workshops in Nigerian cities are considered potentially hazardous wastes since they can be transported underground through pores and/or fissures/fractures (Ipeaiyeda and Dawodu, 2008; Iwegbue, 2007). Used engine oil contains a mixture of chemicals, including PHs, chlorinated biphenyls, additives, decomposition products, and heavy metals from engine wear (Kidman and Boehlecke, 2011; Wang et al., 2000). These waste categories, such as oil filters, scrap metal parts, lead batteries, and abandoned vehicles, are resistant to biodegradation (Ang et al., 2005). The presence of environmental pollutants often leads to the accumulation of heavy metals in the soil, which can then be absorbed by plant tissues (Vwioko et al., 2006). The migration of spent oil and the percolation of leachates from contained materials pose serious threats to surface and groundwater quality (Olugboji and Ogunwole, 2008; Ololade, 2014; Osayande and Nwokedi, 2019). Ibrahim et al. (2019) stated that disposing of these heavy metals as well as petroleum and its derivatives, into the environment is a major source of environmental pollution. Environmental pollution, according to Muze et al. (2020), not only impacts the health of plants and animals but also alters the physicochemical characteristics of groundwater and the geotechnical properties of soil. Indiscriminate disposal causes toxic emissions during abrasion and contributes to metal contamination in auto-repair workshops (Arubela and Ajayi, 2012; Darma et al., 2022). Copper, chromium, cadmium, lead, mercury, silver, cobalt, iron, zinc, and arsenic are significant heavy metals typically released from auto-repair workshops.

Currently, in this research, the government has not provided any public pipe-borne water supply to the Elekahia mechanic workshop and its surroundings. This has led to numerous private boreholes being drilled in the area, causing residents to rely heavily on these privately drilled sources as their main supply of potable water. Regardless of ownership, the quality of water for human consumption is essential, as contamination from the mechanic workshop could expose residents to serious health risks. This will aid the private owners and local users in knowing the effect the Mechanic workshop poses to the boreholes within the vicinity. By estimating aquifer configurations, it is feasible to assess the quality of underground water. This is demonstrated in the work of Anomoharan (2011), Anomoharan (2013), Okon et al. (2019), Okiongbo and Ogobiri (2011), and Oseji et al. (2005). Therefore, increasing awareness of aquifer formation and features in the area is vital to determine whether the aquifer is susceptible to contamination. This necessitates an assessment of groundwater quality in the Elekahia mechanic workshop and its surroundings, as the occupants consume water in its natural state. This involves ascertaining the extent and distribution of heavy metal contamination, analyzing the correlation between heavy metals in the sample and control, and identifying specific zones prone to contamination.

2 Geology of the study area

The Elekahia Mechanic village study area is situated in the Port Harcourt metropolis, which is part of the Niger Delta basin in Nigeria. The terrain of the site is quite level. Upon direct observation of the surface and from road cuts in the area, it is evident that the geological deposits predominantly consist of sand.

The Niger Delta covers an area of approximately 256,000 square kilometers and was originally developed over an older transgressive Paleocene proto-delta. Small basins with different tectonic configurations evolved from translational to compressional toe thrust regions. The major subsurface lithostratigraphic units include the transgressive marine Akata shales, the oil-bearing paralic Agbada formation, and the continental Benin sands. The Akata Formation was formed after the tectonic process, followed by the deposition of the Agbada Formation in the Eocene and the Benin Formation in the Oligocene, which is still being deposited today. Due to its tectonic structure, the overall basin is divided into depobelts. An extensional zone on the continental shelf is caused by the thickened crust. The Benin Formation, which is Oligocene and younger, is comprised of continental floodplain sands and alluvial deposits (Etu-Efeotor, 1981). A regional lithostratigraphic interpretation is provided for the upper 0-300m of the Benin Formation, where groundwater is extracted in Rivers State, Nigeria. The Benin formation mainly consists of sandy units and has displayed significantly high intergranular stresses, as well as moderately to higher pile axial capacity attributes, making the presence of sand on the surface particularly noteworthy. The sandy unit of the Benin Formation is viewed as a potential source of construction material for reclamation projects, road sub-bases, shoreline nourishment, and as a constituent of asphalt for road pavements. The Benin Formation is well-known for its hydraulic properties and groundwater-yielding potential (Nwankwo and Emujakporue, 2012) due to its predominantly uniform and granular composition, allowing for reasonably high permeability. The aquifers are primarily composed of sand beds with minor clays, lignite, and conglomerate intercalations. The sands are predominantly very fine to coarse-grained, subangular to subrounded, and mostly lithic arenites, ranging from poorly to fairly well sorted. Most of the conglomerate beds have a matrix support fabric and are mainly found to the east, similar to the lignite beds. An east-west trending belt, approximately central to the state, appears to contain more clay interbeds.

The study area falls inside the southern

Nigeria sedimentary basin, and its component units have been properly documented (Nwachukwu, 1972) (Figure 1). From the literature, it is believed that the area comprises Cretaceous to Recent thick sedimentary rocks. They are: Asu River Group (Albian), Coastal Plain Sands, Nkporo Shale (Campanian), Sombreiro – Warri Deltaic Plain (Pliocene), Ajali Sandstones, Alluvium (Recent Quaternary), Nsukka Formation (Maastrichtian), Mamu Formation (Lower Coal Measures), Imo Shale (Paleocene), and the Ameki Formation (Eocene) (Figure 2).

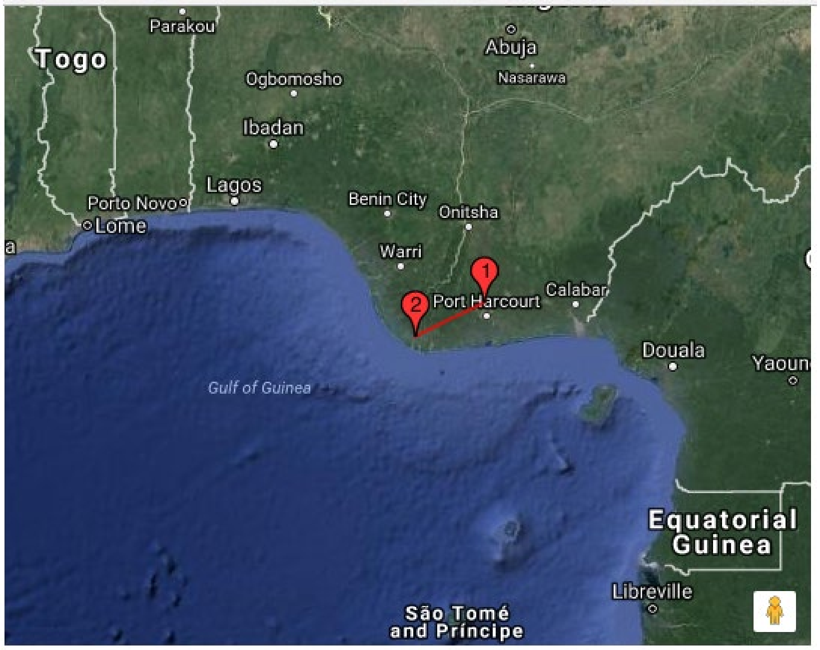

Figure1. The area of study (Doust and Omatsola, 1990).

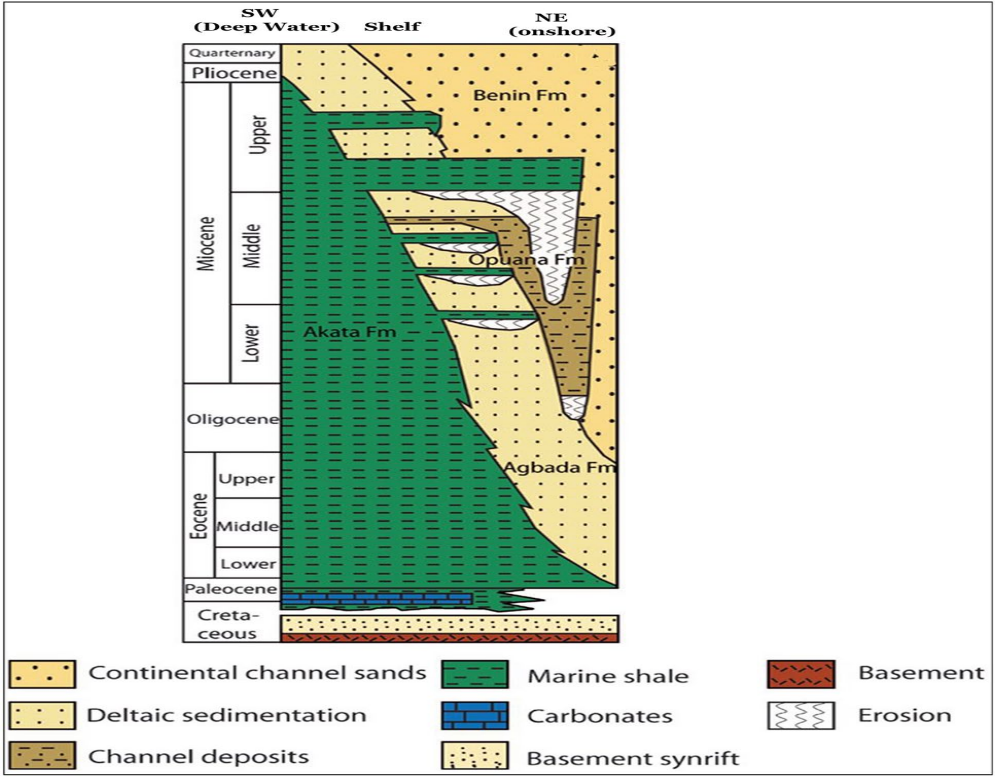

Figure 2. Niger Delta stratigraphy with its dip (Doust and Omatsola, 1990).

It was during the Eocene that the Ameki Formation was deposited. It is made up of fossiliferous grayish sandy clay with calcareous shale and white clayey sandstones. This formation shows swift side-by-side facies variations and may locally display shaly development or inclusions of white and mottled claystone and sandstone (Onu et. al., 2012). Deposited during the Paleocene is the Imo Shale. It is made up of dense blue-grey shales with thin lateral sandstone that is thin. It is also made up of marl and limestone, having clay, iron stone. Nsukka Formation, which is made up of an alternating succession of sandstone, dark shales, and sandy shale, was dumped during the Upper Maastrician. The formation has thin coal seams at distinct horizons. During the Maastrician, the Ajali Formation, also known as False Bedded Sandstones, was dumped. The Sandstone is thick, friable, and poorly sorted. The Formation is typically white, is iron-stained, and made up of thin bands of mudstone and shale occurring at intervals. This Formation is believed to be overlain by a certain amount of red earth (Simpson, 1955). Like the Ajali Sandstone, the Mamu Formation, consisting of sandstone, shales, mudstone, and sandy shales with coal seams at several intervals, was deposited throughout the Maasstrician. The Nkporo Shale assemblage was deposited through the Campanian. The assemblage/group is made up of dark blue and grey friable shales with sporadic tinny limestone and sandstone beds. These formations seldom outcrop, and data on them comes largely from boreholes, and they display recurrent strident facies changes. Laterally equivalent to the Nkporo Formations are the Owelle /Afikpo sandstone and Enugu-Asata Shales. They unconformably overlie older folded beds. The Nkporo Shale has a thickness of about 1000m (Onu et. al., 2012). The Asu River is the oldest sediment in the lithologic sequence within Southern Nigeria. In the sediments are poorly bedded sandy shales known as Abakiliki shales that have Awe sandstone and limestone lenses (Mfamosing limestone. The sediments are linked to lead-zinc mineralization and intrusive bodies (Peters et. al., 1982).

It was enunciated by Weber (1975) that growth fault-linked rollover structures trap hydrocarbon. Faults are vital in hydrocarbon exploration because they form a migratory path from overpressure marine clays. The production of hydrocarbon in a well is greatly affected by reservoir deposits in the environment (Weber, 1975). Petroleum was founded in 1955, and by 1958, production started from the Oloibiri and Afam fields (Weber, 1975). Thereafter, there was a steady increase in the discovery of oil wells (Doust and Omatsola, 1990). Presently, about twelve companies existing within the Niger Delta, cooperated with the Nigerian National Oil Corporation (Weber, 1975).

In Nigeria, many basic depositional cycles are distinguished (Reijers, 1996). These depositional actions led to about eight sedimentary basins being formed in Nigeria where petroleum mining activities are attempted (Tuttle et al., 1999). The basins include Niger Delta Basin, Anambra Basin, Benue Trough, Benin Basin, Bida Basin, Bornu Basin, Dahomey Basin, and Sokoto Basin (Nuhu, 2009; Reijers, 1996). An elongated rift basin is established within the Delta region, Biafra Bight, and São Tomé and Príncipe. This is located within the western Nigerian continental margin (Michele et al., 1999). The Basin has suspected contact with Cameroon and São Tomé. The basin is economically viable because of its quantity of petroleum. The sedimentary thickness varies between 9 -12 km (Fatoke, 2010). Various geologic formations that depict how the basin has been formed are evident within the province. The basin falls within the southwestern area of Benue Trough, which has superior tectonics. The Volcanic Cameroun Line bound the Niger deltas other side (Michele et al., 1999). Moving away from the South American-African plate guided the creation of Niger Delta. The opening of the South Atlantic also caused the structuring of the basin. Following such separation, several faults were built. Deposited sequentially owing to large transgression are the Akata and Agbada Formations (Fatoke, 2010). The Agbade and Benin Formations were then deposited till today during the Oligocene (Michele et al., 1999).

3 Materials and Methods

3.1 Materials

In electrical resistivity prospecting, the basic equipment required is the resistivity meter (Terrameter). This is comprised of the Transmitter, receiver, processing, and display units, all housed in one unit. Other accessories are four non-polarizable electrodes (two current and two potential electrodes), a 12V battery power source for low-frequency alternating current supply, hammers, and four reels of wire (2 current + 2 potential wires). Data was processed using RES2DINV and IPI2WIN software for subsequent interpretation. Global Positioning System (GPS) was also employed.

3.2 Methods adopted

In this study, the geoelectrical method was used extensively, followed by the physicochemical analysis of water samples within the study area. The fieldwork was carried out in Elekahia mechanic village in the Port Harcourt metropolis using vertical electrical sounding (VES) and the 2D resistivity techniques. For good contact with the earth, some water or salt solution was poured on the ground around the electrodes.

3.3 Field Procedures and Data Acquisition

The potential and current cable reels were connected to the terminals P_1 and P_2 and then C_1 and C_2 of the Terrameter after terminations from the potential and current electrode pairs along the traverse. Then, the whole setup is now connected to an external 12V battery for power supply.

The field procedure adopted in this study is the vertical electrical sounding (VES) using the Schlumberger electrode configuration and the 2D resistivity profiling using the Wenner electrode configuration. Four electrodes comprising two current electrodes A and B, and two potential electrodes M and N, were placed along a straight line on the land surface such that the current electrode spacing AB is more than five times the potential electrode spacing MN. A total of four profiles were occupied, having measured lengths of 100m, which is the length of the profile. The maximum AB/2 and MN/2 are 50m and 100m, respectively. A total of four Vertical Electrical Sounding (VES) were run in this work using the Schlumberger electrode array with a maximum current electrode spread of 100m and four additional profiles using the Wenner electrode array, to determine the lateral spread of the contaminated zones. The Terrameter was placed between the potential electrodes M and N, away from A and B, the current electrodes. The coordinates were taken using the Geographical Positioning System (GPS) at the mid-point, starting point, and end point of the profile.

The Wenner configuration, carried out after the Schlumberger, was for the 2D resistivity profiling. Measurement was made 5m each from the starting point to the endpoint. Electrodes were mounted side by side with the wire reels and connected. After each reading, the wire reels and the electrodes were moved five meters away until it got to the end, then it returned after jumping twice the 5m, which is 10m.

3.4 Water Sample Collection/Analysis Methods

A total of four groundwater samples were collected from four boreholes: Three at the auto-mechanic workshop and one at the Elekahia Housing Estate, 50m away from the workshop as a control. All sampling bottles were washed and rinsed with distilled water as a quality control measure before the collection of the water samples. The sample bottles were rinsed twice with the groundwater to be sampled before filling the containers to the brim with the samples and labeled properly at the point of collection. The samples were stored in an ice-packed cooler and transported to the laboratory for analysis within 24 hours. All sampling points were geo-referenced with the use of the Geographical Positioning System (GPS). The samples were coded BH1, BH2, and BH3 for samples from the mechanic workshop and BH4C for samples from the control site.

The following physicochemical parameters were analyzed: temperature, pH, turbidity, Total Dissolved Solids(TDS), Electrical conductivity, nitrate, and heavy metals including Nickel (Ni) Zinc (Zn), Cadmium (Cd), Iron (Fe) Lead (Pb) Copper (Cu), and Chromium (Cr).

The pH sensor was used to check the level of acidity to alkalinity content in the groundwater sample. The conductivity meter was used to measure the conductivity of the groundwater sample, while we used the electric cooker to boil the groundwater sample to a drying point when carrying out the nitrate measurement.

3.5 Data Processing and Analysis

3.5.1 Vertical Electrical Sounding (VES) Resistivity Data

Based on the fundamental principles and methodologies of the geophysical survey, the collected data are interpreted quantitatively in the case of VES and qualitatively in the case of 2D profiling to determine the thickness, nature, and vertical and lateral variations of the geological formations which can be used to obtain a complete geological picture of the area. VES data were entered into the computer, and curves were plotted using IPI2WIN interpretation software. The true resistivity and layer thicknesses were converted into useful geological meaning using knowledge of the geological history

3.5.2 2D Resistivity Data

2D resistivity survey data are entered into the computer using RES2DINV. The RES2DINV is a 2-D forward modeling program that was used to calculate the apparent resistivity pseudo-section for the 2-D subsurface. The horizontal position of a data point was the average of the locations of the electrodes in the array used to make the measurement. The pseudo section gave a distorted picture of the subsurface as a result of the shapes of the contours, and this depends on the type of array that was used as well. The 2-D model, consisting of a large number of rectangular cells was the one commonly used to interpret the data (Nwankwo et al, 2012). The resistivity of the cells is allowed to vary in the vertical and horizontal direction, but the size and position of the cells are fixed. An inversion scheme is used to determine the resistivity of the cells that will produce a response that agrees with the measured resistivity values.

4 RESULT

The results of the geoelectrical investigation and physicochemical analysis of groundwater samples in Elekahia Mechanic Village are presented. The results of the vertical electrical soundings (VES) are shown as 1-D resistivity curves, with resistivity varying with depth. Electrical resistivity tomography (ERT) is illustrated as a 2-D pseudosection of electrical resistivity variations, both laterally and vertically along the traverses, while the groundwater analysis results are detailed in terms of various physicochemical parameters of the groundwater samples.

4.1 Result presentation of Vertical Electrical Sounding (VES)

The vertical electrical sounding data, presented as a 1-D resistivity curve based on electrode spacing, were utilized to study the impact of mechanical activities on the groundwater aquifer within the study area. The modeled results of the VES data interpretation for the study area are displayed in Figures 3, 4, 5, and 6, while Tables 1, 2, 3, and 4 present the lithology of various rock types, delineated from the resistivity values. The analysis also revealed the geoelectric section of the lithology. Overall, the VES results illustrate four geoelectric sections (Figures 7, 8, 9, and 10) depicting the lithology of the mechanical village.

A combination of K- and A-type curves with four geoelectric layers and resistivity increasing uniformly with depth was identified (Figs. 3, 4, 5, and 6). The resistivity and depth values range from 83.98 to 537.60 Ωm and 2.01 to 18.23 m, respectively, for VES road 1. For VES road 2, the resistivity and depth values are 80.23 to 506.20 Ωm and 2.09 to 18.6 m, respectively. For roads 3 and 4, the resistivity and depth values are 78.64 to 582.40 Ωm and 2.01 to 18.23 m, and from 67 to 398.10 Ωm and 2.01 to 18.60 m along the traverses.

The geoelectric layers are interpreted as a first layer of topsoil, a second layer of lateritic sand, and third and fourth layers of sands, respectively (Tables 4.1, 4.2, 4.3, and 4.4) and the geoelectric section (Figs 7, 8, 9, and 10). The groundwater table and aquifers were delineated at average depths of 5 and 18m, respectively.

For VES road 1 probable aquifer is delineated at a depth of 18.23 m with a thickness of 12.86 m. It has a resistivity value of 266.70 Ωm. For VES road 2, at a depth of 18.6m with a thickness of 13.12m, a probable aquifer is delineated and it has a resistivity value of 306.90 Ωm. For VES road 3, a probable aquifer is delineated at a depth of 18.23m and with thickness and resistivity values of 12.86 m and 300.80 Ωm, respectively. Finally, for VES road 4, the likely aquifer is delineated at a depth of 18.60m. The aquifer has a thickness of 13.34 m and a resistivity value of 222.80 Ωm.

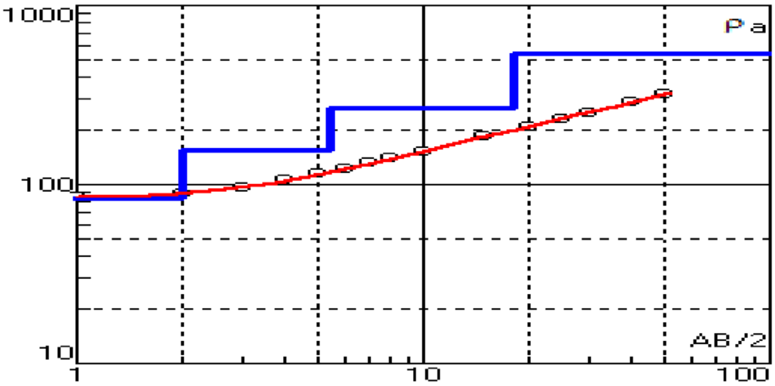

Figure 3. K-A type curve for VES road 1.

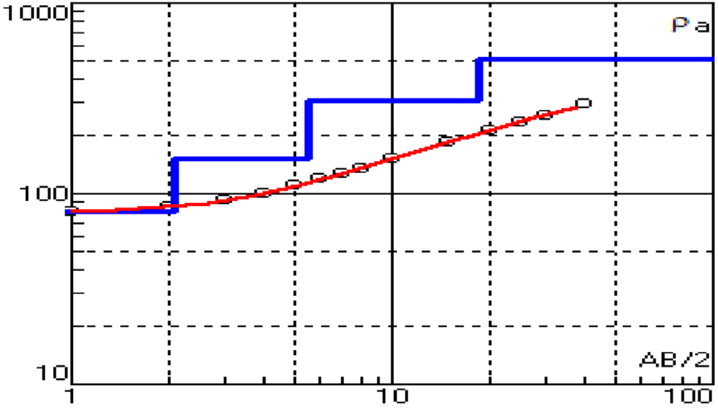

Figure 4. K-A type curve for VES road 2.

ROAD THREE VES DATA INTERPRETATION

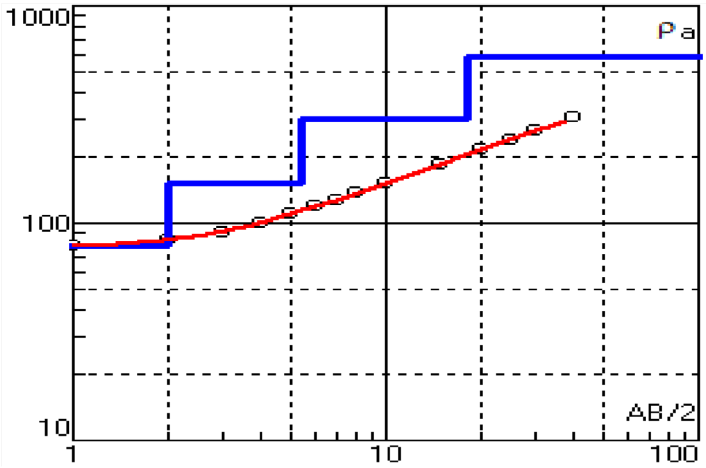

Figure 5. k-A type curve for VES road 3.

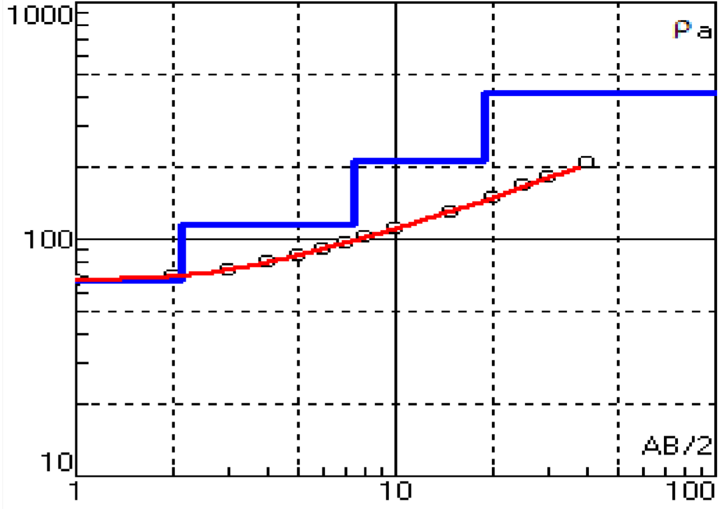

Figure 6. K-A type curve for VES road 4.

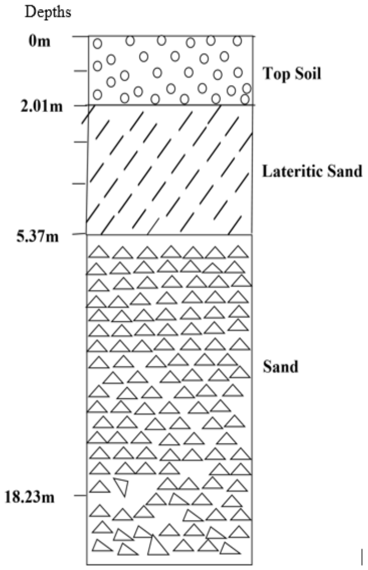

Figure 7. Geoelectric section for VES road 1.

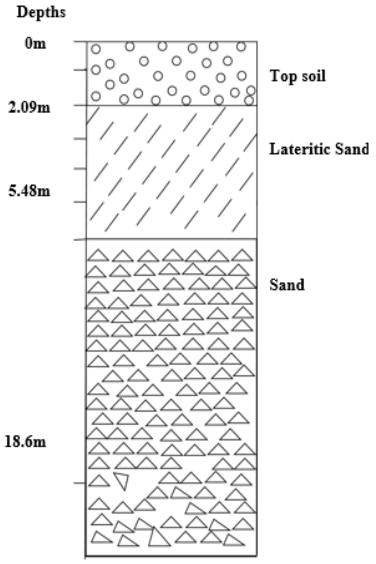

Figure 8. Geoelectric section for VES road 2.

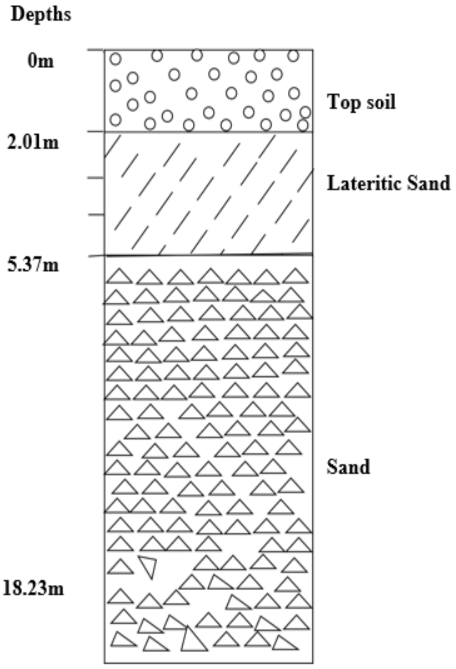

Figure 9. Geoelectric section for VES road 3.

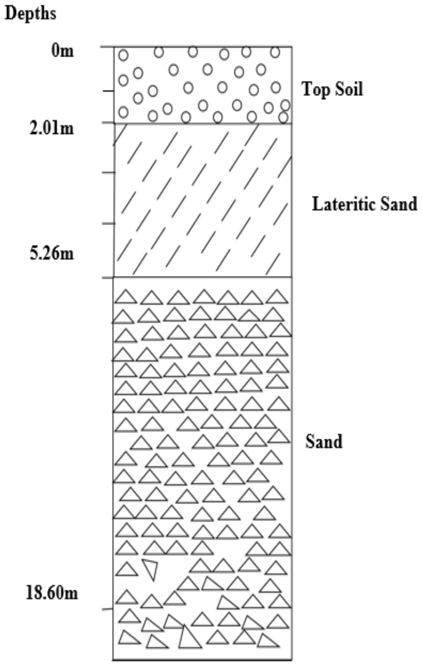

Figure 10. Geoelectric section for VES road 4.

Table 1. Resistivity values, depths, thickness and the lithological units for VES road one.

Layer	Resistivity(Ωm)	Depth(m)	Thickness(m)	Lithological unit
1	83.98	2.01	2.01	Top Soil
2	155.40	5.37	3.36	Lateritic Sand
3	266.70	18.23	12.8	Sand
4	537.60	- - - - - - -	- - - - - - -	Sand

Table 2. Resistivity values, depths, thickness and the lithological units for VES road two.

Layer	Resistivity (Ωm)	Depth(m)	Thickness(m)	Lithological unit
1	80.23	2.09	2.09	Top Soil
2	152.30	5.48	3.39	Lateritic Sand
3	306.90	18.6	13.12	Sand
4	506.20	- - - - - - -	- - - - - - -	Sand

Table 3. Resistivity values, depths, thickness and the lithological units for VES road three.

Layer	Resistivity (Ωm)	Depth(m)	Thickness(m)	Lithological unit
1	78.64	2.01	2.01	Top Soil
2	152.30	5.37	3.36	Lateritic Sand
3	300.80	18.23	12.86	Sand
4	582.40	- - - - - - -	- - - - - - -	Sand

Table 4: Resistivity values, depths, thickness, and the lithological units for VES Road four

Layer	Resistivity (Ωm)	Depth(m)	Thickness(m)	Lithological unit
1	67.00	2.01	2.01	Top Soil
2	115.40	5.26	3.25	Lateritic Sand
3	222.80	18.60	13.34	Sand
4	398.10	- - - - - - -	- - - - - - -	Sand

4.2 Presentation of 2D resistivity Results

The results of the electrical resistivity tomography along the four (4) traverses are presented as 2-D Pseudo sections of the subsurface resistivity varying both laterally and vertically in the mechanic village. For the road one tomo, two isolated zones of low and high anomalous resistivity zones and a background resistivity zone were delineated (Fig. 11). The low resistivity zones were delineated at surface points 70 to 86m and depths 0.469 to 8.28m. This zone has resistivity values between 66.1 and 121 Ωm. The high resistivity zones were delineated at surface points 40 to 48m and depths 2.26 to 8.29 m with a resistivity greater than 221 Ωm. These low resistivity zones are interpreted as degraded hydrocarbon-contaminated soils, while the high resistivity zones are interpreted as hydrocarbon uncontaminated zones in the soil resulting from spills due to mechanic activities in the mechanic village over time.

For the road two tomo, low resistivity zones alternating with background resistivities along the entire traverse were delineated (Fig. 12). Low resistivity anomalous zones were delineated at surface points 12 to 20m with depths of 4.29 to 7 m, respectively. Low resistivity values were also delineated at surface points 27 to 29 m with a resistivity value of 98.5 Ωm and depths of 0.469 to 4.31 m. Other zones with low resistivity values are at surface points 35 to 46m with a resistivity value of 166Ωm. This zone occurs from 0.469 to 4.30 m. At surface points 52.5 to 94 m with depths 0.469 to 4.29 m, a low resistivity area can also be identified. These low resistivity anomalous zones are interpreted as degraded hydrocarbon-contaminated soil.

The high resistivity anomalous zones extending to depths beyond 16m from Surface points 28 to 86m have resistivities greater than 236Ωm. These high-resistivity anomalous zones are interpreted as uncontaminated aquiferous sand zones.

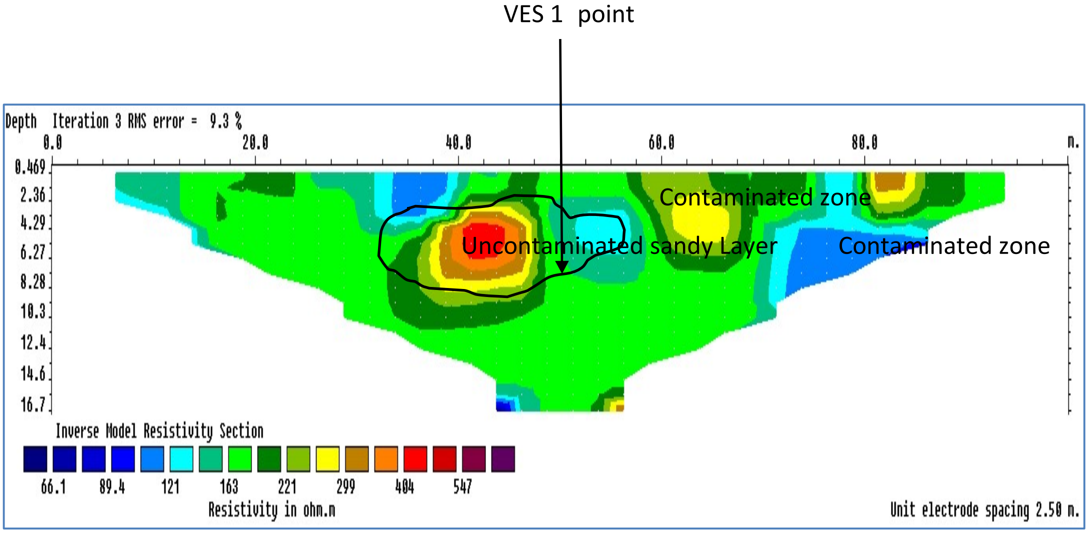

Figure 11. 2D Resistivity-Depth Structure of Traverse 1.

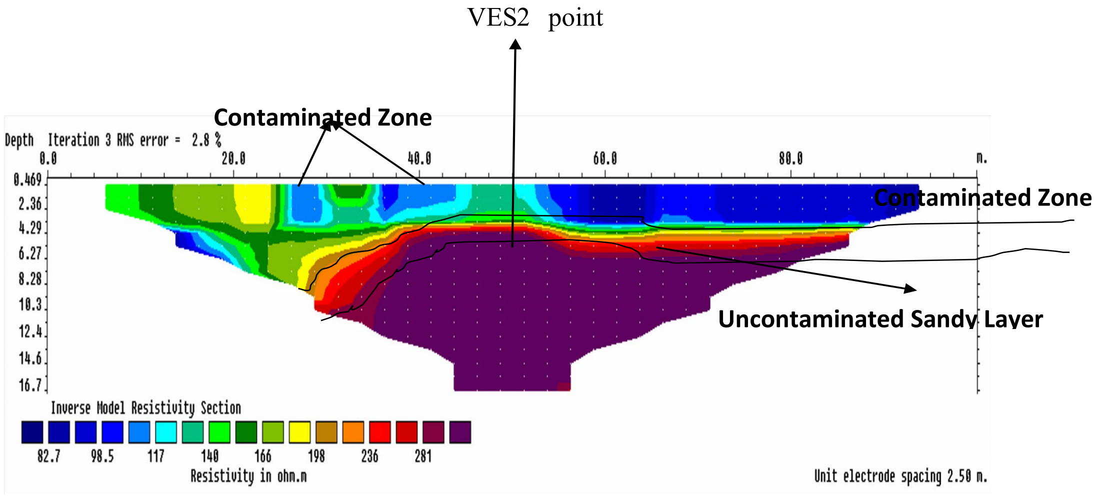

Figure 12. 2D Resistivity-Depth Structure of Traverse 2.

For the road three tomo, low resistivity anomalous zones alternating with high resistivity zones along the length of the traverse were delineated (Fig. 13). Low resistivity zones were delineated at surface points 15 to 25m at depths of 0.469 to 9.27m with resistivity values ranging from 16 to 52.8 Ωm. From 61 to 63.5 m and 0.496 to 3.36 m depth values, we have the low resistivity anomalous zone isolated along the length of the profile having a resistivity range of 0.135 to 1.47 Ωm. At 70 to 100 m and a depth, of 0.469 to 6.27 m, with a resistivity range of 16 to 52.8 Ωm, a low resistivity zone is apparent. These low resistivity anomalous zones are interpreted as degraded contaminated hydrocarbon sand zones. The high resistivity zones are at surface points 6 to 10 m and depths 0.496 to 2.36 m, 25 to 30m, and depths 0.496 to 3.10m with resistivities greater than 52.8 Ωm. These zones of high resistivity are interpreted as recent hydrocarbon spills in the soil which is the uncontaminated zone.

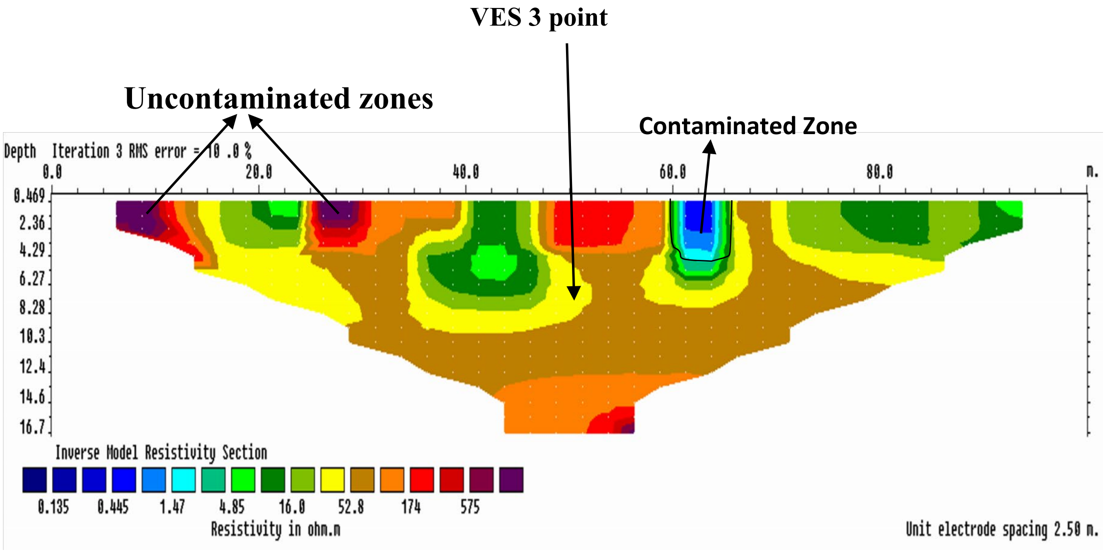

Figure 13. 2D Resistivity-Depth Structure of Profile 3.

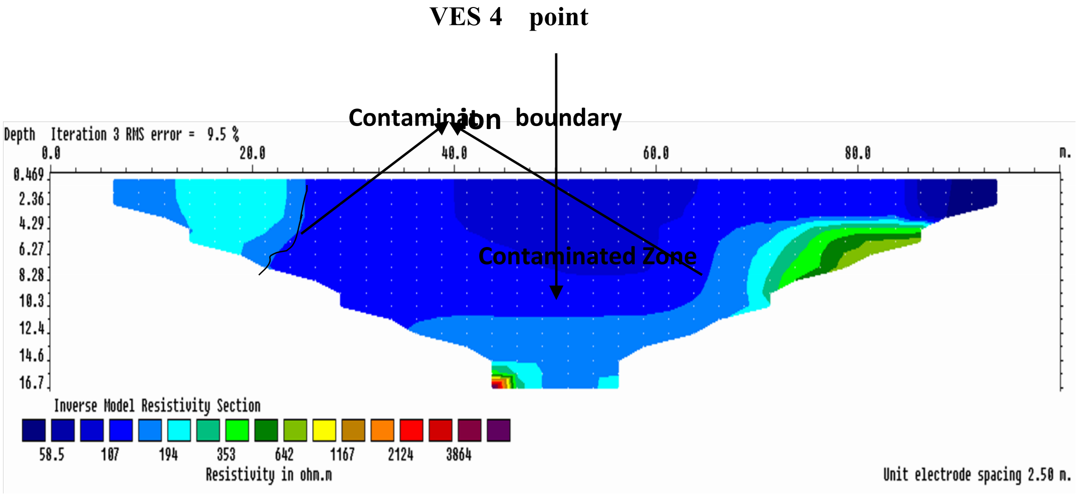

Figure 13. 2D Resistivity-Depth Structure of Profile 4.

For the road four tomo, generally low resistivity anomalous zones in the entire length of the profile extending to depths beyond 16 m and resistivities less than 194 Ωm were delineated (Fig. 14). The predominant low resistivity (< 58.3Ωm) zones were delineated at surface points 40 to 67m and 85 to 100m at depths of 0.469 to 8m and 0.469 to 4m, respectively. These low resistivity anomalous zones are interpreted as hydrocarbon-contaminated soil at various stages of degradation, probably due to mechanic activities in the workshop.

4.3 Presentation of Physico-Chemical and Heavy Metal Analysis of Borehole Water Samples

The results of four (4) groundwater samples, (BH1, BH2, BH3, and BH4C) for the physicochemical parameters such as Temperature, pH, Nitrate, Total dissolved solids (TDS), and Conductivity and also for the heavy metals such as Nickel, Iron, Lead, Manganese, Zinc, Chromium, Cadmium and Copper, are presented regarding their World Health Organization WHO (2004) and Nigerian Standard of Drinking Water Quality (NSDWQ) 2007 results.

The pH values for all the boreholes were below the WHO (2004) limit of 6.5 to 8.5 for potable groundwater. From the results, the groundwater at the mechanic village is moderately acidic, with BH1, BH2, and BH3 being more acidic than BH4C, which is the control. This could be attributed to the impacts of the auto mechanic village on the groundwater.

The temperature readings of the groundwater at the mechanic village for BH1, BH2, BH3, and BH4C are 29˚C, respectively. The temperature of the water sample in the mechanic village for BH1, BH2, BH3, and BH4C is higher than the World Health Organization WHO (2004) and Nigerian Standard of Drinking Water Quality NSDWQ. The temperature observed by the World Health Organization WHO, 2004) and the Nigerian Standard of Drinking Water Quality NSDWQ, 2007) is 25˚C in the study area.

Electrical conductivity result for BH1 is 64.1ϰs/cm, BH2 is 62.2ϰs/cm, BH3 is 63.13ϰs/cm and BH4C is 66.033ϰs/cm, respectively. The pH values of the water samples in the mechanic village for BH1, BH2, BH3, and BH4C are 4.1, 4.6, 3.9, and 5.4. Nitrate results for BH1 are 3.098, BH2 is 1.765, BH3 is 2.858, and BH4C is 2.65mg/l, and the Total Dissolved Solids (TDS) results for BH1, BH2, BH3, and BH4C are 113.33, 20.0, 193.33, and 106.0mg/l, respectively. For the heavy metals Ni, Fe, Pb, Mn, Zn, Cr, Cd, and Cu, values for BH1, BH2, BH3, and BH4C are presented. For Nickel, BH1 is <0.015mg/l, while in BH2, Ni is not detected yet, nor are BH3 and BH4C. The WHO (2004) standard for drinking water results for Nickel is 0.02mg/l, and the NSDWQ (2007) result is 0.02mg/l. Iron result for BH1 is <0.142mg/l, BH2 is <0.154mg/l, BH3 is 0.544mg/l, and in BH4C, Iron is not detected yet. The WHO (2004) standard for drinking water results for Fe is 0.3mg/l, and the NSDWQ (2007) result is 0.3mg/l. Lead results for BH1 is <0.118mg/l, BH2 is <0.277mg/l, BH3 is <0.136mg/l and BH4C is <0.124mg/l. The WHO (2004) standard for drinking water results for Pb is 0.05mg/l, and the NSDWQ (2007) is not detected yet. Manganese result for BH1 is 0.001mg/l, BH2 is <0.004mg/l, BH3 is <0.052mg/l and BH4C is <0.025mg/l. The WHO (2004) standard for drinking water results for Mn is 0.5mg/l, and the NSDWQ (2007) result is not yet detected. Zinc result for BH1 is 0.09mg/l, BH2 is 0.104mg/l, BH3 is 0.115mg/l and BH4C is 0.089mg/l. The WHO (2004) standard of drinking water result for Zn is 3.0mg/l, NSDWQ (2007) result is 3.0mg/l. Chromium result for BH1 is <0.045mg/l, BH2 is <0.022mg/l, BH3 is <0.090mg/l, BH4C is <0.003mg/l. The WHO (2004) standard for drinking water result is 0.05mg/l, NSDWQ (2007) result is 0.05mg/l. Cadmium result for BH1 is <0.024mg/l, BH2 is <0.012mg/l, BH3 is <0.043mg/l and BH4C is <0.024mg/l. The WHO standard for drinking water is 0.003mg/l, and the NSDWQ is 0.003mg/l. Finally for copper BH1 is <0.082mg/l, BH2 is <0.016mg/l, BH3 is <0.082mg/l and BH4C is <0.063mg/l. The WHO standard for drinking water is 1.00mg/l, and the NSDWQ result is 1.5mg/l. The heavy metals Ni, Pb, Mn, Zn, Cr, Cd, and Cu are in small concentrations and lower than the WHO (2004) and NSDWQ (2007) standards of drinking water. However, Fe^{2+} exceeded the WHO (2004) and NSDWQ (2007) of 0.3mg/l by 0.544mg/l.

4.4 Discussion

For the geoelectrical survey that was carried out in Elekahia mechanic village, VES road 4 resistivity values are less compared to those of road 3, VES road 3 resistivity values are also lower compared to road 2, but they are still low resistivities at shallow depths. For VES road 1, we have high resistivity values from the range of 83.98 to 537.60 Ωm, having depths of 2.01 to 18.23 m and thicknesses of 2.01 to 12.8 m, respectively. The lithological units from the first to fourth layers are topsoil, lateritic sand, and sand. This sequence of lithology is also the same for VES roads 2, 3, and 4. For VES road 2, we have a high resistivity value, but not higher than that of VES road 1. The resistivity ranges from 80.23 to 506.20 Ωm. It has depths of 2.09 to 18.6 m and thicknesses of 2.09 to 13.12 m, respectively. For VES road 3, we have high resistivity values, but not higher than those of VES road 2. It ranges from 78.64 to 582.40 Ωm, having depths 2.01 to 18.23 m and thicknesses 2.01 to 18.23 m. For VES road 4, we have low resistivity values in the sense that all the others are higher than it. Its resistivities range from 67.00 to 398.10 Ωm, having depths 2.01 to 18.60 m and thicknesses 2.01 to 13.34 m. The resistivity values for the probable aquifer for VES roads 1 to 4 are 266.70, 306.90, 300.80, and 222.80 Ωm, respectively, with depths of 18.23, 18.6, 18.23, and 18.60 m, and thicknesses of 12.8, 13.12, 12.86, and 13.34 m. The lithology of the probable aquifer is sand. Generally, for the geoelectric section, the VES type curve generated for these sections is a K-A type curve; each VES is separated from the other by 50 m.

For Tomo Road 1, the contaminated hydrocarbon zones were delineated at surface points 32 to 40 m along the traverse and depth 0.469 to 3.68 m. Also contaminated zone was inferred at surface points 72 to 86 m, having a range of resistivities 66.1 to 121 Ωm. The uncontaminated hydrocarbon zones were delineated at surface points 33 to 48 m and depths 4.29 to 8.28 m with resistivity ranges of 221 to 404 Ωm. Tomo Road 2 delineated contaminated zones at shallow depths, 0.469 to 4.29 m at surface points 26 to 29 m with resistivity ranges 82.7 to 117 Ωm; it also delineated contaminated zones at surface points 50 to 100 m with depth 4.29 m. Below shallow depths down the aquifer, we have uncontaminated zones at surface points 28 to 87 m and at depths 4.29 to depths below 16 m, with ranges of resistivity 236 to 281 Ωm. Tomo Road 3 delineated generally uncontaminated zones throughout the traverses except at an isolated zone of surface points 60 to 65 m with ranges of resistivity of 0.135 to 1.47 Ωm and at depth 0.469 to 4.29 m, which is the contaminated zone along the traverse. The uncontaminated zones have resistivities ranging from 16.0 to 575 Ωm, respectively. Tomo Road 4 delineated generally contaminated zones at depths below 16 m throughout traverses. The predominant low resistivity (<58.3 Ωm) zones were delineated at surface points 40 to 67 m and 85 to 100 m at depths of 0.469 to 8.0 m and 0.469 to 4 m, respectively.

The depths to the aquifer and their resistivity values are for road1 18.23 m and 266.70 Ωm, respectively. Road 2 is 18.6 m with a resistivity value of 306.90 Ωm, road 3 is 18.23 m with a resistivity value of 300.80 Ωm, and finally, road 4 is 18.60 m with a resistivity value of 222.8 Ωm. The lithology is sand, and the depth to the water table for roads one to four is 1 m to the aquifer. The depth to the water table for Road 1 is 17.23 m, for Road 2 is 17.6 m, for Road 3 is 17.23 m, and for Road 4 is 17.6 m. The resistivity values for the water table for Road 1 is 265.7 Ωm, for Road 2 are 305.9 Ωm, for Road 3 are 300.80 Ωm, and finally for Road 4 is 221.8 Ωm.

Results show that the liquid waste generated through the mechanic workshop activities is mainly petroleum hydrocarbons. These liquid hydrocarbons are gasoline, diesel, lubricating oil, and brake fluids. The spilled petroleum hydrocarbon infiltrates into the subsoil down to the water table as free-phase hydrocarbon if the release is a massive gasoline or diesel; otherwise simply wets the vadose zone (unsaturated zone) and then leaches into the groundwater aquifer undesirably, which affects the bulk electrical property of the soil.

The physicochemical analysis carried out on groundwater samples for the area showed differences in pH values between the mechanic village and the control, which may be because in the mechanic villages the biodegradation of oil-impacted soil gave rise to the production of CO_2, H_20, and organic acids. The organic acids reacted with the soil, generating more CO_2 and oxides of the metals. The reduced pH in the workshop resulted in greater availability of H^+ ions, thus making more cations Ca^{2+}, Na^+, $Fe^{2+,}$ and Mn^{2+} soluble in the water. These resulted in elevated levels of total dissolved solids (TDS) in the groundwater. These increases in TDS resulted in to increase in electrical conductivity. The results of the groundwater samples from the mechanic village and the control site are presented in Table 5.

For the physicochemical analysis, the pH result for BH1 is 4.1, BH2 is 4.6, BH3 is 3.9, and BH4C is 5.4. The WHO (2004) result values are 6.5 to 8.5, and the NSDWQ (2007) result values are 6.6 to 9.0. The pH was used to measure the acid content in the water sample. The temperature results are 29.0˚C for all four (4) borehole samples collected, and the WHO (2004) and NSDWQ (2007) temperatures for the four (4) borehole samples collected are 25˚C. The Nitrate values of the water samples in the mechanic village for BH1, BH2, BH3, and BH4C are 3.098, 1.765, 2.858, and 2.65mg/l. The electrical conductivity values of the water samples in the mechanic village for BH1, BH2, BH3, and BH4C are 64.1ϰs/cm, 62.2ϰs/cm, 63.13ϰs/cm, and 66.033ϰs/cm, respectively. Both conductivity values for BH1, BH2, and BH3 are less than BH4C. Electrical conductivity is the ability of water to conduct an electric current and is also a function of the number and types of dissolved solutes in the water.

Finally, the total dissolved solids (TDS) values of the water samples in the mechanic village for BH1, BH2, BH3, and BH4C are 113.33, 20.0, 193.33, and 106.0mg/l, respectively. For the heavy metals, the Nickel result for BH1 is <0.015mg/l, BH2 has not been detected yet so as are BH3 and BH4C. The WHO (2004) standard for drinking water results for Nickel is 0.02mg/l, and the NSDWQ (2007) result is 0.02mg/l. For Iron, BH1 is <0.142mg/l, BH2 is <0.154mg/l, BH3 is 0.544mg/l and BH4C is not detected yet. The WHO (2004) standard for drinking water results for Fe is 0.3mg/l, and the NSDWQ (2007) result is 0.3mg/l. For Lead BH1 is <0.118mg/l, BH2 is <0.277mg/l, BH3 is <0.136mg/l and BH4C is <0.124mg/l. The WHO (2004) standard for drinking water results for Pb is 0.05mg/l, and the NSDWQ (2007) has not been announced yet. For Manganese, BH1 is 0.001mg/l, BH2 is <0.004mg/l, BH3 is <0.052mg/l and BH4C is <0.025mg/l. The WHO (2004) standard for drinking water results for Mn is 0.5mg/l, and the NSDWQ (2007) result is still uncertain. For Zinc BH1 is 0.09mg/l, BH2 is 0.104mg/l, BH3 is 0.115mg/l and BH4C is 0.089mg/l. The WHO (2004) standard of drinking water result for Zn is 3.0mg/l, NSDWQ (2007) result is 3.0mg/l. For Chromium BH1 is <0.045mg/l, BH2 is <0.022mg/l, BH3 is <0.090mg/l, BH4C is <0.003mg/l. The WHO (2004) standard for drinking water result is 0.05mg/l, while the NSDWQ (2007) result is 0.05mg/l. For Cadmium BH1 is <0.024mg/l, BH2 is <0.012mg/l, BH3 is <0.043mg/l and BH4C is <0.024mg/l. The WHO standard for drinking water is 0.003mg/l, and the NSDWQ is 0.003mg/l. Finally for copper BH1 is <0.082mg/l, BH2 is <0.016mg/l, BH3 is <0.082mg/l and BH4C is <0.063mg/l. The WHO standard for drinking water is 1.00mg/l, and the NSDWQ result is 1.5mg/l.

Table 5. Results of Physico-Chemical Analysis of Groundwater Samples.

S/N		**BH1**	**BH2**	**BH3**	**BH4-CONTROL**	**WHO (2004)**	**NSDWQ (2007)**
	GPS Location	N04^{0}49′18.0″ E07^{0}01′18.6″	N04^{0}49′19.1″ E07^{0}01′25.4″	N04^{0}49′14.5″ E07^{0}01′16.5″	N04^{0}49′06.7″ E07^{0}01′33.5″		
	Physico-Chemical						
1.	$TEMP$(^{0}C)	29.0	29.0	29.0	29.0	25	25
2.	pH	4.1	4.6	3.9	5.4	6.5 – 8.5	6.6 – 9.0
3.	Nitrate (mg/l)	3.098	1.765	2.858	2.65	10.0	50.0
4.	TDS (mg/l)	113.33	20.0	193.33	106.0	1000.0	500.0
5.	COND (µ s/cm)	64.1	62.2	63.13	66.033	1000.0	1000.0
	Heavy metals						
6.	Nickel (mg/l)	<0.015	ND	ND	ND	0.02	0.02
7.	Iron (mg/l)	<0.142	<0.154	0.544	ND	0.3	0.3
8.	Lead (mg/l)	<0.118	<0.277	<0.136	<0.124	0.05	— —
9.	Manganese (mg/l)	0.001	<0.004	<0.052	<0.025	0.5	— —
10.	Zinc (mg/l)	0.096	0.104	0.115	0.089	3.0	3.0
11.	Chromium (mg/l)	<0.045	<0.022	<0.090	<0.003	0.05	0.05
12.	Cadmium (mg/l)	<0.024	<0.012	<0.043	<0.024	0.003	0.003
13.	Copper (mg/l)	<0.082	<0.016	<0.082	<0.063	1.00	1.5

5 Conclusion

The integration of geoelectrical methods and physicochemical analysis of borehole water samples in this study has been effectively used to assess the impacts of mechanic activities on groundwater in the study area. The VES results were displayed in four (4) geoelectric sections showing the lithology in the mechanic village. The K-A type curve with four (4) geoelectric layers and resistivity increasing uniformly with depth was delineated. The resistivity ranges from 83.98 to 537.60 Ωm and depths 2.01 to 18.23 m for VES road 1, 80.23 to 506.20 Ωm and depths 2.09 to 18.6 m for VES road 2, 78.64 to 582.40 Ωm and depths 2.01 to 18.23 m for VES road 3 and 67 to 398.10 Ωm and depths 2.01 to 18.60 m for VES road 4 along the four traverses; each VES is separated from each other by 50 m. Also, the ERT results presented as 2D Pseudosections of the subsurface resistivity varying both laterally and vertically in the mechanic villages had results showing high and low anomalous resistivity zones obtained through their resistivity values. Tomo 4 delineated low resistivity anomalous zones less than 194 Ωm in the entire length of the profile extending to depths beyond 16 m; it also delineated the predominant low resistivity zones with resistivity less than 58.30 Ωm. The physicochemical results were able to identify sites far away from the study area where we have both highly acidic groundwater and less acidic groundwater. Four (4) borehole water samples collected (BH1, BH2, BH3, and BH4C), three (3) from the study area (BH1, BH2, and BH3) and one (1) away from the study area as a control (BH4C). The results have identified high and low resistivity zones, signifying high and low aquifer contamination zones. High and low acidic zones were established within the area.

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