A GEOPHYSICAL INVESTIGATION OF A SOLID WASTE LANDFILL USING VERTICAL ELECTRICAL SOUNDING METHOD IN ALUU COMMUNITY, RIVERS STATE, NIGERIA.

ABSTRACT

Vertical electrical sounding was conducted at a solid waste landfill in Aluu community for a hydro-geophysical assessment of the contamination of soil and groundwater. The ABEM Terrameter employing the Schlumberger array was used for direct current resistivity model using a maximum electrode separation of AB/2 of 100 m. The acquired data was processed and interpreted using IPI2win software to produce 'A' type curve as well as resistivity and the thickness of the layers with depth. From the result, five layers were obtained and the first layer has a resistivity of 34.7 Ωm with a thickness of 1.84 m and was interpreted as the top soil. Underlying the first layer is a second layer with a resistivity value of 114 Ωm with a depth of 4.29 m and thickness of 2.45 m was interpreted as lateritic sand. The third layer with resistivity value of 215 Ωm with depth of 11.1 m and thickness of 6.83 m was interpreted as sand. There is a fourth layer with resistivity value of 605.0 Ωm with depth of 41.8 m and thickness of 30.6 m was interpreted as coarse sand and this could be the probable aquiferous zone. The fifth layer with resistivity value of 165 Ωm with undetermined depth and thickness was interpreted as clay. The results revealed that the surrounding soil and groundwater close to the landfill have actually been contaminated to depth exceeding 11.1m which is well within the groundwater aquifer system in the area.

Keywords: Aquiferous zones, resistivity imaging, solid waste landfill, leachate plume, groundwater.

Introduction

Groundwater as the main source of potable water supply for domestic, industrial and agricultural uses has been under intense pressure of degradation and contamination due to urbanization, industrial and agricultural related activities. Groundwater is said to be contaminated when it is unfit for the intended purpose and therefore constitute a nuisance to the user. The uncontrolled and indiscriminate dumping of waste materials on the land surface, landfill and water bodies has placed the groundwater at the risk of being contaminated. Various sources of groundwater contamination are indicated in figure 1 below.

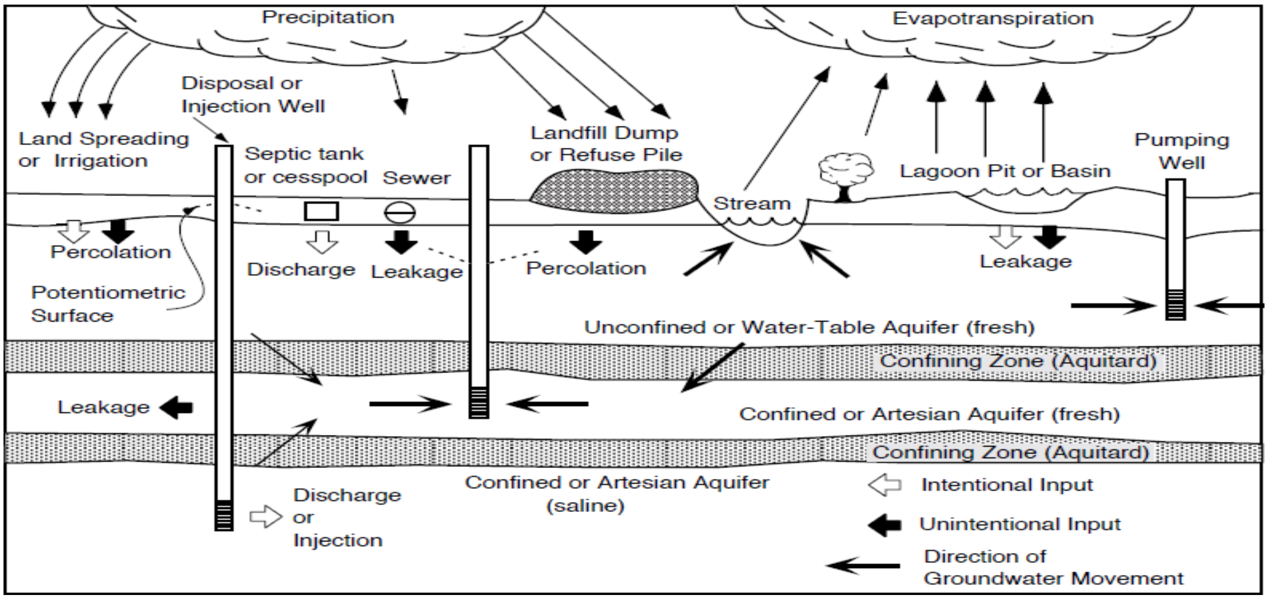

Figure1: How waste disposal practices contaminate the ground water system.
Source: (Philip *et al.,* 2000).

Electrical and electromagnetic methods are widely used for the investigation of groundwater contamination problems because the dissolved solid content is directly related to electrical conductivity and resistivity (Mazac *et al*., 1987; McNeill 1990; Benson *et al.,* 1997; Tezkan 1999).

The flow of groundwater in aquifer does not always mirror the flow of water on the surface. It is therefore necessary to know the direction of groundwater flow since the awareness helps us to map out the land area that recharges the public water supply, wells, streams, rivers, lakes, or creeks and thereby supports steps to ensure that land use activities in the recharge area will not pose a threat to the quality of the groundwater. With this information, one could also predict how contaminants move through the local groundwater system, since contaminants generally move in the direction of groundwater flow. It is also important to know if the groundwater system is a recharge or discharge system (Okengwu *et al*., 2015).

This study seeks to estimate the vertical extent of leachate contamination with little inference on the lateral flow of these contaminations.

At the study area, the problem of inadequate safe water is further exacerbated by contamination from a myriad of sources including industrial discharges, oil and gas activities, sewage disposal, domestic and municipal solid waste disposal. The poor state of solid waste management in rural and urban centres of developing countries is now not only an environmental problem but also a social handicap. Most municipal waste which is usually dumped at open grounds is left to adorn the streets of residential areas and leachate produced from mechanical and chemical action by rain freely contaminates surface and ground water (Woke and Babatunde, 2015).

Nearly 90% of diarrhoea related cases and deaths have been attributed to unsafe and/or inadequate water supplies and sanitation conditions (Abogan, 2014). According to Okiongbo and Ogobiri (2011), in the Niger Delta, water resources are plentiful but lack the quality for human consumption. Increased population due to rapid growth in the oil and gas industry instigated an increase in the demand for usable water. The emphasis is placed on the exploitation of the groundwater resource.

The problems of solid waste management in the city of Port Harcourt seem to be overwhelming, considering the quantity of waste being generated in the city and its environs. The problem of rural -urban migration into Port Harcourt city has agitated the minds of city planner’s. The attendant effect of this population increase is a concomitant increase in solid waste generation. The ineffective management of the solid waste in the city has lead to a number of hazards such as flooding of the city, offensive odours, poor aesthetic conditions, proliferation of disease vectors and traffic obstruction (Elenwo, 2015). Several studies, Elenwo (2015), Baadom *et al.,* (2015) and Owoeye and Okogie, (2013) among others have x-rayed the problems of Landfill in Port Harcourt Area. The works revealed that much are still needed to be done to be done to solve the health and environmental problems caused by the poorly managed landfill sites across the City.

Hydrogeology

In the Niger Delta Basin, Quaternary age sediments underlying the Delta Plain consist of coarse to medium grained unconsolidated sands and gravels with thin peats, silts, clays, and shales, forming units of old deltas. The underlying Miocene age Benin Formation is composed of gravels and sands with shales and clays. This multi-aquifer system formation crops out to the northeast of the coastal belt (Adelani *et al*., 2008).

Regional Hydrogeology: The Niger Delta

The most important aquifers in the Niger Delta are the Deltaic and Benin Formations. Most of the boreholes in the northern parts of the Niger Delta tap unconfined aquifers. In most of these boreholes the geological sequence consists of continuous sandy formations from top to the bottom. However, some aquifers occur under confined conditions resulting in artesian flows. The marked distinction in this area is discussed below.

Unconfined Aquifers

(1) Deltaic Formation: The water-table in the Niger Delta area is very close to the ground surface, ranging from 0 to 9 m below ground level. The aquifers in this area obtain steady

recharge through direct precipitation and major rivers. Rainfall in the Delta is heavy, varying from about 2400 mm a year inland to 4800 mm near the coast. Some proportion of the rainfall is lost by runoff and evapotranspiration.

(2) Benin Formation: The sediments of the Benin Formation are more permeable than those of the Deltaic Plains. The depth to water table ranges between 3 and 15 m below ground surface. A few values for seasonal fluctuations obtained from the area, indicate seasonal differences between 2.1 and 3.6 m. The Benin Formation, is sandy and highly permeable, with specific capacity 150 and 1400m3/d/m (Offodile 1992).

Confined Aquifers

Confined aquifers occur within both the Deltaic Formation and Benin Formation. These formations are characterized by moderately high yielding artesian flows. In some areas the aquifers are confined by a shale or clay bed up to 36 m thick. The total depth of the aquifers below this shale bed is not yet determined, however, borehole data indicate a depth of approximately 100 m. Hydrogeological information indicate a hydrological connection between the confined aquifers along the coastline and the unconfined aquifers of the Benin Formation to the north, inland. The aquifers increase in thickness towards the mainland, while the confining clays thin out. The specific capacity for this formation varies from 90–320m^3/d/m. In the area underlain by the Benin Formation, the confined aquifers occur in the southeastern part of the Niger Delta. The aquifer was confined by several shale and clay beds. The confined aquifers consist mainly of very coarse to medium-grained sands.

Regional Stratigraphic Setting

The Niger Delta stratigraphic sequence comprises an upward-coarsening regressive association of Tertiary clastics up to 12 km thick (figure 2). It is informally divided into three gross lithofacies: (i) marine claystones and shales of unknown thickness, at the base; (ii) alternation of sandstones, siltstones and claystones, in which the sand percentage increases upwards; (iii) alluvial sands, at the top. Three lithostratigraphic units have been recognized in the subsurface of the Niger Delta. These are from the oldest to the youngest, the Akata, Agbada and Benin Formations all of which are strongly diachronous (Dim, 2013).

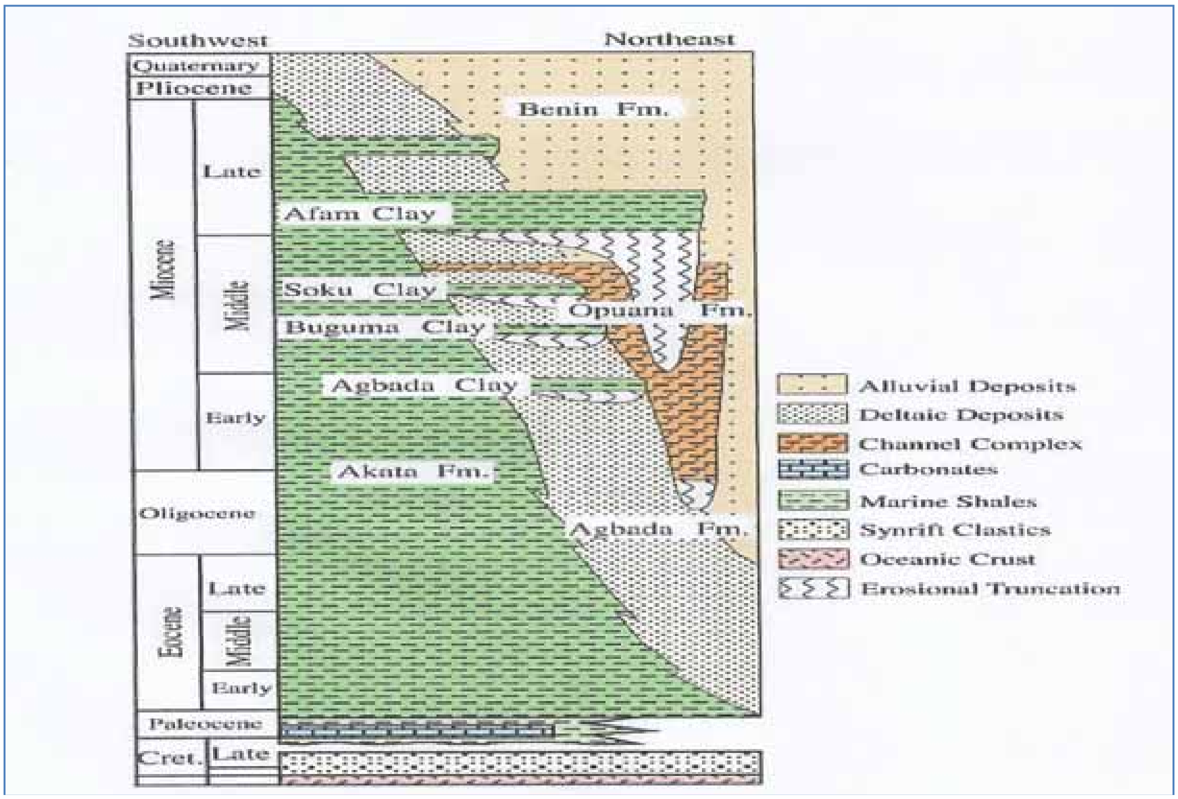

Figure 2: Stratigraphic Column Showing the Three Formations of the Niger Delta (Source: Dim, 2013)

Geology of the Area

The Aluu landfill has coordinates of latitude 04°54’52.4” North and longitude 006°54’28.8” East with an elevation of 20 m within choba community in Obio/Akpor Local Government of Port

Harcourt Metropolis in Rivers State, Nigeria. It has dimensions of about 160m by 35 m and it is accessible through the Aluu tarred road (Figure 3). The site is surrounded by a network of privately owned residential houses. Furthermore, the landfill is approximately 3km away from the University of Port Harcourt. The uncontrolled and indiscriminate dumping of waste materials on the land surface, landfill and water bodies has placed the groundwater at the risk of being contaminated. Aluu region is characterized by alternate seasons of wet and dry (Iloeje, 1972), with total annual rainfall of about 240 cm, relative humidity of over 90% and average annual temperature of 27°C (Udom and Esu, 2004).

Rapidly increasing population, rising standards of living and exponential growth in industrialization and urbanization tends to add pressure on natural resources (Amos-Uhegbu, *et al*., 2014). Most local groundwater supplies in Aluu, Uniport And Choba area comes from an unconfined Aquifer made up of Loose Soil materials such as sands, gravels, and floodplain deposits left by stream and rivers (Oseji *et al*., 2005; and Okolie, *et al*., 2005). Clay which could act as a very good filter for leachate is actually very poorly distributed within the hydrostratigraphic units of Aluu/Choba area (Ugwu and Nwosu, 2009). Hence, the believe of possible penetration of leachate from landfills into the aquifer system. Established lateral flow pattern of groundwater in the study area is towards the south and south-western parts (Okengwu *et al*., 2015).

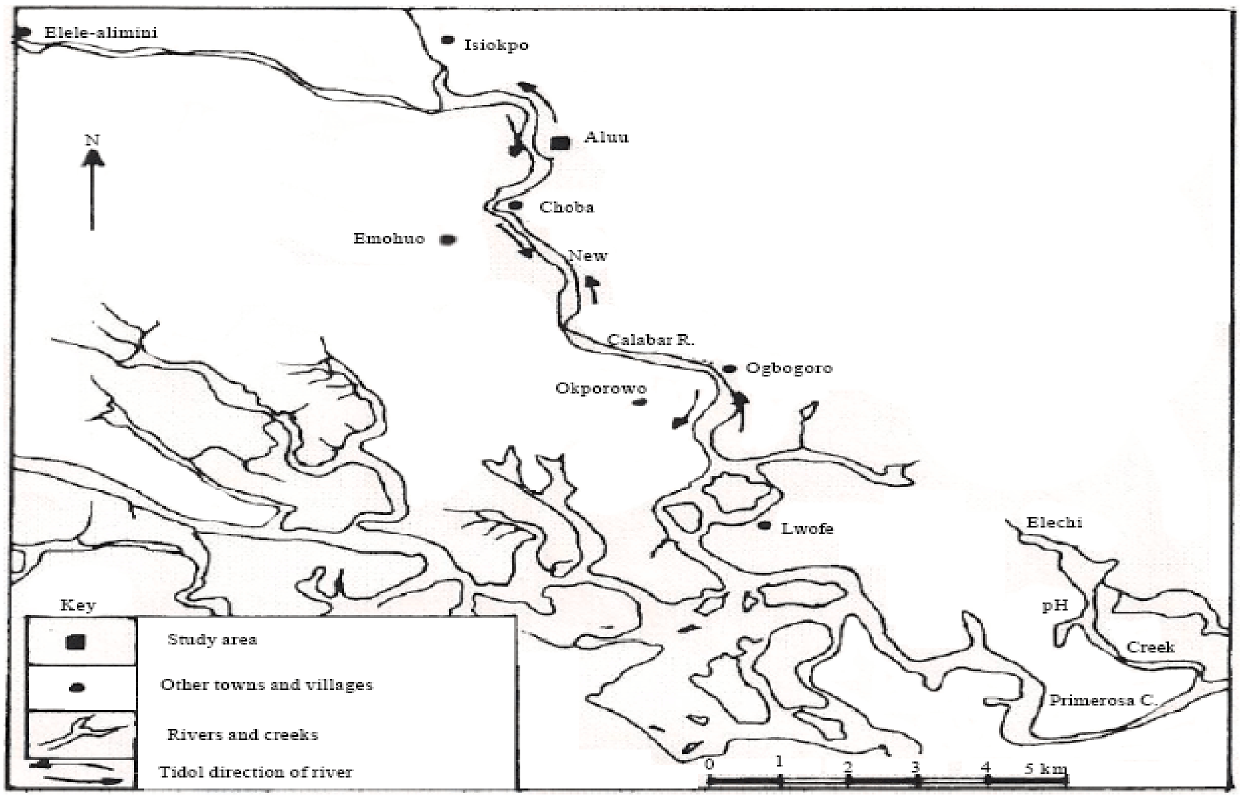

Figure 3: Map of the area (Source: google Search)

Methodology

Geo-electrical resistivity surveys are now commonly used for geotechnical investigations and environmental surveys (Loke, 1999). The resistivity method is based on measurements using two electrodes, of the potential distribution arising when electric current is transmitted into geological layers through two other electrodes. The resistivity of the subsurface is affected by porosity, amount of water in the subsurface, ionic concentration of the pore fluid and composition of the subsurface material (Keller and Frischknecht, 1988).

The electrical resistivity method in general involves passing current I into the ground through a pair of current electrodes and measuring the potential drop V through a pair of potential electrodes. The apparent resistivity of the model earth formation is related to the potential difference and the current by the equation.

$$\rho_a = K\frac{\Delta V}{I} \tag{1}$$

where K is the geometric factor for the electrode array in use.

When the distance between the two current electrodes is finite (figure 4), the potential at any nearby surface point will be affected by both current electrodes. The potential due to C_1 at P_1 is

$$V_1 = -\frac{A_1}{r_1} \quad where\ A_1 = -\frac{I\rho}{2\pi} \tag{2}$$

Because the currents at the two electrodes are equal and opposite in direction, the potential due to C_2 at P_1 is

$$V_1 = -\frac{A_2}{r_2} \quad where\ A_2 = \frac{I\rho}{2\pi} = -\ A_1 \tag{3}$$

Thus, we have

$$V_1 + V_2 = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \tag{4}$$

Finally, by introducing a second potential electrode at P_2 we can measure the difference in potential between P_1 and P_2, which will be

$$\Delta V = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\} \tag{5}$$

Such an arrangement corresponds to the four-electrode spreads normally used in resistivity field work. In this configuration the current – flow lines and equipotentials are distorted by the proximity of the second current electrode C_2.

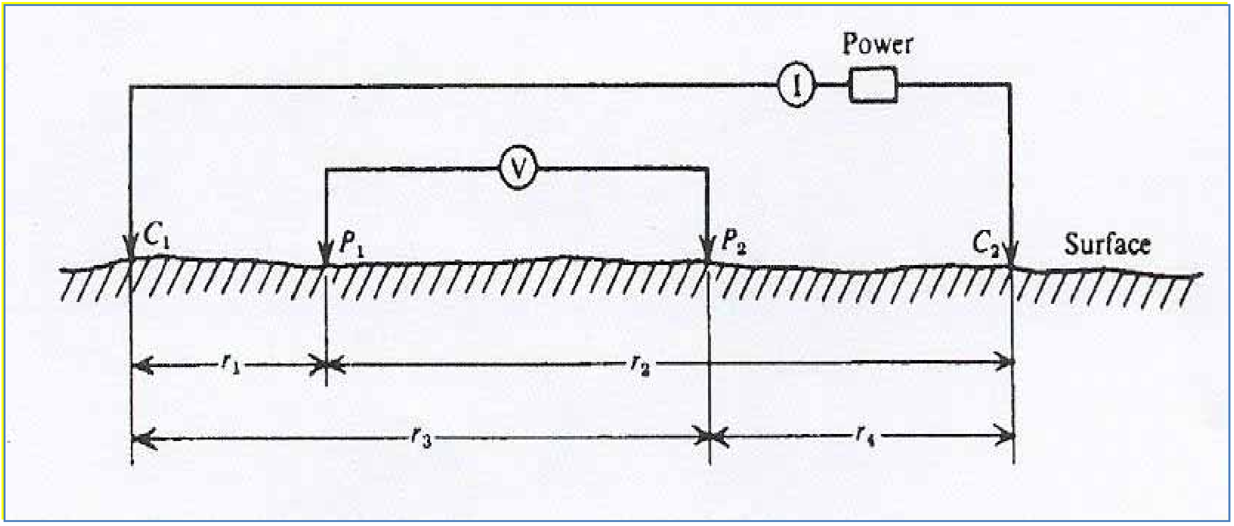

Figure 4: Two current and two potential electrodes on the surface of homogeneous isotropic ground of resistivity ρ (John, 2017)

The Schlumberger electrode configuration was used in all the sounding. In the Schlumberger configuration, all the four electrodes are arranged collinearly and symmetrically placed with respect to the centre. In this array the potential electrode separation is very small compared to the current electrode separation (Figure 5).

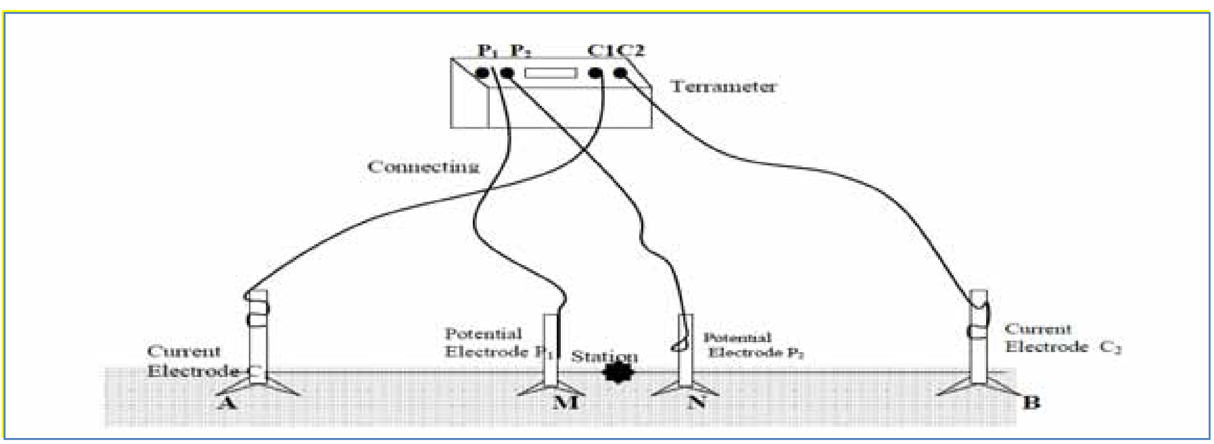

Figure 5: Vertical electrical sounding field layout for Schlumberger array (source: Igboekwe *et al.*, 2011)

One Schlumberger Vertical Electrical Sounding (VES) was carried out using a maximum current electrode separation of AB/2 of 100m. Digital averaging equipment, the ABEM Terrameter, was used for direct current (DC) resistivity work. The instrument displays directly the apparent resistivity of the subsurface under probe. It has an in-built DC power source. Four stainless metal stakes were used as electrodes. Other equipments includes wooden pegs, cables for current and potential electrodes, hammers (3) , measuring tapes and GPS to measure elevation (figure 6). The IPI2win software was used to analyze the data to obtain “A” type curve as well as resistivity and the thickness of the layers with depth.

Figure 6: Photographs of equipment and site view of survey runs

The results from electrical resistivity measurements were analysed together to understand the interrelation between electrical resistivity and soil properties. Correlation between the layer lithology and vertical electrical sounding is achieved by correlating the resistivity values with the standard values of resistivity as shown in Table 1.

Table 1: Resistivity of common geologic materials.

Materials	Normal Resistivity
Ash	4
Laterite	800 – 1500
Lateritic Soil	120 – 750
Gravel (Dry)	1400
Gravel Saturated)	100
Dry sandy Soil	80 – 1050
Sand Clay/Clayed Sand	30 – 215
Sand and Gravel	30 – 225
Saturated Landfill	15 – 30
Glacier Ice (Temperate)	$2 \times 10^6 – 1.2 \times 10^8$
Glacier Ice (Polar)	$5 \times 10^4 – 3 \times 10^5$
Permafrost	10^3 - > 10^4

Source: AbdulRahim *et al.*, 2016.

.

Results and Discussion

The processed field data for VES 1 carried out in the study area yielded an A-type curve (Fig 7) with five (5) geo-electric layers of resistivity values ranging from 34.7 Ωm to 605.0 Ωm. The depth to geo-electric layers also ranges from 1.84 m to 41.8 m.

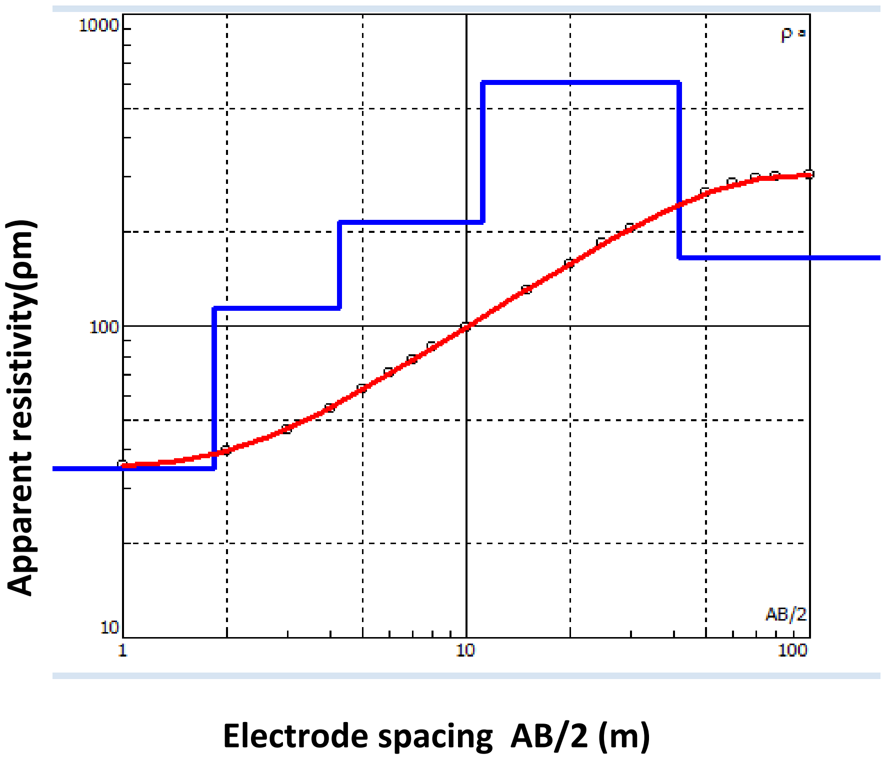

Figure 7: Computer Modeling for VES 1

The first layer has a resistivity of 34.7 Ωm with a thickness of 1.84 m were interpreted as the top soil (Table 2). Underlying the first layer is a second layer with a resistivity value of 114 Ωm with a depth of 4.29 m and thickness of 2.45 m was interpreted as lateritic sand. The third layer with resistivity value of 215 Ωm with depth of 11.1m and thickness of 6.83 m were interpreted as sand. There is a fourth layer with resistivity value of 605.0 Ωm with depth of 41.8 m and thickness of 30.6 m was interpreted as coarse sand and this could be the probable aquiferous zone. The fifth layer with resistivity value of 165 Ωm with undetermined depth and thickness were interpreted as clay. The geo-electric section is shown in Figure 8.

The presence of contaminants, usually in the form of carbonic acid, generally increases the hardness and conductivity of groundwater (Schneider, 1978). From our results, the first two layers show a clear evidence of groundwater contamination, going by the higher conductivity values. The conductivity value drops in the third layer indicating a layer with minor contamination.The fourth layer shows a very sharp increase in resistivity value. By our interpretation, we believe this to be an unconfined aquifer zone yet to be penetrated by the leachates.

The drastic drop in the resistivity value of the fifth layer suggests a possible clay interbed leading to a confined aquifer system. This interpretation agrees with the work of Ugwu and Nwosu (2009). Our results cannot possibly provide any information regarding the lateral extent of contamination. However, going by the report of Okengwu *et al.,* (2015), we also believe there is a possible lateral flow of the contaminants south-western of the landfill.

The results from this study is in agreement with the results obtained by Ugwu and Nwosu (2009). The duo worked on Effect of Waste Dumps on Groundwater in Choba using Geophysical Method, which is within the same study area for this work revealed that the first two layers at the dumpsite has resistivities of 59.91 and 20.10 ohm.m respectively and at the Demonstration Secondary school as 173.00 and 512.00 ohm.m respectively, showing that the groundwater at the dumpsite is polluted because of the high conductivity . This was confirmed by the laboratory water sample analysis from the environs.

Table 2: The resistivity value, depth, thickness and the lithologic units for VES 1

Resistivity (Ωm)	Depth (m)	Thickness (m)	Lithological Units
34.7	1.84	1.84	Top Soil
114	4.29	2.45	Lateritic Sand
215	11.1	6.83	Sand
605	41.80	30.6	Coarse Sand
165	…….	……….	Clay

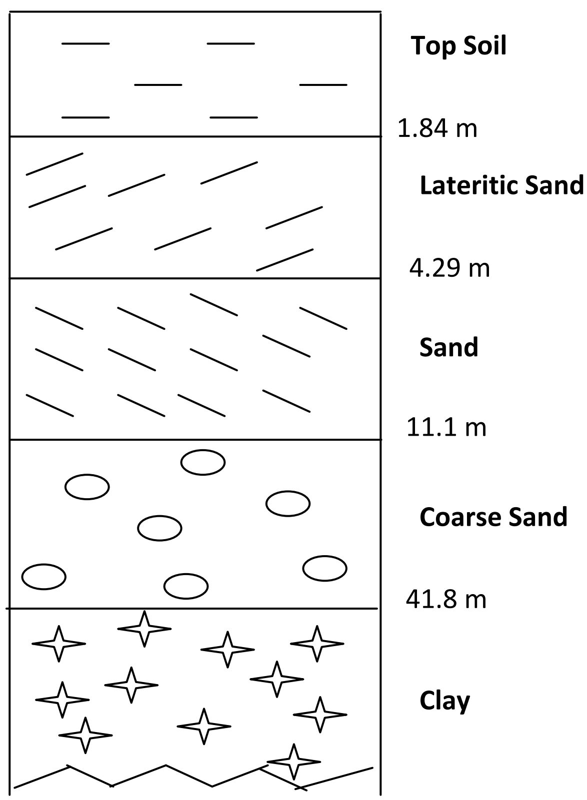

Figure 8: Geoelectric section of the study area

Conclusion

This work has clearly shown that the aquifer system within the area of study has been contaminated with leachates. The subsurface of the area has been contaminated down to a depth of about 11.1 m which means that, for one to drill a borehole in the area, it should be drilled to a depth range of 26-40 m. A possible lateral contamination of the surrounding groundwater system has also been inferred. The results here are in agreement with results from similar studies and previous researches in the area. We recommend these results as a preliminary basis for any major drilling work in the area, however, a more in-depth geophysical/geotechnical approach could equally be attempted for better interpretations.

References

AbdulRahim Asif1, Syed Samran Ali, Nazish Noreen, Waqas Ahmed, Sarfraz Khan, Muhammad Younis Khan and Muhammad Waseem (2016), Correlation of electrical resistivity of soil with geotechnical engineering parameters at Wattar area district Nowshera, Khyber Pakhtunkhwa, Pakistan. Journal of Himalayan Earth Sciences 49(1): 124-130

Abogan, O.S. (2014). Sanitation and Personal Hygiene: Antidote to Cholera Epidermic Outbreak in Challenging Environment in Nigeria. *Global Journal of Human Social- Science B: Geography, Geo-Sciences, Environmental Disaster Management*.14(1): 1-7 .

Adelani S. M. A., Olasehinde P. I., Bale R. B., Vrbaka P., Edet A. E. and Goni I. B. (2008), Applied Groundwater Studies in Africa – Chapter 11, An Overview of the Geology and Hydrogeology of Nigeria. 171-198. www.researchgate.net/publication/265686958.

Amos-Uhegbu, C., Igboekwe, M.U., Chukwu, G.U., Okengwu, K.O. and Eke, K.T., (2014). "Aquifer Characteristics and Groundwater Quality Assessment in Ikwuano Area of South eastern Nigeria: Journal of Scientific Research & Reports 3(2): 366-383.

Baadom Livinus E., Anselemi Ernest A. and Kpalap Elgior M. (2015), Environmental Issues in the Urban Fringe of Port Harcourt, Rivers State, Nigeria. International Academic Journal of Educational Research. 1(1): 42-53

Benson AK, Payne KL, Stubben MA (1997) Mapping groundwater contamination using dc resistivity and VLF geophysicalmethods – a case study. Geophysics 62:80–86

Dim Chidozie Izuchukwu Princeton (2013), Regional Stratigraphic and Structural Framework of Parts of the Eastern Coastal Swamp Depo-Belt of the Niger Delta. M.Sc. Thesis, Department of Geology, University of Nigeria, Nsukka. Unpublished.

Elenwo E. I. (2015), Solid Waste Management Practices in Port Harcourt Metropolis: Problems and Prospects. Journal of Geographic Thought and Environmental Studies, 13(1): 60-81. ISSN 1118-00064

Igboekwe, M.U., Efurumibe, E. L., Akaninyene, O. A. (2012). "Determination of aquifer characteristics in Eket, Akwa Ibom State, Nigeria, using the vertical electrical sounding method" International Journal of Water Resources and Environmental Engineering. 4(1): 1-7.

Iloeje N.P. (1972), "A new Geography of West Africa. Longman Group Ltd. Nigeria" 22-26.

John N. Louie (2017), Lecture Note on resistivity Methods. Available at: www.crack.seismo.unr.edu/ftp/pub/louie

Keller, G.V. and Frischknecht, F.C. 1988. *Electrical Methods in Geophysical Prospecting*. Pergamon Press Inc.: New York, NY. 38-39,519.

Loke, M.H. (1999). *Electrical Imaging Surveys for Environmental and Engineering Studies. A Practical Guide to 2D and 3D Surveys*. Advanced Geosciences, Inc.: Austin, TX. 57.

Mazac O, Kelly WE, Landa I (1987) Surface geoelectrics for groundwater pollution and protection studies. J Hydrol 93: 277–294

Mcneill JD (1990) Use of electromagnetic methods for groundwater studies. In: Ward SH (ed) Geotechnical and environmental geophysics, vol 1. Soc Expl Geophys, Tulsa, Oklahoma, 191– 218

Offodile, M. E. 1992. *An approach to ground water study and development in Nigeria*. Mecon, Jos, Nigeria, 246-247.

Okengwu, K. O., Nyenke, N.W. (2015), Groundwater Flow Pattern in Choba And Its Environs, Niger Delta, Nigeria. International Journal of Engineering Sciences & Management. Issn 2277 – 5528. 83-92

Okiongbo K.S. and Ogobiri G. (2011), Geoelectric Investigation of Groundwater Resources in Parts of Bayelsa State, Nigeria. Research Journal of Environmental and Earth Sciences 3(6): 620-624. ISSN: 2041-0492

Okolie, E. C., Osemeikhian, J. E. A., Oseji, J. O., and Atakpo, E., (2005). "Geophysical Investigation of the source of River Ethiope". Ukwuani Local Government area of Delta State. Nigeria Institute of Physics.17.

Oseji, J. O., Atakpo, E., and Okolie, E. C. (2005), "Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Kwale, Delta State".Nigeria Journal of Applied Sciences and Environmental Management 9(1):157 – 1600. ISSN 1119 – 8362. www.bioline. org.br.ja.

Owoeye I. O. Gani and Okogie O. H. (2013), Environmental Audit of a refuse Dump Site in the Niger Delta Region of Nigeria. Journal of Public Health and Epidemiology. 5(2): 59-65. ISSN 2141-2316. www.academicjournals.org/JPHE.

Philip, B., Hanadi, S., and Charles, J. (2000). "Ground Water Contamination;Transport and Remediation". Prentice Hall; 2 edition. ISBN-10**:** 0130138401

Schneider, W.A., (1978), Generalized Regional Geology of Nigeria with Emphasis on Niger Delta and MPN offshore license Terms MPNMXR – 307: 57 -70.

Tezkan B (1999), A review of environmental applications of quasi-stationary electromagnetic techniques. Surv Geophys 20: 279–308

Udom, G.J.and Esu, E.O. (2004), A preliminary Assessment of the Impact of Solid wastes on soil and groundwater system in parts of Port-Harcourt City and its Environs, Nigeria. 4(1): 23-32.

Ugwu, S. A. and Nwosu, J. I. (2009), Effects of Waste Dumps on Groundwater in Choba Using Geophysical Methods. Journal of Applied Sciences and Environmental Management. 13(1): 85-89.

Woke G. N. and Bolaji Babatunde B. (2015), Journal of Natural Science Research. ISSN 2225-0921. 5(24): 8-14. www.iiste.org