IMAGING AND CHARACTERIZATION OF THE SUBSURFACE ROCKS AT AMENYI DUMP SITE, AWKA, SOUTHEASTERN NIGERIA, USING THE ELECTRICAL RESISTIVITY METHOD

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Abstract
Two-dimensional (2D) Electrical Resistivity survey has been conducted at the dumpsite located at Amenyi, Awka, Anambra state, Nigeria, in order to investigate subsurface rock characteristics and delineate subsurface contamination plume. Three profiles at the dump site and one profile away from the dump site which serves as control were conducted using Wenner array. The field data was analyzed using the Res2Div inversion software. Grain size analysis was also done to characterize the rocks in the area and model their hydraulic properties. Hydrogeochemical analysis of groundwater samples collected in the area was carried out to investigate the effects of the dump site on the groundwater resources in the area. The results of the 2D resistivity survey showed that leachates from the waste dumps are infiltrating downwards and also laterally ways from the dump. The leachate plumes are associated with the low resistivities (Ωm) interpreted from zones at depth ranging from 0 to 8 m. The leachate transport is enhanced by the nature and geology of the overburden as hydraulic property modelled from grain size distribution analysis showed that the overburden rocks are significantly permeable. This collaborates with the inferences from the aquifer protective capacity analysis of the overburden rocks from resistivity data which classifies the aquifer protective capacity of the overburden rocks as weak. The results of the Hydrogeochemical analysis showed that the groundwater in the area has been contaminated by leachates from the waste dump as samples gave higher concentrations of chloride, total dissolved solids and electrical conductivity. It is therefore recommended that the dump site be relocated from the present location and established in other locations where the overburden geology is such that leachate are contained and prevented from infiltrating and polluting groundwater. Such areas should be underlain by rock of very low permeability.

Keywords: Subsurface characteristics; Resistivity; Niger Delta.

1. Introduction
Resistivity survey is a type of geophysical survey carried out using a resistivity meter with its accessories. Resistivity surveys are applied to detect resistivity variations/distributions of the subsurface rocks. 2-D electrical resistivity method has been found to be valuable and particularly adaptable to work involved in environmental studies. According to (10), resistivity methods use artificial sources of

current to produce an electrical potential field in the ground. In almost all resistivity methods, a current is introduced into the ground through point electrodes and the potential field is measured using two other electrodes (the potential electrodes). As the potential, the current and the electrode configuration are known, the resistivity of the ground can be determined and it is referred to as the "apparent resistivity". The aim of generating and measuring the electrical potential field is to determine the spatial resistivity distribution or its reciprocal (conductivity) in the ground.

Two- dimensional resistivity imaging combines sounding and profiling in a single process to investigate complicated geological structures with strong lateral resistivity changes. This combination provides detailed information both laterally and vertically along the profile and is frequently applied in environmental studies. 2D inversion yields a two-dimensional distribution of resistivity in the ground.

The region around the Amenyi dump site area is becoming populated and therefore characterization of the surface and subsurface rock distribution and properties are important for sustainable management of the groundwater resources (Figure 1). The deduced soil characteristics of the Amenyi dump site are used as preliminary information to determine the suitability of the site for its current use. If this crucial step is omitted, concealed geologic features within the subsurface may lead to groundwater contamination in the area.

The municipal waste of the Amenyi dump site contains nitrates, heavy metal and organic materials that are sources of pollution to underground aquifers. (1). The resultant leachate which percolates into the soil after much precipitation is associated with high ionic concentrations. These ionic concentrations which reduce rock resistivity values makes electrical delineation of generated contaminant leachate plume plausible (23; 24).

Figure 1: Amenyi Dump Site Front view

2. Literature Review

Regional Tectonics and Stratigraphic Setting of the Study Area

The study area covers latitudes 06°13'00" N to 06°14' 00"N, and longitudes 07°05' 30"E to 07°06' 00"E, with an area extent of about 150km². The origin of the Niger Delta Basin is related to the development of the Benue Rift (14). The Benue rift originated as an aulacogen during the breakup of the super Continent-Gondwanaland which led to the opening up of the Southern Atlantic and Indian oceans in the Jurassic (2; 19; 8). The Niger Delta Basin occupies the coastal and ocean ward part of a much larger and older tectonic feature, the Benue trough. The Benue trough is a NE-SW folded rift basin that runs diagonally across Nigeria (14; 2).

The initial synrift sedimentation in the embryonic trough occurred during the Aptian to early Albian and comprised alluvial fans and lacustrine sediments of the Mamfe Formation in the southern Benue Trough (18). The stratigraphy of the southern Benue Trough was described by (9) in the concept of three tectonic sedimentary cycles. The first cycles which occurred from Aptian to Coniacian and was ushered in by the opening up of the Benue Trough during the Jurassic to Aptian times, led to the deposition of synrift sediments in environments varying from continental to shallow marine (14; 9). The second cycle occurred after the Santonian folding and uplift of the sediments of the first cycle and then the Anambra Basin together with the Afikpo sub basin experienced subsidence (14; 2; 16; 21). The third cycle started after the filling up of the Anambra Basin and Afikpo sub basin with Campanian to early Paleocene facies (20) and the subsequent lateral basin ward shift (progradation) of the sediments into the modern Niger Delta Basin from the late Paleocene to recent.

The study area is underlain by the early-middle Paleocene Imo Formation (22; 14) and the Eocene Ameki Group. The Imo Formation has also been considered to be the basal unit of the Tertiary Niger Delta Basin which overlies the Nsukka Formation of the Anambra Basin (15) and its subsurface equivalent to be the pro-delta Akata Shale (25).

A major marine transgression was induced by the subsidence in the early Paleocene which led to the deposition of the Imo Formation and its subsurface equivalent, the Akata Formation. This was followed upwards by the Eocene to Oligocene regressive events during which the Ameki Group (Ameki Formation, Nanka Formation and the Nsugbe Formation), Ogwashi-Asaba and their subsurface equivalent, the Agbada Formation were deposited. Deposition in the basin was capped by the continental (Fluviatile) Benin Formation (13; 25; 15).

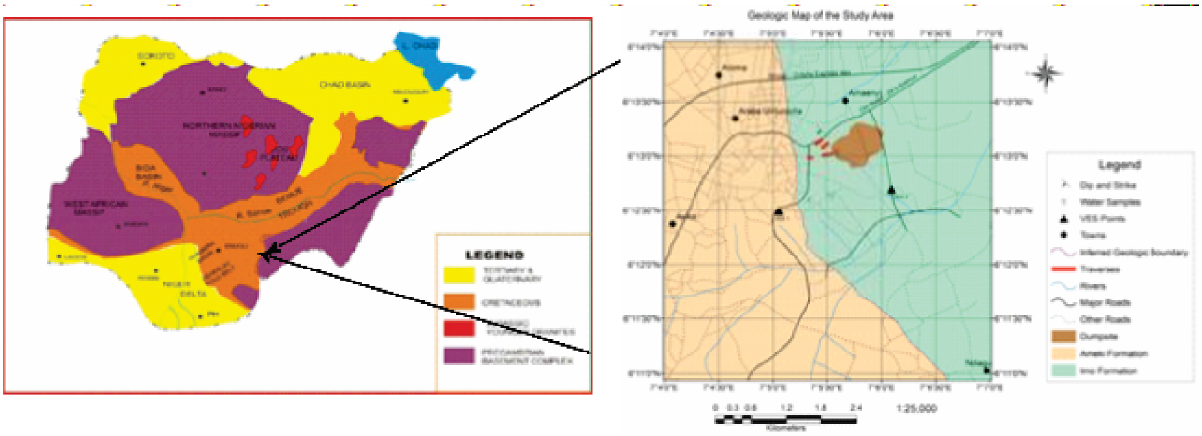

Figure 2: Geologic Map of the Study Area. (Nigerian Geological Survey Agency NGSA)

3. Data acquisition and methodology.

The electrical resistivity data was obtained using the Ohmega earth resistivity meter, manufactured by Allied Associates Geophysical Limited and the field data were processed using the inversion software RES2DINV (5; 12). A total of four lines of 2D electrical resistivity imaging were performed along profiles. Wenner electrode configuration was used during the resistivity measurements with electrode spacing of 3m, 6m, 9m, 12m, 15m and 18m. The two outer current electrodes (C_1 and C_2) supply the constant electric current (I), while the inner electrodes (P_1 and P_2) measured the voltage difference (ΔV). The apparent resistivity of the subsurface can be computed using the following formula:

$$\rho = 2\pi aR \qquad 3.1$$

Where a=electrode spacing and R=resistance.

Surface geological mapping was also carried out in order to investigate the lithologic and structural character of the formations underlying the dumpsite which is of significant importance to the suitability or otherwise of the area for use as dumpsite. Appropriate sand samples were collected randomly around the dumpsite for particle size distribution analysis using the sieve machine after which the readings were tabulated and the cumulative weight passing was plotted against the sieve size (mm). Results from the grain size analysis was used to model the hydraulic properties of the various lithologies surrounding the dump site.

Hydrogeochemical data analysis was carried out using three groundwater samples that were collected from wells located close to the dump site, and were investigated for various physio-chemical parameters such as: conductivity, total dissolved solid (TDS), pH, Hardness (H), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^-), carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), nitrates (NO_3^-), sulphates (SO_4^{2-}) dissolved oxygen, total coli form and fecal coli form. The samples were stored in a sterilized 50cl bottles and transferred to the laboratory for analyses

4. Results and Discussions

4.1 Geophysical Analysis.

The inversed resistivity models of the four resistivity lines after filtering and enhancement are represented figures 3 -6. Figure 3 represented the pseudo-section of the profile line located away from the dump site which will serve as control in the interpretation of the other profile lines / pseudo-sections taken at the dump site and presented as figures 4-6. Areas/zones with anomalously low resistivities (higher conductivities) within the pseudo-sections within the dump site profiles were interpreted to represent leachate plumes, which appear to have seeped through the underground soil to depth as far as 8m below surface. Comparing figures 4 -6 against figure 3, it can be seen and interpreted that zone of low resistivity (dark blue) occur at the surface and near surface regions. These low resistivity distributions are relatively less prominent the controls station profile (figure 3), and it is interpreted to be leachate plumes form the waste within the dump site.

Information from the 2D resistivity sections gave an indication of the travel path of leachate from the dump site to be in the Southeastern direction of the study area as can be seen from the profiles in Figure 4-6. The lateral spread of plume could not be fully delineated in view of the limitation of covered area.

The inverse resistivity model section for profile 1 (Figure 3) which serves as control consists of three zones of low resistivity anomalies occurring at horizontal distances between 4.5m-10 m and 15m-20m (major plume), an evidence of leachate plume accumulation, and 48-60 m (minor plume) an evidence of leachate plume transport.
As shown in Figure 4, the resistivity model of profile 2 shows three zones of low resistivity anomalies at horizontal distance of 4.5m-18m (major plume), with resistivity value less than 100Ωm, an evidence of leachate plume accumulation, and 48-88 m (minor plume) with resistivity value greater than 100 Ωm but less than 200 Ωm, an evidence of leachate plume transport.

Similarly, for profile 3 (Figure 5), low resistive zones with resistivity values below 100Ωm occur at horizontal distance of 24-92 m (major plume), and 9-23m (minor plume). The low resistive zones extend from the surface up to 8.06 m depth.

The inverse resistivity model section for profile 4 (Figure 6) showed that the resistivity distribution is much well horizontally layered which suggest the influence of rock layering as the main cause of resistivity distribution, however those of Figure 3 and 4 are much chaotic and less horizontally distributed which suggest the influence of leachate dispersion other than only rock distribution/layering. More so, it can be deduced from Figure 6 that there was massive leachate transport/flow due to the topography of the area. The migration of the contaminant leachate plume downwards is an indication that it is denser and may get to the zone of the water bearing units. This suggests that the soil and groundwater around the dump area may be contaminated since there are shallow boreholes in the study area.

4.2: VES Analysis/ Correlation of Geo-Electric Log and Lithology Log

Resistance data (in ohms) for the two VES point locations were converted to apparent resistivity (in ohmmeter) by multiplying it with the appropriate geometric factor. The apparent resistivity data ρ (Ωm) were used as inputs to a computer aided processing code (interpex analysis software) to generate model curves. These model curves were adjusted through a minimization procedure in an iterative manner to ensure a match with the field curve from which appropriate models were obtained. The results, which gave RMS error of <5%, revealed four to five geoelectric layers/units with their corresponding thicknesses and type KA and HA curve respectively. Also Litho-log data was correlated with the borehole log from the study area. Figure7 & 8 shows the Geo-electric logs and the correlation of geo-electric logs and borehole log of the study area respectively.

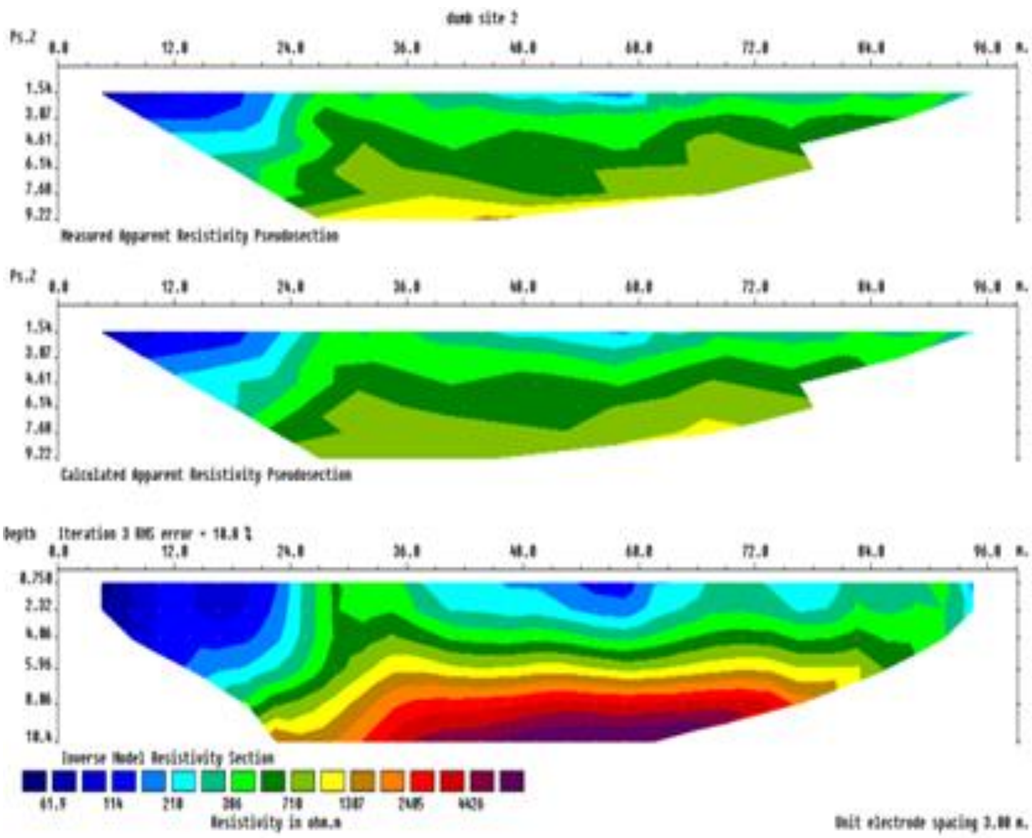

Figure 4: Measured apparent resistivity pseudo-section for control profile 1.

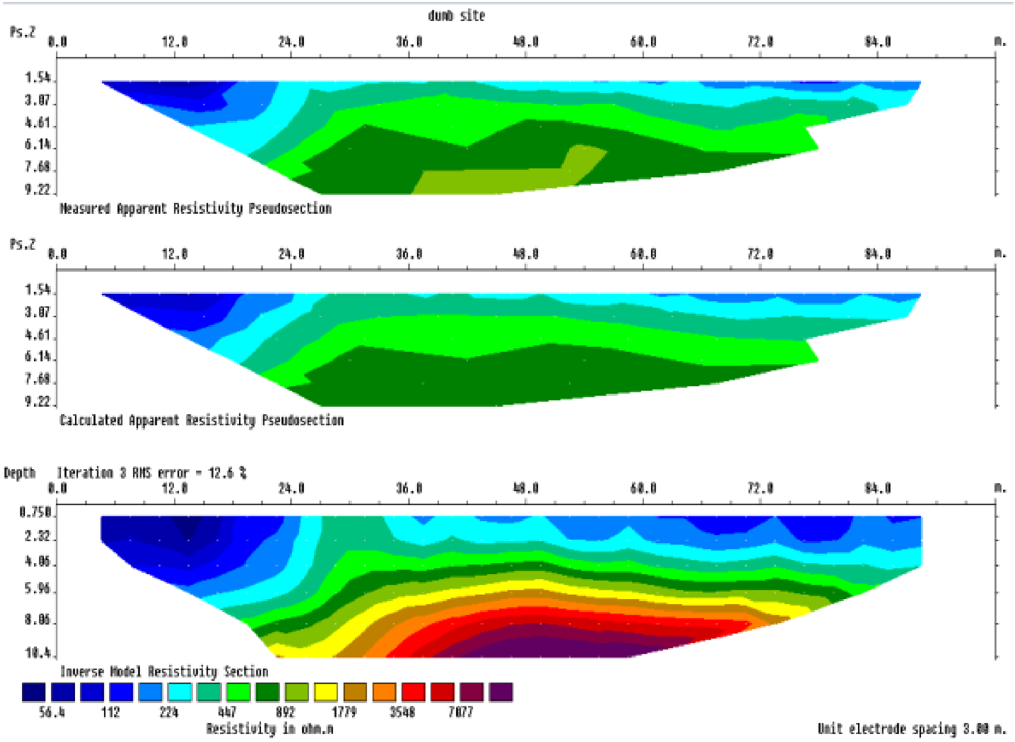

Figure 4: Measured apparent resistivity pseudo-section for profile 2.

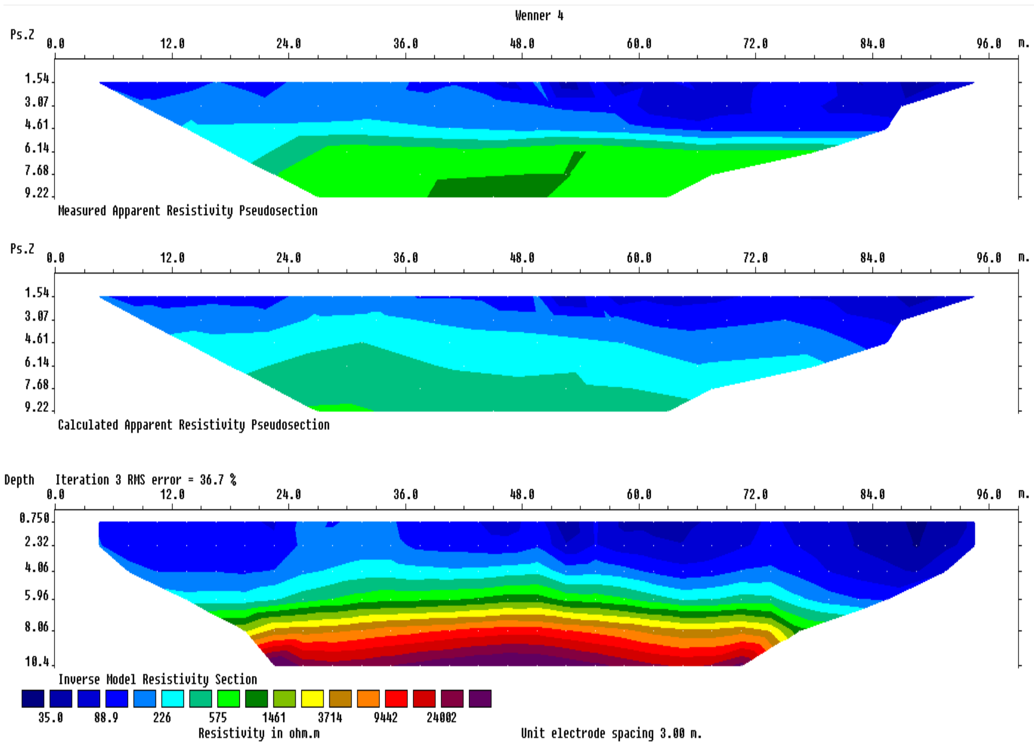

Figure 5: Measured apparent resistivity pseudo-section for profile 3.

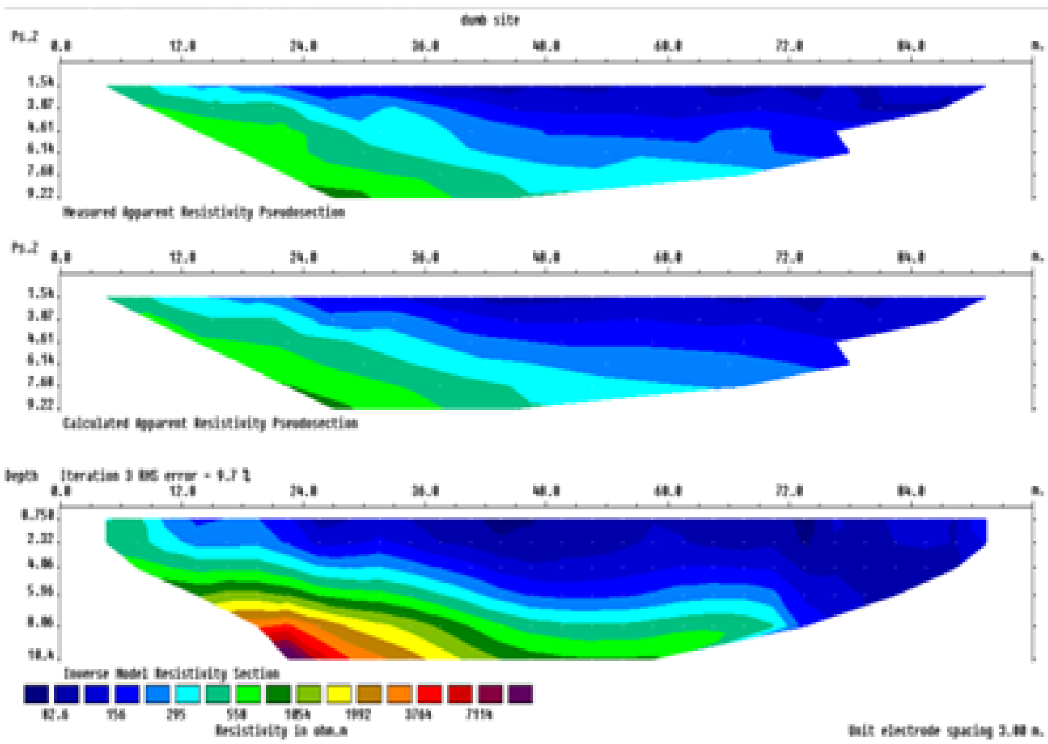

Figure 6: Measured apparent resistivity pseudo-section for profile 4.

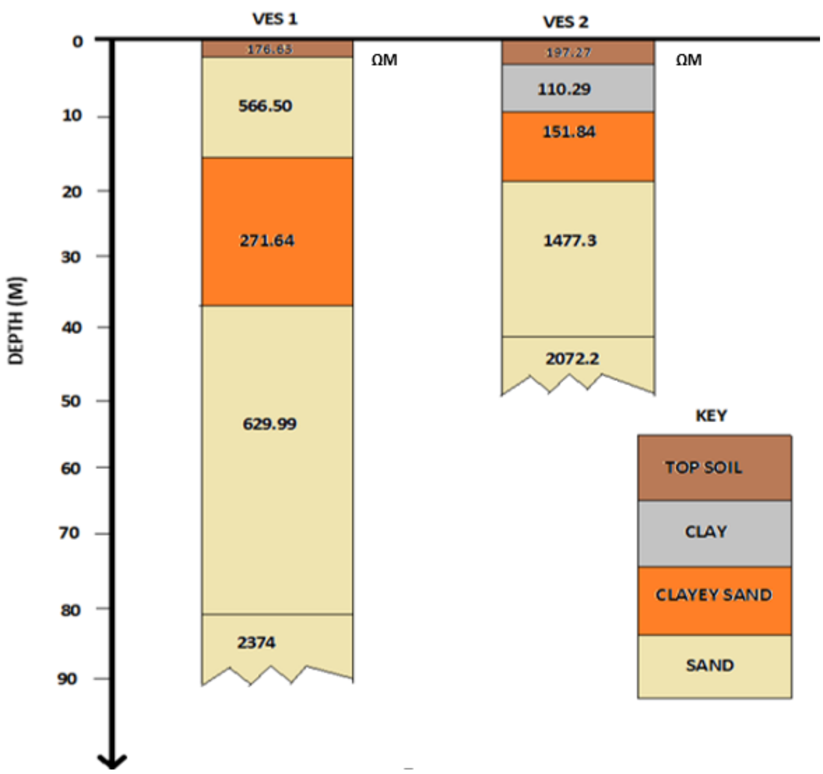

Figure 7: Geo-electric sections generated from VES 1 and 2.

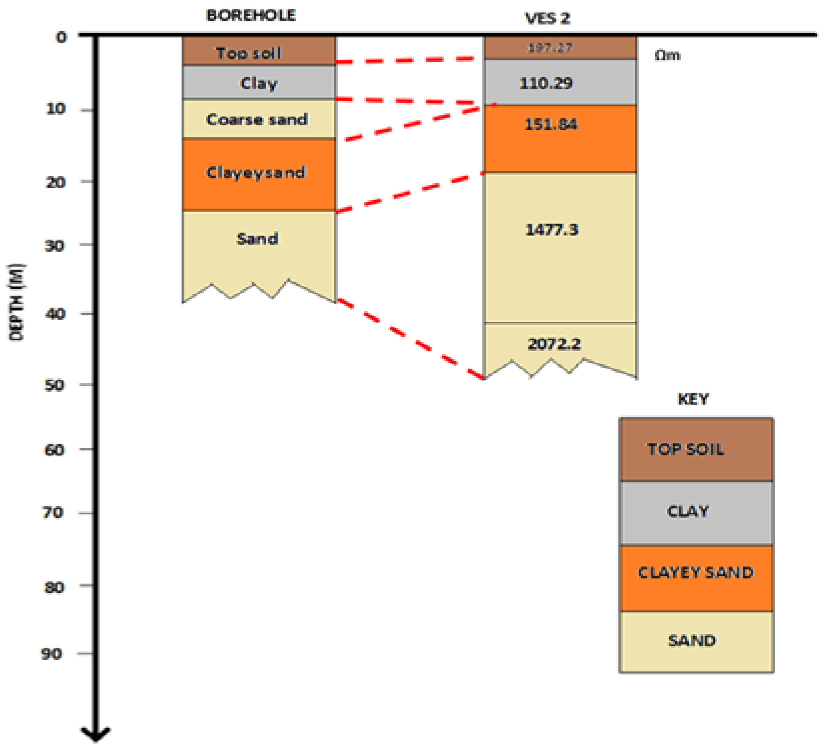

Figure 8: Correlation of the Borehole log and the Geo-electric log.

From figure 7, it is seen that the first geo-electric layer has an apparent resistivity value of 197.27 Ωm and corresponds to the first lithology layer (Top soil) which consists of sandy shale. The second geo-electric layer with apparent resistivity value of 110.29 Ωm corresponds to the second lithology layer (Shale). The third lithology layer appears missing in the geo-electric section, while the third geo-electric layer with apparent resistivity of 151.84 Ωm corresponds with the fourth Lithology layer (Clayey sandstone). The fourth and fifth geo-electric layer corresponds to the fifth lithology layer which is sandstone.

4.3 Overburden Aquifer Protective Capacity

Making reference to the thicknesses of the layers and their apparent resistivity values calculated from the geo-electric survey, longitudinal unit conductance of the overlying overburden was estimated. The values range from 0.153 to 0.182. Longitudinal Conductance relates to Aquifer Protective Capacity Rating (7; 18 and 17), and this was used to classify the protective capacity of the overburden strata into various degree of protection. The result indicates that the study area has poor protective capacity and hence vulnerable to leachate infiltration as summarized in Table 1. It therefore implies that the aquifers in these locations are vulnerable to contamination through infiltration.

Table 1: Longitudinal conductance, and the protective capacity of the VES points.

VES Location	**Layer**	**Resistivity** (Ωm)	**Thickness (m)**	**Depth** (m)	**Longitudinal Conductance (S)**	**Overburden Capacity**
1.	1 2 3 4 5	176.65 566.50 271.64 629.99 2374.0	1.9985 13.731 21.626 42.161	1.9985 15.729 37.355 80.516	0.0113 0.0242 0.0796 0.00669	0.182 Weak
2.	1 2 3 4 5	197.27 110.29 151.84 1477.3 2072.2	2.2539 7.6786 8.5326 22.982	2.2539 9.9325 18.465 41.447	0.0114 0.0696 0.0562 0.0156	0.1528 Weak

4.4. Hydraulic property characterization using grain size distribution results.

Samples were collected from the site and analyzed for grain size distribution at the Nnamdi Azikiwe University Geological Sciences Laboratory. The results were tabulated in Table 2. Table 3 was used to interpret the results and it shows that the area is made of about 98% sand and only about 2% of silt and clay and the sediments were found to be loose and friable.

Table 2: Summary of Statistical Parameters for Samples 1 to samples 5.

Sample no	**Median**	**Mean**	**Standard Deviation (Sorting)**	**Skewness**	**Kurtosis**	**Coefficient of Uniformity (CU)**	**Coefficient of Curvature (Cc)**
1	0.6	0.7033	0.54628 (moderately sorted)	0.489	1.14018	2.667	0.66777
2	0.39	0.41	0.3097 (very well sorted)	0.2589	2.0129	4.44	1.736
3	0.38	0.56	0.6084 (moderately sorted)	0.620	1.96	4.5	0.98
4	0.6	0.65	0.3349 (very well sorted)	0.563	1.070	1.57	0.831
5	0.30	0.35	0.2305 (very well sorted)	0.6032	2.434	1.84	0.72

Table 3: Descriptive measures of grain size distribution (Folk and Ward, 1957).

Mean	**Skewness**	**Kurtosis**	**Sorting (SD)**
0-1 (coarse sand)	-1.0 to -0.30 (very negatively skewed)	<0.67(very platykurtic)	≤0.35 (very well sorted)
1-2 (medium sand)	-0.30 to -0.1 (negatively skewed)	0.67 to 0.90 (platykurtic)	0.35 to 0.50 (well sorted)
2-3 (fine sand)	-0.1 to 0.1 (symmetrical)	0.90 to 1.11 (mesokurtic)	0.50 to 1.00 (moderately sorted)
	0.1 to 0.3 (positively skewed)	1.11 to 1.50 (leptokurtic)	1.0 to 2.00 (poorly sorted)
	0.30 to 1.00 (very positively skewed)	1.50 to 3.00 (very leptokurtic	2.00 to 4.00 (very poorly sorted)
		>3.00 (extremely leptokurtic)	>4.00 (extremely poorly sorted)

Peamebility, which refers to the ease of flow of fluid in rock, and has implications for groundwater flow and leachate transport, was estimated from the results of the grain size distribution analysis results using the Hazen (1982) and the results presented in Table 4.

$$K\,(m/s) = CD_e^2 \qquad (4.1)$$

WhereC is a constant with value of *0.02, and D* is characteristic effective grain size which is determined to be equal to D_{10}. From the soil permeability classes for civil Engineering (Table 5), it can be seen that the rock samples fall within the permeable range, implying that the formation will enhance leachate transport and probable pollution of groundwater.

Table 4: Calculated values of permeability.

Sample no	*K (m/s)*	D_{10}
1	0.001682	0.29
2	0.0002	0.1
3	0.000288	0.12
4	0.000968	0.22
5	0.00045	0.15

Table 5: Lower and upper limit values of permeability.

Soil permeability classes	Coefficient of Permeability (K in m/s)	
	Lower Limit	Upper Limit
Permeable	2×10^{-7}	2×10^{-1}
Semi- Permeable	1×10^{-11}	1×10^{-5}
Impermeable	1×10^{-11}	5×10^{-7}

4.5. Hydrogeochemistry.

Hydrogeochemical analysis was done on water samples from groundwater sources around the vicinity of the Amenyi dump site to investigate the effect of the waste dump on the water quality in the area (Tables 6 and 7). The potential contaminant compounds of interest tested for include Nitrates, Phosphates, Lead, Iron, Cadmium, Chromium, Copper, Nickel, Zinc and Mercury due to their hazardous nature and predominance in environmental and health problem. The results of the Microbiological analysis show that sample 1 located at the dump site has been contaminated, likewise sample 3. The results produced higher levels of conductivity, total dissolved solids and chloride values for water collected at close location to dumpsites than those far away from the dumpsites: an evidence for a quantitative assessment of groundwater contamination.

Table 6: Results of the Microbiological analysis of water samples

Parameter	Sample 1	Sample 2	Sample 3	**WHO standard**
Total Coliform	25.00	0.00	2.00	Nil
Fecal Coliform	0.50	0.00	0.01	Nil
Phosphate (Po_4^{3-})	0.843	0.512	0.426	< 0.02

Table 7: Results of Physico-chemical parameters of water samples

Parameters	Sample 1 (Amenyi street dumpsite)	Sample 2	Sample 3	**WHO standard**
Hardness	96	54	38	500
Conductivity	31.9	8.4	8.2	1ms/cm
Ph	5.62	5.38	5.73	6-8.5
Total dissolved solids (TDS)	40.14	10.12	10.2	1000mg/l
Dissolved oxygen	47.74	36.1	35.4	
Chlorine (Cl^-)	40	38	35	600mg/l
NO_3–	5.57	0.72	1.78	50mg/l
CO^{2-}	30	25	35	
H_2SO_4–	119.6	96.26	101.3	
Nh	3.11	2.486	3.886	
Na	0.685	0.625	1.235	200mg/l
Mg	2.543	1.434	3.675	150mg/l
Ca	7.638	8.496	5.384	75mg/l
HCO_3–	45	38	52	
Cd	0.010	0.00	0.00	0.003mg/l
Cr	0.085	0.003	0.016	0.05mg/l
Cu	0.201	0.261	0.03	1mg/l
Fe	0.963	0.630	0.759	1.0mg/l
Ni	0.018	0.009	0.005	0.02mg/l
Pb	0.012	0.005	0.002	0.01mg/l
Zn	2.59	1.15	2.25	3mg/l
Hg	0.0007	0.0003	0.0005	0.001mg/l

5. Conclusions.

Quantitative interpretation of 2D-profiling and vertical electrical soundings of Amenyi dumpsite has yielded information on the effects of the dump site at Amenyi on the rocks underlying the site, and by extension on the groundwater resources in the area. Results show that leachates from the dump site are penetrating downwards and has possibly contaminated the groundwater. This is also seen in the results of the hydrogeochemical analysis performed on water samples from the area. Leachate transport is enhanced by the nature and hydraulic properties of the overburden in the area. Interpretation of grainsize distribution analysis results show that the overburden rocks are permeable. This characteristic (permeability) makes it relatively easy for leachates from the dumpsite to infiltrate and pollute groundwater. It is therefore recommended that the dump site is relocated from the present location and established in other locations where the overburden geology is such that leachate are contained and prevented from infiltrating and polluting groundwater. Such areas should be underlain by rock of very low permeability.

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