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Mapping of Aquifer Contamination Using Geoelectric Methods at a Municipal Solid Waste Disposal site in Warri, Southern Nigeria

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Abstract: *Vertical electrical sounding, 2-D resistivity imaging and hydrogeochemical analysis have been applied in the study of aquifer contamination in a municipal solid waste disposal site in Warri, southern Nigeria. Fourteen sounding points were occupied in the area and the resistivity imaging employing the Dipole dipole configuration was measured along two orthogonal traverse lines cutting across the dumpsite. The geoelectric sections reveal four distinct layers namely topsoil, fine sand, medium grained sand and fine to medium grained sand. The low resistivity values obtained beneath the dumpsite in the southern direction in the N-S geoelectric section, could be attributed to the effect of leachate from the dumpsite. The results of the resistivity imaging show contamination in the W-E and N-S direction, with values ranging from 22 to 100 ohm-m, because the area show low longitudinal conductance of < 0.05 mhos and 0.06 to 0.09 mhos, which depicts weak and low protective capacity respectively. Finally, the results of the hydrogeochemical analysis confirm the concentration of lead and total viable bacteria counts and this is an indication that the aquifer is gradually receiving contamination from the dumpsite.*
Keywords: *Geoelectric, Hydrogeochemical, Leachate, Resistivity imaging, Transmissivity*

I. Introduction

Solid waste disposal on land is the most common waste disposal method in Nigeria without leachate or gas recovery systems. These useless, unwanted and/or hazardous waste are classified as garbage, ashes, large wastes, sewage treatments solids, industrial wastes, mining wastes and agricultural wastes. Indiscriminate disposal of organic waste is detrimental to health because it creates unsanitary environment that have adverse effects for urban residents. Where sanitary facilities are scarce, household solid wastes also tend to be mixed with fecal matter, further compounding the health hazards [1]. These waste disposal sites are more often than not located at the perimeter of major urban centers in open spaces, wetland areas or regions close to surface water sources. Improper management of domestic and industrial wastes will negatively affect the environment and health of the inhabitants. Water-related diseases such as malaria, schistosomiasis and river blindness are some of the causes of high morbidity which impact negatively on the economy of any nation and the health of the people. Infectious diseases linked to poor environmental conditions kill one out of every five children in Africa, with diarrhoea and acute respiratory infections being the two major killers [2]. Other diseases related to sanitation and drinking of poor quality water include guinea worm, trachoma, cholera, hepatitis A, bilharzias, typhoid, polio, hookworm, and tapeworm [3]. Due to industrial advancement in recent years, population in Warri has increased tremendously, and this has led to unprecedented increased in the generation of waste, hence a common feature in the city is that refuse dumps are ubiquitous. The NPA Expressway refuse disposal site, near the David Ejoor Army Barrack which was very far from the inhabited areas in the early 80s is now totally within the fully developed metropolis and is still receiving refuse till date.

Direct Current (DC) electrical resistivity methods of geophysical exploration are popular and have proven to be successful and reliable in the fields of engineering, geoenvironment, hydrogeology and contaminant hydrology. In recent years, one of the new developments is in the application of 2-D electrical imaging techniques to map areas with moderate to complex geology [4]. Also, mapping of changes in the recorded resistivity in the vertical as well as the horizontal direction, gives a more accurate model of the subsurface in two-dimension (2-D).

Electrical resistivity methods for contaminant studies have a wide range of application on shallow groundwater resources, and the advantages include the reduction in the need for intrusive techniques and direct sampling, produces intrinsic properties (electrical conductivity/resistivity) of groundwater chemistry that gives information on contamination, relatively inexpensive, and optimization of the required number of monitoring wells [5] to [7].

In this paper, the geoelectric method adopting the vertical electrical sounding and the collinear 2-D resistivity tomography, employing the dipole - dipole techniques have been used to carry out dumpsite - induced groundwater contaminant studies at a major dumpsite, along the NPA expressway in Warri.

II. Location And Geology Of The Study Area

The dumpsite is located after the David Ejoor Army Barracks along NPA expressway in Warri, within latitude $5^{0}39.000^{I}$N and longitude $5^{0}45.889^{I}$E (Fig 1). It covers an area extent of 150 by 100 m with a dump heigth of 5 m, though reclamation work is currently going on in this area. The study area lies in the sedimentary basin demarcation of Nigeria and is underlain by a sequence of sedimentary formations with a thickness of about 8000 m. This formation from bottom to top include the Akata, Agbada and Benin Formations and the Sombreiro-Warri Deltaic Plan Sands [8] [9]. The Akata Formation ranges in age from Paleocene to Eocene and its thickness could exceed 1000metres, and consists of carbonaceous shale that has gone through intense pressure. The Agbada Formation consists of intercalations of deltaic sand and shale. It ranges in age from Eocene to Oligocene and exceeds 3000metres in thickness. The Benin Formation is the topmost of the Niger Delta stratigraphy and ranges from Oligocene to Pleistocene in age. It is the aquiferous unit of the Delta and contains freshwater continental friable sands and gravel, with some shale intercalations. Generally, the Benin Formation has thickness that exceeds 2000 m but vary in some part. However, in this area, The water table is very close to the ground surface and varies from 0 to 15m. This limited and recent studies have shown that this formation is partly recharged from River Warri.

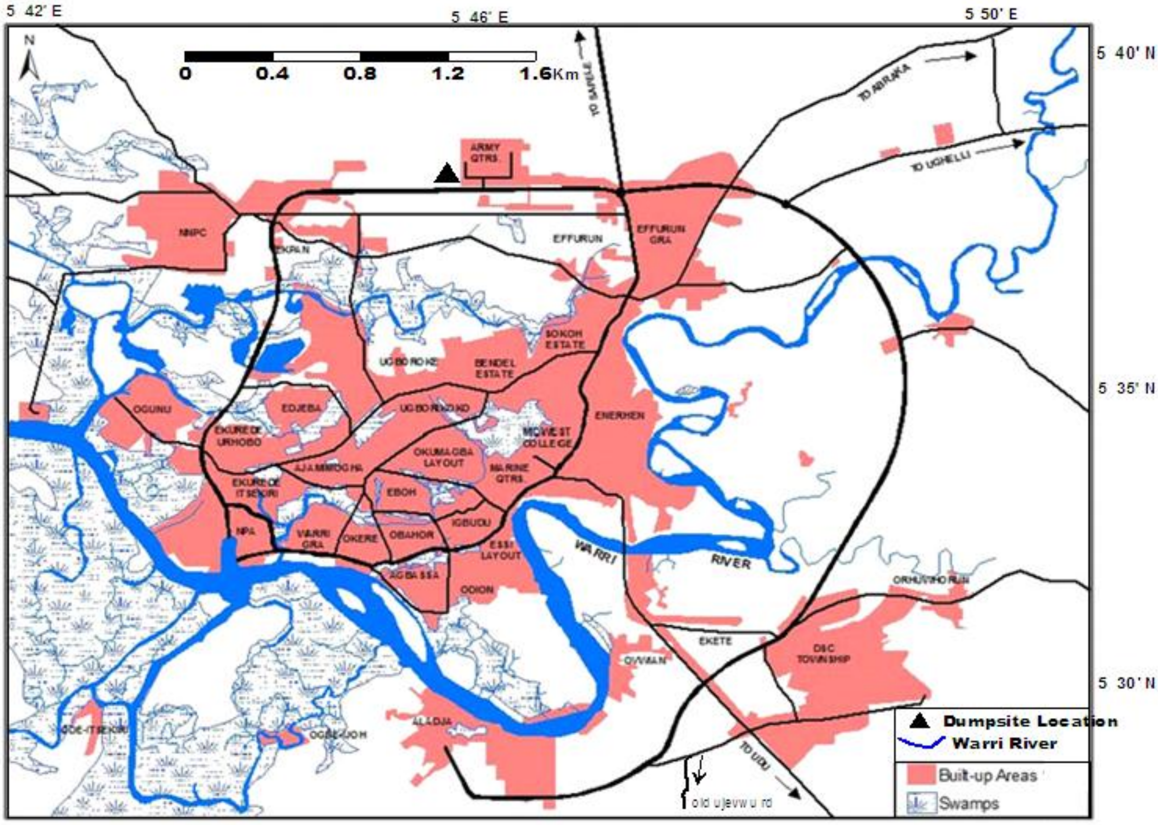

Figure 1: Map of Warri showing the Study Area [10]

III. Methodology

Fourteen (14) vertical electrical sounding (VES) stations spread across the dumpsites area were occupied. Soundings were taken along roads, linear routes between houses and other available undeveloped plots of land and open spaces (Fig 2). VES data were acquired at locations representatively distributed across the entire area, very close to the dumpsites and extended approximately 10 to 100 m outward employing the schlumberger configuration with a electrode spacing ranging from 80 to 450 m. In this configuration, four electrodes were used. Measurements of apparent resistivity were made by increasing the distance between the current electrodes while the potential electrodes remain constant, such that the distance between the current electrodes is five times greater or equal to the separation distance between the potential electrodes.

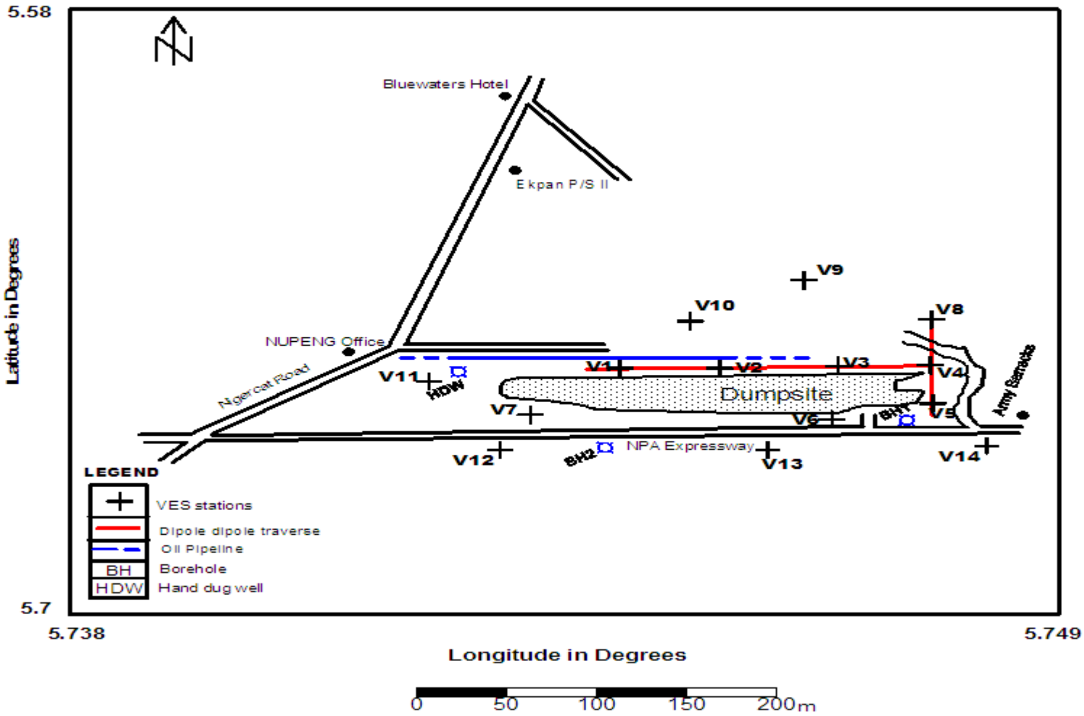

Figure 2: Data Acquisition Map for the study.

The Schlumberger array is widely used to study the variation of resistivity with depth. VES data were plotted on log-log paper with apparent resistivity values on the ordinate and half electrode separation (AB/2) on the abscissa. The sounding curves generated were interpreted qualitatively through visual inspection and later subjected through partial curve matching technique, and iteration with the WinResist computer software for quantitative interpretation to generate the layered apparent resistivity and thickness.

Also, the 2D electrical resistivity tomography employing the collinear dipole dipole array were carried along the two orthogonal traverse lines (Fig 2) with electrode separation of 5 m. VES were taken also along these traverse lines in order to map the possible migration of leachate from the dumpsite and also confirm the application of integrated geophysical methods for aquifer contamination from dumpsite leachate. The dipole dipole resistivity data were imputed into the DIPRO computer software, which converts the result to a 2D resistivity model (Pseudosection). The generated pseudosection gives the variation of resistivity in both the horizontal and vertical direction with respect to depth.

IV. Discussion Of Results

The observed sounding curves of the quantitative interpretation of the 14 VES results were classified into different curve types, and the first and second order geoelectric parameters generated are presented in Table 1.

Table 1: Interpreted VES results for the study area

VES Station	Computer iterated Resistivity $\rho_1/\rho_2/\rho_3/......\rho_n$ (Ωm)	Computer iterated Depth $z_1/z_2/z_3/......z_n$ (m)	Curve Type	Transmissivity, T (Ωm^2)	Protective capacity, P_c (mhos)
VES1	399/295/152/381/100	0.8/4.2/19.4/78.3	QHK	22479	0.11287
VES2	370/224/115/858/155	1.1/4.1/13.0/34.5	QHK	18361	0.09375
VES3	343/249/540/164	0.8/2.2/5.9	HK	2052	0.00755
VES4	255/121/608/225/123	0.6/1.7/4.2/15.8	HKQ	2610	0.01556
VES5	94/379/642	0.9/11.0	A	3793	0.00957
VES6	53/199/320	1.0/9.7	A	1751	0.01887
VES7	116/231/382	1.0/7.5	A	924	0.00862
VES8	195/101/554/148	0.9/2.9/14.2	HK	6316	0.02441
VES9	456/298/180/115	1.1/5.7/26.2	QQ	1401	0.00241
VES10	532/404/307/702/78	1.3/12.1/38.9/85.2	QHK	32573	0.11647
VES11	230/459/1146	1.1/9.7	A	3947	0.00478
VES12	564/853/1495/507	1.1/8.0/45.7	HK	5800	0.00195
VES13	210/391/1240	1.1/11.5	A	4027	0.00524
VES14	99/341/944/107/1793	1.5/3.7/11.7/94.0	AKH	7552	0.02160

Two geoelectric sections were generated for the dumpsite area, along the W-E and N-S direction, and the other two in the SW-NE directions (Figs 3 to 6). The geoelectric sections when compared with a borehole log in the study area reveal four distinct layers namely topsoil, fine sand and medium grained sand and fine to medium grained sand. Along the W-E direction, the resistivity of the topsoil varies from 130 to 483 ohm-m, with thickness of 0.7 to 1.3 m respectively. The topsoil is composed of 'made ground' and clayey sand/sandy clay. There are no visible impacts of the dumpsite on the topsoil as shown by the resistivity values in the geoelectric sections.

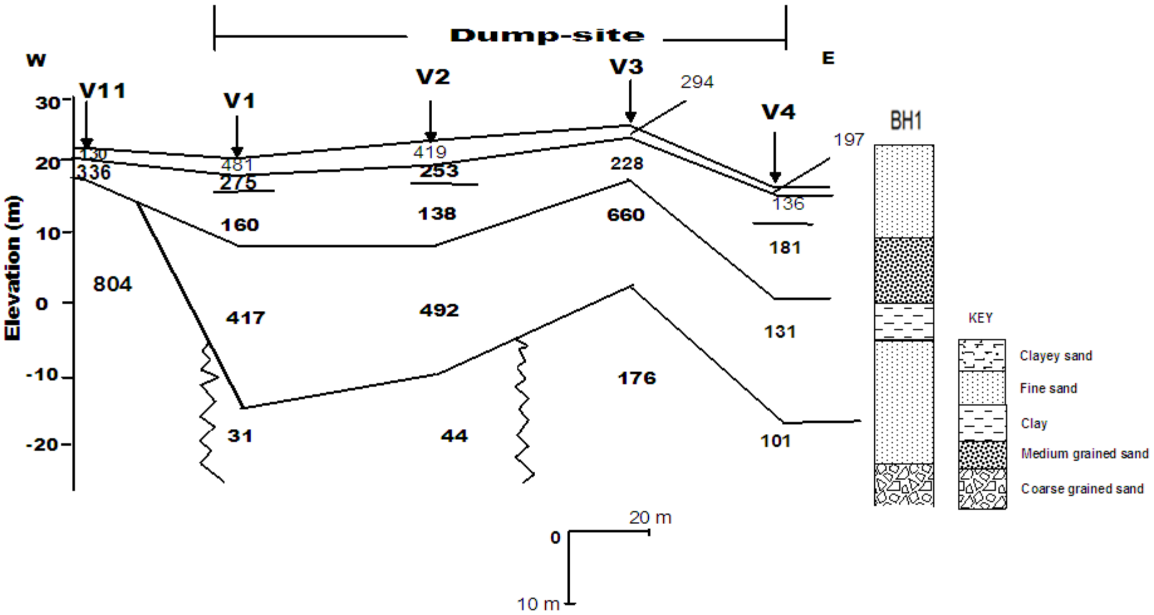

Figure 3: Geoelectric Section along the SW-NE Direction across the dumpsite area

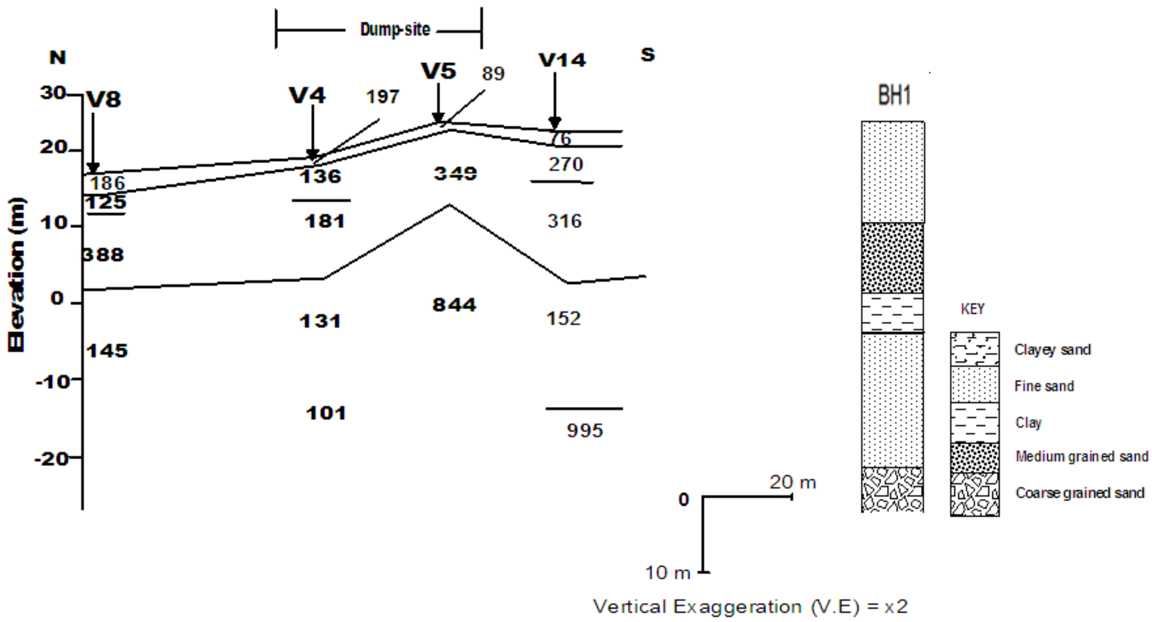

Figure 4: Geoelectric Section along the N-S Direction across the dumpsite area

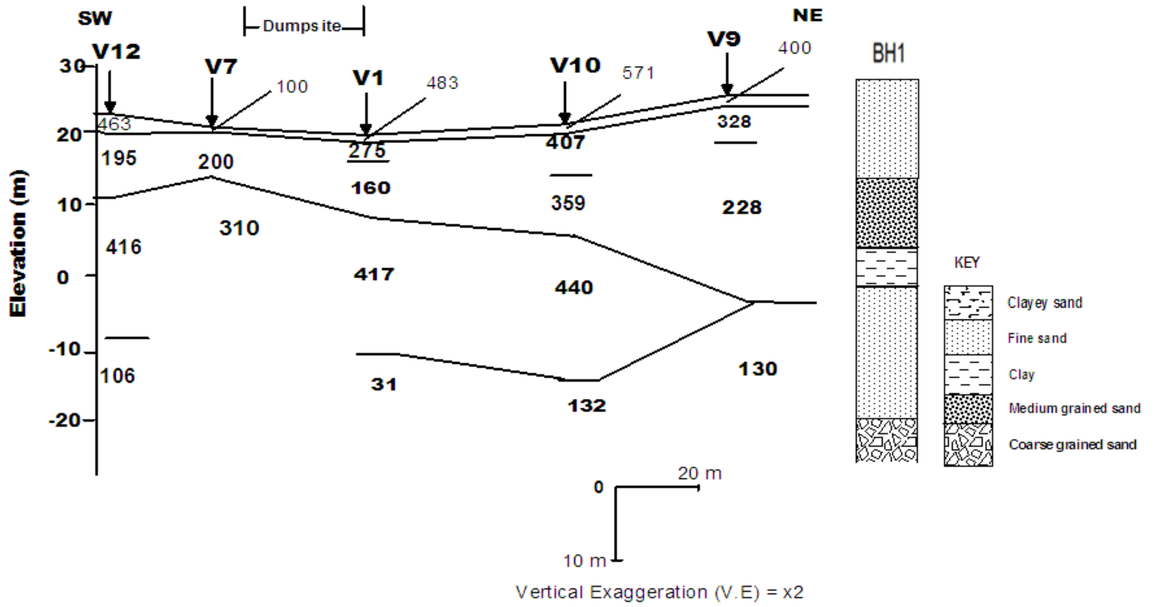

Figure 5: Geoelectric Section along the SW-NE Direction across the dumpsite area

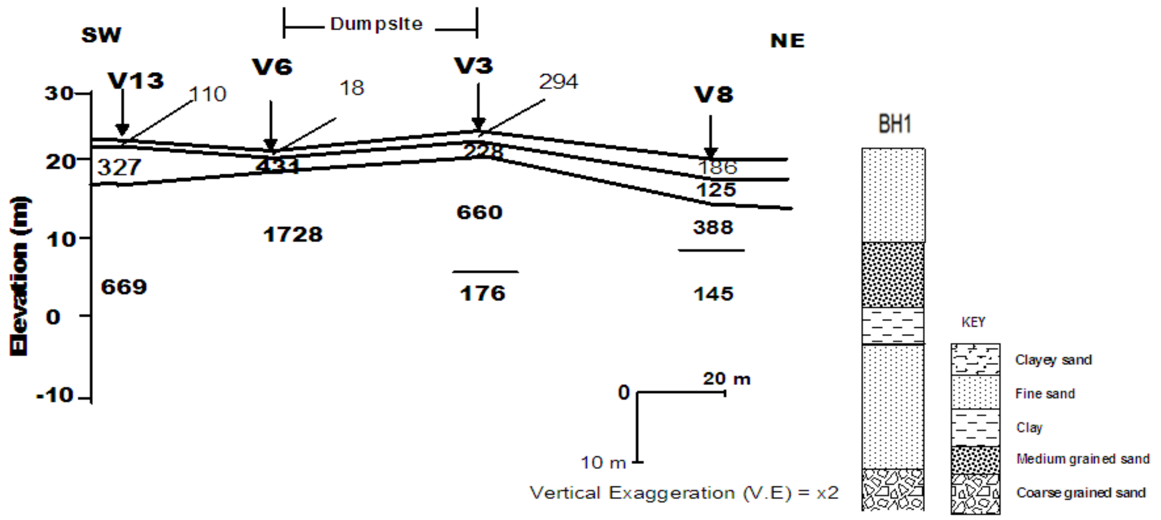

Figure 6: Geoelectric Section along the SW-NE Direction across the dumpsite area

The second geoelectric layer is composed of fine sand with resistivity varying from 136 to 336 ohm-m, and a thickness of 3.3 to 17.3 m respectively. The probable lithology of the third geoelectric layer is the medium grained sand and it has resistivity ranging from 129 to 492 ohm-m and a thickness of 6.0 to 17.6 m. The fourth layer has resistivity ranging from 101 to 804 ohm-m.

Also, the geoelectric sections along the N-S and the SW- NE directions (Figs 4 - 6) reveal three probable distinct layers namely topsoil, fine sand and medium to coarse grained sand. The low resistivity values obtained beneath the dumpsite in the southern direction in the N-S section, could be attributed to the effect of leachate from the dumpsite.

The 2-D inverted resistivity models were generated from measurements along the traverses in the W-E and N-S directions across the dumpsite area (Figs 7 and 8). This is to detect and map possible migration of the leachate across the dumpsite area. The 2-D inverted resistivity sections image the subsurface geologic sequence and the structural disposition of the subsurface layer. The sections reveal basically a maximum of three subsurface layers, which is in agreement with the results of the VES geoelectric section. The 2-D resistivity structure along the W-E direction (Fig 7) shows that the topsoil has virtually merged with the second layer (light green colour band) in some stations, and with the third layer in other station (yellowish – red – purple colour band). The resistivity of the various layers ranges from 36.9 to 3077 ohm-m. However, a low resistivity structure is found at a depth of about 8 m with resistivity ranging from 37 to 102 ohm-m (in blue colour), which is indicative of the presence of leachate from the dumpsite.

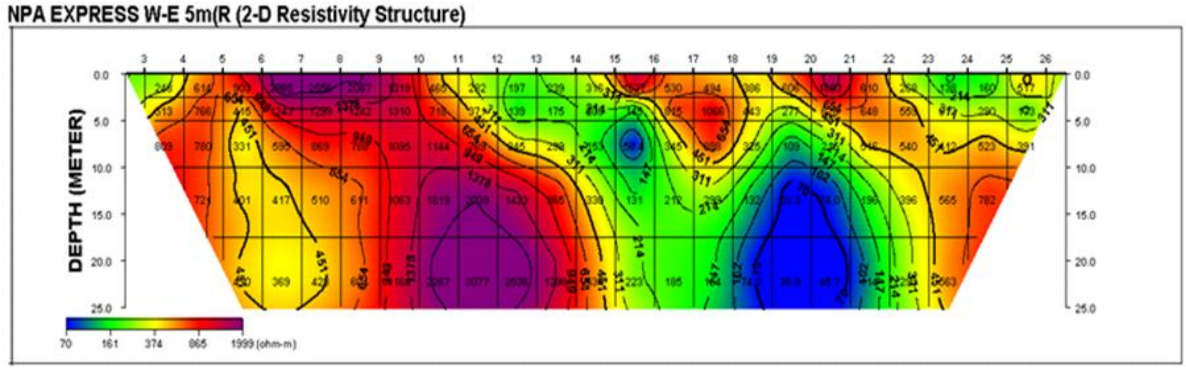

Figure 7: 2-D Resistivity Structure at a= 5 m in the W-E Direction Across the dumpsite area

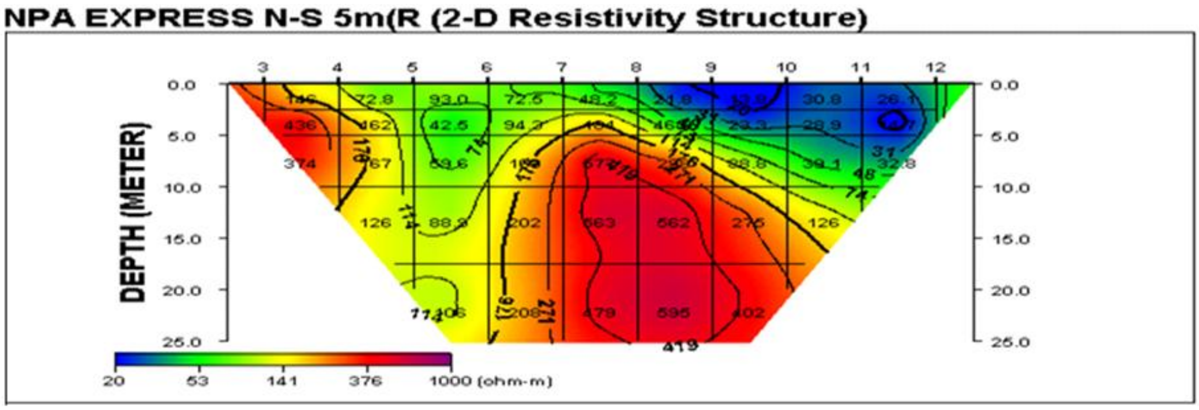

Figure 8: 2-D Resistivity Structure at a= 5 m in the N-S Direction Across the dumpsite area

In the N-S direction, the resistivity of the topsoil in blue colouration ranges from 22 to 31 ohm-m. This low resistivity of the topsoil is diagnostic of the impact of leachate. Also, the impact of the leachate on the subsurface is also evident in the second layer (light green colour band) with resistivity ranging from 88 to 100 ohm-m. The low resistivity of the second layer also indicates that the layer has also been impacted by leachate from the dumpsite. The third layer is composed of medium to coarse grained sand and has resistivity ranging from 126 to 595 ohm-m.

The second order geoelectric parameters comprising of longitudinal unit conductance, transmissivity and transverse resistance generated from the first order quantities were used to produce maps which give an indication of aquifer protection capability and hydrologic properties. The longitudinal unit conductance values in mhos is found to be directly related to the aquifer protective capacity. This rating according to Oladapo et al (2004) [11] in the basement complex of Nigeria gave the longitudinal conductance/protective capacity rating as >10 (Excellent), 5 – 10 (Very Good), 0.7 – 4.9 (Good), 0.2 – 0.69 (Moderate), 0.1 – 0.19 (Weak) and <0.1 (Poor). Ofomola (2014) [12] modified this further to >1(Excellent), 0.5 – 1 (Very Good), 0.1 – 0.49 (Good), 0.06 – 0.09 (Moderate), 0.01 – 0.05 (Weak) and <0.01 (Poor) for sedimentary environment in part of Warri, and that zones with poor and weak protective capacity has a high propensity to be contaminated in the event of pollution. Also, for this study aquifer transmissivity rating is according to the standard of Gheorghe (1978)[13].

The longitudinal unit conductance map showing the overburden protective capacity and aquifer transmissivity map of the study area are shown in Figures 9 and 10. Low longitudinal conductance values of < 0.05 mhos depicts area with weak and low protective capacity, while around V4, V5, V8, V3, V6, V2 and V14, the longitudinal conductance ranges from 0.06 to 0.09 mhos, depicting moderate protective capacity.

Also, the aquifer transmissivity map shows a range of 300 to 20300 ohm-m^2 with contour interval of 2000 ohm-m^2. The high transmissivity values (> 500 ohm-m^2) across the entire area suggest that the aquifer materials are highly permeable to fluid movement within the aquifer, this possibly may enhance the migration and circulation of contaminants in the groundwater aquifer system. The fact that the aquiferous materials in the study area are highly permeable and relatively shallow and with the low overburden capacity of the material overlying the aquifer, suggests that the groundwater has a high propensity of being contaminated over large area once the aquifer receives contaminant from any surface source [12] [14].

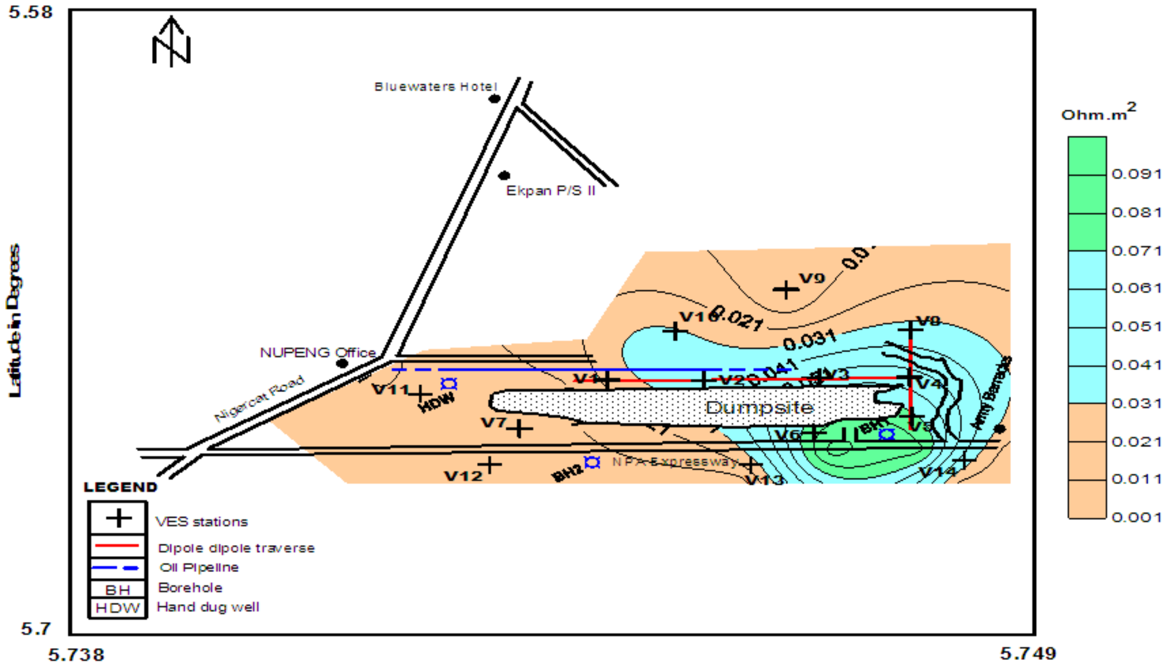

Figure 9: Aquifer protective capacity map over the dumpsite area

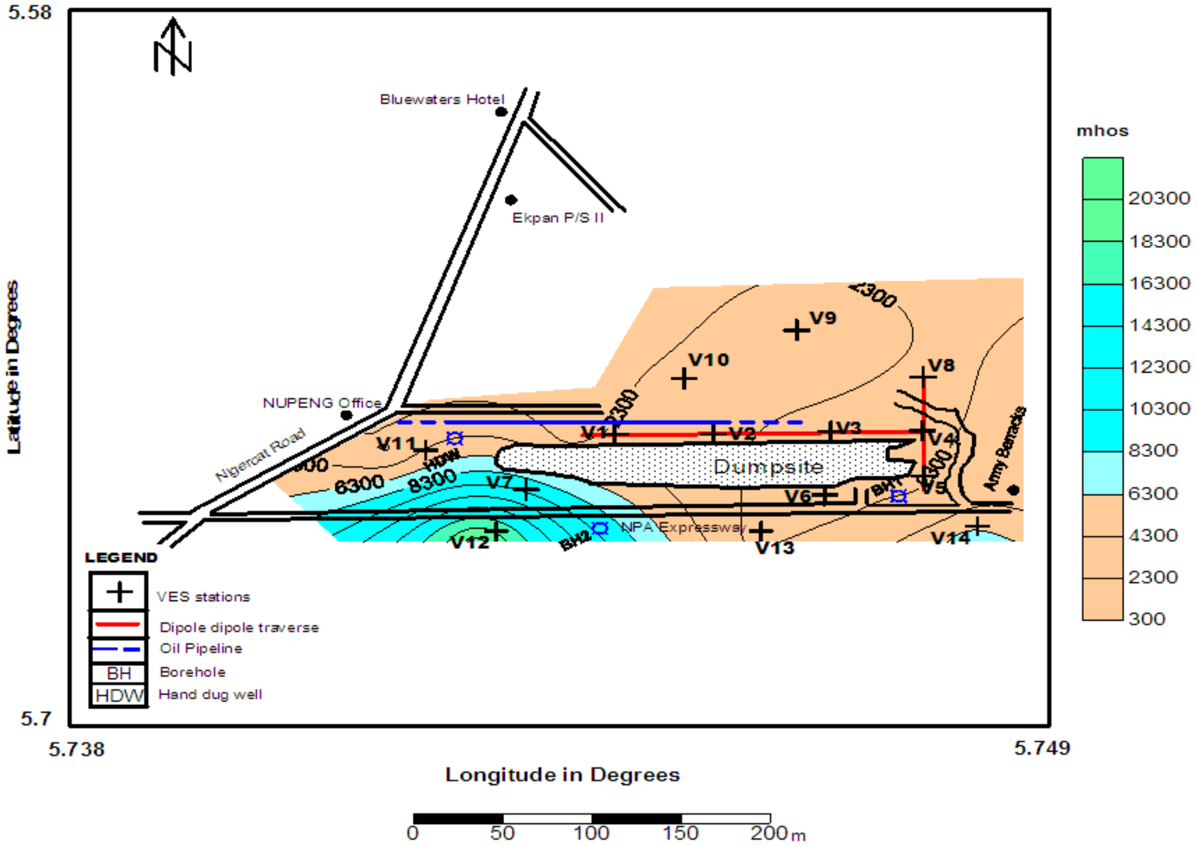

Figure 10: Aquifer transmissivity Map over the dumpsite area

In order to determine the surface and groundwater quality, water samples were collected from different locations, possibly to cover the impacted and unimpacted area around the dumpsites based on earlier field reconnaissance survey for hydrogeochemical analysis. Samples were collected from dug wells and boreholes for hydrogeochemical studies. Analysis was carried out mainly along the methods described in the American Public Health Association, APHA (1985). Parameters such as pH, Temperature, Total dissolved solids (TDS), Electrical Conductivity (EC) and Turbidity were done with calibrated portable meters while heavy metals like Zinc, Copper, Lead, and Cadmium was carried out using the Atomic Absorption Spectrophotometer (Search tech AAS, AA320N) .

The results of the hydrogeochemical analysis carried is presented in Table 2. Most of the parameters determined fell within the World Health Organisation (WHO) and the Nigerian Standard for Drinking water quality (NSDWQ) acceptable limits, apart from the total viable bacteria count. It is also observed that the concentration of lead and total viable bacteria counts in all the samples might be due to the infiltration of used engine/motor oil and petroleum products from the Petroleum tankers office, 100 m away, and faecal migration. This is an indication of contamination of groundwater in the area and calls for urgent attention.

It is worthy of note that there is no significant contamination of the groundwater in the area from dumpsite leachate. However, the concentration of lead and total viable bacteria counts is an indication that the aquifer is already receiving loads of contaminants which will increase over time.

Table 2: Physiochemical parameters of groundwater from the study area

Parameter	NSDQW Max Permissible	WHO's Max Permissible	SAMPLES				Remark
			HDW1	HDW2	BH1	BH2	
P^H	6.5 – 8.5	5.5 – 8.5	6.63	6.72	6.41	5.74	
Total Solids (TS) mg/L		500	15.73	15.90	17.05	17.08	
Total dissolved solids (TDS) mg/L	500	500	15.84	18.34	10.11	10.07	
Total suspended solids (TSS) mg/L	1000	1000	19.89	15.6	15.67	16.01	
Alkalinity (mg/L)			1.68	1.51	0.34	3.82	
Colour			Colourless	Colourless	Colourless	Colourless	
Total Hardness (mg/L)	150		4.36	16.30	17.32	4.79	
Carbonates (mg/L)			1.90	1.96	1.65	0.94	
Chloride (mg/L)	250	200	15.43	16.21	18.78	8.47	
Nitrate (mg/L)	50	50	10.44	12.91	10.34	10.16	
Sulphate (mg/L)	100	200	7.78	7.30	8.36	7.89	
Lead (mg/L)	0.01	0.01	0.02	0.02	0.02	0.012	> WHO, NSDWQ
Potassium (mg/L)			10.29	11.31	6.84	5.63	
Sodium	200		5.94	6.22	4.36	4.73	
Phosphate (mg/L)			4.74	4.30	4.17	2.66	
Calcium (mg/L)		75	13.26	13.82	13.94	13.16	
Magnesium (mg/L)		50	13.81	14.80	14.33	8.42	
Copper (mg/L)	1.0	1.0	ND	ND	ND	ND	Not Detected
Iron (mg/L)	0.3	0.3	0.01	0.02	0.03	ND	
Temperature (^{0}C)			25.50	28.10	25.60	25.50	
Turbidity (NTU)	5.0	5.0	3.09	6.81	6.31	2.11	
Conductivity (µs/cm^3)	1000	500	440.0	270	380.0	415.0	
Total viable bacteria count (cfu/mL)	10	10	12.0	15.2	11.0	4.8	> WHO, NSDWQ

V. Conclusion

The vertical electrical sounding, 2D electrical resistivity tomography and hydrogeochemical studies have been applied in the mapping of aquifer contaminant in a municipal dumpsite in Warri, Nigeria. This was with a view to unravel possible groundwater pollution emanating from the dumpsite leachate. The results from the geophysical investigation showed an insignificant amount of contamination and this is confirmed by the results of the water analysis, having fairly high concentration of lead and total viable bacteria count. This is an is an indication that the aquifer is already receiving loads of contaminants which will increase over time. To ensure safe consumption of portable groundwater in the area, wastes should be evacuated from the area because the area is vulnerable to pollution and as a result of the shallow depth of the aquiferous unit ranging from 0.8 to 19.4 m. It is advised that further dumping of waste should be discontinued and a total clean-up program be embarked upon.

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