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Integrated Geophysical and Hydrogeochemical Studies of Shallow Aquifer Contamination in Osubi, Near Warri, Southern Nigeria

Ofomola, M. O[1]

Abstract

Integrated geophysical and hydrogeochemical studies of shallow aquifer contamination emanating from dumpsites in Osubi area, near Warri, Southern Nigeria has been carried out. This was with a view to mapping contaminant presence and its impact on groundwater in the area. Geophysical methods employed include the Spontaneous Potential (SP), adopting the Gradient and the Fixed Base array techniques, the Dipole-dipole array techniques, and the Electrical Resistivity, adopting the Vertical Electrical Sounding(VES) method. A total of Nine (9) VES stations were occupied across the dumpsite using the schlumberger configuration with electrode separation, AB/2 ranging from 40 to 225 m. Dipole-dipole profiling was carried out along two orthogonal traverse lines of length ranging from 50 to 250 m with electrode separation of 5 m. Spontaneous Potential profiling was also carried out with electrode spacing of 5 and 10 m. From the dumpsite area, water samples were collected from boreholes, hand dug wells, and swamps, close to and far away from the dumpsites for chemical analysis. All these measurements were carried out in both the rainy and dry seasons in order to establish the seasonal variation of the migration of leachate from the dumpsites. The geoelectric sections from the VES generated revealed three to four probable subsurface geoelectric units, which are the topsoil, clayey sand/sandy clay and sand. Around the dumpsites, the resistivity values from the VES and Dipole - dipole measurement to a depth of about 15 m varies from 18 to 400 ohm-m as against higher values of up to 2500 ohm-m outside the dumpsite area. Also, the spontaneous potential (SP) profiles show high positive potential of up to 500 mV outside the dumpsite area to as low as -450 mV around the dumpsite area in both seasons. The low potential and resistivity values around the dumpsite area could be the signature of the oxido-reduction phenomenon occurring at depth in the contaminated groundwater.

Keywords: Contaminant, Oxido-reduction, Dumpsite, Spontaneous potential, Dipole-dipole

[1]Department of Physics, Delta State University Abraka, Nigeria, Tel: +2348035057322

1 Introduction

Osubi is a growing community near Warri. The Warri Airport (also known as Osubi Airstrip) is located in the area, and there is a rapid infrastructural development around the airport region due to the closeness and prominence to the Niger Delta oil-producing area of Nigeria. Osubi is fast becoming a busy modern community with rapid expansion of building projects for the modern living. There is the world-renowned Nigeria Petroleum Training Institute (PTI) nearby, and other infrastructural developments in the area. This has led to the migration of people to the area, and uncontrolled and indiscriminate dumping of both industrial and domestic wastes which are direct threat to the quality of the environment, especially surface and groundwater resources. Leachate generated from industrial and domestic landfill during the rain may eventually percolate and contaminate groundwater. Consequently, pollution from landfills leads to potentially communicable diseases. Groundwater is the subsurface transporting agent for dissolved chemicals including contaminants. Materials dissolved from the wastes may be transported from the burial or disposal site by groundwater flow, with the result that the quality of water from wells is impacted by the contaminated groundwater. In addition, natural discharges of an aquifer, such as at springs and seeps, can return a contaminant to the surface. Because of the low speed of groundwater movement and natural flushing of aquifers, when areas are contaminated, they commonly remain so for decades or longer. Also, contaminant emanating from dumpsites usually enters the aquifer system from the land surface, percolating down through the aerated soil and unsaturated (vadose) zone. This may extend 6 or 9 m into the soil, and many reductive and oxidative biological processes take place and this may also impact negatively on the quality of groundwater (NRC, 1984)[1]. Integrated geophysical and hydrogeochemical methods have been adopted by several authors for aquifer contaminant studies (Adepelumi et al., 2001 [2], Ehirim and Nwankwo., 2010 [3], Ayolabi et al., 2013 [4], Ayolabi and Folashade., 2005 [5], Ugwu and Nwosu., 2009 [6], Alile et al., 2010 [7])

1.1 Location and Geology of the Study Area

Osubi is located in Okpe Local Government Area of Delta state, southern Nigeria (Figure 1). The population is approximately over 8000 people in the 2006 national census. The dumpsite studied is located along the Eku - Warri expressway. It is situated around geographic coordinates of latitude $5^0 39.638^I$ N and longitude $5^0 49.000^I$ E (Figure 2) covering an area of 100 by 100 m.

The area under study falls within the Niger Delta Province, with the regional geology studied by several researchers (Asseez, 1989 [8], Reyment, 1965 [9], Short and Stauble, 1967 [10], Murat, 1970 [11], Merki, 1970[12]). Osubi area is characterised by nearly flat topography sloping very slightly seawards (Akpokodje and Etu Efeotor, 1987 [13]) and underlain by low-lying physiograhic province Quaternary sands of the Sombriero deltaic plain (Figure 2). According to Wigwe, (1975) [14]; Olobaniyi and Owoyemi, (2006) [15], This formation consists of fine to medium and coarse-grained unconsolidated sands that are often feldspathic (with 30 - 40 wt % feldspars) and occasionally gravelly. The plain is generally flat and rises only very gently towards the north and northeast with a gradient of about 1:960 (Odemerho and Ejemeyovwi, 2007) [16], and elevation does not exceed 20 m above sea level. The area is characterized by the proximity of the aquifers to the surface, water table varying from 0 to 4m, flat topography, high annual rainfall, and permeable soil media, which contributes to insignificant runoffs in the site, and implies that the total precipitation goes into storage. This enhances decomposition activities by bacteria and fungi and leaching of contaminants into the aquifer (Olobaniyi and Owoyemi, 2006) [15].

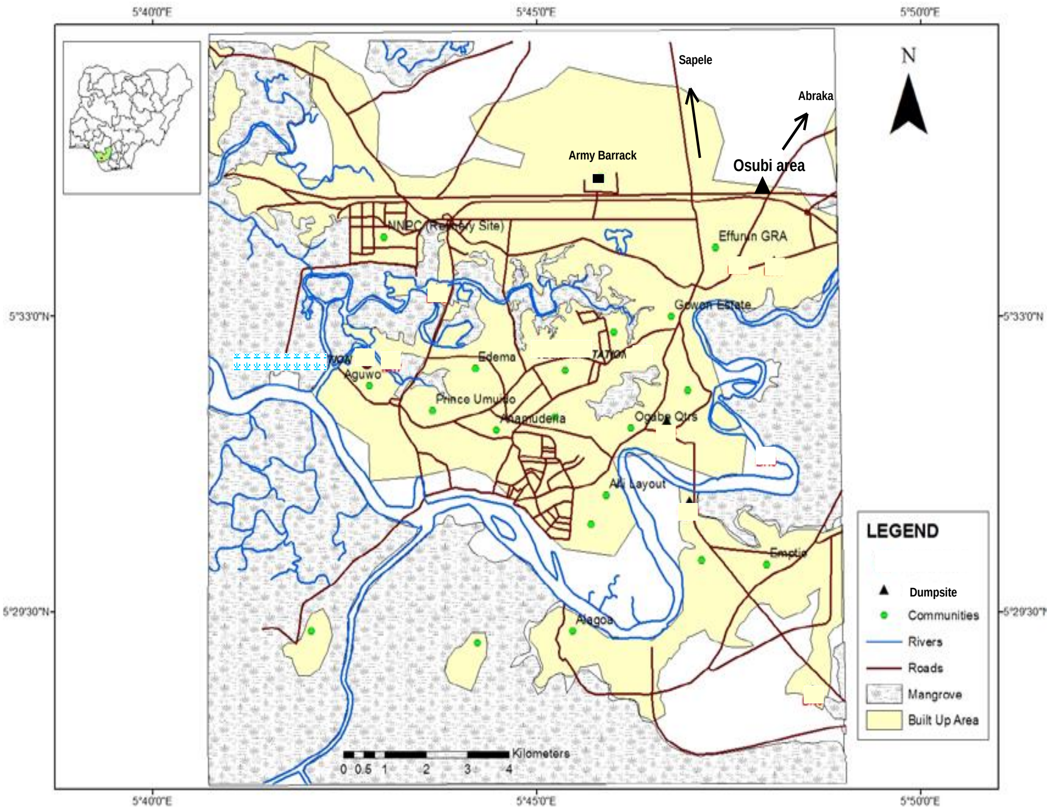

Figure 1: Map of Warri Showing the Osubi Area

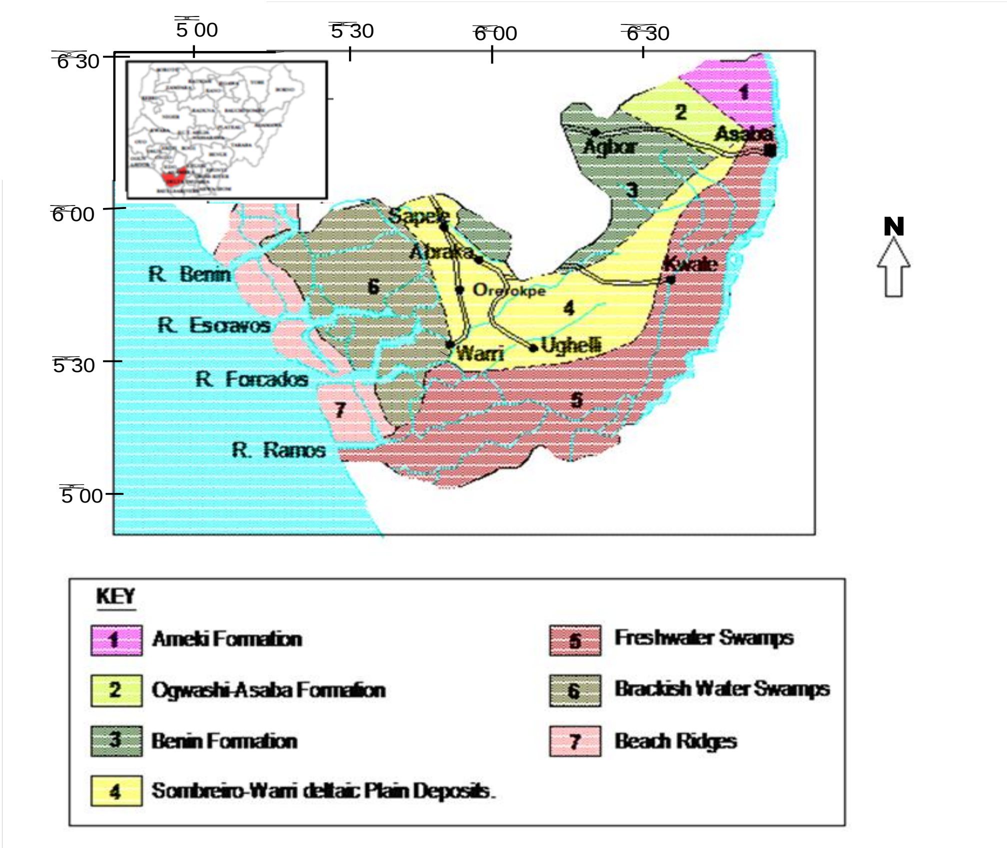

Figure 2: Geological Map of Delta State (After Akpoborie et al, 2011) [17]

2 Methodology

The Spontaneous Potential (SP) data acquisition was carried out along two orthogonal traverse lines in the study area (Figures 3). The gradient and the fixed base techniques were employed with electrode separation of 5 m in both techniques respectively. For the gradient array, the two electrodes were moved successively from one measuring station to another, with the trailing electrode occupying the station of the previous leading electrode with a constant separation (Sharma, 1997) [18]. In this study, the non-polarizable electrodes, copper in copper sulphate ($Cu/CuSO_4$) were used. For the fixed base configuration, measurements were taken with respect to a chosen base station, beginning from electrode separation of 5m respectively and moving outward to the end of the traverse lines. The base station readings were then subtracted from the readings of the other stations.

Also, dipole - dipole measurements were carried out along the two orthogonal traverse lines with respect to the dumpsite for electrode separation of 5 m, to map the migration of the possible leachate plume. Nine (9) Vertical Electrical Sounding (VES) stations were occupied at locations representatively distributed across the entire area, with stations located very close to the dumpsites and extended approximately 100 m to 1km outward. In order to determine the subsurface and groundwater quality, water samples were collected from different locations across the dumpsites, in the study area based on an earlier field reconnaissance survey. Water samples were collected from dug wells, boreholes, streams, burrowed pits, swamps and rivers at regular predetermined time intervals for Hydrogeochemical studies. Geophysical measurements for the study were carried out in both the rainy (June, 2012) and dry (December, 2012) seasons to determine the influence of climatic changes on the generation and migration of leachate and the effects that changes in hydrogeologic conditions (seasonal changes) would have on the response of each method adopted. The ABEM signal averaging system terrameter (SAS 1000) model was used for resistivity and the spontaneous potential (SP) data acquisition. Piezometric levels of wells were taken using the depth measuring tapes, while the coordinates (longitude and latitude) of the VES points, traverse lines, boreholes and wells were obtained with the aid of the global positioning system (Etrex, 2004). Water samples were also collected using the water sample container (2 litres plastic bottles) for hydrogeochemical analysis.

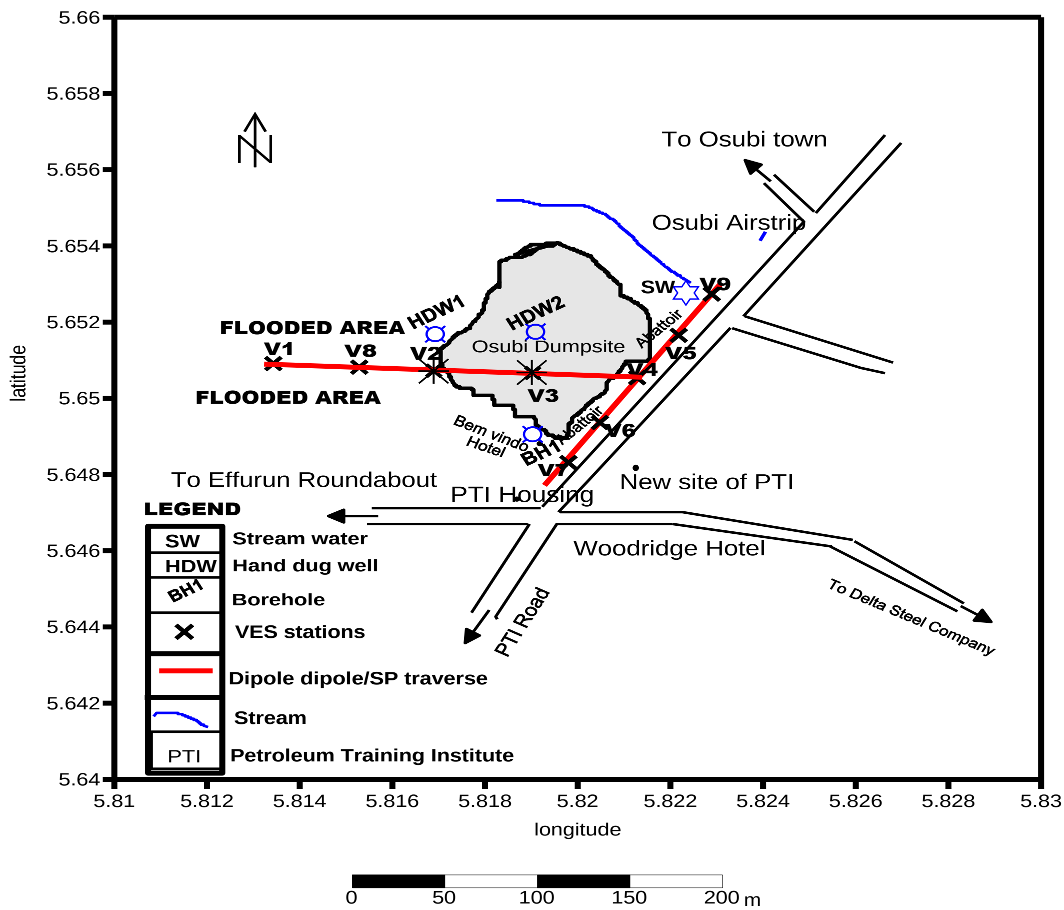

Figure 3: Data Acquisition Map for the Study Area

3 Results and Discussion

3.1 Spontaneous Potential (SP) Profiles across Osubi Area

The SP response employing the gradient array along the W-E direction (Figure 4) shows a relatively low potential of less than 20 and 40 mV/m outside the dumpsite area in the rainy and dry season respectively, using electrode spacing of 5 and 10 m. The responses under the dumpsite area reduce further to as low as -50 mV/m in both seasons which is indicative of the presence of leachate from the dumpsite. This movement from positive to negative which is more prominent at a distance between 120 and 170 m is indicative of the movement of leachate and the presence of buried metallic materials from the dumpsite. However, the response from the fixed base array in both the rainy and dry seasons (Figure 5) shows positive values to as high as 20 mV and 80 mV under the presupposed undisturbed area in both seasons to as low as -20 mV around the dumpsite area with the major anomalous zone at a distance of 20 to 80 m and 120 to 170m respectively . In the SW-NE direction, the gradient array profiles (Figure 6) show a steady decrease of about 20 to 100 mV outside the dumpsite area to as low as -100 mV under the dumpsite area in both the rainy and dry seasons. Also, from the fixed base array in the SW-NE direction (Figure 7), the response around the dumpsite area ranges from 10 to -25 mV with the major anomalous zones at a distance of 60 to 120 m.

3.2 Dipole: Dipole Pseudosections across Osubi Area

The dipole dipole 2-D resistivity structure in the W-E direction with electrode spacing of 5 m shows three distinct layers in both seasons (Figures 8). The topsoil with blue coloration has resistivity ranging from 21 to 38 ohm-m in the rainy season, and the topsoil has been merged with the second layer in the dry season showing around stations 9 and 10, and stations 20 to 26, with resistivity ranging from 18 to 52 ohm-m. The low resistivity of the topsoil may be an indication of the presence of leachate from the dumpsite. The second layer characterised by the light green colour band is composed of fine sand and has resistivity ranging from 52 to 95 ohm-m, and 54 to 130 ohm-m; and a thickness ranging from 1.5 to 5.5 m, and < 25 m in the rainy and dry season respectively. The third layer characterised by the yellowish – red colour is composed of the medium to coarse grained sand. The modelled layer resistivity values are generally between 136 to 1077 ohm-m, and 203 to 1864 ohm-m in the both seasons respectively.

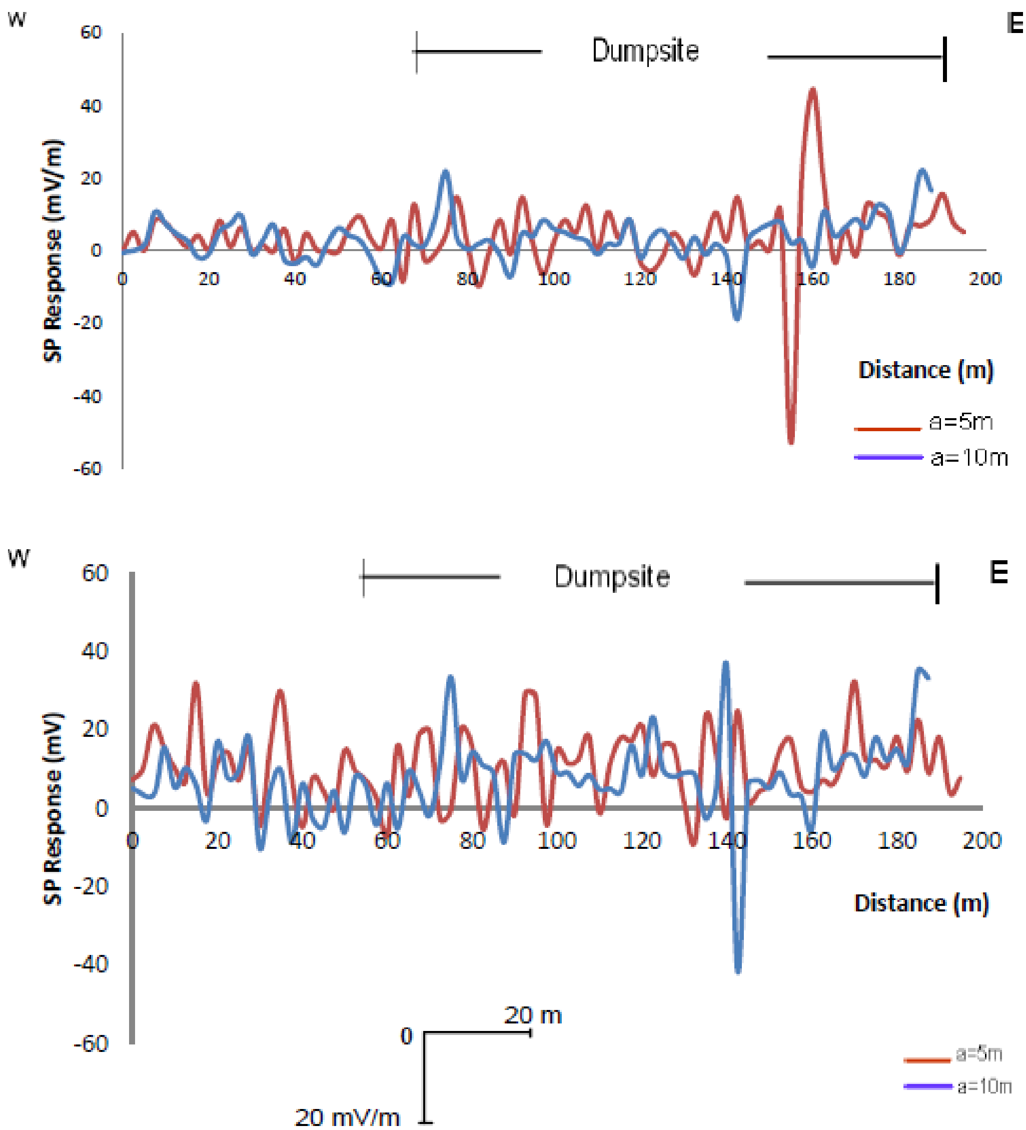

Figure 4: SP Response Using Gradient Array at 'a' of 5 and 10 m in the W-E Direction Across the Dumpsite During the (a) Rainy Season (b) Dry Season

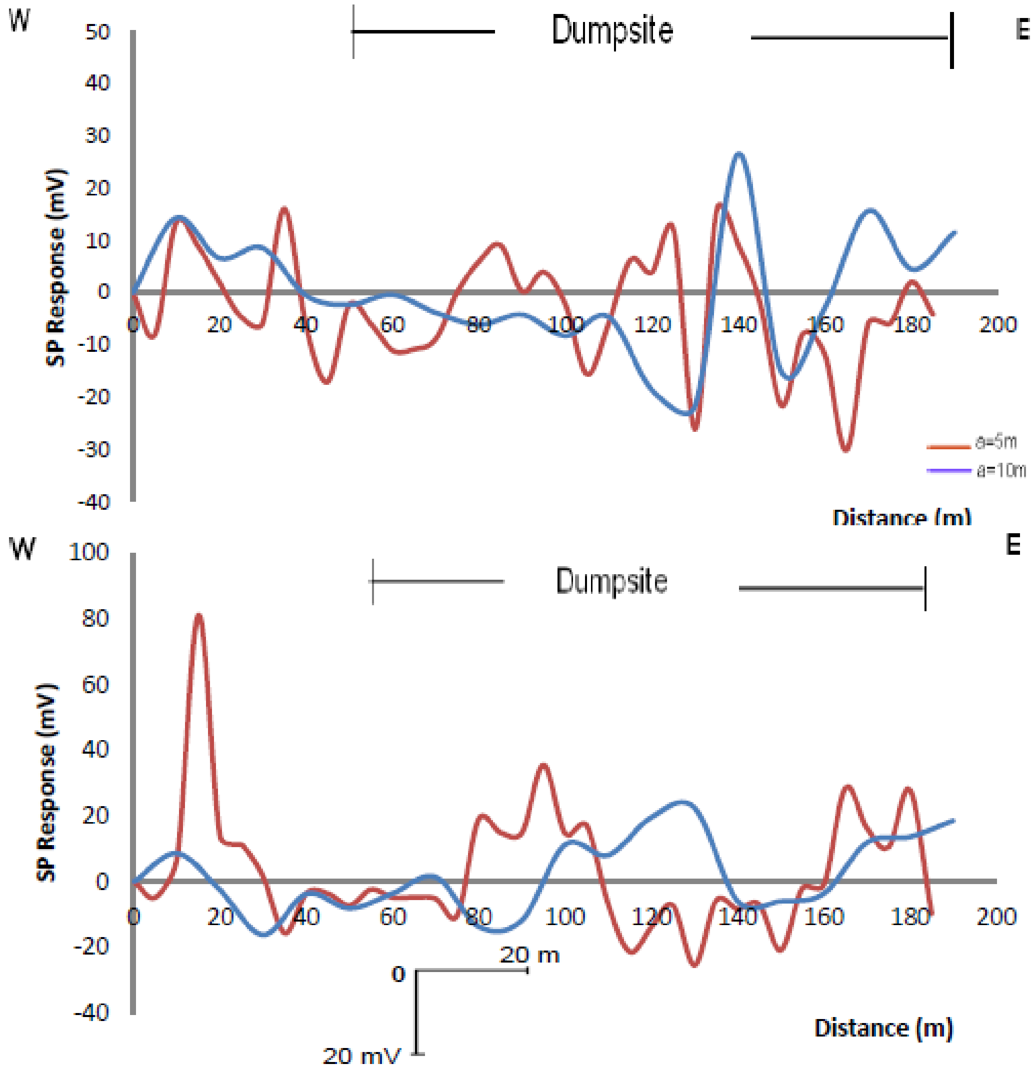

Figure 5: SP Response Using Fixed Base Array at ‘a’ of 5 and 10 m in the W-E Direction Across the Dumpsite During the (a) Rainy Season (b) Dry Season

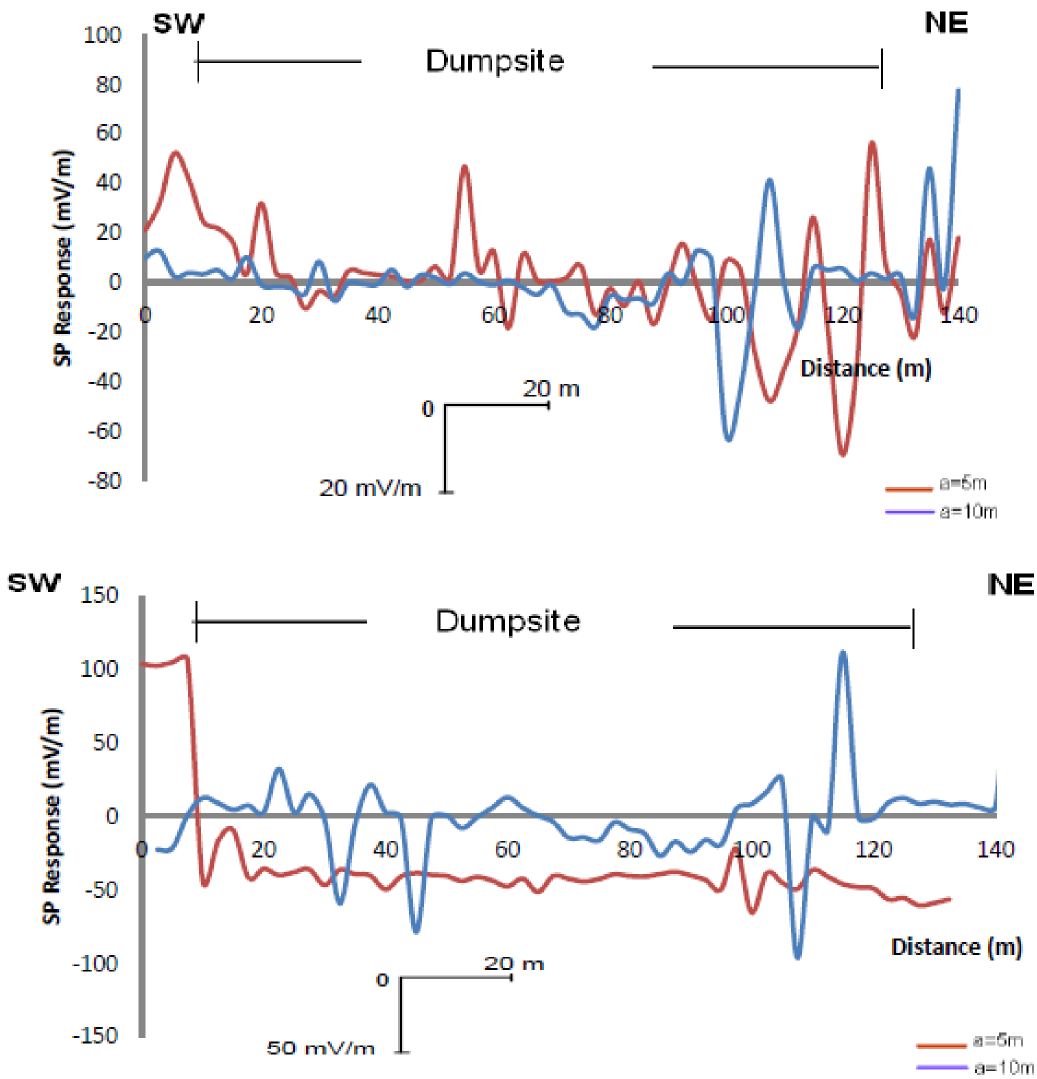

Figure 6: SP Response Using Gradient Array at ‘a’ of 5 and 10 m in the SW-NE Direction Across the Dumpsite During the (a) Rainy Season (b) Dry Season

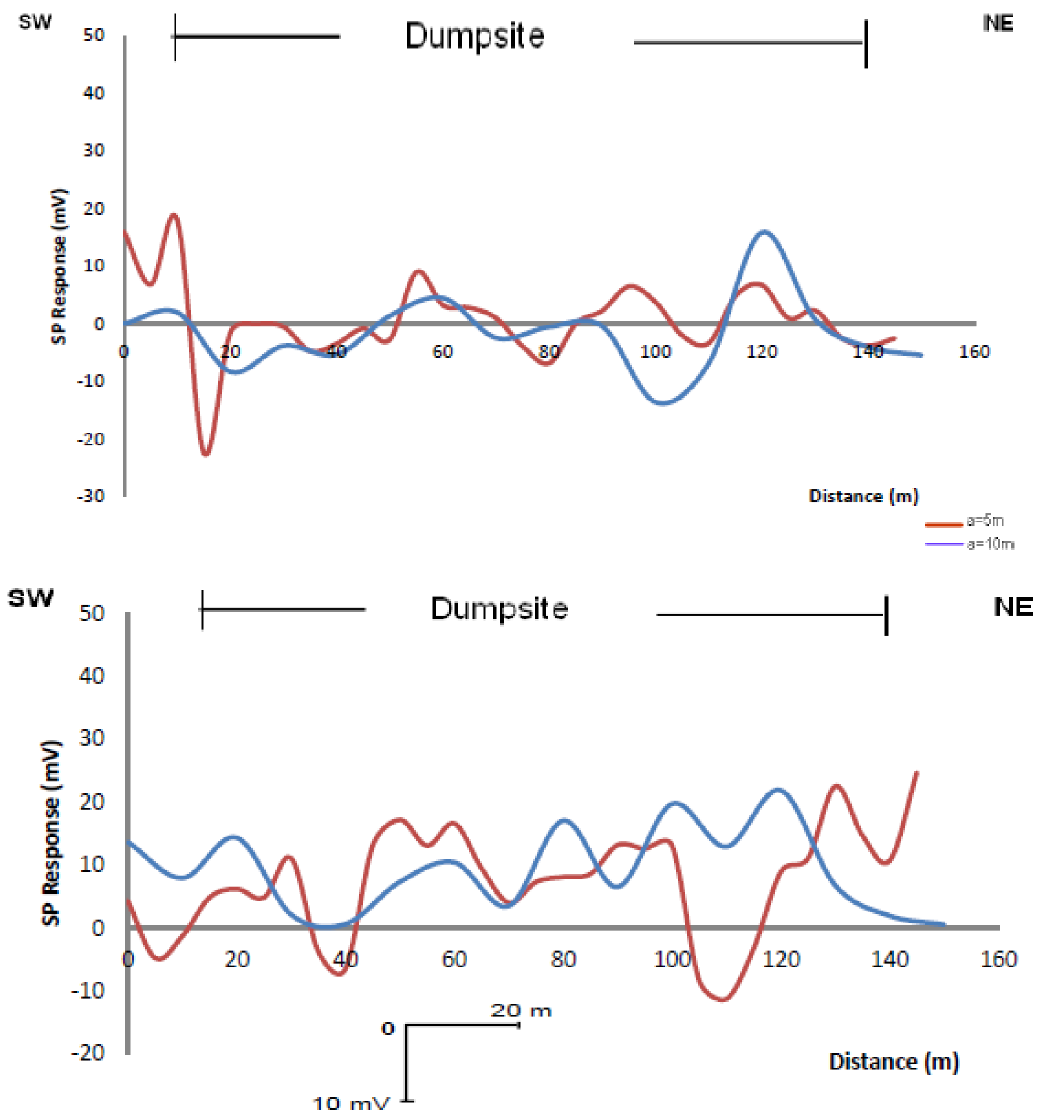

Figure 7: SP Response Using Fixed Base Array at ‘a’ of 5 and 10 m in the SW-NE Direction Across the Dumpsite During the (a) Rainy Season (b) Dry Season

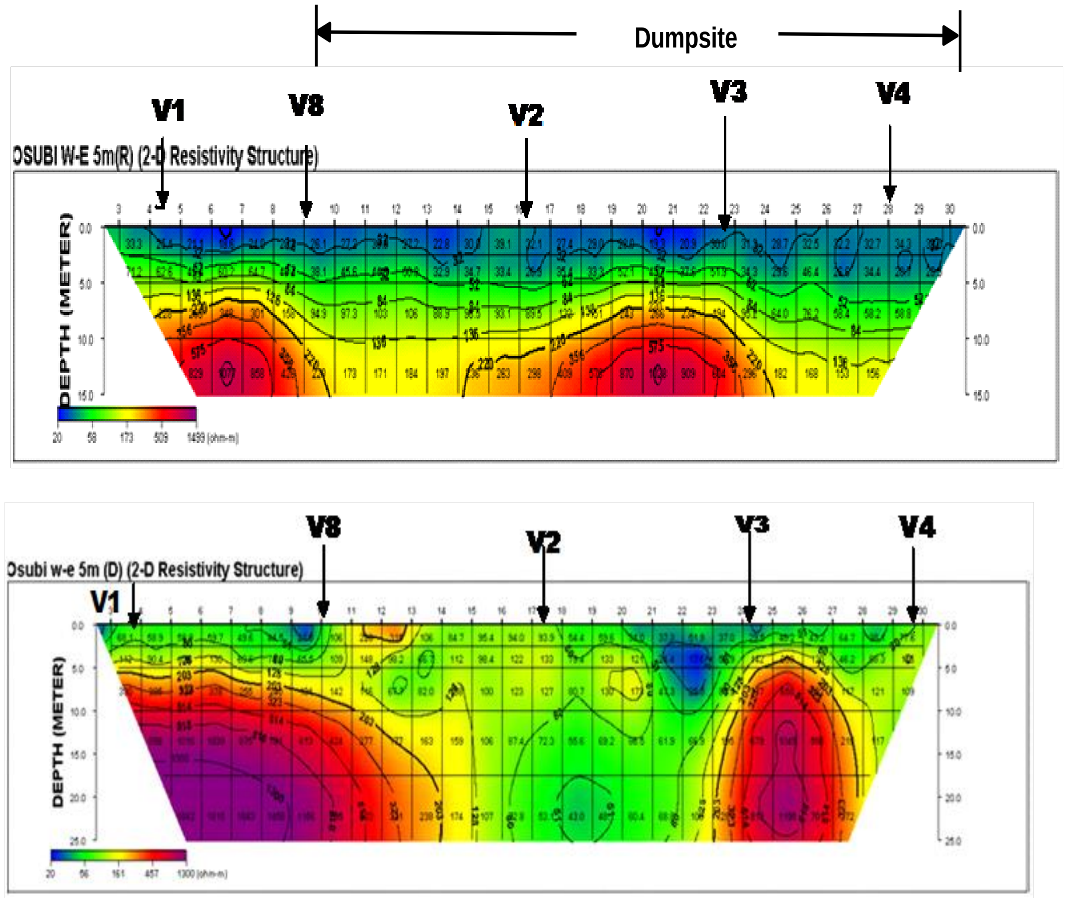

Figure 8: 2-D Resistivity Structure at a=5 m in the W-E Direction Across the Dumpsite During the Rainy and Dry Season respectively

Also, the 2-D resistivity structure in the SW-NE direction across the dumpsite shows three distinct subsurface layers (Figures 9). With electrode spacing of 5 m, the topsoil display characteristically very low resistivity in deep blue colour band of 10.9 to 52.6 ohm-m, and 12.9 to 60.1 ohm-m in the rain and dry season respectively. The topsoil within the identified zones may have been contaminated by the leachate from the dump. The second layer characterised by deep blue/ greenish colouration has resistivity generally less than 200 and 220 ohm-m in both seasons respectively.

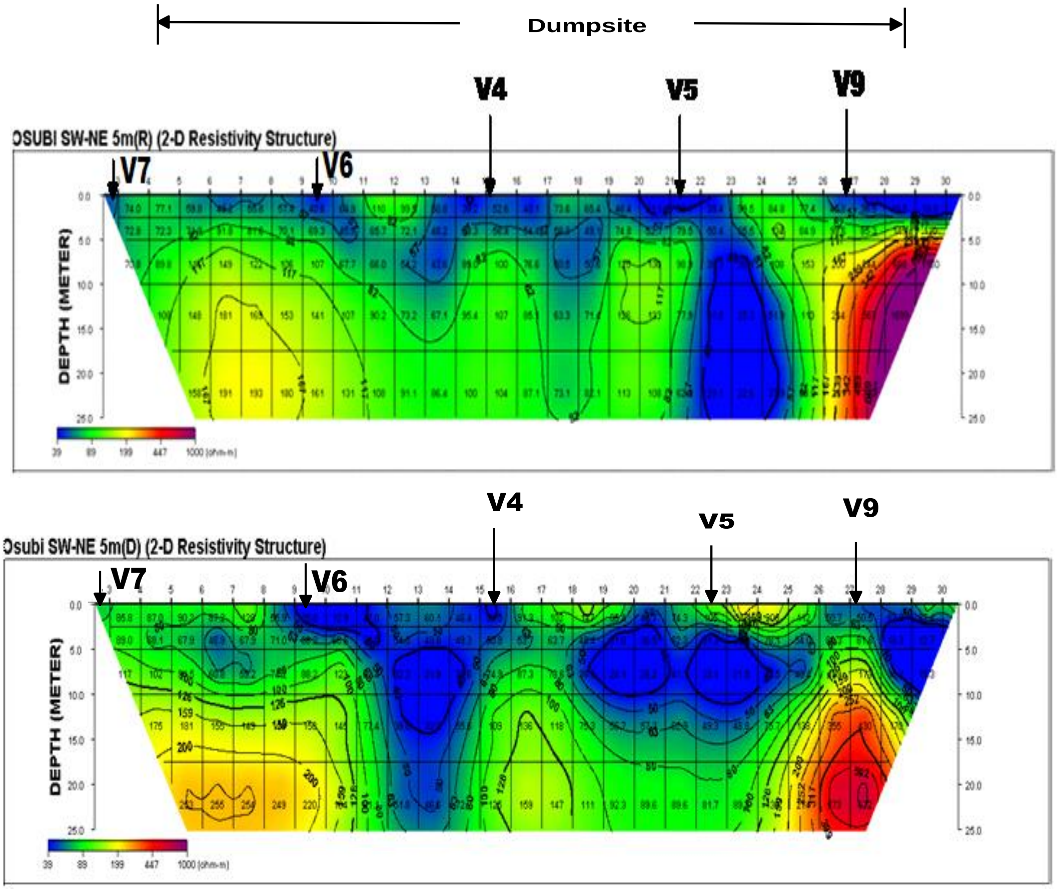

Figure 9: 2-D Resistivity Structure at a= 5 m in the SW-NE Direction Across the Dumpsite During the Rainy and Dry Season

The patches of very low resistivity zones (in deep blue colour) embedded within the low resistivity second layer are diagnostic of the presence of contamination from the dumpsite. The third layer with yellowish – red – purple colour band is the medium to coarse grained sand which has a resistivity of 338 to 1700 ohm-m, and 317 to 600 ohm-m in both seasons respectively. Along this traverse, the leachate is found to be moving in the north eastern direction and also vertical migration between VES 6 - 9, to a depth of over 25 m and this will have direct impact on the quality of groundwater in the area.

3.3 Vertical Electrical Sounding Results

The field curves of the geoelectric data show the relation between the apparent resistivity and half the current electrode spacing (Figure 10). The First order geoelectric parameters of resistivity (ρ) and depth (z) from the results of the VES is presented in table 1, during the two seasons.

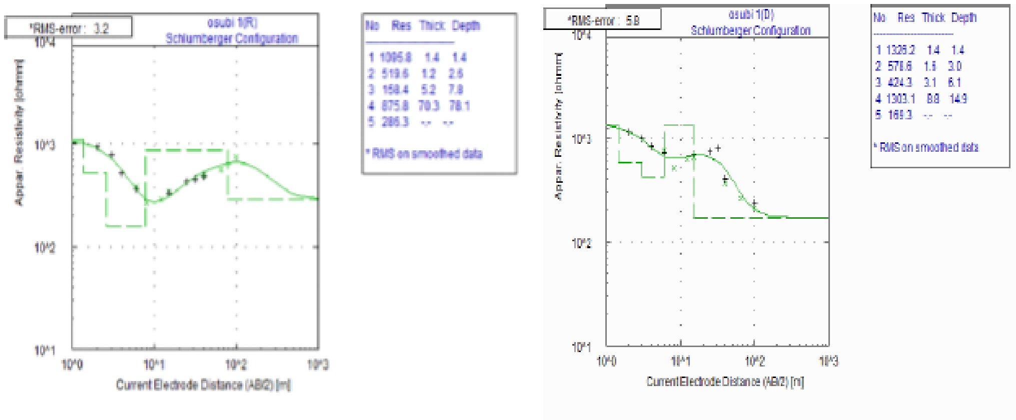

Figure 10: Typical VES curve obtained from the study area

Table 1: Interpreted VES results for Site 1 (Osubi Dump-site) in the rainy season

VES Station	Rainy Season: Computer iterated Resistivity $\rho_1/\rho_2/\rho_3/.........\rho_n$ (Ωm)	Rainy Season: Computer iterated Depth $z_1/z_2/z_3/.........z_n$ (m)	Dry Season: Computer iterated Resistivity $\rho_1/\rho_2/\rho_3/.........\rho_n$ (Ωm)	Dry Season: Computer iterated Depth $z_1/z_2/z_3/.........z_n$ (m)	Curve Type
VES1	1096/520/158/876/286	1.4/2.6/8.1/78.4	1326/579/424/1303/169	1.4/3.0/6.1/14.9	HAK
VES2	47/15/155/349	0.8/2.2/15.7	49/45/131/455	0.8/1.9/18.3	A
VES3	44/13/119/4667	0.8/2.0/4.5	64/18/785/13492	0.8/2.3/5.6	HA
VES4	39/16/152/957	0.8/2.3/10.9	88/54/60/724	0.7/2.1/14.1	HA
VES5	47/171/18/975	0.5/1.3/4.0	33/183/23/1627	2.0/4.8/9.0	KH
VES6	69/22/123/198	0.8/1.7/15.7	79/16/158/1271	2.0/4.8/9.0	HA
VES7	49/28/84/732	0.9/2.6/6.2	95/19/176/615	0.5/1.3/10.8	HA
VES8	562/374/657	1.5/20.3	496/367/730	1.4/24.9	H
VES9	46/19/214/258	0.9/3.5/19.0	79/18/436/898	0.8/2.7/19.0	HA

3.4 Geoelectric Sections across Osubi Area

Two geoelectric sections along the W-E and the SW-NE directions were generated for the rainy and dry seasons data across site 1, (Figures 11 and 12. The subsurface layers delineated from these sections when compared with the borehole logs in the area include; the topsoil, clayey sand, fine sand and the medium to coarse grained sand.

From the W-E geoelectric section which consists of VES 1,8,2,3 and 4, the topsoil resistivity ranges from 40 to 1096 ohm-m, and 49 to 1326 ohm-m, and thickness varying from 0.7 to 1.5 m, in the rainy and dry seasons respectively. The low resistivity values in the eastern part of this layer is be attributed to the effect of leachate from the dumpsite.

The second geoelectric layer which is composed probably of clayey sand, has resistivity varying from 14 to 16 ohm-m, and 22 to 54 ohm-m; and a thickness of 2.2 to 2.6 m, in the rainy and dry seasons respectively. Also, the infiltration of leachate into this layer is probably responsible for the low resistivity values exhibited.

The third geoelectric layer is likely made up of fine sand and it has resistivity ranging from 120 to 374 ohm-m and 60 to 579 ohm-m; with a thickness varying from 8.1 to 20.3

m, and 7.8 to 20.3 m in the rainy and dry seasons respectively. Comparison with the lithologic information from drilled well shows this layer is water bearing and the preferred source for portable water for the inhabitants in the area.

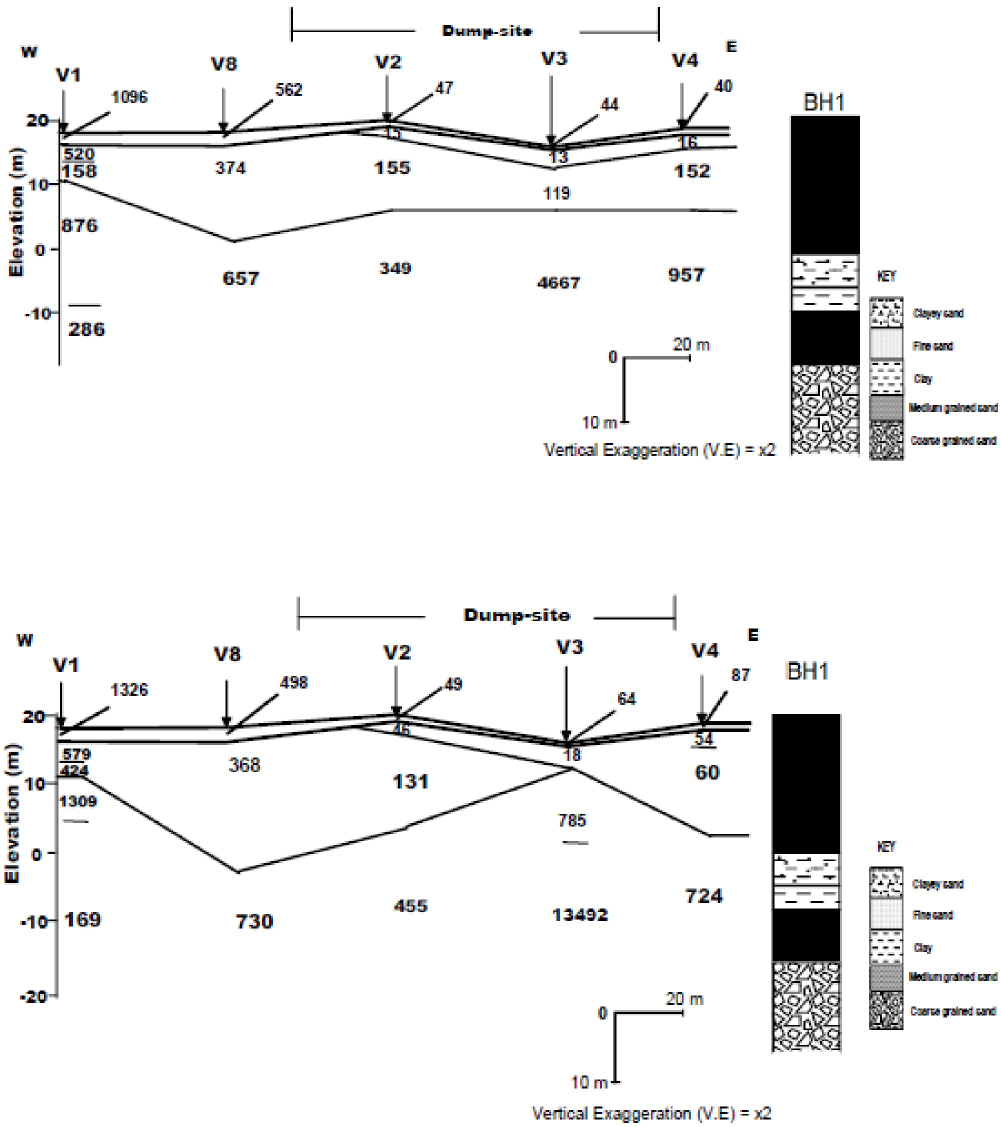

Figure 11: Geoelectric Section along the W-E Direction in Site 1 (Osubi) During the (a) Rainy Season (b) Dry Season

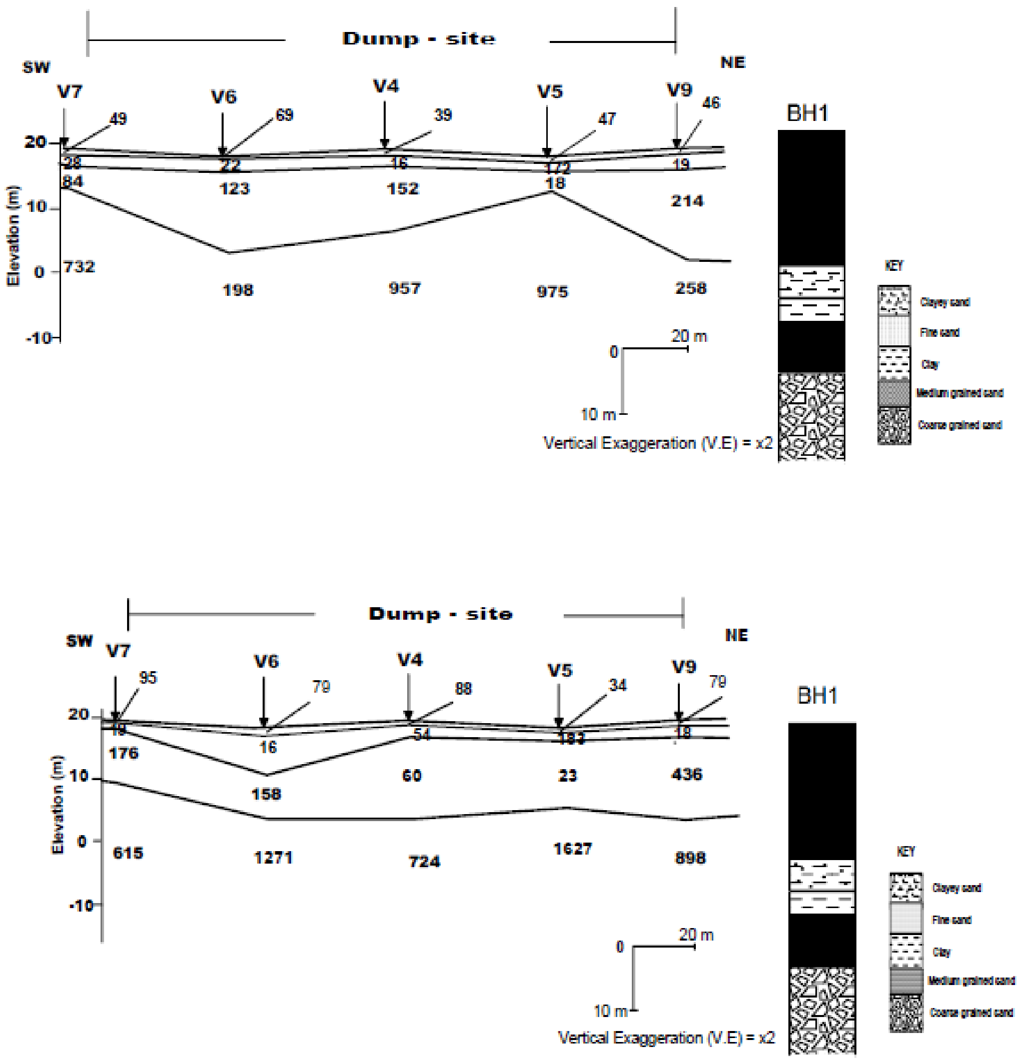

Figure 12: Geoelectric Section Along the SW-NE Direction in Site 1(Osubi)
During the (a) Rainy Season (b) Dry Season

The SW-NE geoelectric section consists of VES 7, 6, 4, 5and 9. The topsoil resistivity ranges from 39 to 69 ohm-m, and 34 to 95 ohm-m, and thickness varying from 0.5 to 0.9 m, in the rainy and dry seasons respectively. The low resistivity obtained in this layer could be attributed to the effect of leachate from the dumpsite.

The second geoelectric layer which is probably composed of clayey sand, with resistivity varying from 16 to 172 ohm-m, and 16 to 183 ohm-m; and a thickness of 1.3 to 3.5 m, and 1.7 to 3.5 m in the rainy and dry seasons respectively. The infiltration of leachate into this layer and lithology could be responsible for the low resistivity exhibited. The third geoelectric layer is probably made up of fine sand and it has resistivity ranging from 18 to 214 ohm-m and 60 to 436 ohm-m; with a thickness varying from 4.0 to 19.0 m, in the rainy and dry seasons respectively. The fourth geoelectric layer is composed of medium to coarse grained sand. The resistivity varies from 198 to 957 0hm-m, and 615 to 1627 ohm-m in the both seasons respectively.

3.5 Correlation Between the SP Responses, Dipole: Dipole Pseudosections and the Geoelectric Sections across the Study Area

A comparison between the results of the SP, Dipole dipole and VES methods were carried in order to look at the study from an integrated geophysical point of view, and to have robust information on the leachate migration and groundwater contamination in the study area.

The correlation of the results of the various methods employed across the study area is shown in Figures 13 and 14. In the W-E direction, the SP responses of both the gradient and the fixed base array display low potential of between 20 and -40 mV/m around the dumpsite area. This SP response correlates with the 2-D resistivity structure from the dipole – dipole pseudosection, which shows a low resistivity of 21 to 95 ohm-m within the topsoil and the second layer (blue and light green colouration respectively). Also, the resistivity of the topsoil and the second layer to a depth of about 5 m in the vertical electrical sounding (VES) geoelectric section shows a low range of 49 to 87 ohm-m around the dumpsite area as against 498 to 1326 ohm-m outside the dumpsite in both the rainy and dry seasons. These correlations clearly indicate the presence of leachate around the dumpsite area. The gradual decrease of the SP responses and the topsoil resistivity values towards the east in both seasons is indicative that the groundwater/contaminant flow could be in the W-E direction. The SW-NE SP responses (Figures 15 and 16) of both the gradient and the fixed base array also display low potential ranging from 20 to -40 mV/m and -40mV around the dumpsite area. There is also a correlation of the SP responses with the resistivity from the 2-D structure with values ranging from 22 to 54 ohm-m in the topsoil and the second layer. From the geoelectric section, the resistivity of the topsoil and the second layer to a depth of about 5 m shows a low range of 30 to 95 ohm-m around the dumpsite area in both the rainy and dry seasons. These correlations clearly show the presence of leachate and the migration of contaminant in the SW-NE direction.

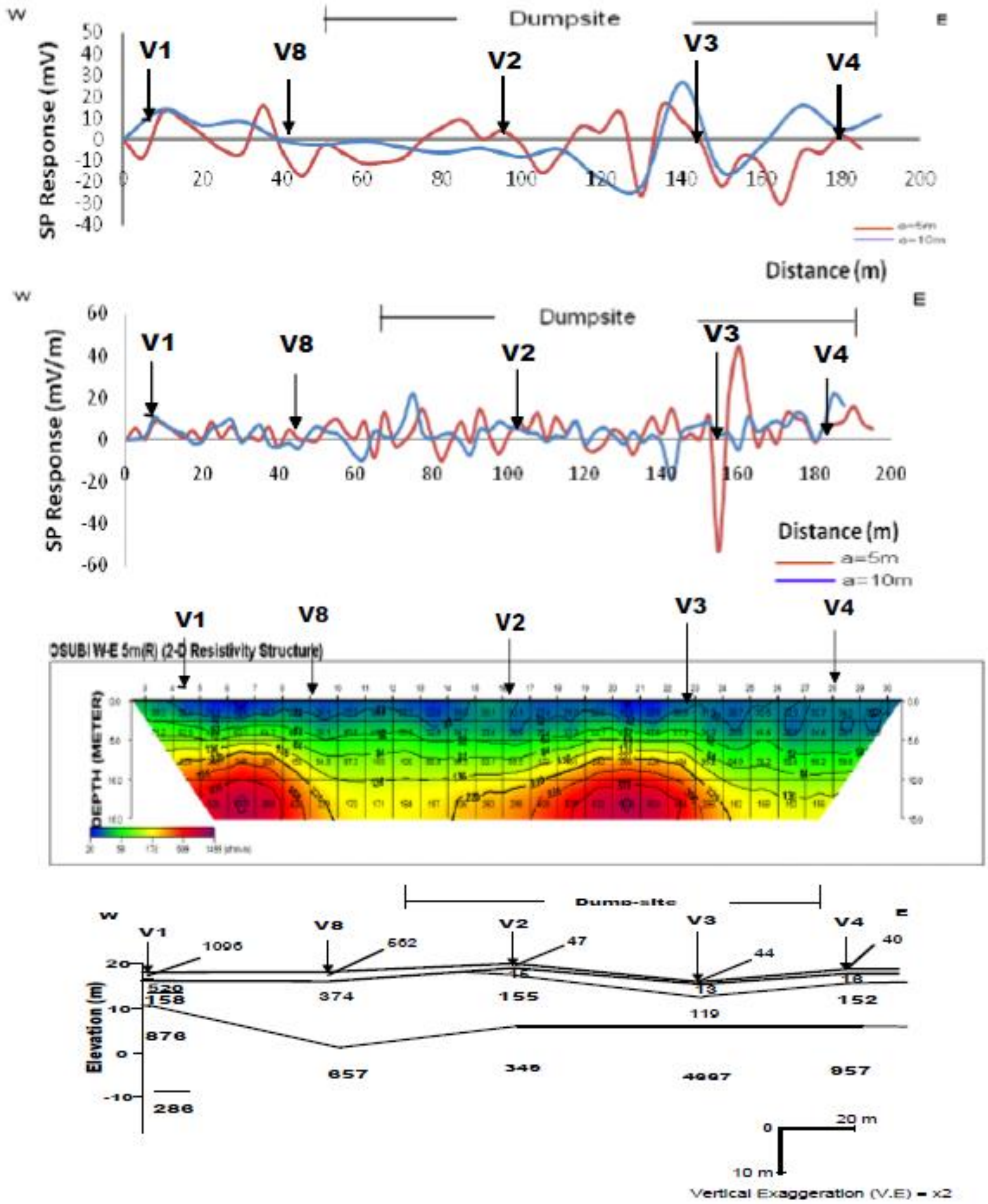

Figure 13: Gradient and Fixed Base array Responses, 2D Resistivity Structure at a = 5m and Geoelectric Section at the W-E Direction over Site 1 (Osubi area) during the Rainy Season

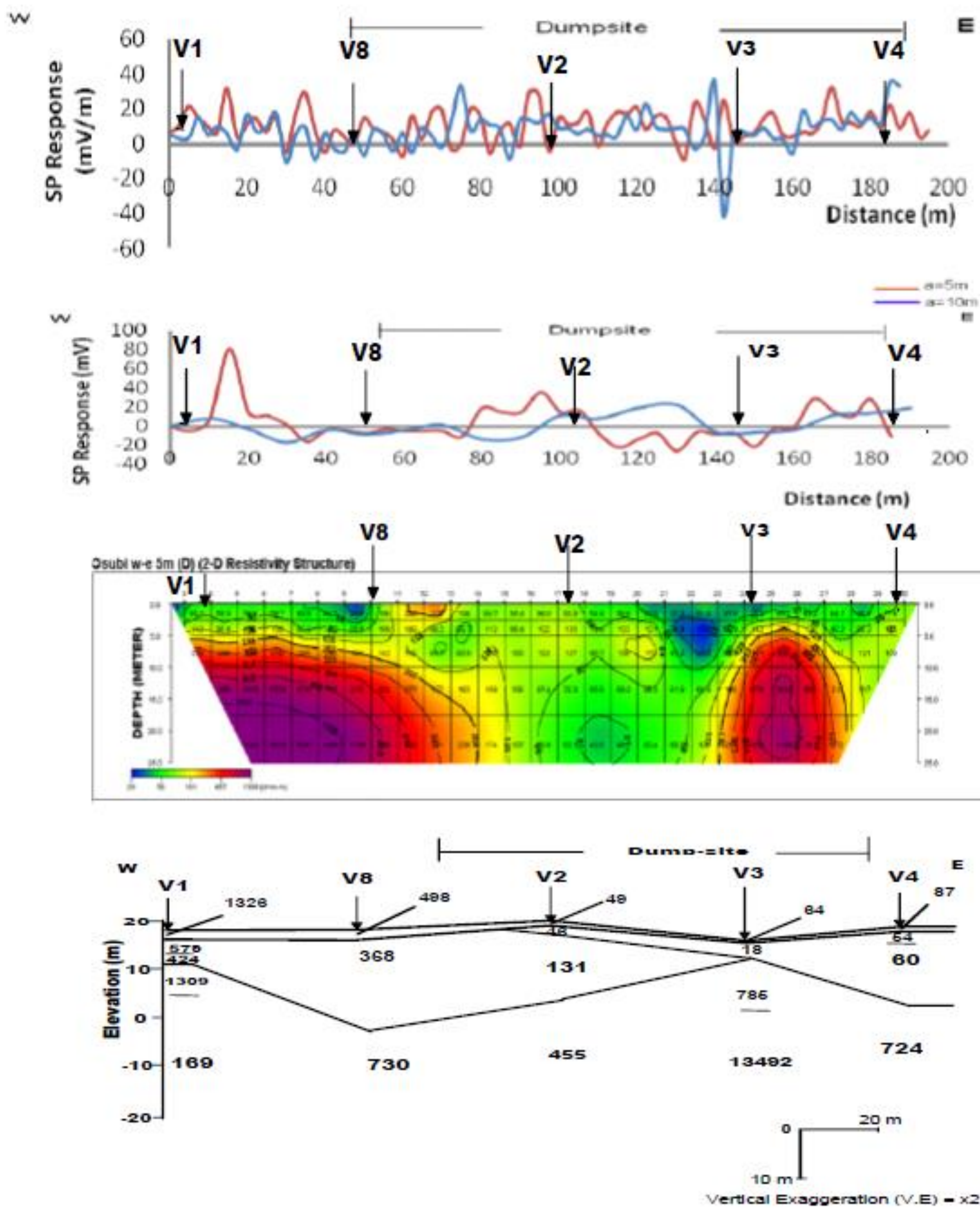

Figure 14: Gradient and Fixed Base Array SP Responses, 2D Resistivity Structure at a = 5m, and Geoelectric Section in the W-E Direction Over the Dumpsite During the Dry Season

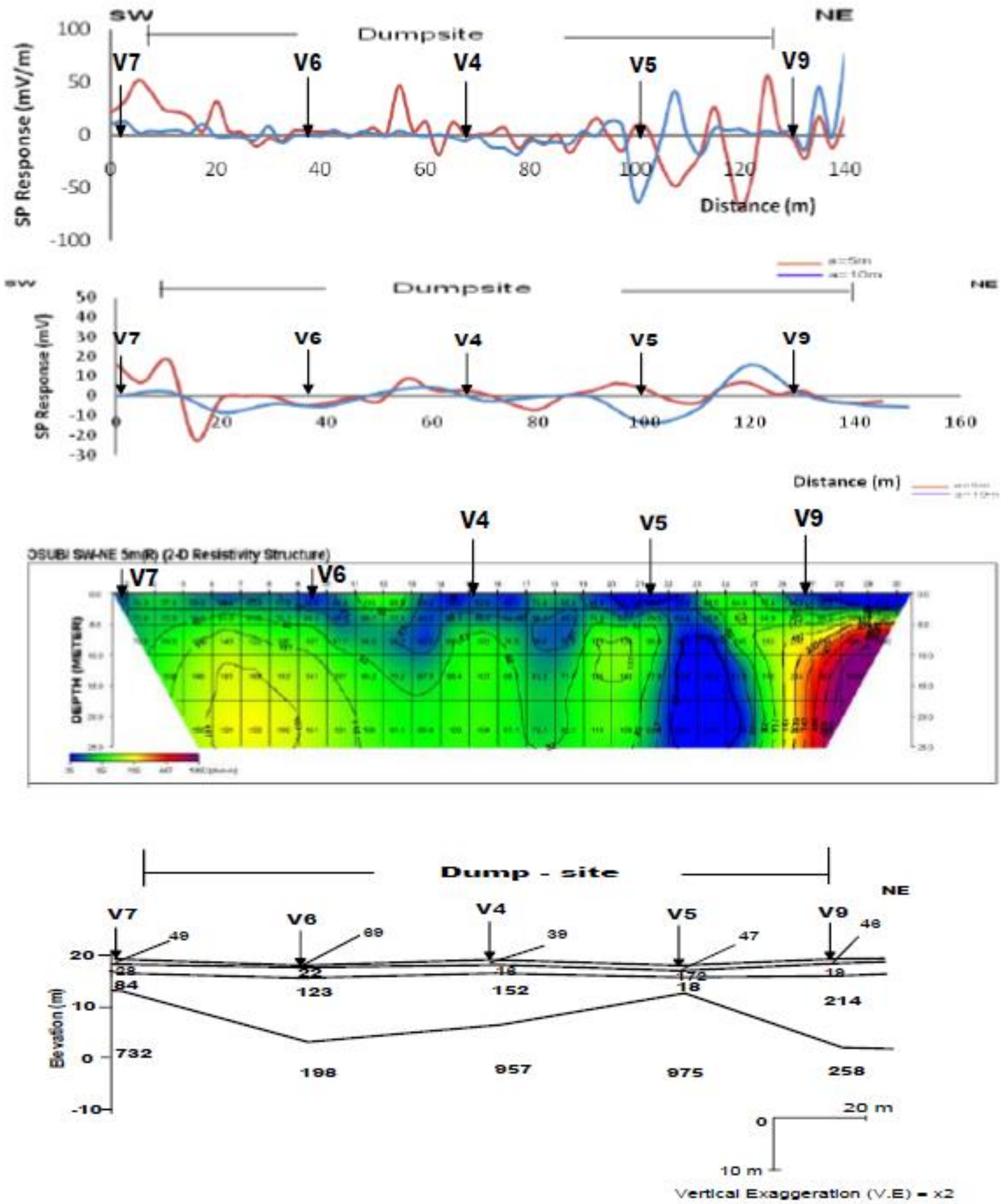

Figure 15: Gradient and Fixed Base Array SP Responses, 2D Resistivity Structure at a = 5m, and Geoelectric Section in the SW-NE Direction Over the Dumpsite During the Rainy Season

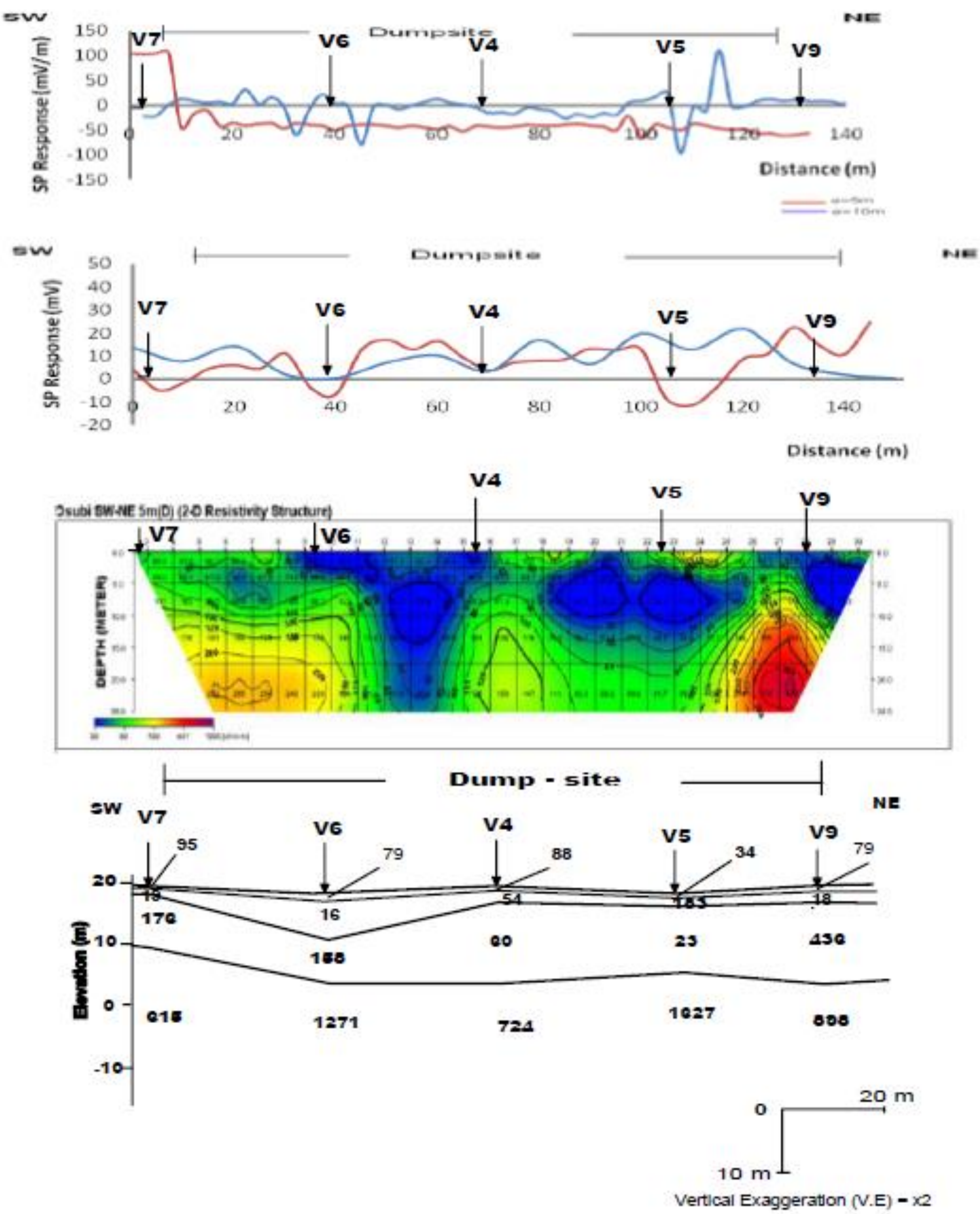

Figure 16: Gradient and Fixed Base Array SP Responses, 2D Resistivity Structure at a = 5m, and Geoelectric Section in the SW-NE Direction Over the Dumpsite During the Dry Season

3.6 Hydrogeochemical Analysis

Table 2 show the results of samples collected from two hand dug wells, a borehole and swamp around the dumpsite in both the rainy and dry seasons. Most of the parameters determined fell within the World Health Organisation (WHO) and the Nigerian Standard for Drinking water quality (NSDWQ), under the Standard Organisation of Nigeria (SON), acceptable limits. Comparing the rainy and dry season results, there is a decrease in the concentration of total dissolved solids (TDS), total suspended solids (TSS) and chloride in the dry season. This could be attributed to the breaking down of much of the biodegradable mass with time, while the decomposition of the organic components of the waste by the action of micro organisms increases the level of organic matter for the period of the rainy season. The high concentration of detrimental substances such as iron, lead and total viable bacteria counts in all the samples call for urgent attention. This could be as a result of corrosion of metallic scraps, infiltration of used engine/motor oil and faecal contamination respectively. Also, the electrical conductivity of SW, HDW1 and HDW2 close to the dumpsite is observed to be fairly high, > 200 $\mu s/cm^3$ in the rainy season and >500 $\mu s/cm^3$ in the dry season. This is in agreement with the low resistivity of < 100 ohm-m observed in VES 2 and 3 close to the wells.

Table 2: Physiochemical parameters of groundwater from the study area in the rainy and dry seasons

Parameter	NSDQW Max Permissible	WHO's Max Permissible	RAINY SEASON				DRY SEASON			
			HDW1	HDW2	SW	BH	HDW1	HDW2	SW	BH
P^H	6.5 – 8.5	5.5 – 8.5	6.40	7.00	6.60	6.50	6.85	7.50	7.63	6.52
Total Solids (TS) mg/L		500	34.91	39.26	37.84	19.57	34.26	39.26	35.54	19.23
Total dissolved solids (TDS) mg/L	500	500	19.28	28.63	12.43	11.94	19.14	27.87	18.65	11.52
Total suspended solids (TSS) mg/L	1000	1000	28.63	28.76	29.41	11.63	26.31	28.15	27.64	11.54
Alkalinity (mg/L)			2.63	7.94	0.94	0.50	2.45	7.55	0.63	0.50
Colour			Reddish brown	Golden green	Golden green	Colourless	Reddish brown	Golden green	Golden green	Colourless
Total Hardness (mg/L)	150		34.70	35.51	29.43	25.64	34.55	34.93	26.95	25.61
Carbonates (mg/L)			2.30	11.90	1.20	1.40	2.10	11.45	2.45	1.25
Chloride (mg/L)	250	200	18.47	16.58	18.84	12.43	15.35	15.53	15.86	10.87
Nitrate (mg/L)	50	10	11.07	10.46	10.73	8.64	10.65	10.15	10.43	8.55
Sulphate (mg/L)	100	200	9.43	8.16	7.89	7.63	8.76	8.05	7.35	7.41
Lead (mg/L)	0.01	0.01	0.021	0.416	0.017	0.02	0.016	0.405	0.018	0.02
Potassium (mg/L)			11.47	11.34	0.98	0.78	14.65	15.43	6.84	0.83
Sodium	200		6.16	5.78	8.41	4.63	8.56	7.34	12.54	4.85
Phosphate (mg/L)			4.17	3.84	5.64	2.94	5.73	8.05	6.23	2.96
Calcium (mg/L)		75	18.63	24.63	16.31	3.47	22.86	28.23	19.54	3.52
Magnesium (mg/L)		50	16.16	21.63	11.16	8.04	19.65	24.15	15.23	8.16
Copper (mg/L)	1.0	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Iron (mg/L)	0.3	0.3	0.11	0.14	0.38	0.03	0.18	0.18	0.45	0.03
Temperature (^{0}C)			25.60	25.60	25.60	25.70	25.60	25.60	25.60	25.70
Turbidity (NTU)	5.0	5.0	22.0	28.03	16.16	6.17	25.0	29.85	21.32	6.25
Conductivity (µs/cm^3)	1000	500	510.0	653.0	655.0	465	340.0	350	300.0	340
Total viable bacteria count (cfu/mL)	10		31.6	34.7	48.4	10.4	24.8	29.5	41.5	8.2

4 Conclusion

The integrated geophysical and hydrogeochemical methods have shown that the shallow aquifer around the dumpsite area has been contaminated by leachate emanating from the dumpsite. It is therefore recommended that continuous groundwater quality monitoring and treatment should be encouraged in the area. Also, Efforts should be made by government to drill boreholes to deeper depth, and construct proper and well designed landfill sites at areas far away from the metropolis and proper environmental measures should be taken to safeguard the aquifer from contamination.

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