2-D RESISTIVITY IMAGING AND HYDROGEOCHEMICAL ANALYSIS FOR LEACHATE MIGRATION AT DUMPSITES IN SOUTH-SOUTH NIGERIA

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ABSTRACT

Vertical electrical sounding, 2-D tomography and hydrogeochemical analysis was applied to investigate dumpsite leachate plume generation, migration and its impact on the surrounding soil and groundwater aquifer at a municipality in the Western Niger Delta. Twelve vertical electrical sounding (VES) was investigated using the Mini-Res Resistivity Meter with the Schlumberger array. The VES survey result was interpreted with Winglink software. Five hand-dug well water and 5 tap/borehole water samples was collected for hydrogeochemical analysis using the sterile plain bottles and 1-litre plastic bottles. Resistivity results delineated 5 layers of lateritic topsoil, sandy clay, fine coarse-sand, medium coarse-sand and coarse sand. The VES and 2-D tomography mapped and identified 2 distinct zones viz:zone of low resistivity of 91Ωm and 394Ωm at depth of 5m to >28m indicating area of leachate contaminant plume and zone of high resistivity value of 422Ωm and 5102Ωm suspected to be dumpsite gases such as NH_3, CH_4, SO_2 and CO_2. The 2-D resistivity imaging also revealed that the generated dumpsite leachate contaminant plume was migrating from the Northern part of the burrow-pit dumpsite towards its Eastern part and to the Northern part of the dumpsite at Scot road/Sakponba road. Hydrogeochemical parameter results showed that colour, pH, iron, Lead and coliform bacteria exceeded permissible standard indicating that the leachate plume has migrated to the groundwater aquifer. Closed municipal landfill whose base is made of concrete and paved surfaces should be adopted in the area to prevent leaching of poisonous substances into groundwater aquifer.

Keywords: *Aquifer, Dumpsite Leachate, Hydrogeochemical, Tomography*

1.0 INTRODUCTION

Wastes are the useless, unwanted and hazardous materials or substances generated by human activities which are of no economic value and demand. They include domestic wastes, industrial wastes, mining wastes and agricultural wastes which are generated daily in the urban cities of Nigeria and are indiscrimately disposed of on lands, in the rivers, streams and lakes without consideration to underground water environment. This poses problems to groundwater purity. Indiscriminate disposal of organic and inorganic wastes is detrimental to the environment and health of the inhabitants in the area since it creates unsanitary environment associated with lots of adverse effects. Where sanitary facilities are scarce, household solid wastes also tends to be mixed with faecal matter, further compounding the health hazards [1], [2]. Most of the dumpsites in Oghara municipality in the Western Niger Delta are indiscrimately located within residential areas, markets, farmlands, at sea and road sides. These wastes which are generated by human and industrial activities release toxic substances into the environment when they decompose or biodegrade. In the presence of infiltrating water, these toxic substances produce organic liquids known as leachates (NO_3^-, SO_4^{2+}, Cl^-) which contaminate groundwater with time as they migrate resulting in environmental pollution and disease outbreak. The leachate plumes normally have low resistivity values due to high ion concentration [3] thus giving the dumpsite low pH value because of high conductivity signatures and causing problems to groundwater purity. The intensity and extent of these problems are hardly investigated. With increase in environmental awareness and control, electrical resistivity has become a fundamental and diagnostic tool to environmental studies [4] especially to determine the subsurface resistivity distribution in areas requiring subsurface delineation of leachate plume generation, migration and areal extent in the contamination of underground water. In recent years, one of the new developments in the fields of engineering, geo-environment, hydrogeology and contaminant hydrology is the application of 2-D electrical imaging techniques to map areas with moderate to complex geology [5]. Authors such as [6], [7], [8], [9], [10], [11], [12], [13], [14], [2], [15], and [16] have carried out studies on the application of 2-D resistivity imaging to delineate contaminant plume from waste dumpsite in the Niger Delta region. However, no studies using 2-D tomography to investigate dumpsite leachate migration have been done at Oghara in the Western Niger Delta. This study uses vertical electrical sounding, 2-D tomography and hydrogeochemical analysis to investigate dumpsite leachate plume generation, migration and its input on the groundwater aquifer at Oghara, Delta State, Nigeria.

2.0 THE STUDY AREA

2.1 Regional Geology and Topography

Oghara, in Ethiope West Local Government Area of Delta State, Nigeria, is located approximately on Latitude 05^0 59' North of the Equator and Longitude 05^0 42' East of the Greenwich Meridian (Fig. 1). The area is part of the *Benin Formation* often referred to as *the Coastal Plain Sands* of the lower Quaternary period and Pliocene-Pleistocene epoch. The inclusive Aluvium belongs to the upper Quaternary (Recent Sediments) and consists of silty clayey sands, sand and gravels. Topographically, the area is flat lying with both marine and fluvial sediments. The flat-floored river Ethiope traversed the area and drains into the Atlantic

Ocean. The flood plains are prone to flooding in the wet season mainly due to heavy rainfall, high ground water table and the flat-floored valleys.
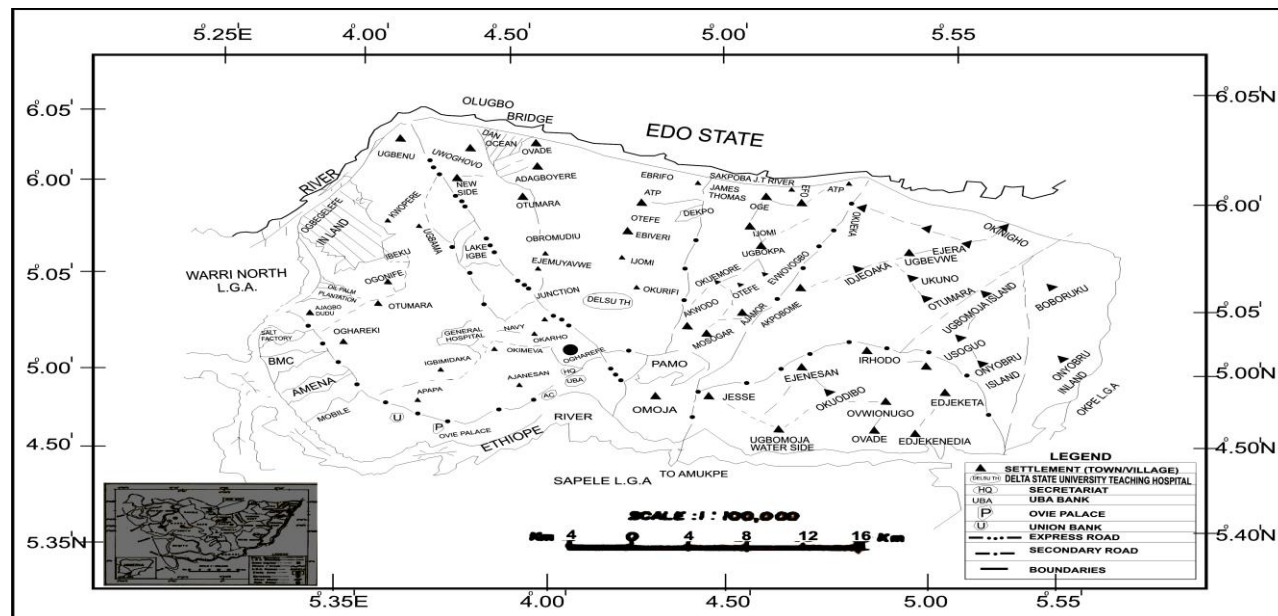

Figure 1: Map of Ethiope West Local Government showing Location of the study Area

2.2 Dumpsite Locations in the Study Area

Solid and liquid wastes are indiscriminately deposited in Oghara municipality in open dumpsites without regard to proximity of inhabited homes/houses, the nature of soil, and the hydrogeology of the area. The study investigated 2 dumpsites viz: (1) A burrow-pit that lies within 5° 56' 50.10''N and 5° 39' 34.12''E located at Ibori road opposite Keldor hotel, Ogharefe. The dimension of the burrow-pit is 20m by 40m and the age is conservatively between 20 and 30 years. The burrow-pit is where the residents in the area dump their domestic solid and liquid wastes. Liquid wastes from swimming pool, laundary and dirty dishes generated at Keldor hotel are also channeled through underground waste pipes and emptied into the burrow-pit (Fig. 2); (2) The dumpsite located within the residential area enclosed by Scot road and Sakponba road in Ogharefe which lies on co-ordinates 5° 56' 52.58''N and 5° 39' 34.45''E. The dumpsite covers a total length of about 632m from Otorho road by Scot road junction to Sakponba road. It is the belief of the local inhabitants that this dumpsite has been in existence for over 50 years (Fig. 3).

3.0 MATERIALS AND METHODS

3.1Data Acquisition

3.1.1 Geophysical Data Acquisition

The geophysical survey data was acquired using the *Mini-Res Resistivity meter* which is a signal averaging system where consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is displayed as resistance automatically.

A total of 12 Vertical Electrical Soundings (VES) were carried out for the study and were run at the 2 dumpsites. The VES stations were taken 10m away from each of the 2 dumpsites on the northern, southern and eastern side. Electrode spacing of 1m, 2m, 3m, 4m, 6m, 8m, 10m, 12m, 14m, 16m, 18m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 60m, 70m, 80m and 90m was used with a total distance of 100m. These electrode spacing were chosen closely together so that minor or suppressed layer can easily be detected and this helped in identifying the leachate plume and its migration path. Again, since environmental geophysical surveys are concerned with near surface of depths less than 30m according to [11], small electrode spacing was adopted in order to provide considerable details of any plumes related to leachates from the dumpsites. A maximum current electrode expansion (AB/2) of 100m and potential electrode expansion (MN/2) of 10m were utilized in the survey using Schlumberger array because it is faster, more economical to use and less sensitive to lateral variation. For each resistivity station where measurement was made, a reading of resistance R of the volume of the earth material within the electrical space of the electrode configuration was obtained. The measured resistance values (R) were converted into apparent resistivity (ρ_a) by multiplying with a geometric factor (k), such that:

$$\rho a = \pi R \frac{[(AB/2)^2-(MN/2)^2]}{MN} \qquad (1)$$

Where:

$$\left\{ \frac{[(AB/2)^2-(MN/2)^2]}{MN} \right\} \quad \text{is the geometric factor} = K \qquad (2)$$

ρa = apparent resistivity (Ohm-m), R = resistance (Ohm), AB = distance between current electrodes (m), MN = distance between potential electrodes (m), π = Constant = 3.142.

Six VES stations were carried out at the burrow pit dumpsite. (Fig. 2). VES 1 was located 10m away from the dumpsite on the northern section. VES 2 was carried out with maximum AB/2 of 50m and MN/2 of 5m and located 10m away from the burrow pit dumpsite on the eastern section. VES 3 was located 5m away from the dumpsite on the southern section which was also very close to a residential building (BLD$_1$) with borehole (BH$_2$). VES 4 which
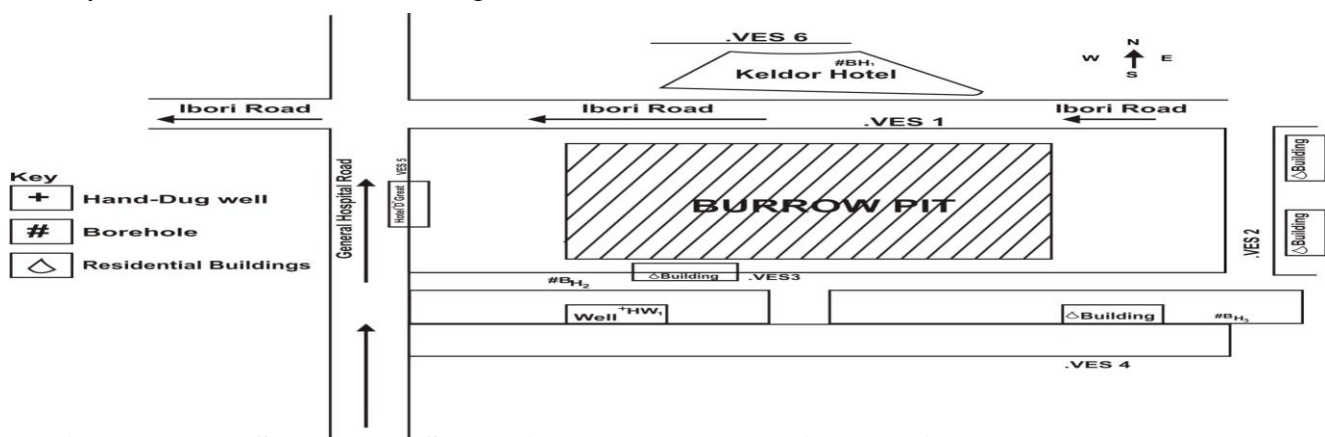

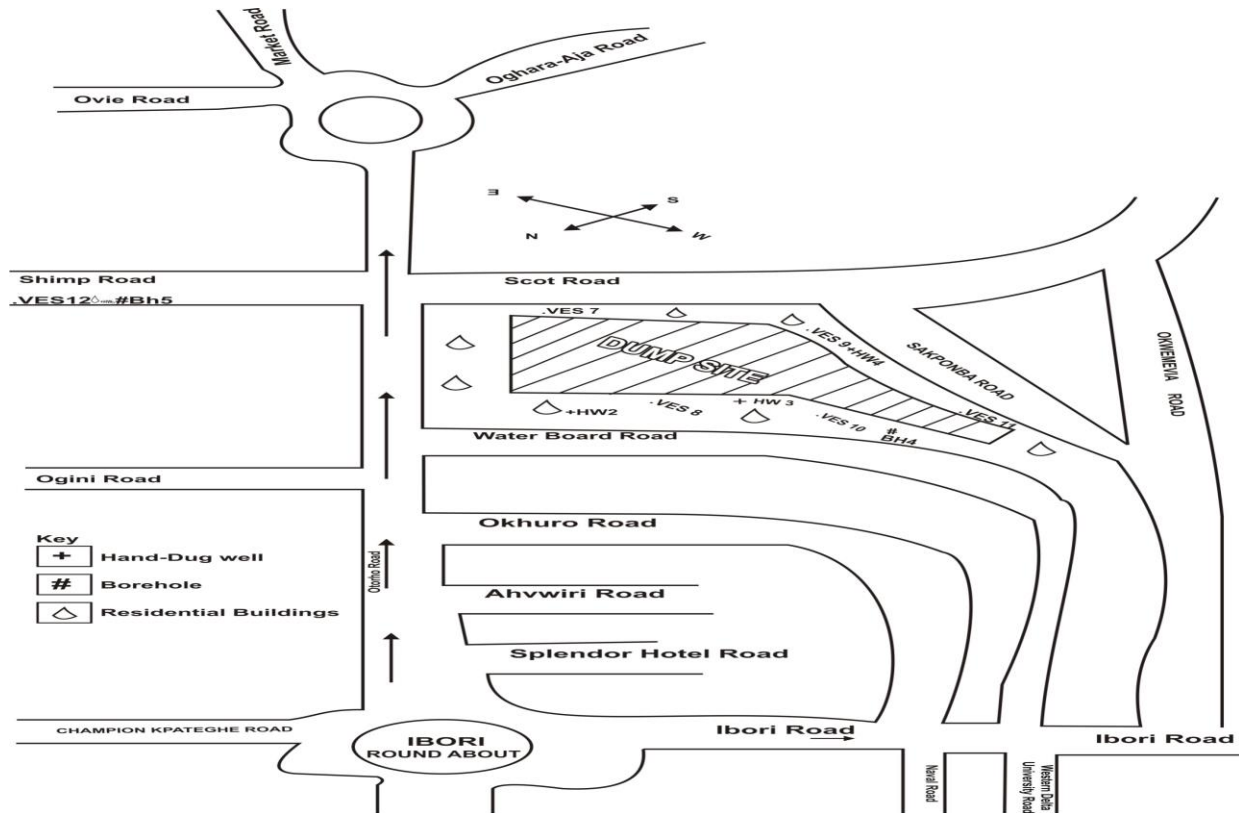**Figure 2: Map Showing VES Locations at the burrow pit dumpsite**

Figure 3: Map Showing VES Locations at the dumpsite enclosed within Scot and Sakponba Road

was sounded 200m away from the dumpsite, but parallel to VES 3 was also located on the southern section of the burrow pit dumpsite. Again, VES 4 was sounded close to a residential building (BLD_2) with a borehole (BH_3), and also close to a hand-dug well (HW_1). VES 5 was located 30m away from the dumpsite on the western section. VES 6 was located 60m away from the dumpsite on the northern section which is parallel to VES 1, but it is behind Keldor hotel with borehole (BH_1).

Six VES stations were also run at the Dumpsite enclosed within Scot Road and Sakponba Road (Fig. 3). Four out of the 6 VES (ie VES 7, VES 8, VES 9 and VES 12) were carried out with maximum current electrode spacing AB/2 of 100m and potential electrode separation MN/2 of 10m. VES stations 7, 8 and 9 were each located 10m away from the edge of the dumpsite. The station distance between VES 7, VES 8 and VES 9 was respectively 50m apart. VES 12 which was located along shrimp road was sounded 850m away from the dumpsite at VES station 7. The other 2 VES stations (VES 10 and VES 11) were also carried out on the dumpsite with maximum current AB/2 of 50m ad MN/2 of 5m. They were each located 15m away from the beginning of the dumpsite.

Due to space constraint in the field arising from residential buildings, the constant separation traversing (CST) was not run. Instead the 1-D sounding curves were converted to 2-D using the X-section of the Winglink software and are displayed as output in pseudo-sections of inverted model resistivity sections versus depth of the subsurface along three profiles for the two dumpsites. The 2-D resistivity imaging (or tomography) was therefore used to determine the source, the direction of leachate contaminant flow and the depth of the contaminant. These pseudo-sections show structures with variations on the detailed level with depth which was visually inspected and was used to delineate areas of anomalously low resistivity relating to leachate plume formation and migration which was tagged very high impact zones.

3.1.2 Hydrogeochemical Data Acquisition

Water samples were collected from 5 existing boreholes and 5 hand-dug wells in the early hours of the day within the study area in order to determine the hydrogeochemical (physico-chemical) parameters in the water samples. The water samples were collected with well washed and sterilized 1.5 litres containers and sterile plain bottles. The Sterile plain bottles were used to collect water samples to test for the presence of coliform bacteria. The bottles were labeled as follows: BH_1: water sample collected from borehole at Keldor hotel at VES 6, BH_2: water samples collected from borehole in a building that is 5m away from the burrow pit dumpsite at VES 3, BH_3: water samples collected from borehole in a building that is 200m away from the burrow pit dumpsite at VES 4, BH_4: water sample collected from borehole from a building close to the dumpsite at VES 10, BH_5: water sample collected from a building in Shrimp road at VES 12. HW_1: water sample collected from hand-dug well, 200m away from the burrow pit dumpsite at VES 4, HW_2: water sample collected from hand-dug well at the dumpsite at VES 8, HW_3: water sample collected from hand-dug well at the dumpsite at VES 10, HW_4: water sample collected from hand-dug well at the dumpsite at VES 9. HW_5: water sample collected from hand-dug well in a building close to a dumpsite along Shrimp road at VES 12. The tap/borehole waters were collected after about 10 minutes of pumping in order to ensure that the waters were stirred-up and properly mixed together to give a true representative from the underground aquifer. The hand-dug well waters were collected with a bucket attached to a rope and was manually brought to the surface before pouring into the collection containers. All the containers were covered with black polyethelyene bags after collection of the water samples so as to avoid photolytic effect on the original sample content and were stored in coolers at a regulated temperature of about 4°C. They were subsequently taken to the laboratory of Benin Owena River Basin Development Authority for analyses using international regulatory methods as recommended by [17], [18] and [19]. The laboratory analysis of the water samples was run for 9 physico-chemical parameters (ie Lead (Pb^{2+}), Iron (Fe^{2+}), Chloride (Cl^-), colour, total dissolved solids {TDS}, pH, conductivity, NO_3^- and coliform bacteria) and the results were compared with international permissible standards for portable water. The sample locations were geo-referenced showing the locations and the coordinates (Table 1).

Table 1: Geographical locations of the VES Stations, Boreholes (BH) and Hand-dug wells (HW) as well as Elevation above Sea Level in the Study Area

S/No	VES Stations, Borehole (BH) and Hand-dug Wells (HW) Locations	GPS Locations		Elevation Above Sea Level (m)	Remark
		Northings	Eastings		
1	VES 1	5°56'50.1000"	5°39'34.1280"	7.000	
2	VES 2	5°56'49.0920"	5°39'35.7840"	9.000	
3	VES 3, BH$_2$	5°56'46.7520"	5°39'33.4800"	7.000	
4	VES 4, BH$_3$, HW$_1$	5°56'43.3320"	5°39'32.1480"	8.000	
5	VES 5	5°56'51.0720"	5°39'29.7000"	13.000	
6	VES 6, BH$_1$	5°56'52.5840"	5°39'34.4520"	15.000	
7	VES 7	5°56'01.3560"	5°39'57.6360"	12.000	
8	VES 8, HW$_2$	5°56'02.6520"	5°39'57.5280"	13.000	
9	VES 9, HW$_4$	5°56'05.9640"	5°39'55.3320"	13.000	
10	VES 10, BH$_4$, HW$_3$	5°56'11.2920"	5°39'49.3920"	11.000	
11	VES 11	5°56'14.2800"	5°39'51.3360"	13.000	
12	VES 12, BH$_5$, HW$_5$	5°55'50.5200"	5°40'05.9880"	11.000	

4.0 RESULTS AND DISCUSSION

4.1 VES Data Results

The result of the 1D resistivity survey and the curve types are HKH, KH, KHK, KHA and QH as shown in Figure 4a and 4b. The apparent resistivity values and the corresponding lithology of the 5 delineated layers of lateritic topsoil, sandy clay, fine coarse sand, medium coarse sand, and coarse sand are presented in Table 2. The result of the 2D resistivity survey is divided into 3 profiles as follows:

Profile 1: This profile joins VES 1, VES 2, VES 3 and VES 4 (Figure 5). It runs in North-South direction around the burrow pit dumpsite opposite Keldor hotel. It has a total length of about 290m and a dimension of 20m by 40m. Four zones were delineated beneath this profile. Zone 1 is a low resistivity zone (deep blue colour) with resistivity value ranging from 93 Ω-m to 133 Ω-m. This zone is interpreted to be the dumped waste and the generated leachate plume cum the impacted soil. It starts from the surface to a depth of 10m at the middle of the profile. This zone is classified as the very high impact zone Zone 2 is a zone of moderately low resistivity values ranging between 134 Ω-m and 191 Ω-m. This resistivity value suggested that this zone had been impacted by the migrating leachate to a depth of 15m. It is classified as high impact zone and forms an oblate shape pointing towards the south, revealing that the leachate is probably migrating towards the south under this profile. Zone 3 is the zone with resistivity value varying from 192 Ω-m to 274 Ω-m, this zone is classified as moderate impact zone. Zone 4 is classified as low to no impact zone as it forms the flank of the north and the south with the resistivity value varying from 274 Ohm-m to greater than 812 Ohm-m. The lower end of this range is designated as low impact zone, while the high resistivity value range is classified as no impact zone.

Profile 2: This profile joins VES 5, VES 1 and VES 2 together (Figure 6). It runs in East-West direction around the burrow pit dumpsite opposite Keldor hotel. It has a total length of about 200m. Four zones were delineated beneath this profile. Zone 1 is a low resistivity zone (deep blue colour) with resistivity value ranging from 100 Ω-m to 207 Ω-m. This zone is interpreted to be the dumped waste and the generated leachate plume cum the impacted soil. It starts from the surface to a depth of 5m at the middle of the profile. This zone is classified as very high impact

zone. Zone 2 is a zone of moderately low resistivity values ranging between 207Ω-m and 264 Ω-m. This resistivity value suggested that this zone had been impacted by the migrating leachate up to 15m depth and it is classified as high impact zone. The zone forms an oblate shape pointing towards the west, showing that the leachate is probably migrating towards the east under this profile. The third zone is the zone with resistivity value varying from 247 Ω-m to 347 Ω-m and it is classified as moderately impacted zone. Zone 4 is classified as low to no impact zone. This zone forms the flank of the north and the south with the resistivity value varying from 337 Ohm-m to greater than 1635 Ohm-m. The lower end of this range is designated as low impact zone, while the high resistivity value range is classified as no impact zone.

Profile 3: This profile was done at Ogharefe quarters and it joins VES 7, VES 8, VES 9, VES 10, VES 11 and VES 12 together (Figure 7). It runs in South-East - North-West direction. It has a total length of about 1,482m. This profile consists of series of dumpsites that had existed for well over 50 years. Four zones were delineated beneath this profile. Zone 1 is a low resistivity zone (deep blue/purple colour) with resistivity value ranging from 91 Ω-m to 242 Ω-m. This zone is strewn along the entire profile line except around VES 10. The zone is deeper on the southern end of VES 7. It starts from the surface to a depth of 28m, while it extends to 10m under between VES 8 and VES 10. This zone is classified as very high impact zone. Zone 2 is a zone of moderately low resistivity values ranging between 242 Ω-m and 367 Ω-m. This resistivity value suggested that this zone had been impacted by the migrating leachate to a depth of 15m and it is classified as high impact zone. The zone forms an oblate shape pointing towards the west, revealing that the leachate is probably migrating towards the east under this profile. The third zone is the zone with resistivity value varying from 247 Ω-m to 367 Ω-m, which is classified as moderately impacted zone. Zone 4 is classified as low to no impact zone. This zone forms the flank of the north and the south with the resistivity value varying from 367 Ohm-m to greater than 4442 Ohm-m. The lower end of this range is designated as low impact zone, while the high resistivity value range is classified as no impact zone.

Thus, the 2-D tomography mapped and identified 2 distinct pollutants within and around the dumpsites. These pollutants are compounds of anomalously high resistivities which range between 422Ωm and 5102Ωm suspected to be dumpsite gases (such as ammonia, methane, sulphur dioxide and carbon dioxide) at depth exceeding 28.7m; and leachate contaminant plumes of low resistivities between 91Ωm and 394Ωm at depth between 5m to more than 28m.

Table 2: Lithologic Delineation and Curve types of the 1D Inversion Model from the VES Stations

VES Points	Location	Layer	Resistivity(Ωm)	Thickness(m)	Depth(m)	Lithology	Curve Type
VES1		1	102.97	0.52	0.52	Lateritic Top Soil	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$
		2	31.05	0.58	1.10	Sandy Clay	
		3	36.06	0.35	1.45	Fine Coarse Sand	HKH
		4	984.43	6.07	7.52	Medium Coarse Sand	
		5	192.68	21.24	28.76	Coarse Sand	
		6	913.80	-	-	Sand	
VES 2		1	88.65	0.57	0.57	Lateritic Top Sand	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	208.10	1.35	1.92	Sandy Clay	
		3	1431.55	3.64	5.56	Fine Coarse Sand	KH
		4	107.09	8.81	14.37	Medium Coarse Sand	
		5	95398.52	-	-	Coarse Sand	
VES 3		1	72.75	0.30	0.30	Lateritic Top Sand	$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$
		2	385.85	0.95	1.25	Sandy Clay	
		3	81.83	1.78	3.03	Fine Coarse Sand	KHK
		4	1062.55	4.17	7.20	Medium Coarse Sand	
	WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD,IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE	5	130.11	21.64	28.84	Coarse Sand	
		6	1583.74	7.00	35.84	Sand	
		7	143.00	-	-	Fine Sand	
VES 4		1	161.82	0.52	0.52	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4<\rho_5$
		2	3230.69	0.50	1.02	Sandy Clay	
		3	239.96	1.43	2.45	Fine Coarse Sand	KHA
		4	795.28	3.84	6.29	Medium Coarse Sand	
		5	1172.98	9.08	15.37	Coarse Sand	
		6	800.00	12.00	27.37	Sand	
		7	1477.35	-	-	Fine Sand	
VES 5		1	95.59	0.58	0.58	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	751.06	9.93	10.51	Sandy Clay	KH
		3	131.80	22.21	32.72	Fine Coarse Sand	
		4	5042.62	-	-	Medium Coarse Sand	
VES 6		1	1121.15	1.76	1.76	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	2753.54	3.95	5.71	Sandy Clay	KH
		3	87.09	22.94	28.65	Fine Coarse Sand	
		4	1119.26	-	-	Medium Coarse Sand	
VES 7		1	42.53	0.82	0.82	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	29.72	0.32	1.14	Sandy Clay	KH
		3	155.12	0.34	1.48	Fine Coarse Sand	
		4	66.47	3.59	5.07	Medium Coarse Sand	
		5	111.49	26.00	31.07	Coarse Sand	
		6	853.15	-	-	Sand	
VES 8		1	41.87	0.49	0.49	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	412.73	0.99	1.48	Sandy Clay	KH
		3	65.20	7.06	8.54	Fine Coarse Sand	
		4	262.48	15.20	23.74	Medium Coarse Sand	
		5	1895.65	-	-	Coarse Sand	
VES 9	WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD OGHAREFE	1	37.84	0.40	0.40	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	278.09	0.43	0.83	Sandy Clay	KH
		3	111.01	4.46	5.29	Fine Coarse Sand	
		4	51.69	9.99	15.28	Medium Coarse Sand	
		5	1718.84	-	-	Coarse Sand	
VES 10		1	306.34	0.69	0.69	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	1305.39	1.18	1.87	Sandy Clay	KH
		3	685.77	4.60	6.47	Fine Coarse Sand	
		4	117.90	9.94	16.41	Medium Coarse Sand	
		5	95034.67	-	-	Coarse Sand	
VES 11		1	1409.70	0.34	0.34	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$
		2	984.11	0.13	0.47	Sandy Clay	KH
		3	117.71	6.95	7.42	Fine Coarse Sand	
		4	1004.86	-	-	Medium Coarse Sand	

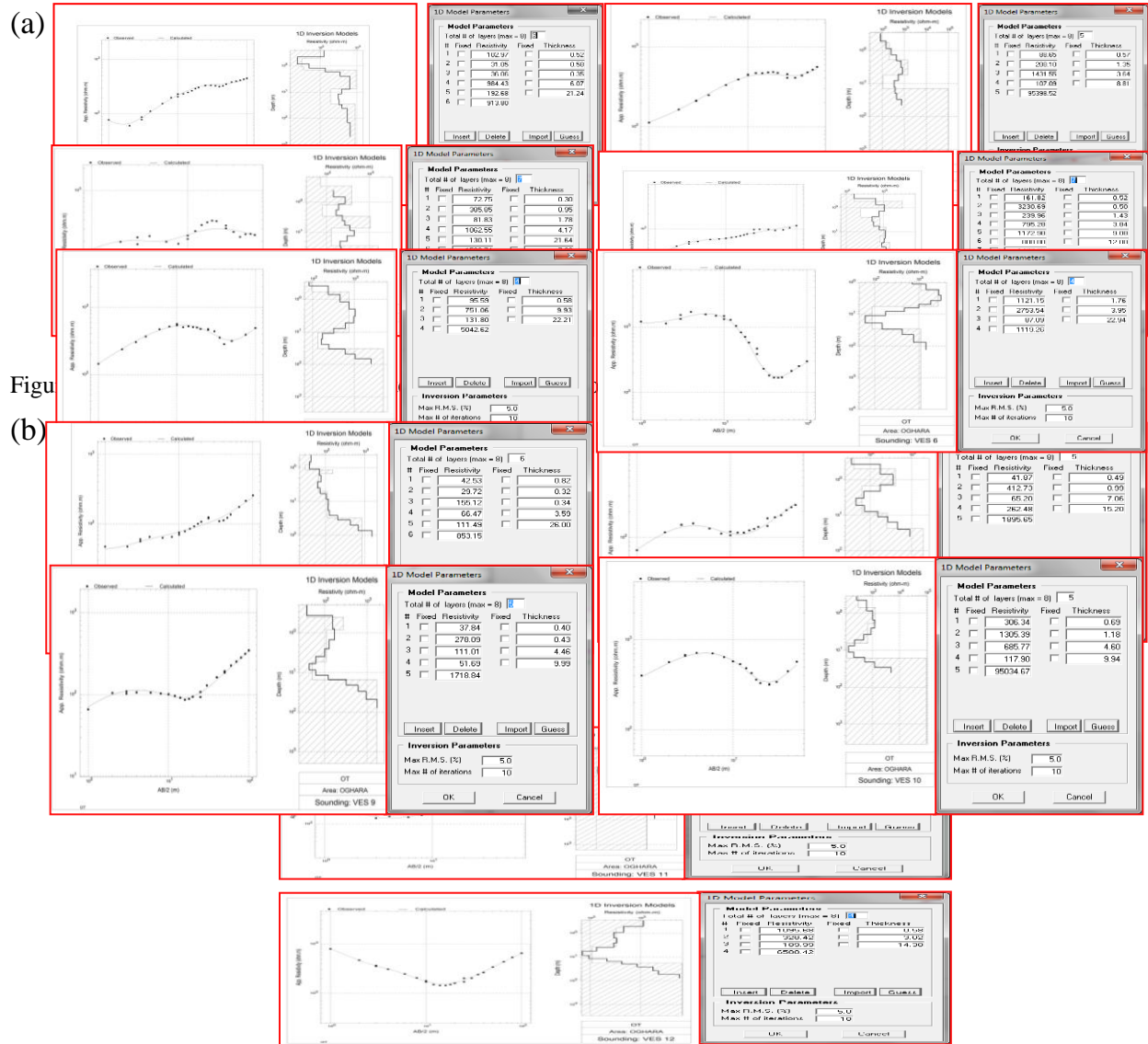| VES 12 | | 1 | 1095.68 | 0.58 | 0.58 | Lateritic Top Soil | $\rho_1 > \rho_2 > \rho_3 < \rho_4$ QH |
		2	328.42	3.02	3.60	Sandy Clay	
		3	109.99	14.38	17.98	Fine Coarse Sand	
		4	6588.42	-	-	Medium Coarse Sand	

Figure 4b: VES Stations at the Dumpsite within Scot Road, Sakponba Road and Shrimp Road

The result showed that leachate is migrating towards the groundwater aquifer, revealing further that the aquifer is highly vulnerable to surface leachate contaminants from the dumpsite waste and therefore it is not protected.

4.2 Hydrogeochemical Parameter Results

Physico-chemical analyses were carried out on water samples collected from 5 tap/boreholes and 5 hand-dug wells in the study area in order to determine the water quality. The result revealed that (Table 3) the values and the mean values of 4 parameters in both the tap/borehole and hand-dug well waters (ie TDS, Conductivity, NO_3- and Cl-) are within the [18], [20] and [19] permissible standards of 1000mg/l, 1000mg/l, 50mg/l and 250mg/l respectively. However, the values of the other measured 5 parameters are above the permissible standards by [18], [20] and [19]. The parameters are as follows:

(i) Colour: Drinking water should ideally have no visible colour. Colour in drinking water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil and it is strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products [20]. The colour of water gives the aesthetic appearance of the water as this may create concerns about the quality and acceptability of a drinking-water supply by consumers. In this study the value of the colour of water from the tap/boreholes and hand-dug wells respectively ranged from 0 to 79 TCU with a mean value of 46TCU, and from 39 to 97 TCU with an average value of 80.20 TCU. These mean and ranges of values of colour for tap/borehole waters and hand-dug well waters are above the recommended permissible limit of 15 true colour units (TCU) by WHO and NSDWQ. Purification of the waters is required to enhance the colour.

(ii) pH: The pH measures the degree of acidity and alkalinity of water. pH value <7 measures degree of acidity while pH>7 measures degree of alkalinity. [18], [20] and [19] set a permissible limit of 6.5-8.5 for portable water. The range of pH values for tap/borehole waters varied from 4.1 to 5.6 with an average of 4.8, and for hand-dug well waters it varied from 3.8 to 5.1 with an average of 4.4. These values are lower than the permissible limit thus confirming that the water from the 2 water supply sources are strongly acidic and are therefore corrosive. The most strongly acidic water was found at HW_2 (ie the hand-dug well close to the dumpsite within Scot road, Shrimp road and Sakponba road at VES 8 location) and it is highly recommended that the inhabitants of the area should discontinue the use of water from this water supply well. The high acidic content of these water supply sources in the study area could be a result of leachate migration due to the abundance of organic matter in the overlying soil as well as the presence of shale intercalations in the aquiferous coastal plain sands. It must be controlled to minimize corrosion of water mains and pipes in household water systems.

(iii) Iron (Fe^{2+}): The iron content in the tap/borehole water ranged from 0.682 to 1.403mg/l with a mean value of 1.037mg/l while for the hand-dug well water it ranged from 0.263 to 0.682mg/l with an average value of 0.410mg/l. These values are higher than the permissible standard of 0.3mg/l by [18], [20] and [19] indicating that the water in this area is high in iron content. Therefore, when water in this area is exposed to air, Fe^{2+} will be oxidized to Fe^{3+} and precipitate a rust coloured ferric hydroxide that can stain utensils. [21] noted that the water bearing aquifer of Benin formation from where groundwater seeps into the wells are ferruginous and contains iron minerals such as marcasite, hematite, goethite and limonite, thus the mobility and subsequent downward infiltration of these minerals through the porous and permeable formation account for the presence of iron in the water in the study area.

Table 3: Physico-chemical Parameters of Groundwater Samples Compared to Permissible Standards

Sample No	Measured Parameters								
TAP/BOREHOLE WATER									
	Colour (TCU)	pH	TDS (mg/l)	Conductivity (µs/cm)	NO_3^- (mg/l)	Cl^- (mg/l)	Fe^{2+} (mg/l)	Pb^{2+} (mg/l)	Coliform Bacterial (Cfu/100ml)
BH_1	69	4.6	2.7	5	1.5	14.12	0.682	0.024	8.2×10^3
BH_2	79	5.6	5.3	10	1.6	14.12	1.403	0.018	4.0×10^3
BH_3	49	4.9	5.3	10	1.7	7.06	1.263	0.036	6.0×10^3
BH_4	33	5.0	5.3	10	2.8	21.18	0.726	0.027	0
BH_5	0	4.1	68.9	130	31.6	21.18	1.112	0.023	2.0×10^3
Mean	46	4.8	17.5	33	7.84	15.53	1.037	0.03	4.04×10^3
HAND-DUG WELL WATER									
HW_1	39	5.1	15.9	30	8.5	7.06	0.368	ND	2.0×10^3
HW_2	97	3.8	238.5	450	37.2	105.90	0.682	0.023	4.1×10^3
HW_3	88	5.0	68.9	130	14.7	14.12	0.428	ND	2.7×10^3
HW_4	88	4.0	127.2	240	42.0	42.36	0.263	ND	2.8×10^3
HW_5	89	4.2	74.2	140	14.9	35.30	0.311	ND	2.0×10^3
Mean	80.20	4.4	104.94	198	23.46	40.95	0.410	0.023	2.72×10^3
WHO (2006, 2011), NSDWQ (2007) Standard	15	6.5-8.5	1000	1000	50	250	0.30	0.01	≤ 100

(iv) Lead (Pb^{2+}): The lead (Pb) content in tap/borehole water ranged from 0.018 to 0.036mg/l with an average value of 0.03mg/l while that in hand-dug well water ranged from ND to 0.023mg/l. These values of Pb in all the tap/borehole water are higher than the acceptable limit of 0.01mg/l in drinking water by WHO and NSDWQ. It was observed that Pb was detected only in HW_2 (ie the hand-dug well close to the dumpsite within Scot road, Shrimp road and Sakponba road at VES 8 location). The source of Pb in the hand-dug well and tap/borehole waters could be from decay of dead disposed batteries, metal scraps, metal jewelries, broken lead-glazed ceramics and used engine/motor oil that were deposited in the dumpsites which migrated into the soil. The presence of Pb in water above the recommended limit have a wide range of effects including various neuro-developmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. Impaired neurodevelopment in children is generally associated with lower blood lead concentrations than the other effects; the weight of evidence is greater for neuro-developmental effects than for other health effects and the results across studies are more consistent than those for other effects. For adults, the adverse effect associated with lowest blood concentrations for which the weight of evidence is greatest and most consistent is lead-associated increase in systolic blood pressure [20].

(v) Coliform Bacteria: This parameter is used to detect the presence of faecal pollution in water and from table 3 above, the water samples collected from the 2 water supply sources contain coliform bacteria except the one at BH_4. The value of coliform bacteria for the tap/borehole water ranged from 0 to 8.2×10^3cfu/100ml with a mean of 4.04×10^3cfu/100ml. The coliform

bacteria value for hand-dug well water ranged from $2.0x10^3$ to $4.1x10^3$cfu/100ml with an average value of $2.72x10^3$cfu/100ml. These values are above the permissible standard of 100cfu/ml by WHO and NSDWQ. The presence of coliform bacteria in the water sources indicated recent contamination by human sewage or animal droppings and could be attributed to infiltration of faecal migration from the dumpsites and nearby sewage septic tanks. Their presence in water also indicates the potential of disease causing organisms which would cause serious human illness. These water sources should therefore be treated and purified before use and consumption by humans living in the area.

The hydrogeochemical parameter result therefore showed that (i) all the sampled tap/borehole waters have higher content of Pb compared to international recommended standards by WHO and NSDWQ. Pb was not detected in other hand-dug wells in the study area except in hand-dug well HW_2 which is located close to the dumpsite within Scot road, Sakpoba Road and Shrimp road (ie at VES 8 location). The high presence of Pb in all the sampled tap/borehole water as well as in the hand-dug well water labeled HW_2 above the recommended limit would expose the inhabitants of the area to have a very high chance/risk of contracting various neuro-developmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes; (ii) all the sampled tap/borehole waters have higher iron (Fe) content than those of the hand-dug well waters as observed in their mean values. The mean value of Fe in tap/borehole water was 1.037mg/l while that of hand-dug well waters was 0.41mg/l. The high values of Fe in all the tap/borehole waters above the recommended standard could lead to iron stain laundry and plumbing fixtures. Again, iron promotes the growth of "iron bacteria" which derive their energy from the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) and in the process deposit a slimy coating (rust-coloured deposits) on the walls of tanks, pipes and channels, and carry over of deposits into the water. Formation of ferric iron in water may lead to corrosion and rusting of metallic pipes; (iii) all the sampled tap/borehole waters have higher value of coliform bacteria counts than those of the hand-dug well considering the mean value of coliform bacteria in tap/borehole water which is $4.04x10^3$ cfu/100ml while that of the hand-dug well water have a mean value of $2.72x10^3$ cfu/100ml revealing more infiltration of faecal migration from the dumpsites and nearby sewage septic tanks/latrines into the groundwater aquifer due to weak aquifer overburden layer. Their presence in groundwater indicates the potential of disease causing organisms which would cause serious human illness.

Arising from above, we can infer that the high value of coliform bacteria, Fe and Pb in tap/borehole waters more than those in hand-dug well waters were probably due to porous and weak aquifer overburden protective capacity which accounts for the high infiltration rate of leachate contaminants into the aquifer.

5.0 CONCLUSION

The VES field data revealed that the area comprises 5 formations of lateritic topsoil, sandy clay, fine coarse sand, medium coarse sand, and coarse sand. 2-D resistivity imaging mapped and identified 2 distinct pollutants around the dumpsites. These pollutants are compounds of anomalously high resistivities which ranged between 422Ωm and 5102Ωm suspected to be dumpsite gases (such as ammonia, methane, sulphur dioxide and carbon dioxide) at depth

exceeding 28.7m; and leachate contaminant plumes of low resistivities between 91Ωm and 394Ωm at depth between 5m to more than 28m. The result showed that the dumpsites have generated leachate contaminant plumes that is migrating actively from the Northern part of the area at VES 1 and VES 3 (which is described as high and moderate impact zones in the burrow-pit dumpsite located opposite Keldor hotel) towards the eastern part at VES 2 and northwestern part at VES 7, VES 8 and VES 9 (located at the dumpsite enclosed within Scot road and Sakponba road). These are areas of low resistivity values ranging from 91Ωm to 394Ωm at depths between 5m and beyond 28m signifying the presence of conducting fluid that is migrating towards the groundwater aquifer. This infers that the aquifer is highly vulnerable to surface leachate contaminants from the dumpsite waste, therefore not protected. The hydrogeochemical parameter results was used to corroborate with the VES results revealing groundwater contamination of the tap/boreholes and hand-dug wells water with low pH; high Fe, Pb and coliform bacteria at VES stations 1, 2, 3, 4, 5, 7, 8 and 9 since their resistivity values are low and the hydrogeochemical parameters exceeded the permissible standard. The presence of coliform bacteria in the water sources indicated recent contamination by human sewage or animal droppings and could be attributed to infiltration of faecal migration from the dumpsites and nearby sewage septic tanks. Their presence in water also indicates the potential of disease causing organisms which would cause serious human illness. These water sources should therefore be treated and purified before use and consumption by humans living in the area. Again due to the high vulnerability of groundwater aquifer contamination by dumpsite leachates, the people living at the northern/eastern part of the burrow-pit dumpsite and at the northwestern part of the dumpsite enclosed within Scot road and Sakponba road will be exposed to health challenges arising from consumption of contaminated water abstracted from the groundwater aquifer in the area. It is recommended that the existing waste dumpsites be evacuated and relocated from the area and further dumping of waste be discontinued. A total clean up programme should be embarked upon. Government policy should address the issue of indiscriminate disposal of solid wastes in order to safeguard the groundwater resources in the area. Open dumpsite waste disposal system should be phased out in order to safeguard public health as regards groundwater pollution. Closed municipal landfill whose base is made of concrete and paved surfaces should be adopted in the area as this will prevent leaching of poisonous substances into groundwater aquifer.
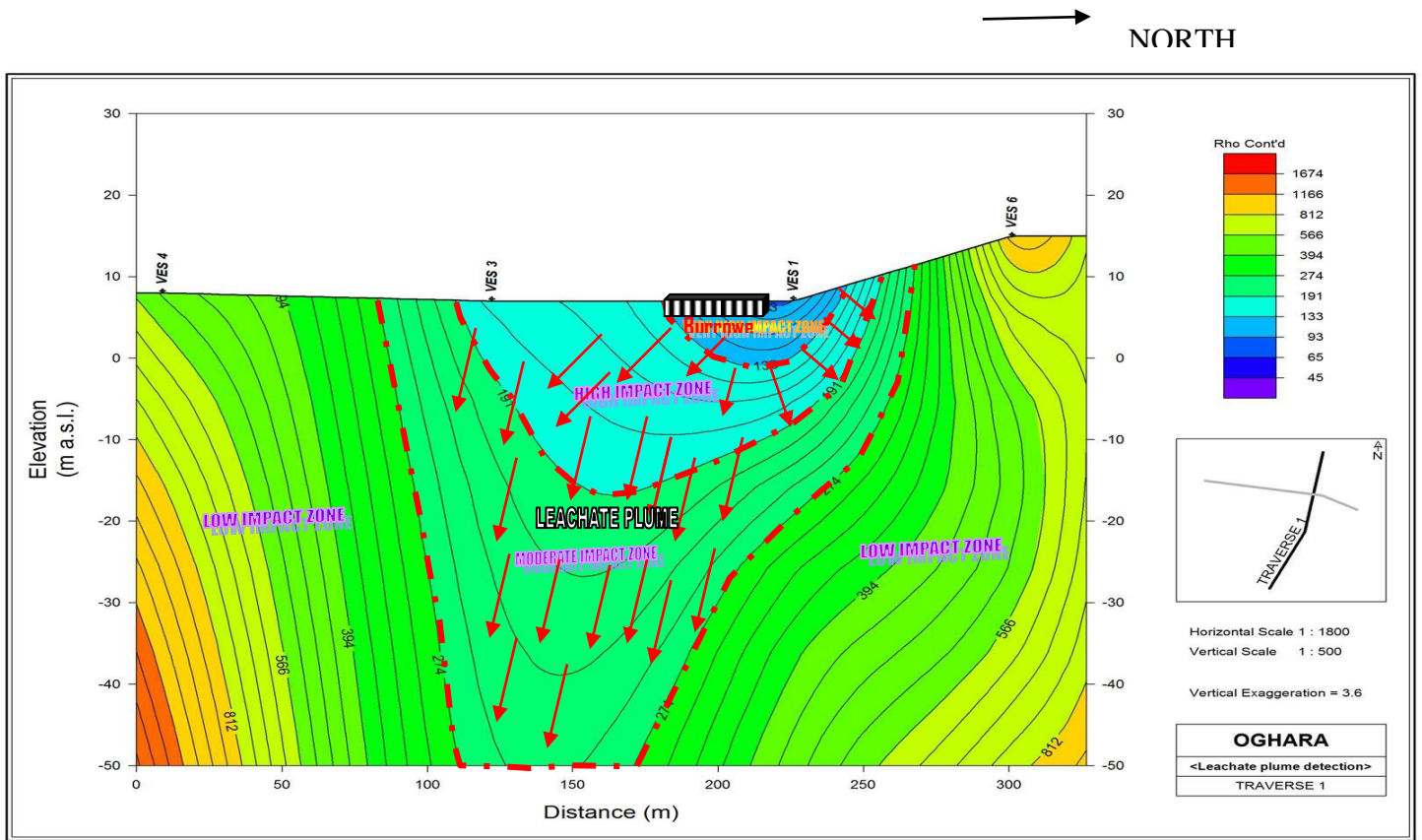
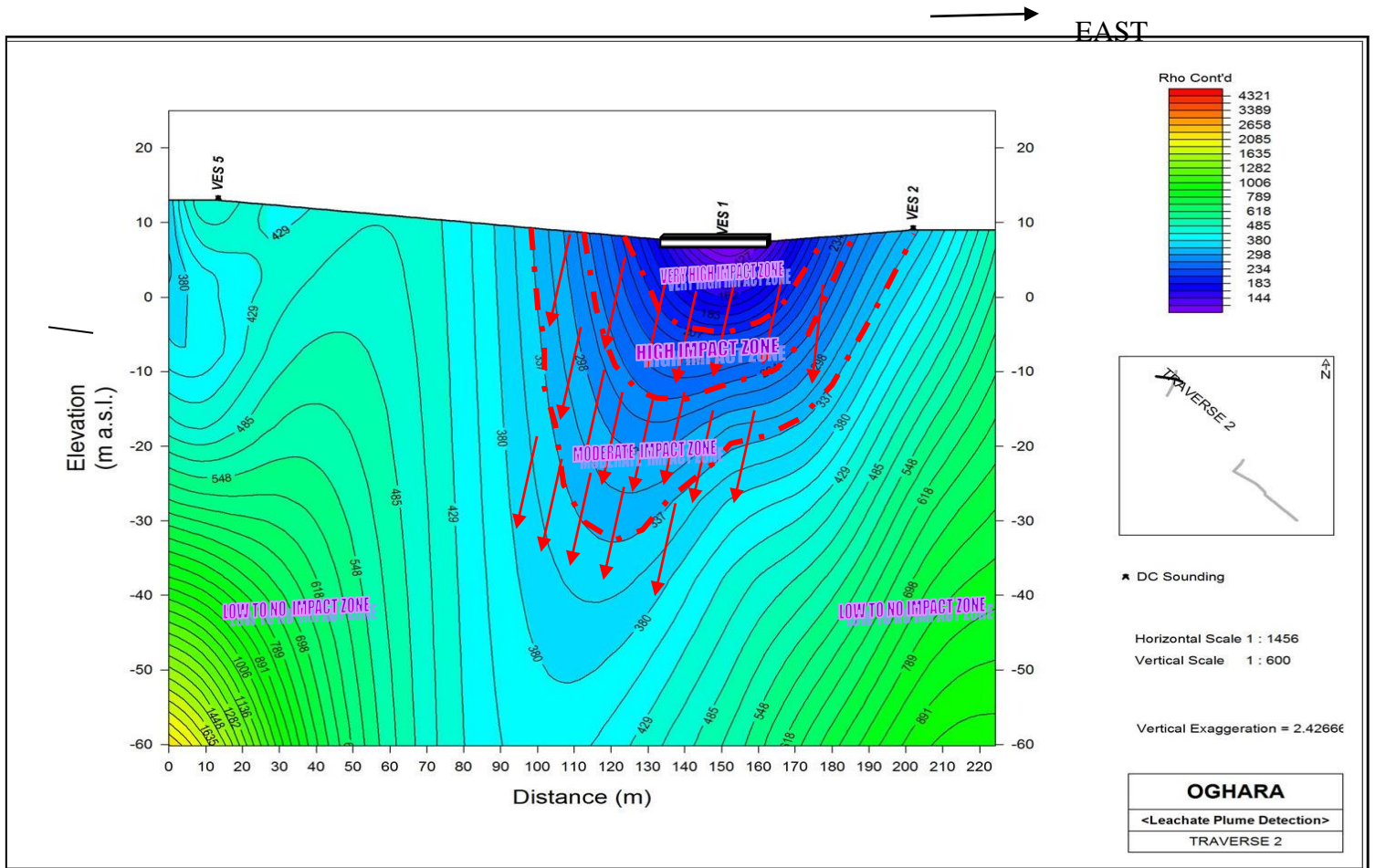**Figure 5:** The 2-D Section Beneath Profile 1
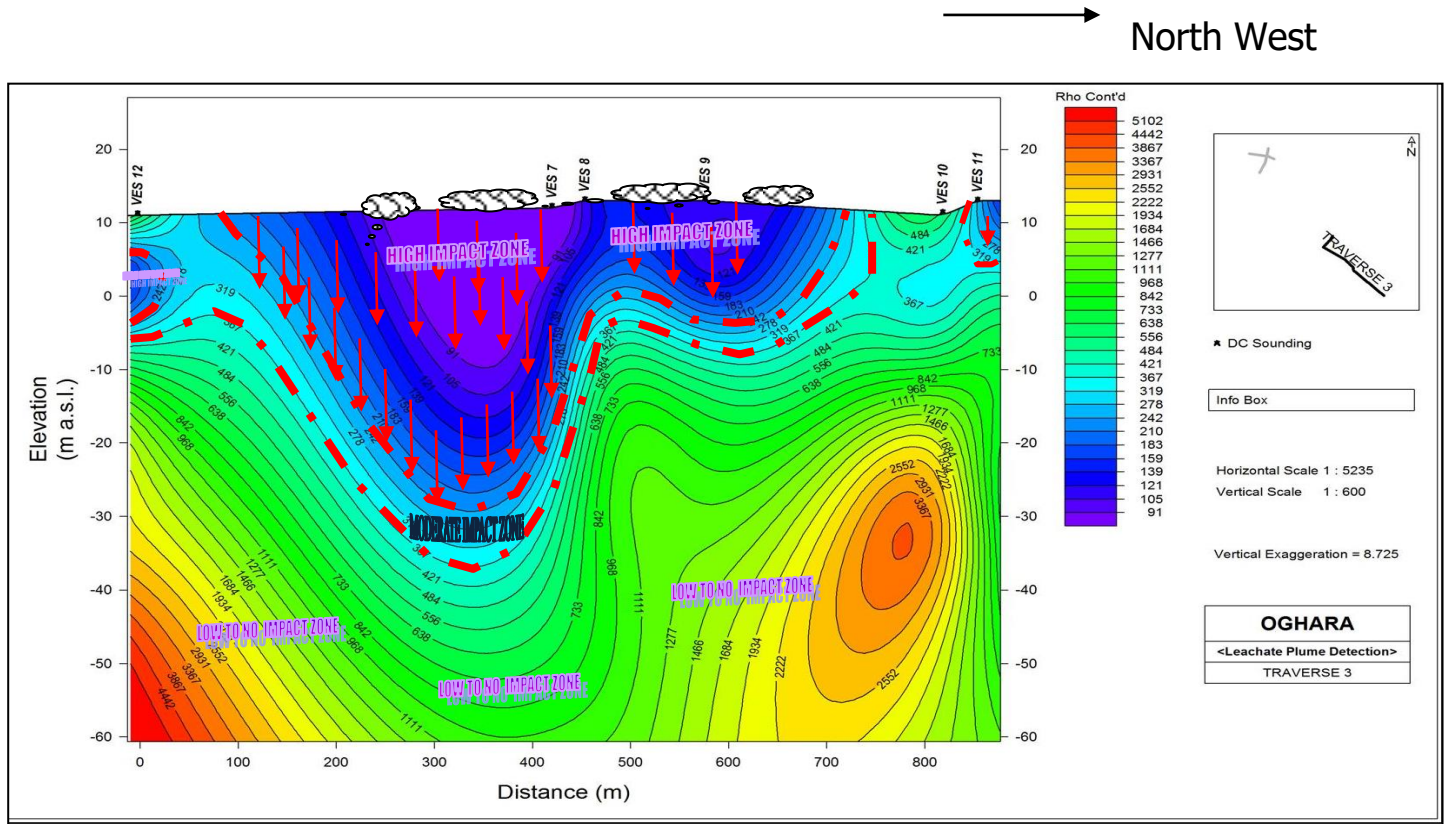
Figure 6: The 2-D Section Beneath Profile 2

Figure 7: The 2-D Section Beneath Profile 3

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