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Electrical Resistivity Investigation for Aquifer Vulnerability to Surface Contaminants at Dumpsites in Western Niger Delta

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Abstract:- Vertical electrical sounding, 2-D resistivity imaging and Dar-zarrouk parameters were used to investigate leachate plume generation, migration and the strength of the overlying protective capacity to prevent contamination of the groundwater aquifer at a municipality in the Western Niger Delta. Twelve vertical electrical sounding was investigated using the Mini-Res Resistivity Meter with the Schlumberger array. Dar-zarrouk parameters were employed to determine the protective capacity of overburden rock and the vulnerability of the aquifer to surface contaminants. The VES result was interpreted with Winglink software and 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 of low resistivity values 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. The Dar-zarrouk parameters showed that the total longitudinal conductance is low ranging from 0.01 Siemens at VES 4 to 0.09 Siemens at VES 6 which is less than the critical value of 1.0 Siemens suggesting that the overburden protective capacity do not have significant clay/shale impermeable beds. The total transverse resistance at each VES station varied from 286.55Ωm^2 (at VES 9) to 4,949.18Ωm^2 (at VES 6) interpreted as layers of high transmissivity indicating that the aquifer materials are porous and permeable to fluids flow. The aquifer overburden protective capacity and vulnerability ratings are respectively poor and extremely high vulnerability. The low values of overburden protective capacity of the sandy-clay layer and the high transmissivities of the vadose zones and the aquifers will aid the seepage and migration of contaminants within and around the dumpsites subsurface layers. Proper hydrogeophysical characteristics of the area should be considered before citing and drilling of boreholes.

Keywords: *Aquifer, Dar-zarouuk Parameters, Dumpsite Leachate, Protective Overburden Capacity, Vulnerability.*

I. INTRODUCTION

Groundwater resource is a source of clean portable water for human consumption, but in recent times this resource has been under increasing stress all over the world arising from pollution from surface contaminants. One of the agenda of the Sustainable Development Goals (SDGs) by the United Nations is access to clean water and sanitation which includes protecting this natural resource from pollution. Unfortunately, this goal have suffered some setbacks due to the contamination of groundwater aquifer from dumpsite wastes generated mostly in the urban areas occasioned by the astronomical increase in domestic, agricultural and industrial activities by the inhabitants. Wastes are the useless, unwanted and hazardous materials or substances generated by human activities which are considered valueless and of no economic demand. They are classified as solid, liquid and gaseous which comprises domestic wastes, industrial wastes, mining wastes and agricultural wastes generated daily in the urban cities where they are indiscriminately disposed of on lands, in the rivers, streams and lakes without consideration to underground water environment. This poses problems to groundwater purity occasioned by infiltration of toxic substances to the aquifer. However, 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 are indiscriminately 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 [16]. [17] asserted that once an aquifer is excessively depleted or contaminated, the damage is essentially permanent and efforts to reduce the contamination are extremely costly. The leachate plumes normally have low resistivity values due

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to high ion concentration [3] thus giving the dumpsite low pH value because of high conductivity signatures and causing problems to groundwater purity.

The study area is known for high rainfall, close proximity of the aquifer to the surface, flat topography and permeable soil that enhances seepage flow. The nearness of the aquifer to the surface makes it vulnerable to surface pollutants emanating from dumpsites. Nevertheless, the earth materials act as natural filter to percolating fluids, therefore, its ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity [4], [5]. Aquifer vulnerability thus combines the hydraulic inaccessibility of the saturated zone to the penetration of pollutants with the attenuation capacity of the strata overlying the saturation zone [6], [7]. With increase in environmental awareness and control, electrical resistivity has become a fundamental and diagnostic tool to environmental studies [8] especially to determine the subsurface resistivity distribution in areas requiring depth to water table, depth to bedrock, thickness of subsurface soil, and subsurface delineation of leachate plume generation, migration and areal extent in the contamination of underground water. The Dar-zarouuk parameters are employed in aquifer protection studies and evaluation of hydraulic properties of aquifers [9]. This study adopted electrical resistivity to measure the subsurface properties of the area. The measurements were used to estimate the Dar-zarrouk parameters (ie longitudinal conductance and transverse resistance) from the resistivities and thickness values of the layers and hence the hydraulic conductivities and transmissivities were used to evaluate the vulnerability of the aquifer to surface contaminants from dumpsites at Oghara in the Western Niger Delta region of Nigeria.

II. THE STUDY AREA

A. 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* 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.

B. Dumpsite Locations in the Study Area

Solid and liquid wastes are indiscriminately deposited in Ogharefe 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 5º 56' 50.10''N and 5º 39' 34.12''E located at Ibori road opposite.

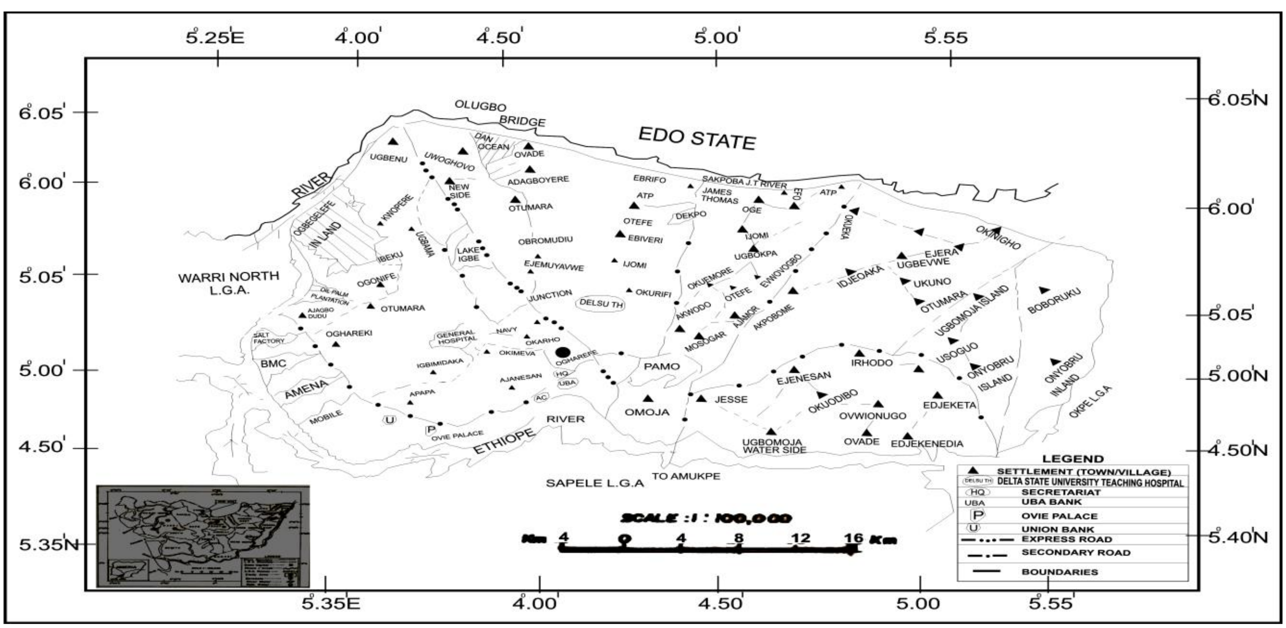

Fig. 1: Map of Ethiope West Local Government showing Location of the study Area

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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 5o 56' 52.58''N and 5o 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).

III. MATERIAL AND METHODS

A. 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. It uses a micro-processor to monitor and control all the measurement so as to ensure optimal accuracy and sensitivity. 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 geology of depth less than 30m according to [10], 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 was utilized 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:

$$\rho a = \pi R \left[\frac{(AB/2)^2-(MN/2)^2}{MN}\right] = RK \quad \ldots\ldots\ldots (1)$$

Where:

$$\left\{\frac{(AB/2)^2-(MN/2)^2}{MN}\right\} = K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

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 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 and MN/2 of 5m due to space constraint in the field. They were each located 15m away from the beginning of the dumpsite. The VES stations were geo-referenced with their coordinates (table 1).

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, direction of leachate contaminant flow and 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.

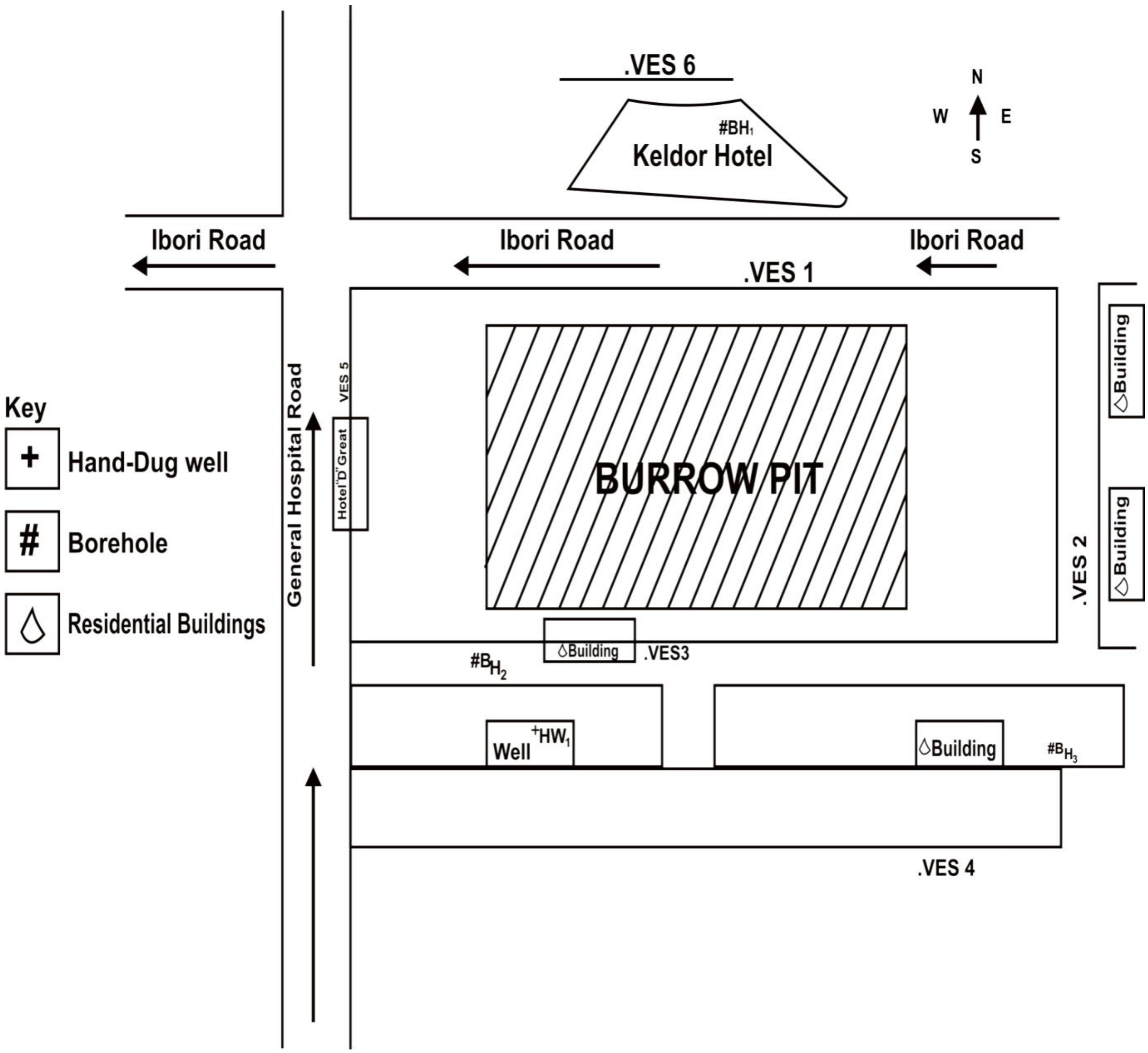

Fig. 2: Map Showing VES Locations at the burrow pit dumpsite

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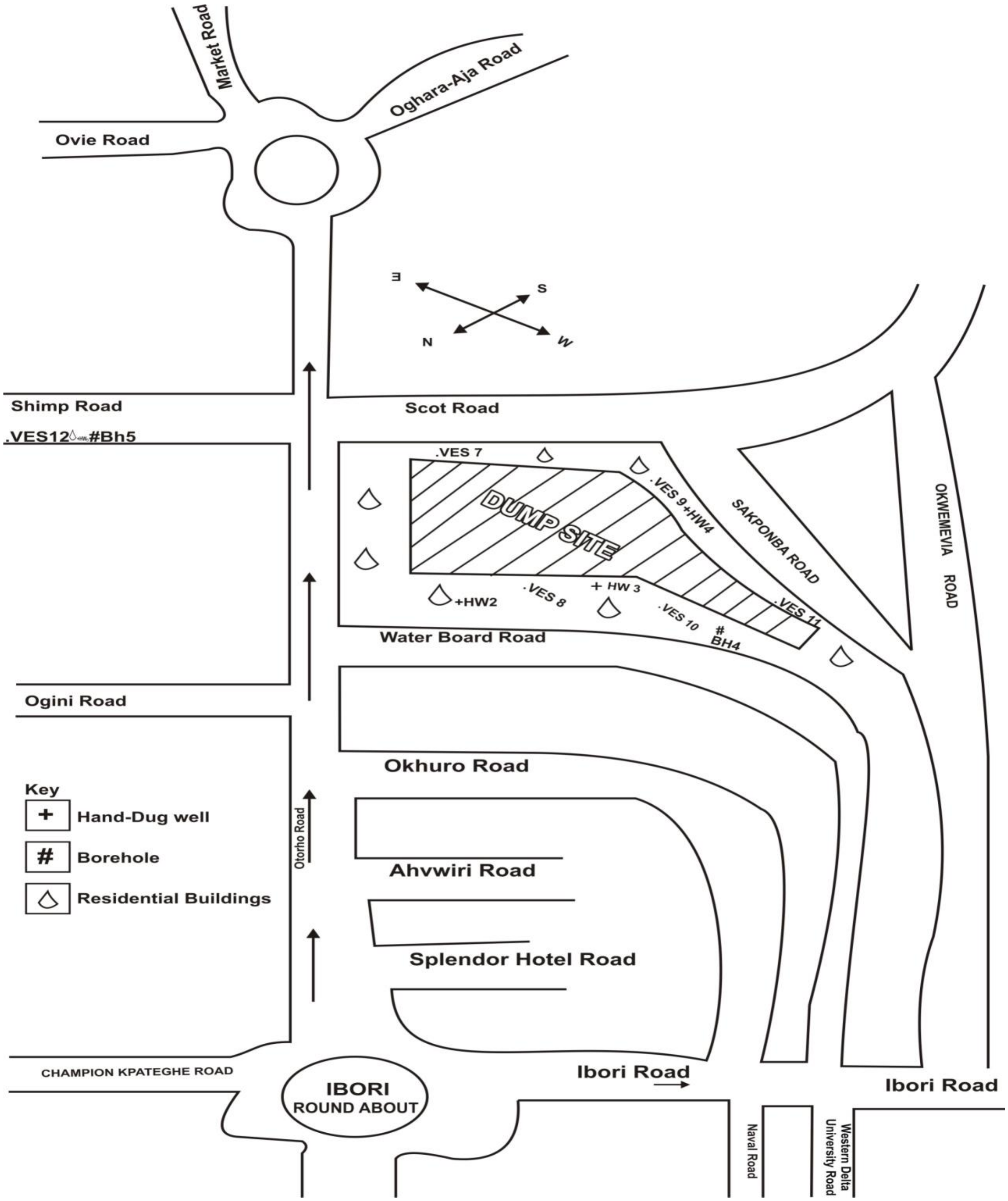

Fig. 3: Map Showing VES Locations at the dumpsite enclosed within Scot and Sakponba Road

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S/No	VES Station 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	5°56’46.7520”	5°39’33.4800”	7.000	
4	VES 4	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	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	5°56’02.6520”	5°39’57.5280”	13.000	
9	VES 9	5°56’05.9640”	5°39’55.3320”	13.000	
10	VES 10	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	5°55’50.5200”	5°40’05.9880”	11.000	

Table 1: Geographical locations of the VES Stations as well as Elevation above Sea Level in the Study Area

B. The Dar-zarrouk Parameters

The vulnerability of the aquifer to surface pollutants from waste dumpsites and other contaminant bodies is a function of the permeability of the soil and nearness of the aquifer to the surface. The concept of aquifer vulnerability is derived from the assumption that the physical environment may provide some degree of protection to groundwater against human impacts, especially with regard to pollutants entering the subsurface (aquifer) [7]. Aquifer vulnerability thus combines the hydraulic inaccessibility of the saturated zone to the penetration of pollutants with the attenuation capacity of the strata overlying the saturation zone [6]. [7] and [9] opined that the hydrogeological characteristics of a site that is useful in the simulation of groundwater flow and in evaluating overburden protective capacity and transmissivity of an area are the Dar-Zarrouk parameters (ie longitudinal conductance (S_L) and transverse resistance {R_T}). The Dar-zarrouk parameters are calculated from the field values of the resistivities and thicknesses of the subsurface layering units. Thus, the derived values for hydraulic conductivities and transmissivities are used in evaluating the protective capacity of overburden rock and the vulnerability of the aquifer to surface contaminants. Figure 4 is a geoelectric unit that is characterized by two parameters (ie the Layer Resistivity (ρ_i) and the layer thickness {h_i}).

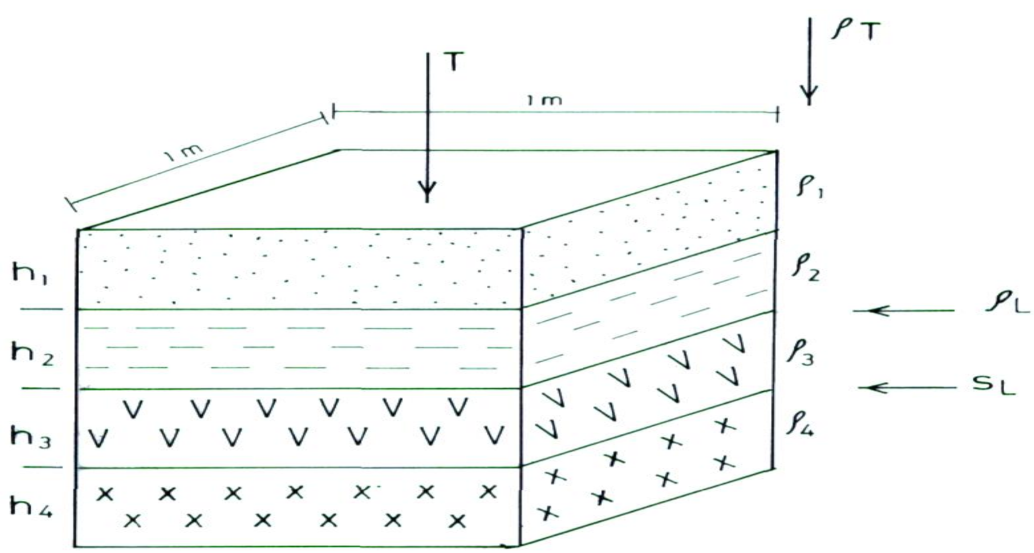

Fig. 4: A Geoelectric Unit showing layer resistivity and layer thickness

The longitudinal conductance is regarded as the medium's ability to retard and filter percolating fluid which is considered as the protective capacity of the aquifer overburden and is expressed as:

Longitudinal unit conductance, $S_L = \sum(h_i/\rho_i)$……...3
$S_L = h_1/\rho_1 + h_2/\rho_2 + h_3/\rho_3 + \ldots + h_n/\rho_n$ …………………4
Equation 3 can also be expressed as $S_L = \sigma h_i$……….. 5

Where σ is the layer conductivity which is analogous to the layer transmissivity (T), given as
$T = Kh = KS_L/\sigma$ …………………………………… 6
The total transverse resistance (R_T) is expressed as:
$R_T = (h.\rho) = \sum(hi.\rho i) = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \ldots + h_n\rho_n$….. 7
Where h is the thickness of the layer and ρ is the resistivity of the layer.

IV. RESULTS AND DISCUSSION

A. 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 5a and 5b. 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 6). 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 7). 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 8). 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, this zone 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 2D 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. 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**.**

B. Vulnerability of Aquifer Overburden Protective Capacity to Leachate Contaminant

The results of the Dar-zarrouk parameters are presented in table 3 and it revealed that the longitudinal conductance for each layer of the respective VES stations in the study area is low ranging from 0.0001 Siemens (at VES 11) to 0.263 Siemens (at VES 6) which are less than the critical value of 1.0 Siemens. Again, the total longitudinal conductivity of the overburden protective capacity at VES station is low ranging from 0.01 Siemens at VES 4 to 0.09 Siemens at VES 6. These suggest that the overburden layers do not have significant amount of clay/shale impermeable beds therefore could be interpreted as zones or layers of probable high risks to aquifer contamination from the leachate migrating from the dumpsite. Using classification ratings in table 4, the low value of longitudinal conductance implies that the aquifer protective capacity of the area is classified as poor.

VES Points	Location	Layer	Resistivity(Ωm)	Thickness(m)	Depth(m)	Lithology	Curve Type
VES1	**IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE**	**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**	
		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**	

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VES 7	**WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD, OGHAREFE**	**1**	**42.53**	**0.82**	**0.82**	**Lateritic Top Soil**	$\rho_1<\rho_2>\rho_3<\rho_4$ **KH**
		2	**29.72**	**0.32**	**1.14**	**Sandy Clay**	
		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**	$\rho_1<\rho_2>\rho_3<\rho_4$ **KH**
		2	**412.73**	**0.99**	**1.48**	**Sandy Clay**	
		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		**1**	**37.84**	**0.40**	**0.40**	**Lateritic Top Soil**	$\rho_1<\rho_2>\rho_3<\rho_4$ **KH**
		2	**278.09**	**0.43**	**0.83**	**Sandy Clay**	
		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**	$\rho_1<\rho_2>\rho_3<\rho_4$ **KH**
		2	**1305.39**	**1.18**	**1.87**	**Sandy Clay**	
		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**	$\rho_1<\rho_2>\rho_3<\rho_4$ **KH**
		2	**984.11**	**0.13**	**0.47**	**Sandy Clay**	
		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**	

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

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(a)

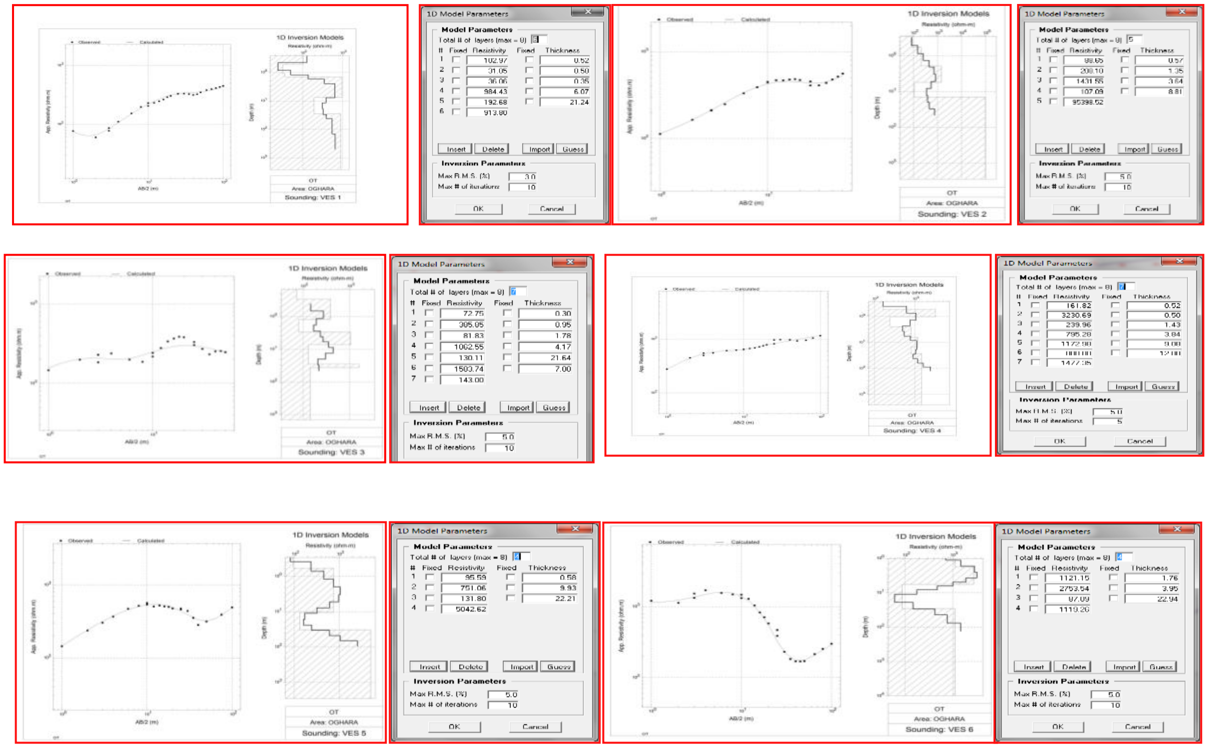
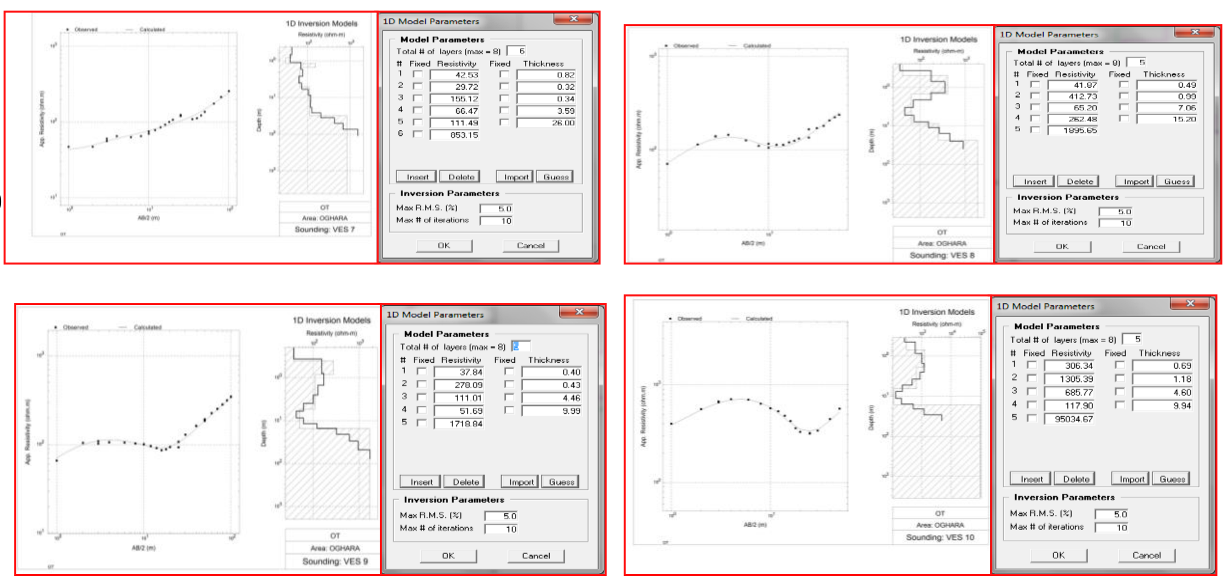


Fig. 5a: VES Stations at the Dumpsite along Ibori Road opposite Keldor Hotel

(b)



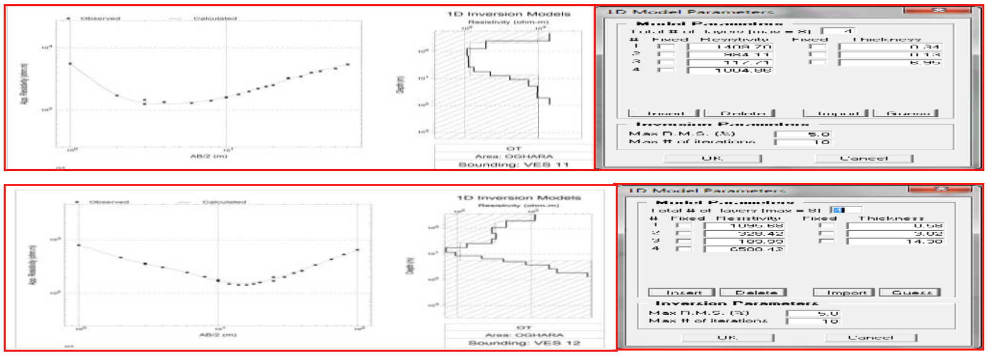


Fig. 5b: VES Stations at the Dumpsite within Scot Road, Sakponba Road and Shrimp Road

The geoelectric sections generated for the overburden units shows that the topmost layers at all the VES stations are mainly lateritic sand while the 2nd layers are mostly sandy clay. The mixture of clay content and sand in this layer are minimal and generally the thickness of the layer is thin at all the VES stations which imply that this mixture provided little or no protection to the underground aquifer. Geologically, clay overburden is characterized with high longitudinal unit conductance in order to provide protection to the underlying aquifer thereby serving as a protective seal. However, underlying these sandy clay bed are porous and permeable sandy formations of varying thicknesses, grain sizes and moisture content that constitute the aquifer. [14] reported that materials such as sand and gravel have low longitudinal conductance arising from their higher resistivity values as a result of having low aquifer protective capacity. The low value of the protective capacity (ie longitudinal conductance) is due to the absence of significant amount of impervious clay material in the study area which enhances the percolation of contaminants into the aquifer from waste dumpsite. It was also observed that the aquifer in and around the dumpsite is prone to contamination since 100% of the longitudinal conductance of the aquifer protective capacity is rated poor at all the VES stations. These areas that are classified as poor are indicative of zones of high infiltration rates from precipitation and such areas are extremely high vulnerability to infiltration of leachate from the waste dumpsites and other surface contaminants [15]. The findings of this study is in agreement with the works of [18] in the study of 2D geoelectric evaluation and imaging of aquifer vulnerability of dumpsite at Ozoro, Isoko South LGA of Delta State where they found that the protective capacity of the area is rated poor. Again, the presence of poor aquifer protective capacity in the area confirms that the aquifer is vulnerable to leachate contaminants at shallow levels.

The transverse resistance (R_T) of the aquifer at each VES station layer varies from 286.55Ωm^2 (at VES 9) to 4949.18Ωm^2 (at VES 6) thus are interpreted as zones or layers of high transmissivity. The high values of transverse resistances (ie Transmissivities) are due to the lithological nature of the aquifer materials which are porous and permeable to fluids flow. Thus, the low values of overburden protective capacity of the sandy clay layer and the high transmissivities of the vadose zones and the aquifers will aid the seepage and migration of contaminants within and around the dumpsites subsurface layers.

The aquifer vulnerability rating in the study area is extremely high vulnerability (table 4). Since the topsoil is interpreted as lateritic with less clayey content, leachate infiltration in and around the dumpsites is enriched by the lack of protective overburden layers as shown by the correlation between longitudinal conductance and overburden protective capacity (table 3). The lateritic topsoil of the study area is porous and permeable and therefore, it is a conduit for leachate plume migration resulting in the pollution of the soils and groundwater resources around the dumpsites.

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VES Points	Location	Layer	Resistivity (Ωm)	Thickness (m)	Longitudinal Layer Conductance (Ω^{-1} or Siemens)	Transverse Layer Resistance (Ωm^2)	Total Transverse Layer Resistance (Ωm^2)	Total Longitudinal Conductivity of Protective Layer(mhos)	Aquifer Protective Capacity Rating	Aquifer Vulnerability Rating
VES 1	**IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE**	1	102.97	0.52	0.0051	53.54	2030.43	0.03	Poor	Extremely High Vulnerability
		2	31.05	0.58	0.0187	18.00				
		3	36.06	0.35	0.0097	12.62				
		4	984.43	6.07	0.0062	5975.49				
		5	192.68	21.24	0.1102	4092.52				
		6	913.80	-	-	-				
VES 2		1	88.65	0.57	0.0064	50.53	1621.44	0.02	Poor	Extremely High Vulnerability
		2	208.10	1.35	0.0065	280.94				
		3	1431.55	3.64	0.0025	5210.84				
		4	107.09	8.81	0.0823	943.46				
		5	95398.52	-	-	-				
VES 3		1	72.75	0.30	0.0041	21.83	3144.44	0.03	Poor	Extremely High Vulnerability
		2	385.85	0.95	0.0025	366.56				
		3	81.83	1.78	0.0217	145.66				
		4	1062.55	4.17	0.0039	4430.83				
		5	130.11	21.64	0.1663	2815.58				
		6	1583.74	7.00	0.0044	11086.18				
		7	143.00	-	-	-				
VES 4		1	161.82	0.52	0.0032	84.15	4224.53	0.01	Poor	Extremely High Vulnerability
		2	3230.69	0.50	0.0002	1615.34				
		3	239.96	1.43	0.0059	343.14				
		4	795.28	3.84	0.0048	3053.88				
		5	1172.98	9.08	0.0077	10650.66				
		6	800.00	12.00	0.015	9600.00				
		7	1477.35	-	-	-				
VES 5		1	95.59	0.58	0.0061	55.44	3480.25	0.06	Poor	Extremely High Vulnerability
		2	751.06	9.93	0.0132	7458.03				
		3	131.80	22.21	0.1685	2927.28				
		4	5042.62	-	-	-				
VES 6		1	1121.15	1.76	0.0016	1973.22	4949.18	0.09	Poor	Extremely High Vulnerability
		2	2753.54	3.95	0.0014	10876.48				
		3	87.09	22.94	0.2634	1997.84				
		4	1119.26	-	-	-				
VES 7	**WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD, OGHAREFE**	1	42.53	0.82	0.0193	34.87	646.89	0.06	Poor	Extremely High Vulnerability
		2	29.72	0.32	0.0108	9.51				
		3	155.12	0.34	0.0022	52.74				
		4	66.47	3.59	0.0540	238.63				
		5	111.49	26.00	0.2332	2898.74				
		6	853.15	-	-	-				
VES 8		1	41.87	0.49	0.0117	20.52	1219.78	0.05	Poor	Extremely High Vulnerability
		2	412.73	0.99	0.0024	408.60				
		3	65.20	7.06	0.1083	460.31				
		4	262.48	15.20	0.0579	3989.69				
		5	1895.65	-	-	-				
VES 9		1	37.84	0.40	0.0106	15.14	286.55	0.06	Poor	Extremely High Vulnerabilit
		2	278.09	0.43	0.0015	119.58				
		3	111.01	4.46	0.0402	495.10				

		4	**51.69**	**9.99**	**0.1933**	**516.38**				**y**
		5	**1718.84**	**-**	**-**	**-**				
VES10		**1**	**306.34**	**0.69**	**0.0023**	**211.37**	**1519.55**	**0.02**	**Poor**	**Extremely High Vulnerability**
		2	**1305.39**	**1.18**	**0.0009**	**1540.36**				
		3	**685.77**	**4.60**	**0.0067**	**3154.54**				
		4	**117.90**	**9.94**	**0.0843**	**1171.93**				
		5	**95034.67**	**-**	**-**	**-**				
VES11		**1**	**1409.70**	**0.34**	**0.0002**	**479.29**	**475.10**	**0.02**	**Poor**	**Extremely High Vulnerability**
		2	**984.11**	**0.13**	**0.0001**	**127.93**				
		3	**117.71**	**6.95**	**0.0590**	**818.08**				
		4	**1004.86**	**-**	**-**	**-**				
VES12		**1**	**1095.68**	**0.58**	**0.0005**	**635.49**	**1069.66**	**0.05**	**Poor**	**Extremely High Vulnerability**
		2	**328.42**	**3.02**	**0.0092**	**991.83**				
		3	**109.99**	**14.38**	**0.1307**	**1581.66**				
		4	**6588.42**	**-**	**-**	**-**				

Table 3: Computed Aquifer Overburden Protective Capacity and Vulnerability to Leachate Contaminants

Sum of Longitudinal Conductance (mho or Ω^{-1})	**Overburden Protective Capacity Rating [12]**	**Vulnerability Rating [11], [13]**
>10	Excellent	Extremely low Vulnerability
5-10	Very good	Low Vulnerability
0.7-0.49	Good	Moderate Vulnerability
0.2-0.69	Moderate	High Vulnerability
0.1-0.19	Weak	Extremely High Vulnerability
<0.1	Poor	

Table 4: Aquifer Protective Capacity and Vulnerability Ratings

V. 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. The layer thickness and their corresponding resistivity values were used to determine the Dar-Zarrouk parameters in order to evaluate and characterize the aquifer overburden protective capacity in the dumpsite area. The results revealed that the total longitudinal layer conductance of the overburden were classified as 100% poor while the aquifer vulnerability was rated as extremely high vulnerability implying that the aquifer protective capacity is poor and vulnerable to leachate contaminants from the dumpsites. 2-D resistivity imaging produced 3 profiles where 2 distinct pollutants were mapped and identified 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 93Ωm and 394Ωm at depth between 5m to more than 28m. The result showed that leachate is migrating towards the groundwater aquifer, further validating the fact that the aquifer is highly vulnerable to surface leachate contaminants from the dumpsite waste, therefore not protected. The result further 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 93Ωm 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 waste dumpsite and it is not protected. Thus, 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. Open dumpsite waste disposal system should be phased out in order to safeguard public health as regards groundwater pollution. Government should address the issue of indiscriminate disposal of solid wastes in order to safeguard the groundwater resources in the area. Closed municipal landfill whose base is made of concrete and paved surfaces should be adopted as this will prevent leaching of poisonous substances into groundwater aquifer. Hydrogeophysical characteristics of the area should be considered before citing and drilling of boreholes.

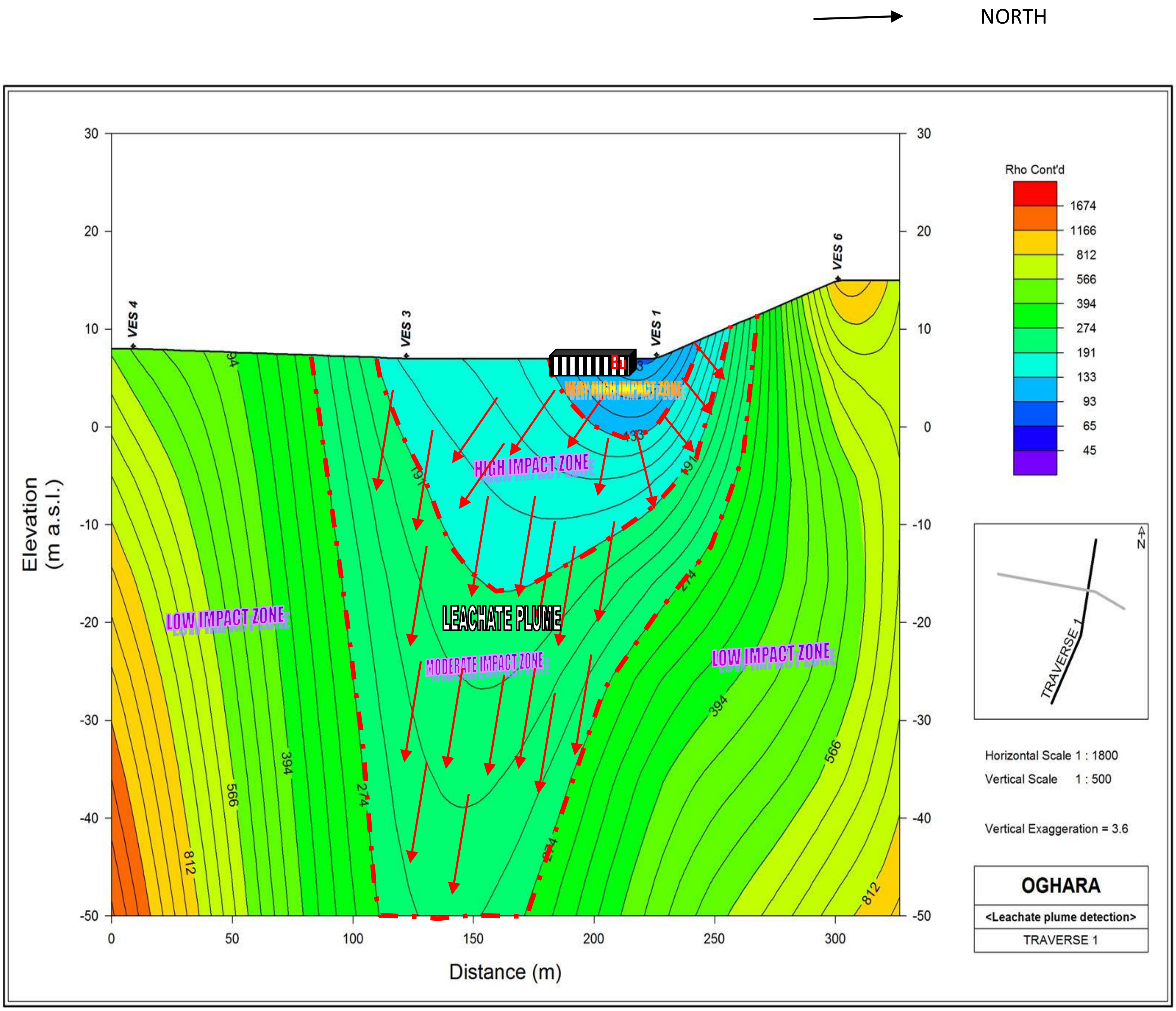

Fig. 6: The 2-D Section Beneath Profile 1

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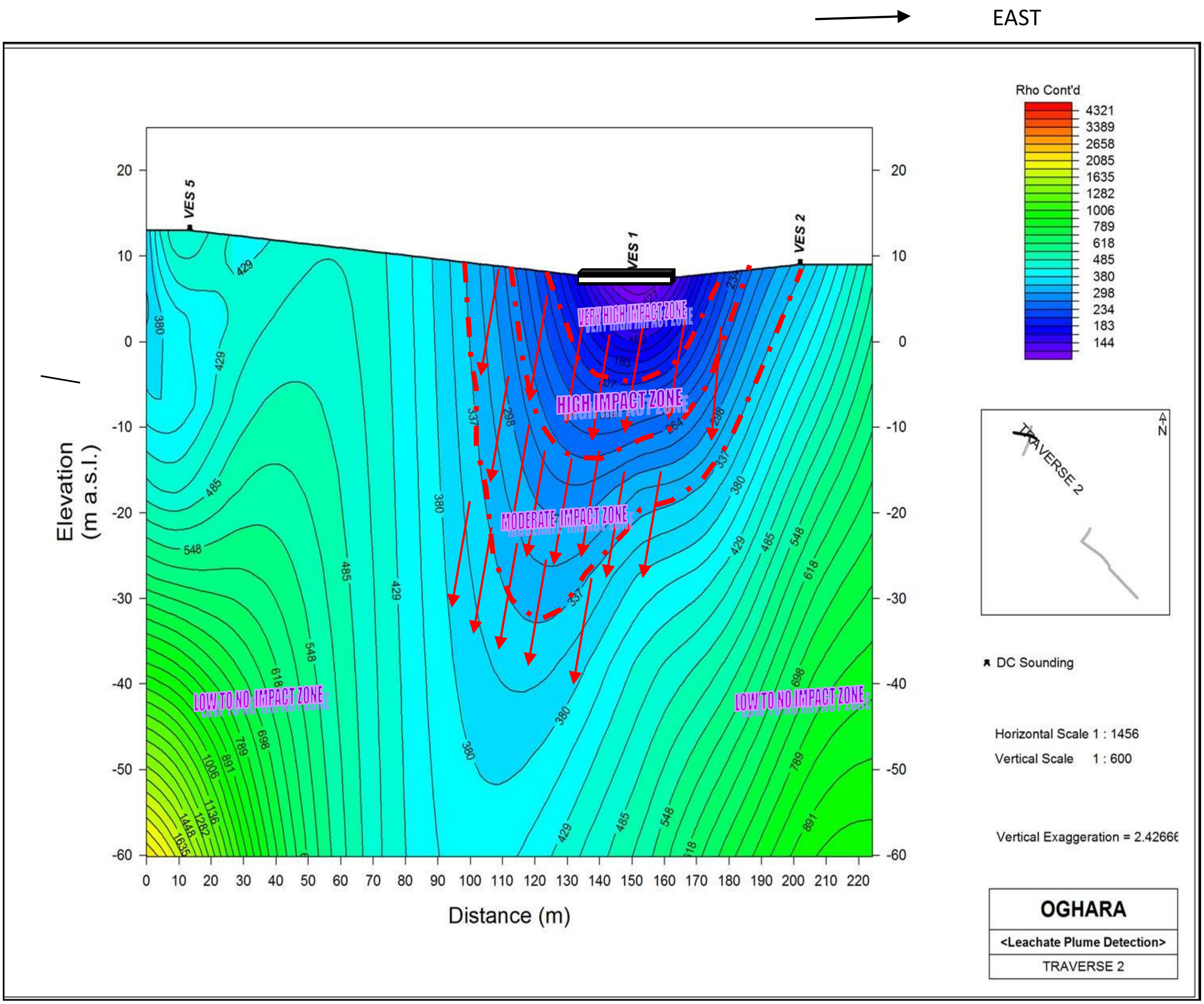

Fig, 7: The 2-D Section Beneath Profile 2

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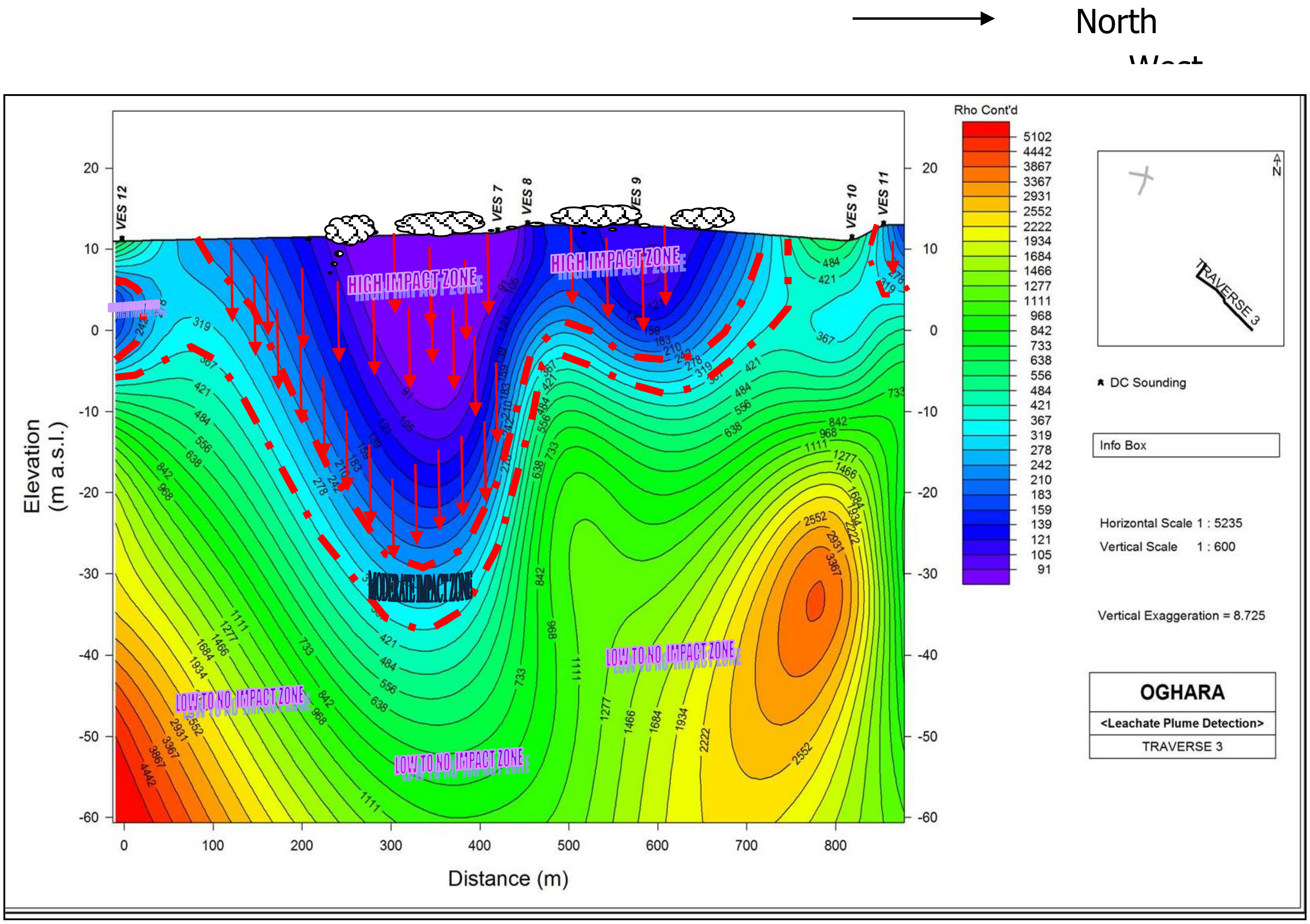

Fig. 8: The 2-D Section Beneath Profile 3

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