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Impact of solid waste on groundwater quality in selected dumpsites in AkwaIbom State, Nigeria using resistivity and hydrochemical data

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Research Article

Keywords:
Schlumberger array, VES curve, Leachate, Transmissivity, Hydrogeological risk model.

ABSTRACT

This study examines the impact of solid waste on groundwater quality around three municipal dumpsites in AkwaIbom State, Nigeria using resistivity and hydrochemical data. Thirty vertical electrical soundings and ten electrical resistivity tomography data were acquired across the area using Schlumberger array. The resistivity data which were analyzed with the aid of IPI2WIN software formed the input data for estimating and modeling leachate parameters. Twelve groundwater samples collected around the area were analyzed for physico-chemical parameters using Atomic Absorption Spectrometer (AAS). The leachate parameters computed from resistivity interpretation across the area show thickness (2 to 56 m); hydraulic conductivity (6.19 to 24.7 m/day); transmissivity (96.63 to 1351.18 m^2/day) and erodibility (104.36 to 2948.94 m/day). The hydrochemical analyses reveal elevated values of Total Dissolved Solids, Cadmium and high electrical conductivity within the area. The leachate migration paths trend predominantly in NW-SE and NE-SW directions at Uyo and Oron, respectively. The hydrogeological risk models reveal that the static water level crisscrosses the leachate at 35 m in Oron, while Uyo area has 25 m gap between the leachate and the static water levels. The study concludes that Oron dumpsites really contaminated the groundwater quality and makes it unfit for the dwellers.

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1. Introduction

Municipal solid waste (MSW) consists of refuse from homes, harmful solid waste from manufacturing, business and organizational firms such as hospitals, marketplaces, yard dissipate, along with avenue sweeping (Ogwueleka, 2009). Dahlin et al. (2010) established that the solid waste dumps consist of essential aspects of the soil hydrological composition along with a severe contamination risk to subsurface and surface water. According to Christensen et al. (1992), the major local environmental problem of solid waste dump is the discharge of leachate into surrounding ground and surface waters. Indeed, the seepage that emanate from urban solid waste dumps is frequently linked with elevated ion concentrations with extremely low resistivity. In line with this, Frohlichet al. (2008) carried out an investigation on harmful effect of organic waste in parts of Western Rhode

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Island of United State of America using electrical resistivity method. The scholars established that there were huge amount of harmful organic contaminants resulting from the dumpsite in the region and it has adversely contaminated the aquifers within the region.

Consequently, the use of waste dump for obvious reasons is not favorable because, it anticipates blowing garbage, foul odors, rodent infestations, increased truck traffic in the neighborhood as the trucks that bring the wastes drive in and out, hide-out for criminals and lowered property values. From an environmental and public health standpoint, probably, the most legitimate concerns about a waste dump are the potential to pollute the underlying groundwater with leaking liquid, called leachate. Contamination of any kind may be a signal that pollutants that are in fact hazardous to health and the environment are being transported from the dumpsites into groundwater reservoirs.

Generally, the management of refuse dumps in Nigeria is distinguished by ineffective collection scheme along with inappropriate dumping of refuse dumps or solid wastes. Due to influx of people in most of our cities in Nigeria including the study area, there are increases in disposal of solid wastes resulting from various consumer goods, which are mostly non-biodegradable materials. More so, both our surface and subsurface waters are not save from this ravaging environmental disasters because almost all companies discharge toxic chemicals in form of industrial wastes. Also, from our respective households, we do discharge raw sewage indiscriminately along with the sewage-truck which consistently dumped raw sewage into different water bodies around the environment, thereby polluting the water bodies within various states in Nigeria. However, a more severe case arises from the prevalent utilization of poisonous farming chemicals such as fertilizers in order to aid yield huge farm produces, but in turn causes groundwater pollution.

AkwaIbom State faces major environmental challenges associated with poor waste management culminating in unregulated waste dumpsites in parts of the state especially at the study areas viz.: Uyo, IkotEkpene and Oron, which are located in the central, north-west and south-east parts of the State respectively (Figure 1). The dumpsites pose great risk to ground water quality as a result of leachate accumulation. Although the layer parameters and geology of the area are essential in understanding the impact of leachate accumulation on groundwater, this information is not known, hence the need for this study. Furthermore, the study area which is predominantly underlain by mostly unconsolidated geological materials will surely pave way for infiltration and leaching of contaminants from the dumpsites into the groundwater body.

However, there is need to carry out a fast, reliable and non-invasive method of geophysical investigation in studying refuse dumps across the study area because investigations of contaminated sites are increasingly needed, both because of the pressure to reuse the land and increasingly stringent legislation to monitor contamination. Thus, the study aimed to determine the impact of solid waste on groundwater quality in selected dumpsites in AkwaIbom State using resistivity and hydrochemistry approach. The scope of this study includes the application of electrical resistivity techniques using vertical electrical sounding (VES) and tomography as well as hydrochemical methods to evaluate the physico-chemical properties of the groundwater. It also includes the interpretation of the rock layers encountered in the study area and evaluation of some layer parameters including the Dar Zarrouk parameters for establishment of major environmental challenges associated with waste generation and inadequate waste disposal and treatment within the study area.

1.1. Local Geology of the Study Area

Geologically, AkwaIbom State falls within two Sedimentary Basins of Nigeria: Anambra and Niger Delta Basins. Thus, the study area is overlain by three distinct lithostratigraphic units: Imo, Ameki and Benin Formations according to Mbipom et al., (1996); (Figure 1). The Imo Formation of Paleocene in age and it is underlying the Ameki Formation and it is mostly a mudrock layer comprising of dark grey to bluish grey shale, with intermittent intercalations of sandstone, ironstone, limestone and siltstone (Mbipom et al., 1996; Nwajide, 2013). Ameki Formation is dated Eocene in age and it is the oldest geological material within the study area and Mbipom et al. (1996) established that the lithology comprises of loose falser bedded, fine to medium sand, with few mudrock breaks. Also, overlying conformably on top of the Ameki Formation is the Benin Formation

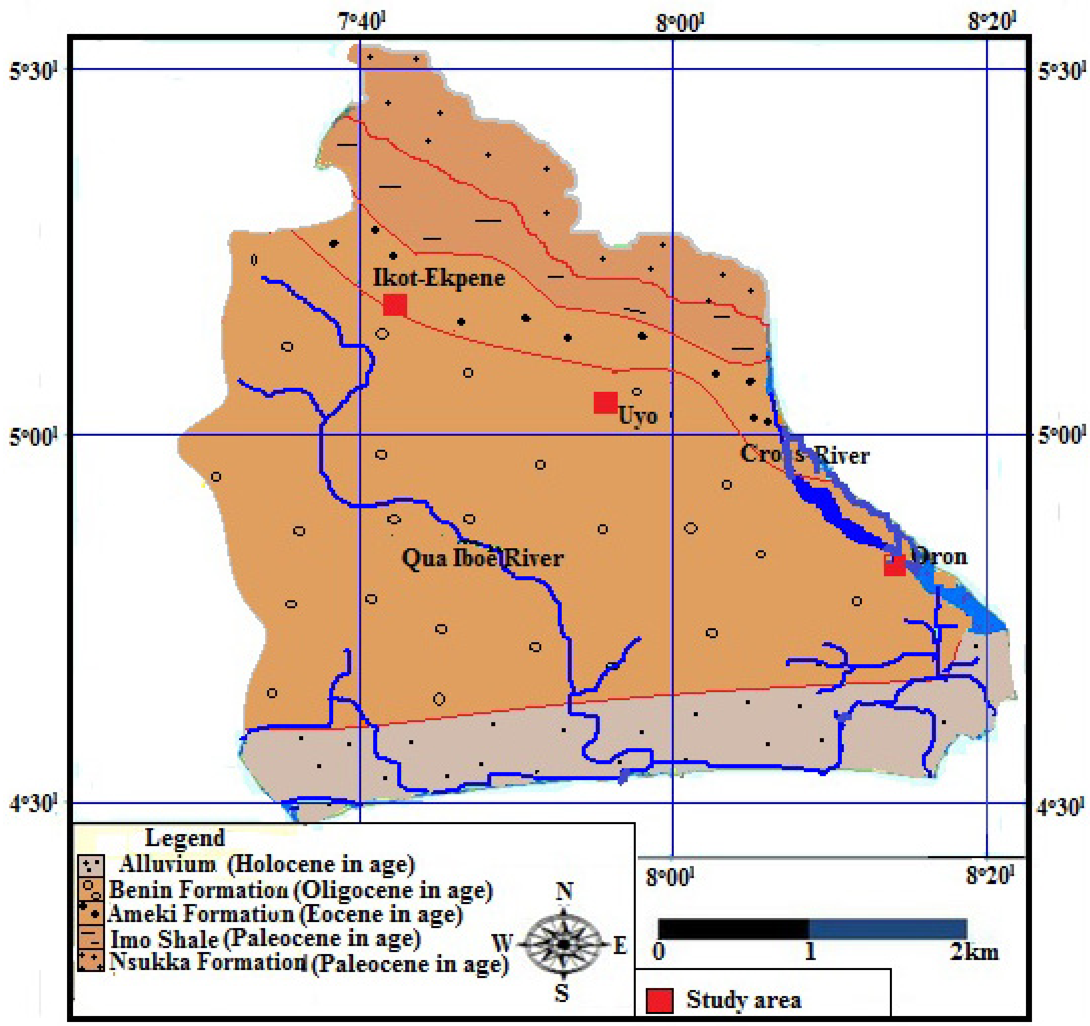
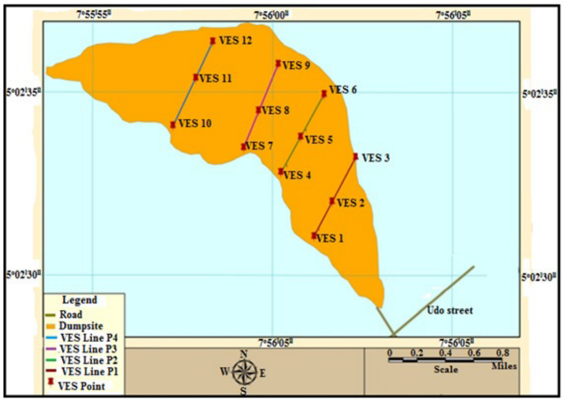


Figure 1- Geological map of Akwa Ibom State, Nigeria (Nigerian Geological Survey Agency, 2006).

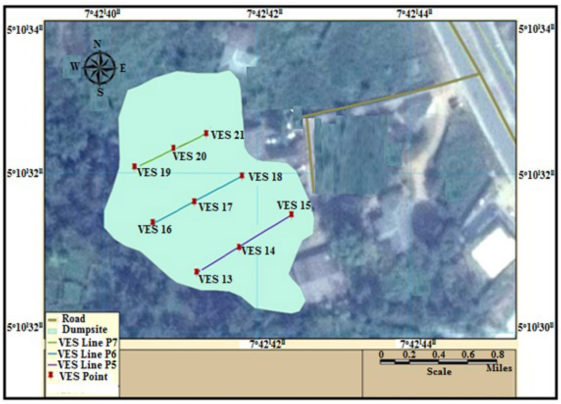
of Oligocene in age which comprises of alternating sequences of gravels and sands of fine to medium/ coarse grain sizes, and Quaternary alluvium (Ugbaja and Edet, 2004). In the view of Edet and Okereke (2002), the Benin Formation is to Recent in age and it is composed of continental materials such as sand (especially from flood plain), and alluvial deposits. It is good to note that the sand members of the Benin Formation are mature, coarse and poorly to moderately sorted with intercalations of silts and clays.

2. Methodology

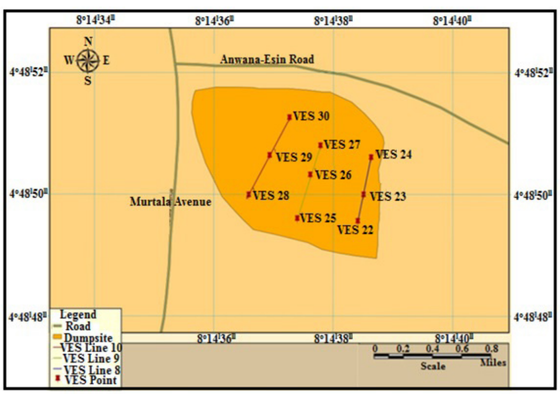
The methodology involved the acquisition of thirty (30) vertical electrical soundings (VES) data along profile lines with survey stations placed at equal intervals (30m) apart using Schlumberger configuration with current electrode spread ranged from 1 to 150 m across the study area (Figure 2). The coordinates of each station were taken using the global positioning system (GPS) equipment as shown in table 1a, b, c. A bi-logarithmic graph was used to plot current electrode spacing against the computed apparent resistivity values from the field data in order to generate various geoelectric attributes of layers penetrated such as resistivity and thickness of the layers. This technique has been functional in groundwater exploration by various investigators such as Heigold et al. (1979), Niwas and Singhal (1981), Olofsson et al. (2005), Onwuemesi and Egboka (2006), Nfor et al. (2007), Oseji and Ujuanbi (2009), Ezeh (2011), Okafor and Mamah (2012), Utom et



a) Uyo dump site



b) Ikot Ekpene dump site



c) Oron dumpsite

Figure 2- Map showing the geophysical VES points and geophysical VES profiles in the area.

Table 1- a) Coordinates of VES Stations at Uyo Dumpsite (VES line P1 – P4).

Label	Longitude (E)	Latitude (N)
P1VES1	7°56'1.303"	5°2'31.051"
P1VES2	7°56'1.812"	5°2'32.025"
P1VES3	7°56'2.457"	5°2'33.135"
P2VES4	7°56'0.398"	5°2'32.773"
P2VES5	7°56'1.043"	5°2'33.628"
P2VES6	7°56'1.518"	5°2'34.857"
P3VES7	7°55'59.325"	5°2'33.454"
P3VES8	7°55'59.885"	5°2'34.462"
P3VES9	7°56'0.291"	5°2'35.708"
P4VES10	7°55'57.861"	5°2'36.303"
P4VES11	7°55'58.369"	5°2'35.708"
P4VES12	7°55'59.014"	5°2'36.048"

Table 1- b) Coordinates of VES Stations at Ikot Ekpene Dumpsite (VES line P5 – P7).

Label	Longitude (E)	Latitude (N)
P5VES13	7°42'41.345"	5°10'30.682"
P5VES14	7°42'41.914"	5°10'30.953"
P5VES15	7°42'42.599"	5°10'31.39"
P6VES16	7°42'40.792"	5°10'31.51"
P6VES17	7°42'41.061"	5°10'31.873"
P6VES18	7°42'41.949"	5°10'31.873"
P7VES19	7°42'41.476"	5°10'31.873"
P7VES20	7°42'41.061"	5°10'32.197"
P7VES21	7°42'41.476"	5°10'32.376"

Table 1- c) Coordinates of VES Stations at Oron Dumpsite (VES line P8 – P10).

Label	Longitude (E)	Latitude (N)
P8VES22	7°56'1.303"	5°2'31.051"
P8VES23	7°56'1.812"	5°2'32.025"
P8VES24	7°56'2.457"	5°2'33.135"
P9VES25	7°56'0.398"	5°2'32.773"
P9VES26	7°56'1.043"	5°2'33.628"
P9VES27	7°56'1.518"	5°2'34.857"
P10VES28	7°55'59.325"	5°2'33.454"
P10VES29	7°55'59.885"	5°2'34.462"
P10VES30	7°56'0.291"	5°2'35.708"

al. (2012), Anakwuba et al. (2014), Chinwuko et al. (2015), Obiora et al. (2016), Amadi et al. (2017), Shaibu et al. (2018), Singh et al. (2018), Adeeko et al. (2019) and others.

According to Wunderlich et al. (2018), geoelectric data can be analyzed in a tomographic inversion process leading to images of the subsurface in terms of resistivity (electric resistivity tomography). Therefore, electric resistivity tomography (ERT) usually results in different subsurface models that perfectly fit observed apparent resistivity values. In practice, four- point Multiple Vertical Electrical Sounding (MVES) such as the Schlumberger array run at constant stations interval along a profile is synonymous with Electrical Resistivity Tomography (ERT) and gives subsurface layered resistivity images in two dimensions when modeled. The advantage of this survey type is that it allows the subsurface variation of resistivity values to be modeled both vertically and laterally, thus giving a clear resistivity image of the subsurface in 2D. The resistivity data was modeled using the computer resistivity iteration and inversion software called IPI2WIN, which is quite efficient in modeling resistivity data both by plotting apparent resistivity values against half-current electrode spacing (AB/2) and also generating pseudo and resistivity cross sections to give the resistivity image of the subsurface in resistivity profiling. Generally, the software has been used in many similar research works and has proven very effective for groundwater investigation and vulnerability studies. The VES results formed the input data for estimating and modelling leachate parameters. The maps of the leachate levels were generated such that, the migration conduits of the leachate could be delineated. Profiles of leachate level and elevation maps were correlated in order to model the groundwater risk factor associated with them.

The hydrochemical study involved laboratory analyses of the collected water samples according to world health organization (WHO) standard practice for physico-chemical and microbial properties. Twelve water samples were collected and the plastic containers used were rinsed three times with the sample to be collected. Duplicate samples were collected and labelled A and B. Sample A was stabilized using three drops of Hydrochloric acid to prevent the metals from adsorbing on the surface of the container. It was filtered with 0.45 mm filter paper and the sample was used for cation analysis. The Sample B which was not filtered because they were used for anion and microbial analyses. The samples were preserved using a plastic cooler with ice to maintain the temperature such that there would be no change in the constituent of the sample. The water was then taken to the laboratory of AkwaIbom State Water Company, Uyo Headquarters, within 24 hours for analyses. Cation analysis was done using Atomic Absorption Spectrometer (AAS), while the anions were analysed using the Ultraviolet (UV) Spectrophotometer. Some parameters were analysed using titrimetric method. Temperature, pH and turbidity were measured in the field in-situ using the portable pH meter, turbidity was measured using turbid meter, and temperature was measured using mercury-in-glass thermometer.

3. Result and Discussion

3.1.Geoelectrical Curves

The geoelectrical curves results generated for the selected profiles from figure 2 yielded some VES curves across the entire area as shown in Figure 3. The VES curves generated at Uyo and Oron areas are typically H and K-curves (Figure 3), which implies that the interpreted VES Curves are quite common in a sedimentary environment for multilayer structures of three or more layers. Uyo resistivity curves show typically H-curves which are quite common in a sedimentary environment for multilayer structures of three or more layers (Figure 3a) according to Anakwubaet al. (2014). At Ikot Ekpene, there are hybrid of K and H curves, A and K curves while one VES station has H-curve (Figure 3b). At Oron, it is predominantly K-curves, with one VES station having A-curve and hybrid KHK-curve (Figure 3c).

Consequently, the results of the VES interpretations in conjunction with the borehole data within the study area (Figure 4) show that Uyo is mainly of three (3) layers namely; top lateritic sand, leachate contaminated sand, and dry fine to medium-grained sand layers, except one Station that is up to five (5) layers of the same characterization with the former (Figure 4a, b). Ikot Ekpene and Oron are of three to four layers, except one Station at Oron, which is of five layers down to the depth of investigation. Figure 4a shows a VES correlation at Uyo which reveal that, the lithologicfacies are sandy lateritic overburden (19.80 – 232.00 ohm-m), leachate contaminated sand (4.06 – 20.00 ohm-m), dry fine to medium grained sand (11315 – 13654 ohm-m) and medium to coarse grained sand (1304.00 – 26542.00 ohm-m). Thin lateritic sand units which overlie the leachate contaminated sand units, signify that the study area is of unconfined region and there is possibility of leachate plume moving down the subsurface. More so, figure 4b shows that the VES correlation at Ikot Ekpene, the lithologicfacies are sandy lateritic overburden (64.60 – 3733.00 Ohm-m), medium to coarse-grained sand (126 – 24849 Ohm-m), fine to medium grained sand (58.30 – 94.90 Ohm-m). Thin lateritic sand units which overlie the medium to coarse-grained sand units, signify that the study area is more of unconfined region.

Furthermore, considering the VES correlation at Oron, the lithologicfacies are sandy lateritic overburden (103 – 167.00 Ohm-m), dry fine to medium

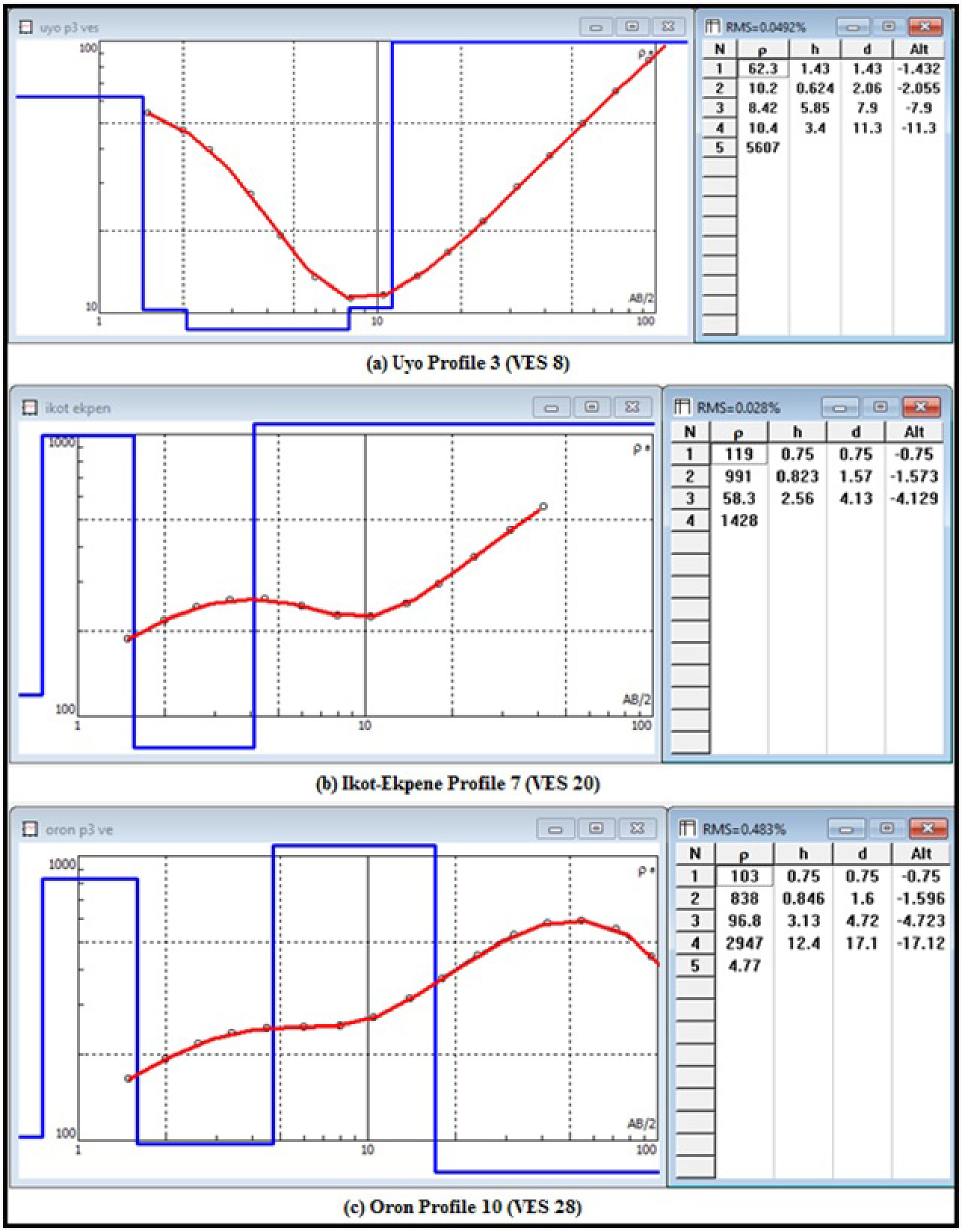
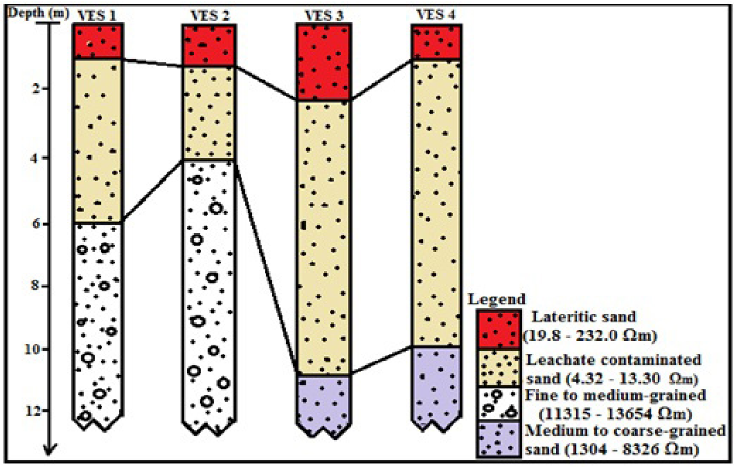


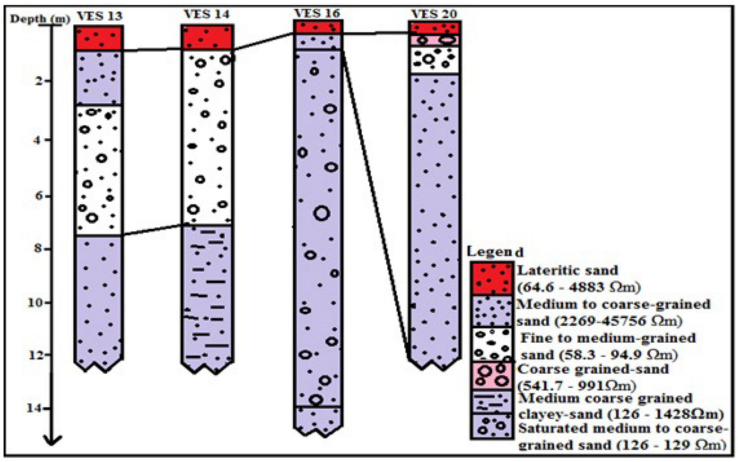
Figure 3- Some VES curves and calculated parameters for a) Uyo, b) Ikot Ekpene and c) Oron.

grained sand (838 – 2632 Ohm-m), medium to coarse grained sand (96.80 – 2947.00 Ohm-m) and leachate contaminated sand (4.77 – 19.00 Ohm-m). Thick sand units which overlie the leachate contaminated sand units, signifying that the study area is of unconfined region and there is possibility of flow of leachate plume down the subsurface.

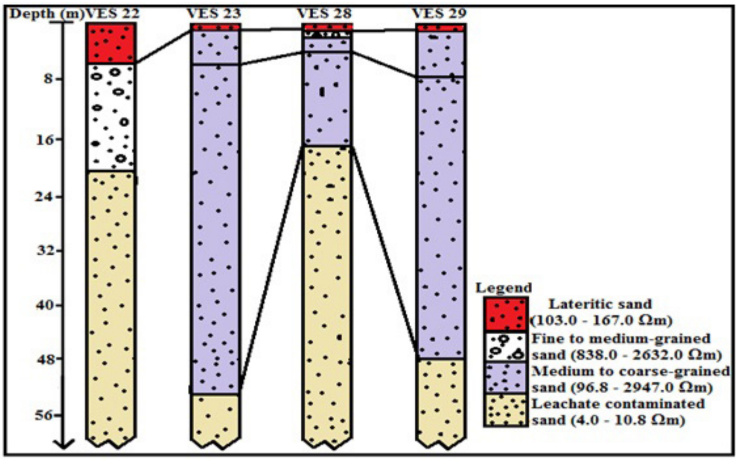
Generally, these delineated layers exhibit some characteristics of the Benin Formation which this area is entirely made up of. The entire profile therefore shows sands of varying composition based on their resistivity attributes. In line with this, Mbipom et al. (1996) established that the study area falls within the sedimentary area of Nigeria and is overlain by coastal plain sands of the Niger Delta sedimentary sequence known as the Benin Formation. It is good to note that the sand members of the Benin Formation are mature, coarse and poorly sorted with intercalations of silts and clays. Ugbaja and Edet (2004) also emphasized that the Benin Formation comprises of alternating sequences of gravels and sands of fine to medium/coarse grain sizes.



a) Along Profile 1 and 2 at Uyo



b) Along Profile 5, 6 and 7 at Ikot Ekpene



c) Along Profile 8, 9 and 10 at Oron

Figure 4- Electrical resistivity sections obtained by combining of VES results (from resistivity-depth parameters).

3.2. Geoelectrical Tomography

In practice, the interpretation of the pseudo cross- sections generated within the study area is based on colour codes depicting variation in apparent resistivity values of the subsurface as shown in figure 5. If this figure is examined, it can deduced that the black colour represents very low apparent resistivity values followed by the blue color code, whereas, the green colour code represents moderate apparent resistivity values followed by the yellow color code with higher apparent resistivity values. The highest resistivity values are represented by the red color code. These interpretations aligned with the already interpreted leachate-prone zones in figure 4. Figure 5 has abnormally low apparent resistivity values, which are designated as plumes of black and light blue colors associated with areas of vulnerability to contamination, while areas with green, yellow and red color codes represent areas of little or no vulnerability to contamination. The prominent trend evident in figure 5 is NE-SW direction across the study area.

In addition, the resistivity pseudo cross- sections of Uyo dumpsite shows three blocks representing VES 1, 2, 3, and each has three layers (Figure 5a). The range of low resistivity values (4.06 - 10.40 Ωm) of the second layers at Uyo dumpsite shows that the second layers are predominately leachate contaminated zones. The thickness of the leachate plumes within the Uyo dumpsite ranges between 4 to 8 meters in depth. The pseudo cross- section generated within Uyo dumpsite shows that the plume has migrated from VES 1 to a little beyond VES 2, which has a distance of more than 30m in the subsurface. Meanwhile, at Ikot Ekpene, the resistivity tomography is represented in figure 5b. The figure signifies that the resistivity values within Ikot Ekpene area range between 58.3 Ωm and above with the Ikot Ekpene dumpsite having no trace and/or very minimal impact of leachate plume. More so, at the Oron dumpsite, the resistivity tomography connotes leachate plume which is very prominent between VES 9 and VES 10 (Figure 5c). There are very low resistivity values of 4.28 – 10.8 Ωm in layer 3 which is interpreted as the leachate contaminated zone within the Oron dumpsite.

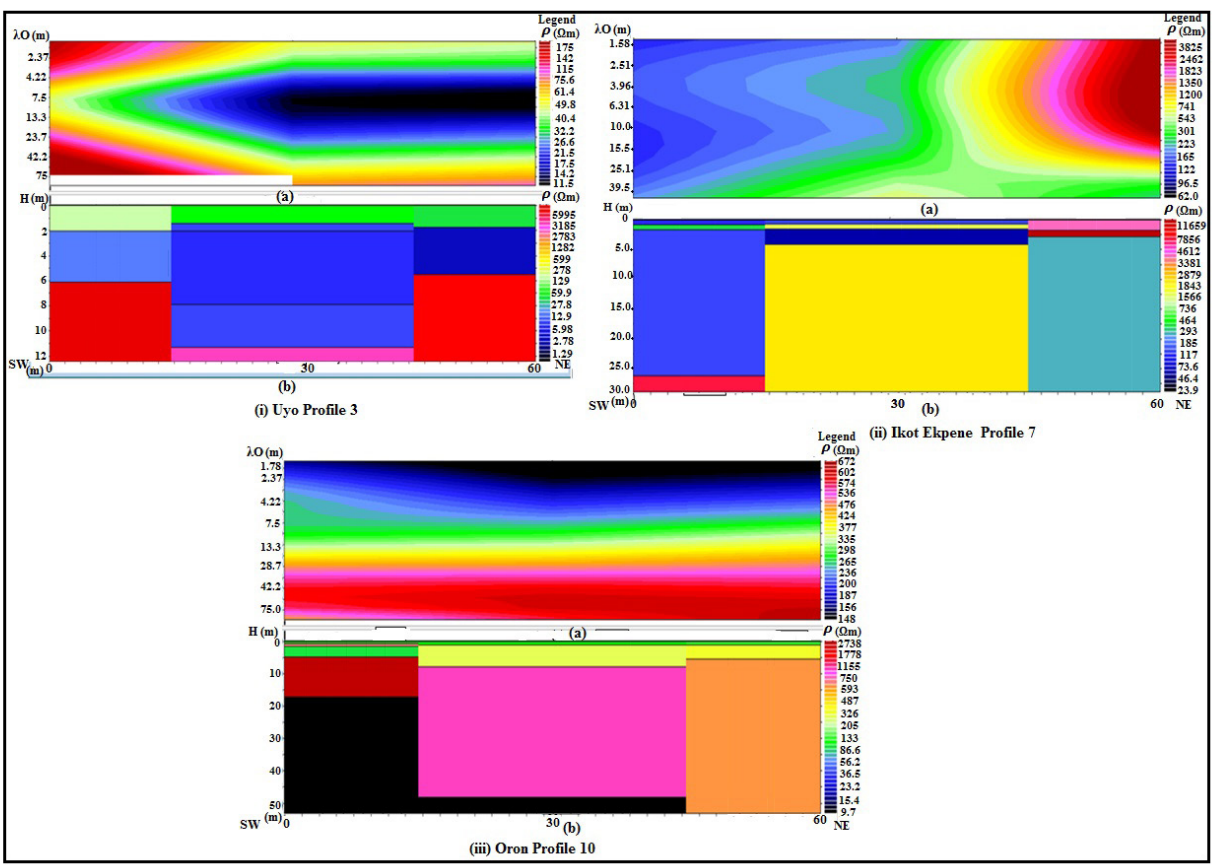


Figure 5- Some geoelectrical Tomography for a) Uyo, b) Ikot Ekpene and c) Oron.

3.3. Estimation of Leachate Parameters

In practice, Da-Zarrouk, Hydraulic Conductivity, and Transmissivity parameters are calculated and presented in table 2. Additionally, the hydraulic conductivity, transmissivity and erodibility distribution maps are shown in figures 6, 7 and 8. If this table is examined, the following deductions can be achieved;

3.3.1. Da-Zarrouk Parameters

The computed leachate Da-Zarrouk parameters result from the interpreted VES data (Table 2) show that, the values of various parameters range from low to high within the study area: for Uyo dumpsite, leachate resistivity varies from 4.06-20.00 Ωm; leachate thickness from 2.85-22.20 m; longitudinal conductance from 0.205-2.637 ohm-m. For Oron dumpsite, leachate resistivity varies from 4.26-19.00 Ωm; leachate thickness from 26.80-62.90 m; longitudinal conductance from 1.411-13.187 ohm-m.

3.3.2. Hydraulic Conductivity

Hydraulic conductivity of the leachate layer (K_L) can be defined as the ease with which any fluid such as leachate or water will be able to travel through voids or cracks within the earth materials or layers. This parameter is dependent on three major factors namely; the intrinsic permeability of the rock unit, the degree of saturation within the rock unit and the density along with viscosity of the fluid such as the leachate. Mathematically, the hydraulic conductivity of the leachate layers (K_l) across the area was estimated using equation 1 generated by Heigoldet al. (1979);

$$K = 386.40R_{rw}^{-0.93283} \quad (1)$$

Where, K = Hydraulic conductivity; R_{rw} =Apparent resistivity of the layer.

At Uyo dumpsite area, the hydraulic conductivity of leachate unit (Table 2) ranges from 23.63 m/day to 104.56 m/day. The distribution map of hydraulic conductivity produced reveals that at the western part of the map (Figure 6a), there is relatively lower hydraulic conductivity of the leachate unit (23.63 – 65.00 m/day), while the pinkish colour at the eastern part corresponds to relatively higher hydraulic conductivity of the leachate unit (70 – 104.56 m/day). At Oron dumpsite (Figure 6b), the northeastern area possesses relatively lower hydraulic conductivity of

Table 2- Calculated leachate parameters for the study area.

Dumpsite/ Profile	VES Point	ρ_l (Ωm)	h (m)	S (mhom)	T (m-Ohm)	C (mho)	κ_l (m/day)	τ_l (m²/day)	κ_l (m/day)
UYO	1	11.4	4.95	0.434	56.430	0.088	39.914	197.574	399.209
P1	2	8.26	2.85	0.345	23.541	0.121	53.908	153.637	756.404
	3	13.3	8.32	0.626	110.656	0.075	34.568	287.606	283.822
	4	6.32	8.69	1.375	54.921	0.158	69.200	601.345	1206.177
P2	5	4.11	4.36	1.061	17.920	0.243	103.378	450.727	2871.435
	6	4.32	9.23	2.137	39.874	0.231	98.682	910.837	2509.543
	7	20	4.09	0.205	81.800	0.050	23.626	96.632	134.529
P3	8	9.67	3.29	0.340	31.814	0.103	46.537	153.108	523.124
	9	4.06	3.78	0.931	15.347	0.246	104.565	395.255	2948.936
	10	4.21	4.18	0.993	17.598	0.238	101.085	422.537	2241.645
P4	11	8.42	22.2	2.637	186.924	0.119	52.952	1175.523	474.803
	12	4.32	9.25	2.141	39.960	0.231	98.682	912.810	2503.604
ORON	22	6.36	58.6	9.214	372.696	0.157	68.794	4031.307	865.329
P8	23	19	26.8	1.411	509.200	0.053	24.784	664.220	104.355
P9	25	4.26	55.2	12.958	235.152	0.235	99.978	5518.792	1877.523
	28	4.77	62.9	13.187	300.033	0.210	89.969	5659.075	1508.921
P10	29	10.8	31.9	2.954	344.520	0.093	41.979	1339.119	310.953
Average		8.45	18.86	3.115	143.434	0.156	67.800	1351.183	1265.901

Key symbols: ρ_l = Leachate resistivity; h= Leachate thickness; S= Longitudinal conductance; T= Transverse resistance; C= conductivity; κ_l= Hydraulic conductivity of leachate; τ_l= Transmissivity of leachate; κ_L= Erodibility of leachate

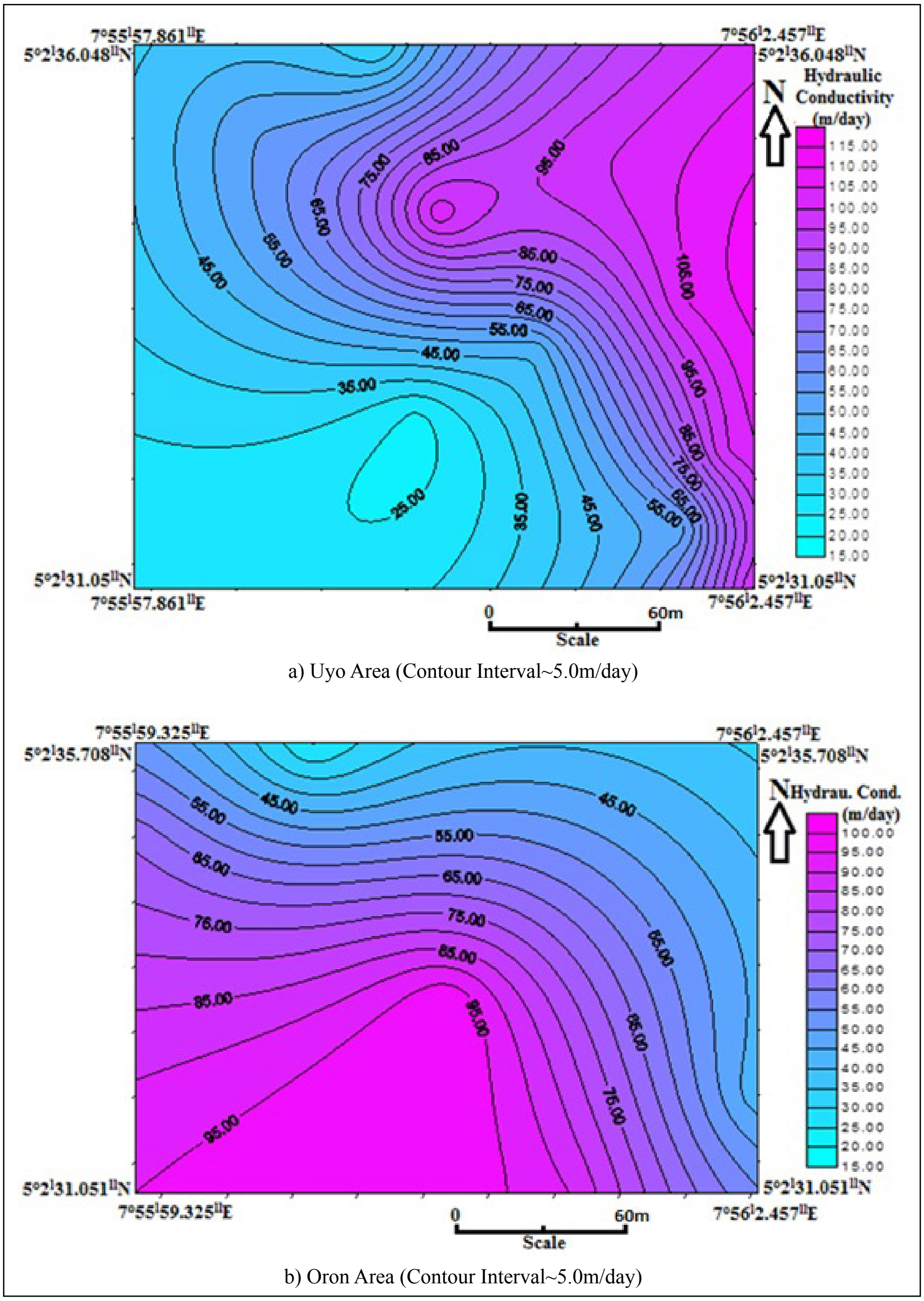
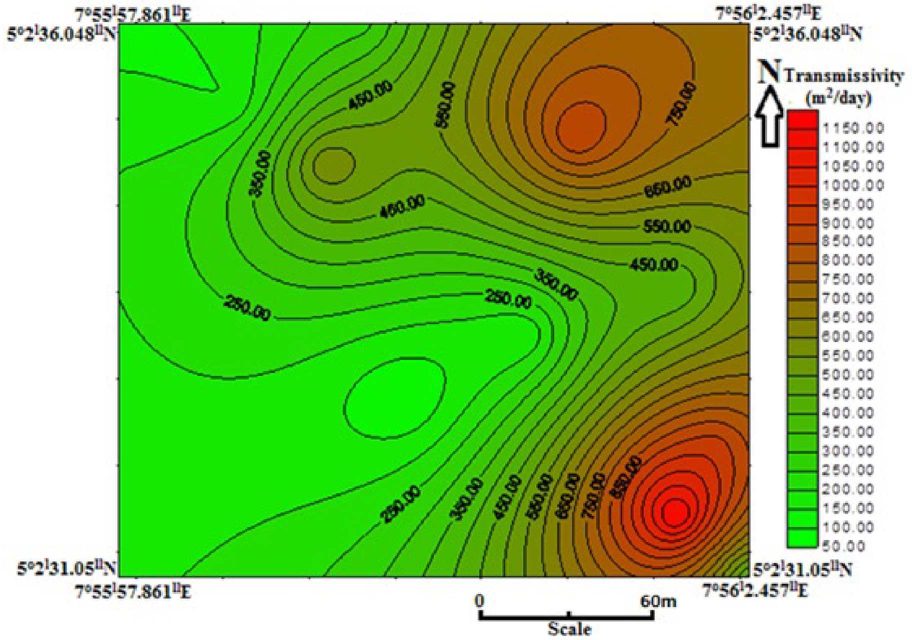


Figure 6-A distribution map showing hydraulic conductivity across a) Uyo and b)Oron areas.

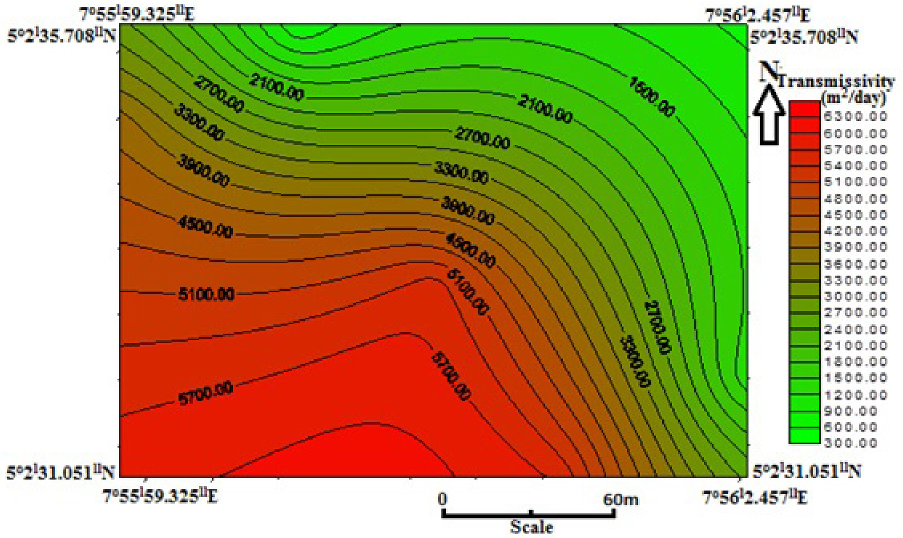
the leachate unit (24.78 – 68.79 m/day), while the pinkish colour at the southwestern part corresponds to relatively higher hydraulic conductivity of the leachate unit (70 – 99.98 m/day). Generally, few of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; which the hydraulic conductivity of the area.

3.3.3. Transmissivity

Transmissivity of leachate is the property which is directly related to hydraulic conductivity and it can be describe as the capacity of a specific fluid unit such leachate of a given thickness to transmit fluid. Mathematically, the transmissivity of the leachate layer (T_L) across the area was estimated using the equation 2 generated by Niwas and Singhal, 1981;



a) Uyo (Contour Interval: 50m²/day)



b) Oron area (Contour Interval: 300m²/day)

Figure 7- A distribution map showing transmissivity across a) Uyo and b) Oron areas.

$$T_L = K_L h_L \tag{2}$$

Where, K_L = Leachate transmissivity; K_L = Leachate hydraulic conductivity; h_L = Leachate thickness.

Consequently, the transmissivity of leachate calculated (T_L) from VES result ranges from 96. 63 to 1175.52 m²/day at Uyo (Table 2 and figure 7a), while at Oron area, the transmissivity of leachate ranges from 664.22 to 5659.08 m²/day (Table 2 and figure 7b). Some of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; which the transmissivity of the area was deduced to vary between 51.39 and 5659.08 m²/day. Figure 7 shows clearly the distribution of transmissivity within the study area. Some of these values compared well with those obtained by Ekwe and Opara (2012) from interpreted VES data around Owerri and its environs, Southeastern Nigeria for leachate plume; with the range of transmissivity of the area obtained to be between 51.39 and 5659.08 m^2/day.

3.3.4. Erodibility

Erodibility can be defined as the inherent yielding or non-resistance of earth materials such as soils and rocks to erosion. A high erodibility implies that the same amount of work exerted by the erosion processes leads to a larger removal of material. Hence, the erodibility of the overburden layers within the study area was calculated using the equation 3 according to Freeze and Cherry (1979);

$$K_z = \frac{b}{\left[\sum_{i=1}^{m}(b_i/K_i)\right]} \tag{3}$$

Where, K_L= erodibility or parallel flow within each lithologic layer; K_i= hydraulic conductivity of each individual layer of thickness; b_i= individual layer of thickness; b= Overall thickness of the sequence.

Subsequently, the obtained results show that the value of erodibility within the area is between 134.53 and 2948.94 m/day at Uyo area while that of Oron area ranges between 104.36 and 1877.52 m/day (Table 2). The leachate erodibility distribution maps were produced across the study area (Figure 8). At Uyo area (Figure 8a), two distinct zones were interpreted namely; a relatively high erodibility (1400 to 2948.94 m/day) and a relatively moderate erodibility (134.53 to 1206.18 m/day). More so, at Oron area (Figure 8b), two distinct zones were interpreted namely; a relatively high erodibility (900 to 1877.52 m/day) and a relatively moderate erodibility (104.36 to 865.33 m/day). Considering the average erodibility of the leachate units at Uyo area as 1404.44 m/day, and that of Oron area as 933.42 m/day, the study area can be classified as having a relatively high erodibility of the leachate units. This implies that the rate of removal of material within the area is considerably high due to the nature of geologic materials available.

3.4. Hydrogeochemical Characteristics

The hydrogeochemical analyses reveal that few water samples from boreholes surrounding the dumpsites (Table 3) exhibit elevated Total Dissolved Solids (TDS), reduced pH and high electrical conductivity. Significantly, of the heavy metals, Cadmium is above the permissible limit (Samples DS3 and DS4). The dumpsite is encroaching albeit with minimal impact at the time of study. The acidic pH is a pointer to things that will happen that have not yet manifested. Both the acidic pH and high Cadmium are signs that things are getting wrong with the groundwater. There are a lot of anthropogenic influences adding Cadmium to the groundwater. The result of hydrogeochemical analyses also reveal that the pH values obtained (3.7-5.8) within the study area are not within the acceptable limits of 6.5-8.5 for human consumption. Indeed, Edet (2017) emphasized that this pH low values obtained in the study area can be as a result of humic acid generated from decaying plant. Also, the result of the analysis shows high amount of dissolve Oxygen in samples DS3 and DS4. This perhaps is due to high microbial activity within the environment as shown on table 3.

3.5. Elevation and Leachate Level Maps

The elevation maps of Uyo and Oron dumpsites (Figure 9) were produced for effective correlation with the leachate level maps. Nevertheless, the leachate levels across Uyo and Oron dumpsites were computed by subtracting depths to leachate layer from the surface elevations obtained during the data acquisition. At Uyo area (Figure 10a), the flow direction of the leachate plume is predominantly in NW-SE direction and hydrogeologically, it is the dominant groundwater flow direction in the area. Also, the thickness of the leachate level increases along this flow direction within this area. Subsequently, the flow direction of the leachate plume at Oron area (Figure 10b) is predominantly in NE-SW direction and hydrogeologically, it is the groundwater flow direction of the area. Hence, the thickness of the leachate level increases along this flow direction within this area. Also, cross sections G-G^1 at Uyo and H-H^1 at Oron were taken along the flow directions in order to unveil the sinks and peaks of the flow direction (Figure 11).

3.6. Hydrogeological Risk Implication Associated with Leachate Level

Different cross sections were taken at both the elevation map (Figure 9) and leachate level map

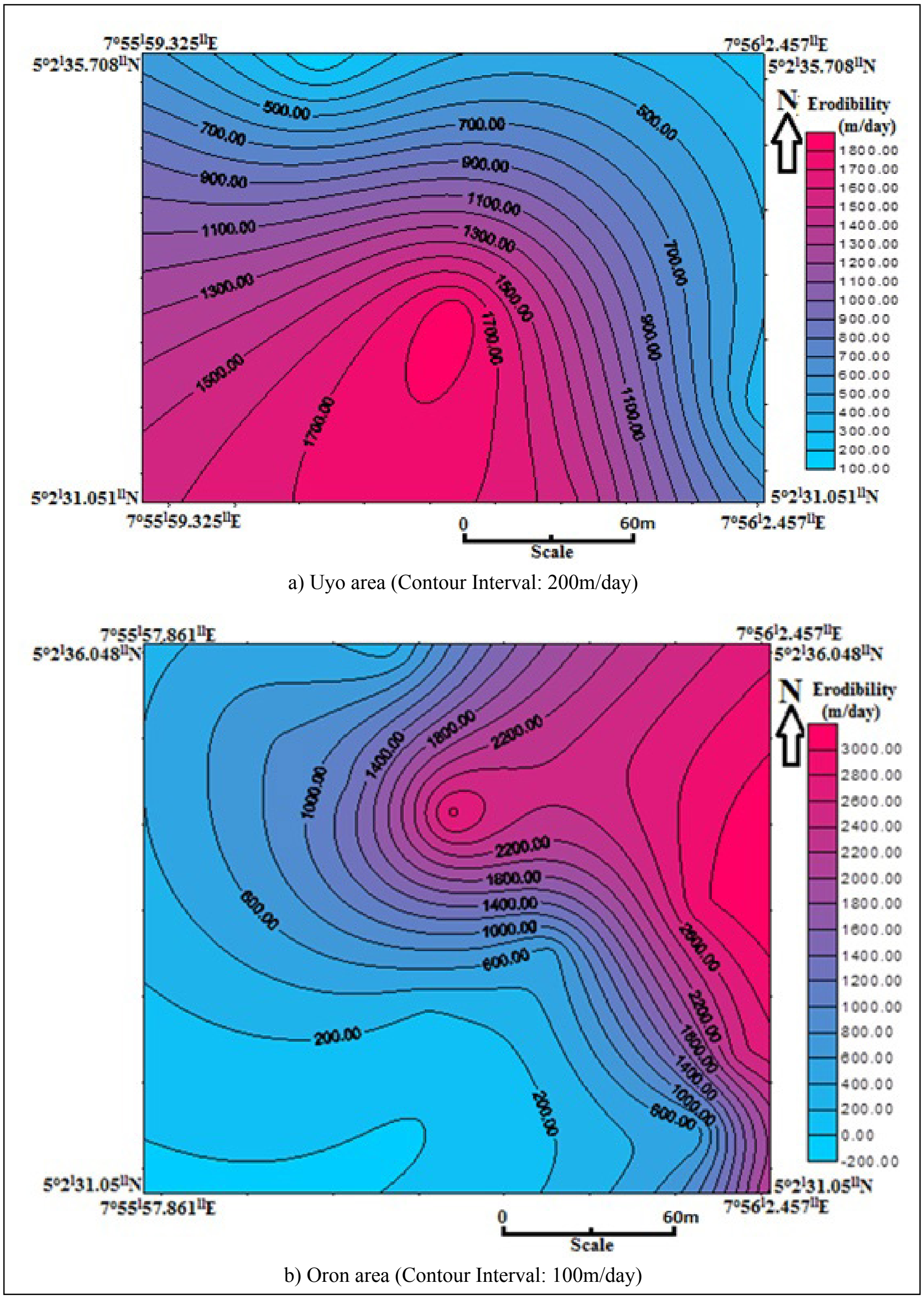


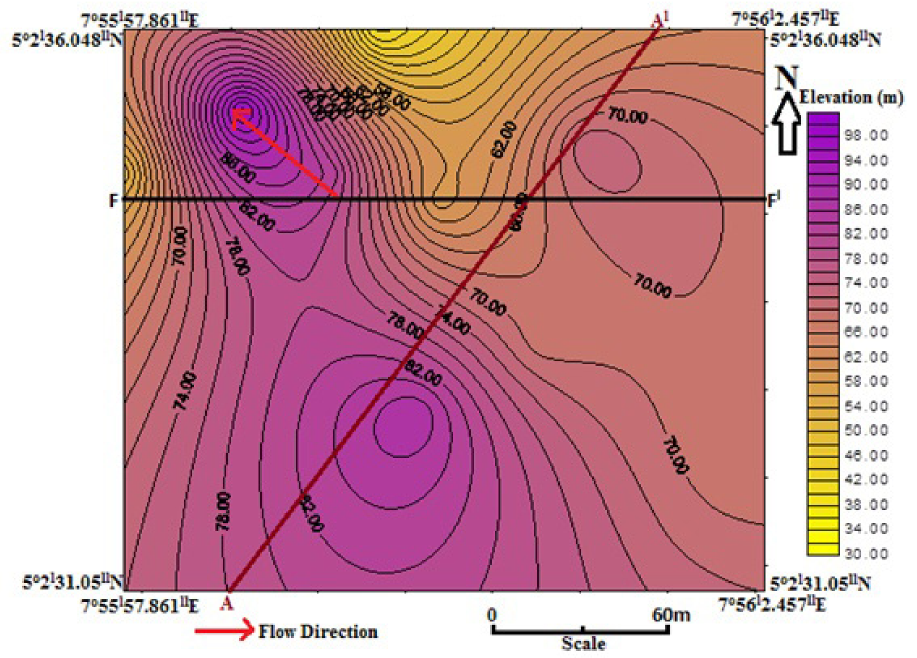
Figure 8- A distribution map showing erodibility across a) Uyo and b) Oron areas.

(Figure 10) at Uyo and Oron areas respectively. At Uyo, profiles running from A-A^{l} at figure 8a and B-B^{l} at figure 9a were superimposed in order to estimate the groundwater risk factor (Figure 12) obtainable in this area. We can deduce from figure 12a that there is close match between leachate level and topography, which implies that the topography controls the configuration of the leachate level (Figure 12a). Also, the gap between the leachate level and the average static water level in Uyo area is 25 m since the depth of the sink leachate level and the static water level is 65 m and 38 m respectively (Figure 12a). This implies that the vertical movement of leachate (contaminate) will be slow thereby allowing physical (filtration), chemical and biochemical processes to remove contaminants before reaching the aquifer. Also, from the

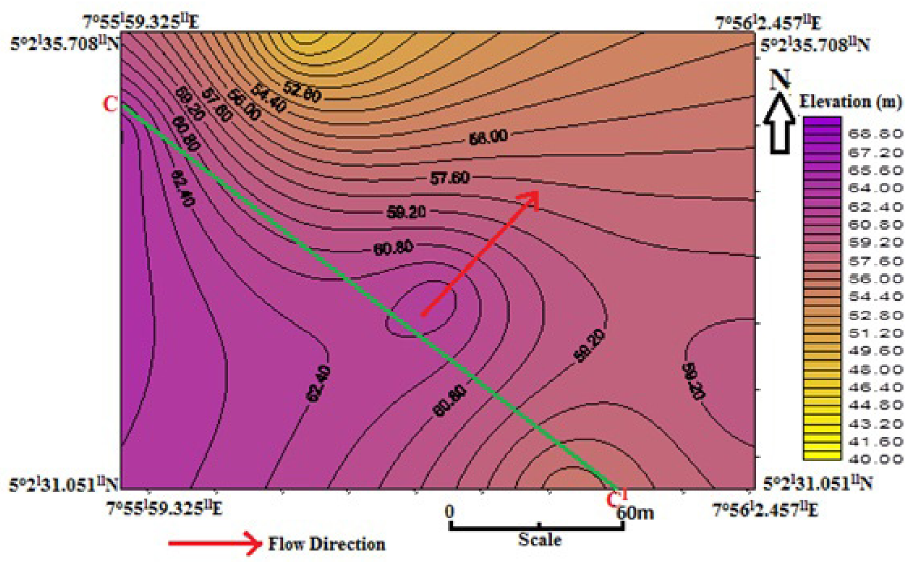
Table 3- Results of hydrogeochemical analysis within the study area.

Parameters	66 Udo St (DS1)	H. Garden (DS2)	64 Udo St (DS3)	58 Udo St. (DS4)	68 Udo St. (DS5)	NSDWQ	W.H.O. (2017)
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	
Colour (HU)	5	5	5	5		15	
Odour	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	
Temperature ^{0}c	27.7	31	29.4	29.2	22.7	Ambient	
pH	5	5.8	3.93	3.7	3.82	6.5-8.5	6.5-8.5
Turbidity (NTU)	1.03	20.1	0.5	0	1.17	5`	
Iron (Fe^{3+})mg/l	0.07	0.08	BD	0.16	0.25	0.3	0.3
Salinity %	0.9	1.3	0	0.1	0.1	0.5	
Electrical Conductivity µs/cm	1813	2059	40	131.4	231	1000	1000
Total Dissolved Solid mg/l	857	1242	16.4	79.3	110.1	500	1000
Residual Chlorine (d_2) mg/l	----	-------	--------	-------	--------	0.2-0.25	
Manganese mg/l	0.08	0.08	0.035	0	BD	-	0.4
Nitrates (No_3) mg/l	0.027	0.336	0.06	-0.02(BD)	0.4	50	50
Nitrite (No_2) mg/l	0.018	0.018	0.006	0.001	0.013	0.2	3
Ammonia(NH_3) mg/l	0.07	0.04	0	0	0	0	0.2
Phosphate (po_1^3) mg/l	0.033	0.001	0.025	0.043	0.006	3.5	
Suspended Solid mg/l	0.4	2.4	8	15	BD	10	
Total silica (SiO_2) mg/l	--------	---------	0.029	0.002	0.035	17	
Sulphate (SO_4) mg/l	11.2	11.2	5	3	5	1000	500
Total Hardness mg/l	72	34	36	46	32	500	
Calcium Hardness (Ca^2) mg/l	70	82	14	20	30	75	
Magnesium Hardness mg/l	2	BD	BD	BD	BD	0.2	
Acidity mg/l	0.8	0.48	0.04	0.64	0.08	4.5-8.2	
Total Alkalinity mg/l	13.2	15.6	4.8	4.88	24	100-200	
Chloride (Cl^-) mg/l	0.83	0.78	0.6	0.1	0	250	
Methyl Alkalinity mg/l	13.2	15.6	4.8		2.4	100-200	
Aluminum ($A1^{3+}$) mg/l	---------	---------	0.01	0.04	0	0.2	0.1-0.2
Selenium (Se) mg/l	-----------	----------	0.101	0.04	0	-	0.01
Chromium (Cr)	0.002	0	0	0.01	0.01	0.05	0.05
Cadmium (Cd^{+2}) mg/l	0	0	1	1	0.004	0.003	0.003
Copper (Cu)mg/l	0.813	0.824	0.17	0.12	0.17	1	2.0
Cyanide (CN) mg/l	------	-------	0.005	0	0.006	0.01	0.17
Lead (Pb^{+2}) mg/l	0.0007	0.0007	0.6	0	0.003	0.01	0.01
Arsenic (As) mg/l	------	-----	0.03			0.01	0.01
Barium (Ba^{+2}) mg/l	------	-----	7	7	BD	0.7	0.7
Dissolved Oxygen (0_2) mg/l	0.77	0.78	43.4	10.8	1.2	1.0-5.0	

Key symbols: DS = Water sample from boreholes proximal to Dump Site; BD= Below Detection Limit



a) Uyo area (contour interval ~2m)



b) Oron area (contour interval ~ 0.8m)

Figure 9- A distribution map showing elevation across a) Uyo and b) Oron areas.

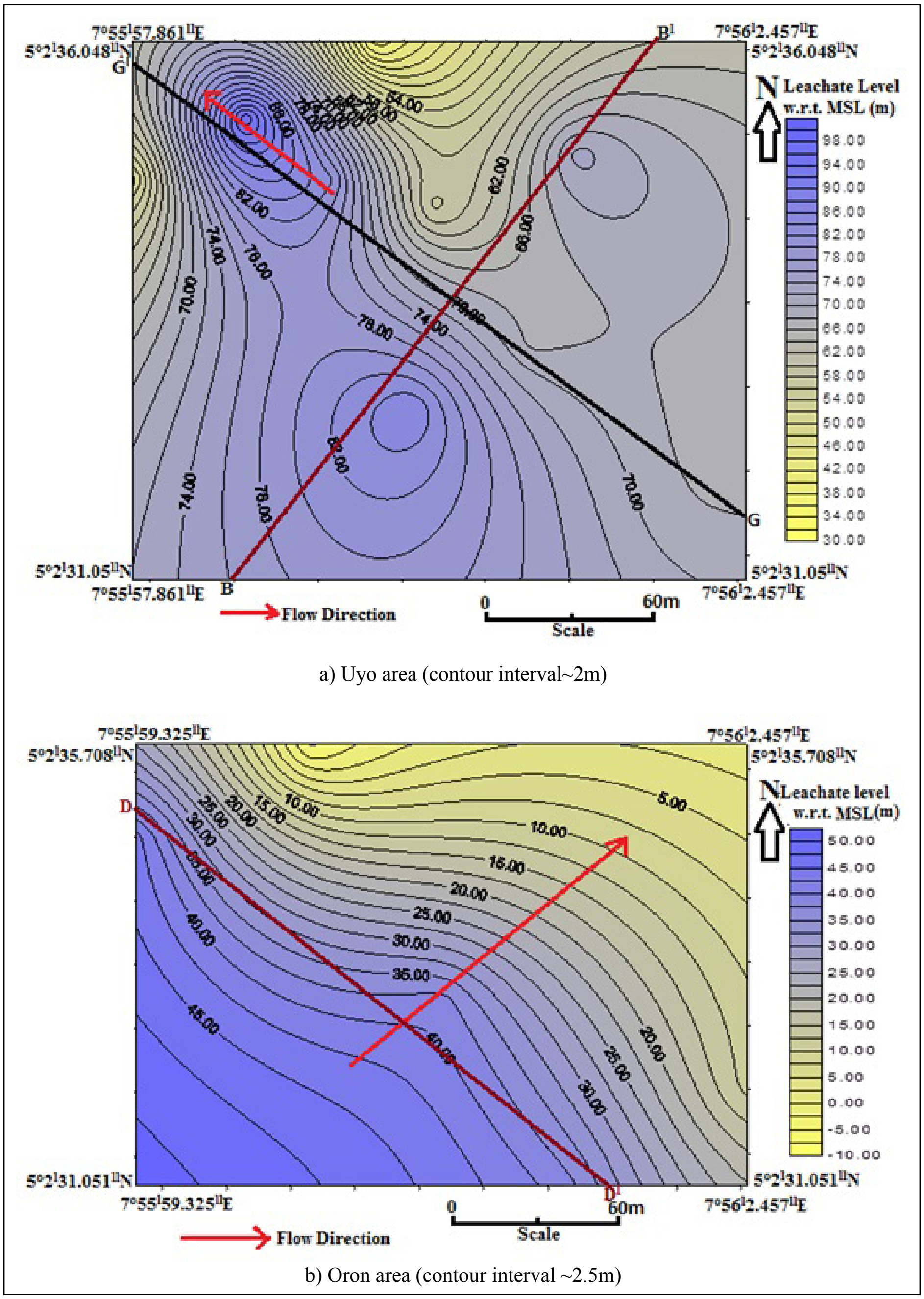


Figure 10- A distribution map showing leachate level across a) Uyo and b) Oron areas.

hydro chemical analysis, some of the indicator parameters at Uyo are very low and may not indicate much contamination from the dumpsite.

Furthermore, at Oron, profiles running from C-C^{l} at figure 9b and D-D^{l} at figure 10b were also superimposed in order to estimate the groundwater risk factor (Figure 12b) obtainable in this area. We can infer from figure 12b that there is close match between leachate level and topography, which implies that the topography controls the configuration of the leachate level. More so, figure 12b shows an intersecting pattern such that the static water level crisscrosses the leachate level surface at 35 m. This implies that the sink of the leachate level is beyond the groundwater level which

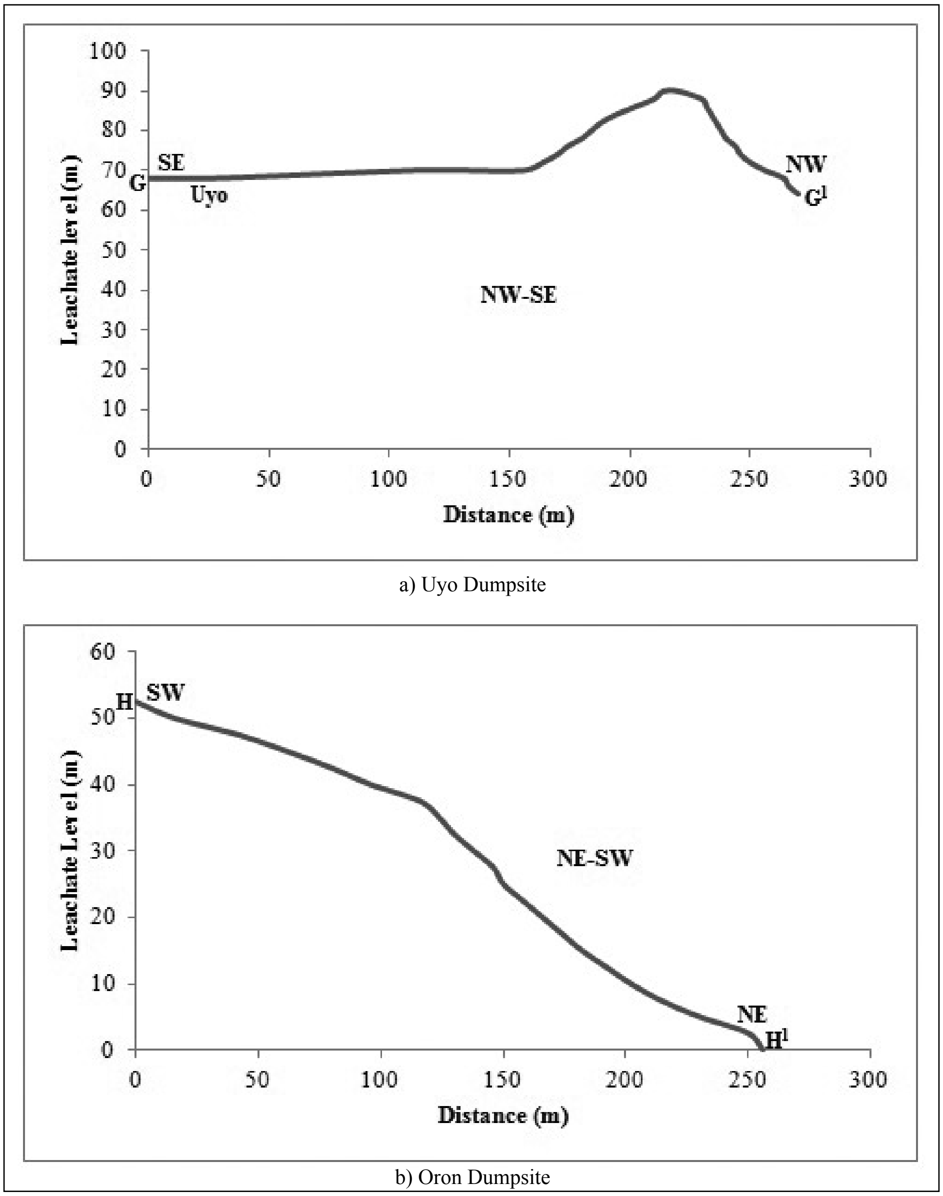


Figure 11- Cross- section showing the direction of leachate flow within across a) Uyo and b) Oron areas.

has contaminated the groundwater at in-situ already, as such; it is very risky for the users in this area. Also, some of the indicator parameters of hydrochemical analysis at Oron are considerably elevated and may indicate to a great extent contamination of groundwater quality within the dumpsite region in addition to it makes the groundwater unfit for the dwellers.

4. Conclusions

The computed results and models showed the capabilities of resistivity and hydrochemical methods in determining impact of solid waste on groundwater quality. The leachate from the Uyo dumpsite has insignificant effect on the groundwater quality compared to the Oron dumpsite, which really

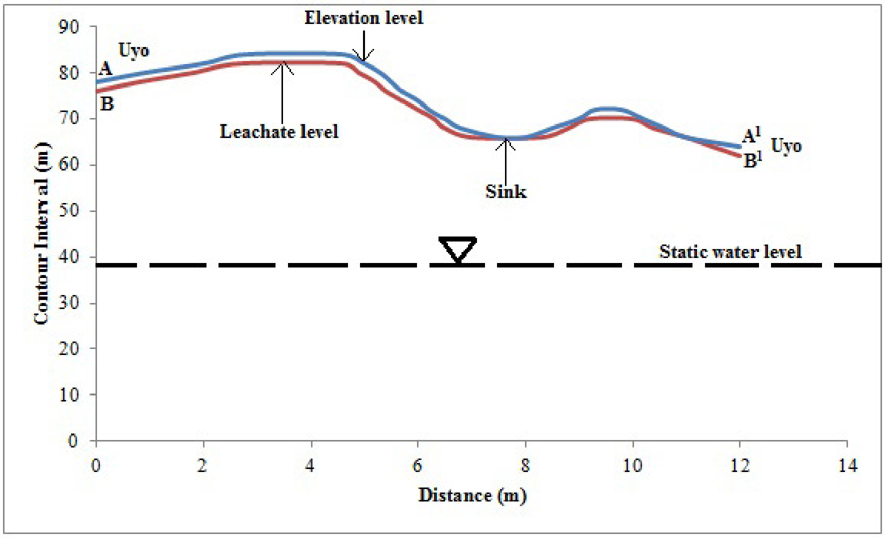


Figure 12- a) Risk model of leachate level within Uyo Dumpsite.

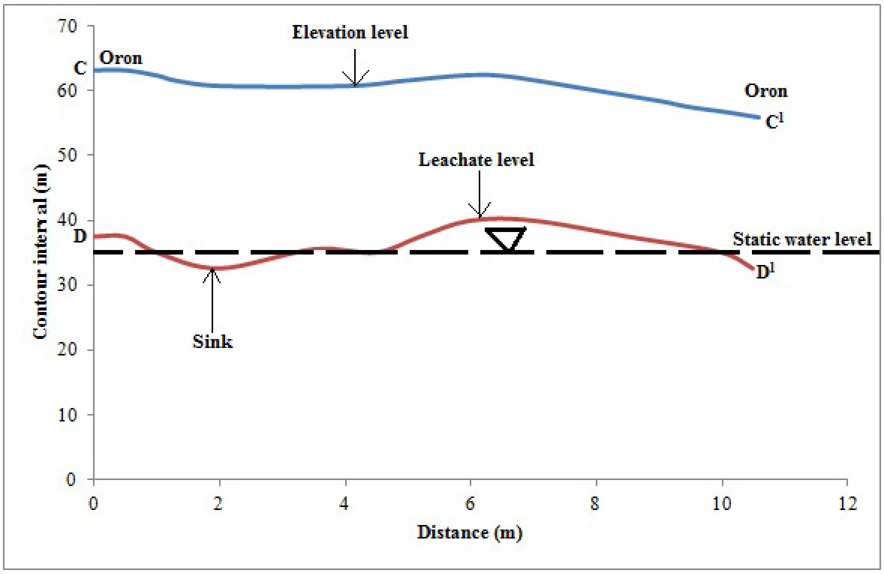


Figure 12- b) Risk model of leachate level within Oron Dumpsite.

contaminated the groundwater quality thereby making the groundwater unfit for the dwellers. The Ikot Ekpene dumpsite on the other hand is yet to affect the groundwater quality.

Acknowledgements

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