SURVEY OF GROUNDWATER CONTAMINATION LEVEL IN SELECTED DUMPSITES IN KADUNA, NORTHWEST NIGERIA, USING RESISTIVITY AND SEISMIC TOMOGRAPHY METHODS

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ABSTRACT

Survey of groundwater contamination level in selected dump sites of Kaduna, Nigeria have been evaluated using integration of resistivity and seismic tomography methods. Schlumberger array was used to acquire one hundred and forty-four VES stations and were interpreted using software – Win Resist. Two hundred and ninety four seismic stations were shot along fifteen profiles with geophone separation of 3m and an offset distance of 1.5m along each profile. A 24 channel ABEM seismograph was used in recording the data and was interpreted using ReflexW software. The VES results obtained reveal that the thickness and resistivity values for various layers are given as; top soil (0.6 to 3.2 m and 13.6 to 128.4 Ω-m), weathered layer (2.3 to 54.9 Ω-m and 15.5 to 554.0 Ω-m), fractured basement (5.7 to 27.4 m and 8.0 to 447.0 Ω-m), and fresh basement (165.5 to 2328.1 Ω-m). The seismic tomography results reveal layer velocity ranges: 250 to 1200 m/s topsoil, 900 to 2600 m/s weathered layer, and 1400 to 1800 m/s fractured basement. The rate of leachate contamination at the area is calculated to be 0.5 m per year, while the depth of contaminations ranges from 6.7 to 15.9 m in the area. The study suggests that Millennium dumpsites truly contaminated the groundwater sources, unlike the NDA dumpsites which is minimal.

Keywords: Leachate, Seismograph, Basement Complex, Schlumberger array, and Geophone.

INTRODUCTION

Groundwater forms a great significant part of the water resources all over the world particularly in the arid regions such as the study area. Many human habitats and industries dwell so much on this subsurface water due to the fact that, it is of high quality and required little or no treatment before use. According to Sampat (2001), bacteria, fungi and other biological pollutants are naturally filtered and diluted as the water penetrate or percolates through the soil. Another reason why ground water is used for domestic and industrial use is that the provision of potable water via the water supply scheme is grossly inadequate for the needs of the people. But as a result of careless management and/or disposal of hazardous materials, fresh groundwater supplies would be greatly decreased within the study area. Presently, the problem of environmental contaminations is one of the concerns of earth scientists and other related researchers around the world. Solid waste landfills constitute integral part of the soil hydrological system (Rosqvist *et al.,* 2003), therefore, pose a serious threat of polluting both groundwater and downstream surface water. There is therefore the need to understand and quantify the hydraulic behavior of landfills.

According to Brown and Donnelly (2005), there are numerous toxic chemicals from well waters in the United States of America as a result of municipal solid waste leachate accumulation which have lots of health hazards such as cancer, birth defects, genetic effects, nervous systems effects, Kidney/Liver effects, circulatory system effects, central nervous system effects and skeletal damage. Most people are ignorant of these health hazards because of the general belief that household materials are relatively safe and would not adversely affect groundwater and public health. The long established method for solid waste disposal that demands a minimum of effort and expense in Nigeria has been the open dumpsites. Drawbacks to such facilities are fairly obvious, especially to those having the misfortune to live near the dumpsites. Apart from polluting the groundwater, open dumps are unsightly, unsanitary, and stinking. Kaduna Municipal as a result of growth and urbanization is not an exception to environmental problem because there are about 342 solid waste sites in Kaduna Metropolis (Ministry of

Environment and Natural Resources, Kaduna State, 2015). The entire 342 waste disposal sites are open dump type, which invariably creates serious threats to local environmental quality and public health.

Consequently, Kaduna metropolis will face critical problem pertaining to its groundwater resources with the coming years if this problem of waste disposal sites which indiscriminately litters the city is not adequately addressed. One of the most frequent demands in metropolitan areas includes detecting the location and extent of contamination patches in areas occupied by dumpsites. In such context, the use of resistivity and seismic refraction tomography provides an important tool in the evaluation and characterization of contaminants generated by urban residues. The resistivity and seismic refraction tomography methods have been found very suitable for such kind of environmental studies. This is due to the fact that generally, ionic concentration of leachate is much higher than that of groundwater and so when the leachate enters the aquifer, it results in a large contrast in electrical properties and the methods will identify these zones as an anomaly which enables the leachate plume to be detected. The use of resistivity and seismic refractions methods applied to landfills studies are well documented (Karlik *et al.,* 2000; Benson *et al.,* 1997; Zhang and Toksoz, 1998; Mukhtar *et al.,* 2000, Fatta *et al.,* 2000; Buselli *et al.*, 1992; Dahlin, 2000; Porsani *et al.,* 2004; Osazuwa and Abdullahi, 2008; Jegede *et al.*, 2011; Udoh *et al.*, 2020). Their results also show the applications and limitations of the geophysical methods in environmental problems associated with ground water contamination due to leachate movement.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area which covers two uncontrolled open waste disposal sites at Millennium City and Nigerian Defense Academic (NDA) is situated within the Kaduna metropolis. The NDA dumpsite is located within latitude 10^o 35^l N and 07^o 19′ E with elevation of 648 meter while the Millennium City dumpsite is located within latitude 10^o 31′ N and 07^o 30′ E with elevation of 619 meter. The total area covered for the study is 120000 square meters in NDA area precisely at northeastern part of Kaduna metropolis and 250000 square meters in Millennium City dumpsite precisely at the northwestern part of Kaduna metropolis (Fig. 1). The dumpsites consist of heterogeneous refuse like household refuse, building rubble and/or industrial refuse.

The survey area lies within the Basement Complex of Northern Nigeria (Fig. 2). The rocks consist of undifferentiated basement complex rocks mainly granites, gneisses, migmatite, quartzite and amphibolites that have been grouped by the British authors as 'Basement Complex' of the Precambrian age. According to McCurry (1976), the whole Basement has been through at least two tectonic – metamorphic cycles and consequent metamorphism, magnetization and granitization have extensively modified the original rocks so that they generally occur as relict rafts and xenoliths in migmatite and granites. Two main groups of granites are present and these are the younger granites and the older granites. The older granites are widespread and often given rise to smoothly domed hills which typically rise to about 170m above the surrounding plains (Russ, 1957). The younger granites which include granites, syenites and rhyolites cover extensive areas in the Plateau province but there are also smaller masses in Kaduna South, Kano, Bauchi and Zaria provinces and some other isolated masses in the Borno province (Russ, 1957).

METHODOLOGY

In this study the data collected were basically from main measuring mode of the Terrameter SAS 4000 (Resistivity). The profiling data were collected using Schlumberger configuration of vertical electrical sounding (VES). Care was taken to ensure that the electrode layout follow a straight line along the N-S profile layout. Similarly, the maximum half current electrode separation of 100 meters and potential electrode separation of 15m were used during VES data acquisition. The Fig. 3 shows the profile layout for VES data collection in both NDA and millennium city, while Plate 1a shows the VES fieldwork within the study area. A total of one hundred and forty-four (144) VES points were sounded in both dumpsites and control site. The apparent resistivity values acquired from the measurement were plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivity, thicknesses and depths of various layers penetrated using Win-resist software. The apparent resistivity outputs generated were used to produce iso-resistivity. In this particular section, contour maps of all the VES points on the dump and control sites were produced. The main purpose of these maps was to correlate the two maps and observe the variation in conductivity of the earth material at various depths in order to delineate the extent of contamination at particular level. Some researchers have written on the need and uses of Schlumberger array in groundwater investigation (Zohdy and Jackson, 1969; Udensi and Salako, 2005; Mohammed *et al.*, 2007; Anakwuba *et al.*, 2012; Anakwuba *et al.*, 2014; Obiabunmo *et al.*,2014; Chinwuko *et al.*, 2015; Osele *et al.,* 2016; Chinwuko *et al.*, 2016, Amadi *et al.*, 2017, Shaibu *et al.*, 2018; Udoh *et al.*, 2020, and others).

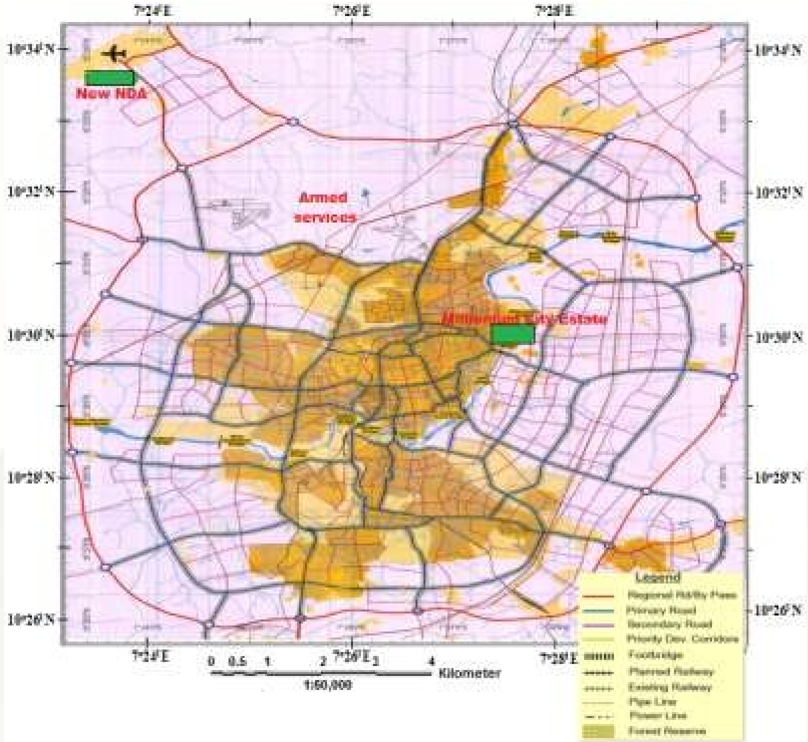


Figure 1: Map of Kaduna showing the accessibility of the study areas (Ministry of Environment and Natural Resources, 2006)

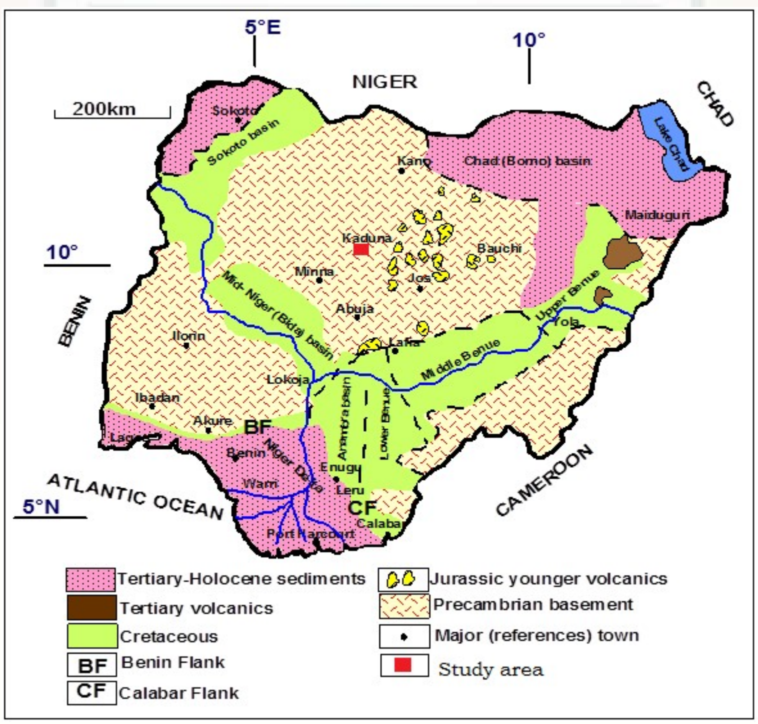


Figure 2: Geological map of Nigeria showing the study area (NGSA, 2006)

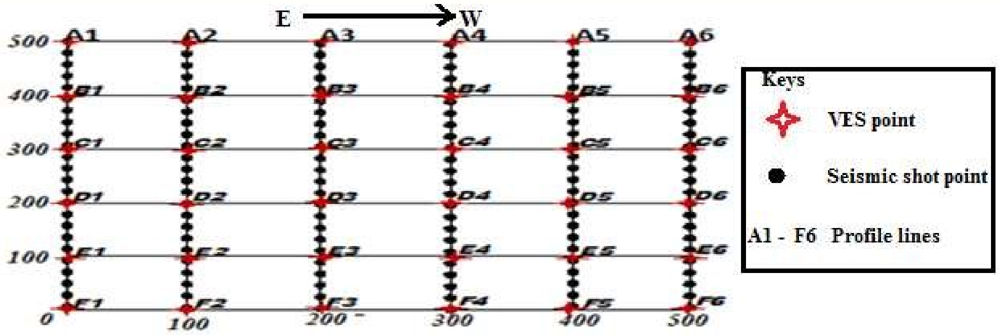


Figure 3: A part of the Profile layout for VES and seismic Data Collection the study area

Figure 4: Data acquisition within the study area: (a) VES layout; (b) Seismic Refraction Tomography layout

In addition, the refraction tomography profiling adopted for this research work was seismic refraction shooting along the profiles, A, B, C, D, E, and F (Fig. 3), with the 24-geophones equipment kept at 3 m interval along each profile line during the survey (Fig. 5). The geophones were connected to the recording instrument called seismograph, which was placed between the 12th (34.50m) and 13th (106.50m) geophones respectively that is the mid-point of the layout. Then, the amplifiers, filters and gains were accurately set. Also, the source was placed at 1.5 meter offset away from the first geophone and then, the first shot was made on the seismograph. Thus, the shots were made between the 6th and 7th geophone, 12th and 13th geophone, 18th and 19th geophone along with 1.5m offset away from 24th geophone. Then the resulting signals were recorded and stored on the Seismograph (Fig. 6). Hence, a total of 360 shot points for the dumpsites and 200 shot points for control sites were made. In addition, the seismic sources and receivers are arranged in such a way that multiple seismic rays pass through each element of the arrangement, thereby obtaining the total travel-time for each ray which was the basic data needed for interpretation. The refraction tomography interpretation and full refraction modeling were done using an inversion software package called ReflexW. Finally, the tomograms generated through the inversions were transformed into velocity models.

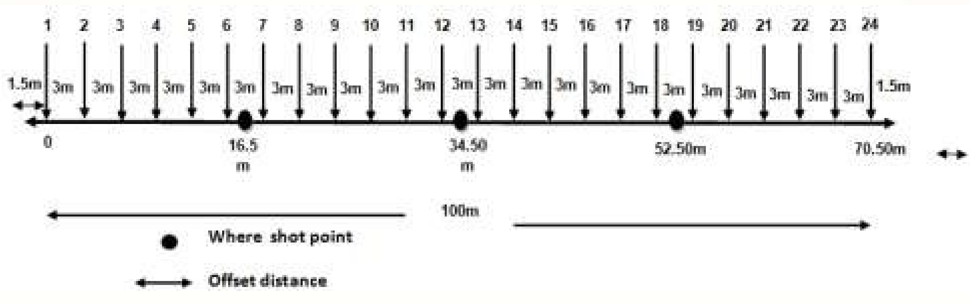


Figure 5: Geophones arrangement during seismic data acquisition

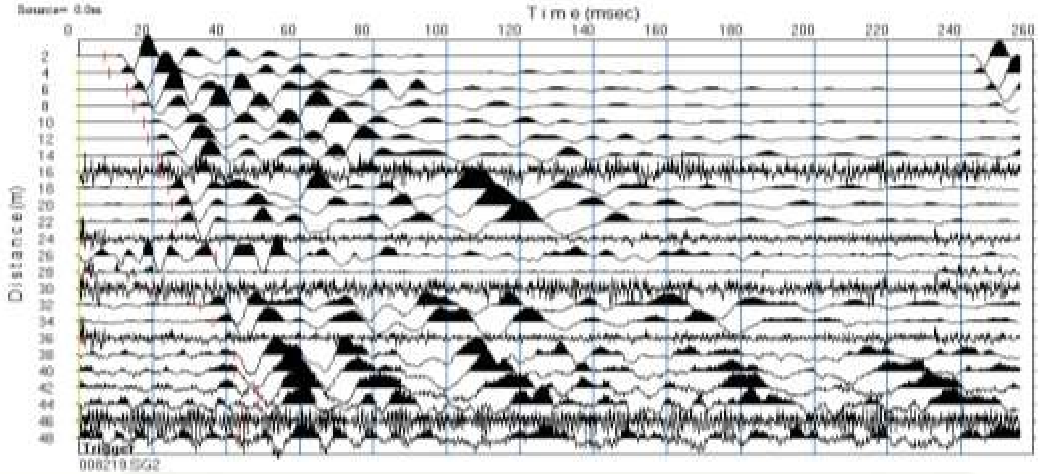


Figure 6: Representative of the seismic arrival signal in a wiggle form and picking of the first arrival

RESULT AND DISCUSSION

VES Curve Interpretation

The results of the qualitative interpretation across the entire one hundred and forty four sounding points reveal that the curve types within the dumpsites and control sites of NDA and Millennium City consist of three distinct layers namely; A, H and KH curve-types (Fig. 7 and Table 1). The predominant curve type within the area is H-curve type with about 52.1% while the remaining 47.9% belongs to KH and A-curve types. Actually, the control sites possess 100% of H-curve type while the dumpsites have three aforementioned curve types across the area.

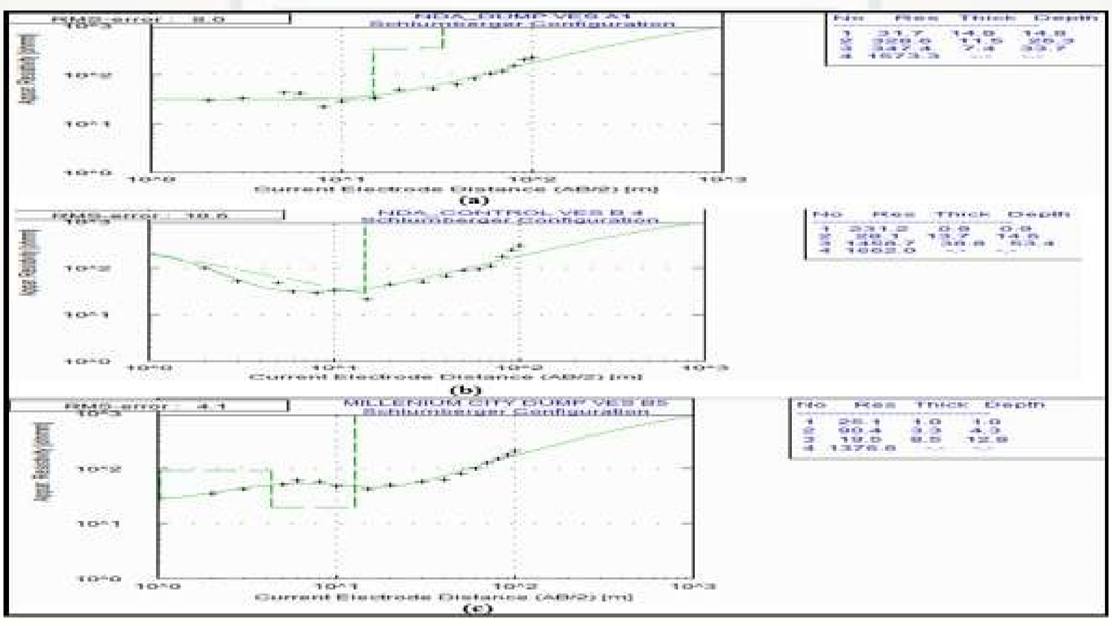


Figure 7: Geoelectric Curves across the study area: (a) NDA Dumpsite, (b) NDA control site (c) Millennium City Dumpsite

Table 1: Curve types within the study area

Curve Type	No of Curve type	% of Curve Type
A	12	8.3
H	75	52.1
KH	57	39.6
Total	144	100

Geoelectric Layer
First Layer
The resistivity values of the first layers across the NDA areas range from 17.2 Ohm-m at VES D_4 to 47.1 Ohm-m at VES F_3 with the thickness range between 0.7m at VES A_3 and A_5 to 17.6m at VES B_1 (Table 2a). The maximum thickness is around VES B_1 whereas the minimum thickness is at VES A_3 and A_5. In Millennium City areas, the resistivity values of the first layers range from 26.6 Ohm-m at VES A_{19} to 57.8 Ohm-m at VES A_{23} with the thickness range between 0.6m at A_{19}, B_{22} and C_{19} to 15.6m at A_{20} and C_{23} (Table 2b). The maximum thickness is around A_{20} and C_{23} while the minimum thickness is at A_{19}, B_{22} and C_{19}. However, the resistivity values of the first layers across the NDA control sites range from 124.0 Ohm-m at VES E_{12} to 244.7 Ohm-m at VES A_{11} with the thickness range between 0.7m at VES F_{10} to 1.4m at VES D_{11} (Table 2c). The maximum thickness is around VES D_{11} whereas the minimum thickness is at VES F_{10}. Although, in Millennium City control sites, the resistivity values of the first layers range from 106.8 Ohm-m at VES A_{22} to 208.5 Ohm-m at VES D_{22} with the thickness range between 0.8m at A_{20} and E_{20} to 2.2m at A_{23} (Table 2d). The maximum thickness is around A_{23} while the minimum thickness is at A_{20} and E_{20}. The first layers are designated as the lateritic topsoil.

Second Layer
The resistivity values of the second layers across the NDA areas range from 13.5 Ohm-m at VES A_5 to 1359.8 Ohm-m at VES C_4, with the corresponding thickness range between 4.5m at VES A_5 to 23.9m at VES C_4 (Table 2a). The thickest VES point is at C_4 and the thinnest is at A_5. But, the resistivity values of the second layers across the Millennium City range from 11.0 Ohm-m at VES E_{17} to 1659.2 Ohm-m at VES B_{15}, with the corresponding thickness range between 3.9m at VES E_{17} to 31.6m at VES A_{14}, B_{15}, and C_{15} (Table 2b). The thickest VES point is at A_{14}, B_{15}, and C_{15} and the thinnest is at E_{17}. Nevertheless, the resistivity values of the second layers across the NDA control sites range from 23.3 Ohm-m at VES B_{11} to 48.0 Ohm-m at VES A_1, with the corresponding thickness range between 9.1m at VES C_{21} to 26.6m at VES D_{22} (Table 2c). The thickest VES point is at D_{22} and the thinnest is at C_{21}. But, the resistivity values of the second layers across the Millennium control sites range from 20.0 Ohm-m at VES A_{24} to 250.9 Ohm-m at VES F_{20}, with the corresponding thickness range between 5.1m at VES D_{22} to 16.5m at VES A_{21} (Table 2d). The thickest VES point is at A_{21} and the thinnest is at D_{22}. The second layers are designated as the weathered basement. This interpretation aligned with that obtained by Ijila *et al.* (2018), where they characterized the basement rocks and delineates groundwater potential zones in a basement complex terrain of Adeyemi College of Education, Ondo, Southwestern Nigeria using vertical electrical sounding. They delineated that the weathered layer within the region range between 128 - 750 Ωm. Also, Aliyu et al. (2014) stated that the weathered basement possessed resistivity range of 100-978Ωm within Zainawa Village, Kano State, Nigeria.

Third Layer
At the NDA dumpsites, the third layers have resistivity values ranging from 266.8 Ohm-m at VES A_2 to 3732.7 Ohm-m at VES A_3 with thickness range from 7.2m at VES E_6 to 19.0m at VES B_6 across the area (Table 2a). The maximum thickness is around VES B_6 and the minimum thickness is at VES E_6. At the Millennium dumpsites, the third layers have resistivity values ranging from 243.3 Ohm-m at VES C_{14} to 2622.5 Ohm-m at VES B_{16} with the thickness range from 7.6m at VES C_{17} to 28.2m at VES C_{18} across the area (Table 2b). The maximum thickness is around C_{18} and the minimum thickness is at C_{17}. Subsequently, at the NDA control site, the third layers have resistivity values ranging from 119.4 Ohm-m at VES A_8 to 1566.3 Ohm-m at VES A_1 with the thickness range from 8.1m at VES A_{21} to 33.7m at VES D_{24} across the area (Table 2c). The maximum thickness is around VES D_{24} and the minimum thickness is at VES A_{21}. At the Millennium control sites, the third layers have resistivity values ranging from 111.4 Ohm-m at VES D_{22} to 1095.9 Ohm-m at VES A_{22} with the thickness range from 7.9m at VES E_{19} to 35.1m at VES C_{19} across the area (Table 2d). The maximum thickness is around C_{19} and the minimum thickness is at E_{19}. The third layers are designated as the fractured basement.

Forth Layer
At the NDA dumpsites, the fourth layers have resistivity values 1300.9 ohm-m at VES B_6 to 2105.3 ohm-m at VES C_3 (Table 2a), while, at the Millennium dumpsites, the fourth layers have resistivity values range from 1044.3 Ohm-m at VES D_{16} to 2335.0 ohm-m at VES B_{15} (Table 2b). The thicknesses of the layers were not reached (Table 2b). Consequently, at the NDA control sites, the fourth layers have resistivity values 1031.2 ohm-m at VES F_{11} to 3240.9 ohm-m at A_9 (Table 2c), whereas, at the Millennium control sites, the fourth layers have resistivity values range from 1031.2 Ohm-m

at VES F_{23} to 3240.9 ohm-m at VES A_3. The forth layers are designated as the fresh basement.

***Iso-Resistivity Map*:** The Iso-resistivity contour maps at 5 m depth for both dump and control sites at NDA and Millennium City are contoured at an interval of 2Ωm respectively (Fig. 8). The contour lines trend toward northeast to southwest directions in both dump and control sites of the two areas (Fig. 8). The maps are produced in order to observe the extent of contamination in this area by correlating the two maps and compared them. At NDA area, the resistivity values of the dump site (Fig. 8a) ranges from 15Ωm to 33Ωm which is extremely very low when compared with the resistivity values of the control site (Fig. 8c) which ranges from 168Ωm to 212Ωm, whereas, at Millennium City area, the resistivity values of the dump site (Fig. 8b) ranges from 26Ωm to 38Ωm which is extremely very low when compared with the resistivity values of the control site (Fig. 8d) which ranges from 168Ωm to 210Ωm. This shows that the dump sites are very conductive at 5 m depth and the conduction is due to the presence of leachate plume contaminant at this depth. Fig. 8 also shows that the regions covered with yellowish to reddish colour are associated with high resistivity compared to the dark bluish regions that have low resistivity across the study area.

Table 2a: Summarized VES interpretation in the NDA Dumpsite

Apparent Resistivity (Ohm-m)					
Layer	Inferred lithology	Minimum	VES Point	Maximum	VES Point
1	Top soil	17.2 Ohm-m	D4	47.1 Ohm-m	F3
2	Weathered basement	13.5 Ohm-m	A5	1359.8 Ohm-m	C4
3	Fractured basement	266.8 Ohm-m	A2	3732.7 Ohm-m	A3
4	Fresh basement	1300.9 ohm-m	B6	2105.3 ohm-m	C3
		Thickness (m)			
1	Top soil	0.7m	A3 and A5	17.6m	B1
2	Weathered basement	4.5m	A5	23.9m	C4
3	Fractured basement	7.2m	E6	19.0m	B6
4	Fresh basement				

Table 2b: Summarized VES interpretation in the Millennium City Dumpsite

Apparent Resistivity (Ohm-m)					
Layer	Inferred lithology	Minimum	VES Point	Maximum	VES Point
1	Top soil	26.6 Ohm-m	A19	57.8 Ohm-m	A23
2	Weathered basement	11.0 Ohm-m	E17	1659.2 Ohm-m	B15
3	Fractured basement	243.3 Ohm-m	C14	2622.5 Ohm-m	B16
4	Fresh basement	1044.3 Ohm-m	D16	2335.0 ohm-m	B15
Thickness (m)					
1	Top soil	0.6m	A19, B22 and C19	15.6m	A20 and C23
2	Weathered basement	3.9m	E17	31.6m	A14, B15, and C15
3	Fractured basement	7.6m	C17	28.2m	C18
4	Fresh basement				

Table 2c: Summarized VES interpretation in the NDA Control Site

Apparent Resistivity (Ohm-m)					
Layer	Inferred lithology	Minimum	VES Point	Maximum	VES Point
1	Top soil	124.0 Ohm-m	E12	244.7 Ohm-m	A11
2	Weathered basement	23.3 Ohm-m	B11	48.0 Ohm-m	A1
3	Fractured basement	119.4 Ohm-m	A8	1566.3 Ohm-m	A1
4	Fresh basement	1031.2 ohm-m	F11	3240.9 ohm-m	A9
		Thickness (m)			
1	Top soil	0.7m	F10	1.4m	D11
2	Weathered basement	9.1m	C21	26.6m	D22
3	Fractured basement	8.1m	A21	33.7m	D24
4	Fresh basement				

Table 2d: Summarized VES interpretation in the Millennium City Control Site

Apparent Resistivity (Ohm-m)					
Layer	Inferred lithology	Minimum	VES Point	Maximum	VES Point
1	Top soil	106.8 Ohm-m	A22	208.5 Ohm-m	D22
2	Weathered basement	20.0 Ohm-m	A24	250.9 Ohm-m	F20
3	Fractured basement	111.4 Ohm-m	D22	1095.9 Ohm-m	A22
4	Fresh basement	1031.2 Ohm-m	F23	3240.9 ohm-m	A3
Thickness (m)					
1	Top soil	0.8m	A20 and E20	2.2m	A23
2	Weathered basement	5.1m	D22	16.5m	A21
3	Fractured basement	7.9m	E19	35.1m	C19
4	Fresh basement				

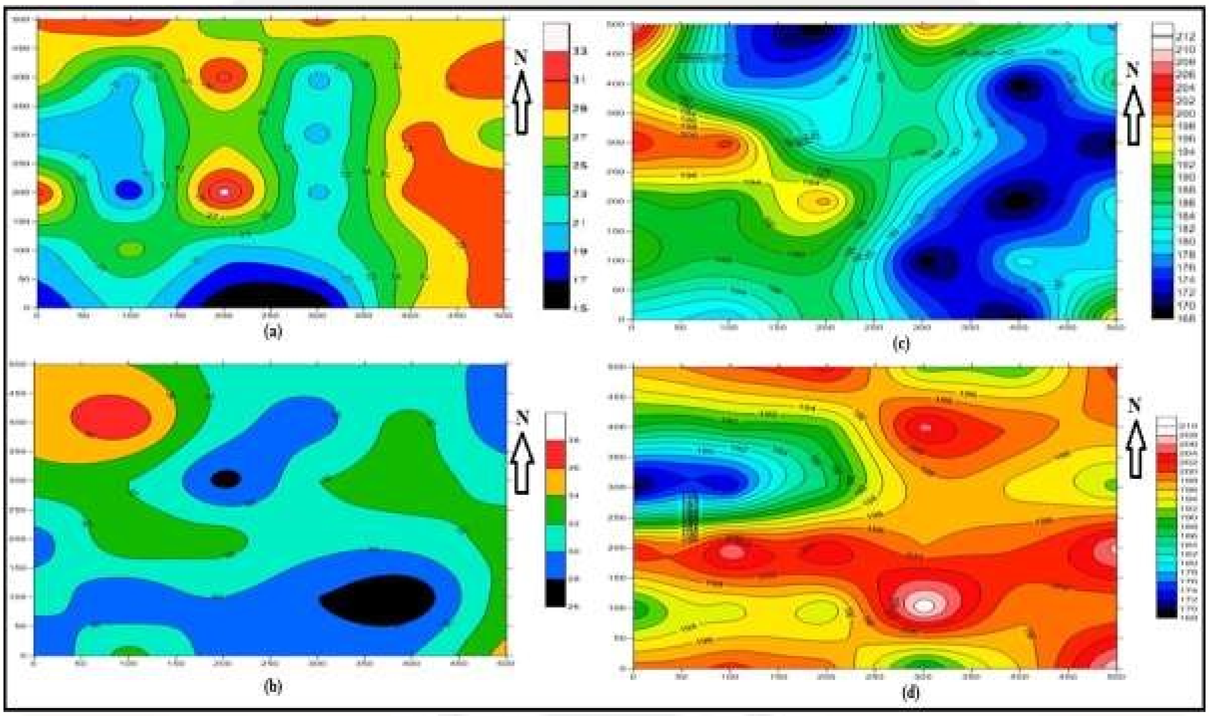


Figure 8: Iso-resistivity at 5 m across the study area (Contour interval~ 2Ωm) (a) NDA dump site, (b) Millennium City dump Site, (c) NDA control Site, (d) Millennium City control site]

In addition, considering the Iso-resistivity contour maps generated at depth of 10 m, 11 m, 12 m, 13 m and 15m for both dump and control sites at NDA and Millennium City, the results show that the dump sites are still very conductive at these depths. This can be attributed to the present of leachate plume contaminant around most portions of the map due to leachate vertical and lateral migration at these depths of the area. The contour lines trend mostly in the northeast and southwest direction on the dump sites, while at the control sites, the contour lines trend toward the northwest and central parts throughout the area. The resistivity values of the dump sites ranges from 18Ωm to 88Ωm while the resistivity values of the control site ranges from 20Ωm to 174Ωm. This implies that the dump sites are more conductive than the control sites such that the area is affected by the leachate contamination. The very low resistivity values on the dump sites have been very consistent within the range of an aquifer potential zone, but differ from the resistivity obtained on the control sites.

Interpretation of Velocity Model

The velocity models generated across the dump sites from the seismic refraction tomography results portray that there are general increase in velocities with respect to depths across the study area (Table 3 and Fig. 9). The interpretations of the models are based on the velocity values attached to the coloured scale bar placed by the right hand side of the models. Considering the tomography models produced across the dump sites, the following attributes are obtained; at NDA area, the overburden layers possess velocity range of 200 to 1000 m/s with depth range of 0.6 to 14.8 m and thickness range of 0.6 m to 14.8 m (Fig. 9a and Table 3a), whereas at Millennium City, the velocity range of 200 to 1400 m/s with depth range of 0.6 to 15.6 m and thickness of 0.6 to 15.6 m (Fig. 9b and Table 3b). More so, the delineated weathered basement at NDA area have velocity range of 1000 m/s to 2000 m/s and average depth of 2.9 m to 26.3 m with average thickness of 2.2 m to 15.7 m, while at Millennium City, the weathered basement have velocity range of 1200 m/s to 2800 m/s and average depth of 2.9 m to 19.3 m with average thickness of 2.1 m to 15.7 m. These zones are delineated as the leachate plume contaminations. In addition, the fresh basement layers at NDA area have velocity range from 2000 m/s to 2400 m/s above with average depth of 8.9 to 25.6 m above, with average thickness of 18.5 m to 21.3 m above, whereas at Millennium City, the velocity range from 2000 m/s to 3000 m/s above with average depth of 8.9 to 36.7 m above, with average thickness of 6.0 m to 21.3 m above.

In the same way, the tomography models produced across the control sites reveal that at NDA area, the overburden layers possess velocity range of 250 to 1400 m/s with depth range of 0.8 to 1.4 m and thickness range of 0.8 to 1.4m (Fig. 9c and Table 3c), whereas at Millennium City, the overburden layers possess velocity range of 250 to 1600 m/s with depth range of 0.8 to 1.7 m and thickness range of 0.8 to 1.7 m (Fig. 9d and Table 3d). The contact area between overburden and the basement showed very much undulation. Also, the delineated weathered basement at NDA area have velocity range of 1000 to 2900 m/s with depth range of 9.9 to 16.5 m with average thickness of 9.1 to 15.5 m, while at Millennium City, the weathered basement have velocity range of 1100 to 3000 m/s with depth range of 8.0 to 17. 3 m and thickness range of 6.3 to 16.0 m. These zones are delineated as the leachate plume contaminations. Likewise, the fresh basement at NDA area have velocity range from 1500 to 3300 m/s with depth range of 22.8 to 24.6m and thickness range of 8.3 to 12.1m, whereas at Millennium City, the fresh basement have velocity range from 2400 to 3700m/s with average depth of 19.6 to 25.5 m and thickness range of 8.1 m to 16.6 m above. This result implies that seismic data point C_{19} have the thickest weathered basement at about 35.1 m while D_{20} possesses the minimum thickness which is about 6.3 m.

More so, these velocities obtained indicate presence of loose material around these zones. The contact area between the overburden and the basement showed a much remarkable level of undulation within the subsurface, and slope down from the end of the profile toward the center of the profile. These zones are situated within the aquifer potential areas. These are in agreement with VES analysis obtained across the area, for instance, at NDA dump site the VES points have average depth to aquifer as 20 meters whereas at Millennium City dump site, the average depth to aquifer is 22 meters. These values obtained are in good agreement with suggestions of Adegbola *et al.* (2016), where the researchers established the multichannel analysis of the surface waves of earth materials in some parts of Lagos State, Nigeria with velocity range from less than 200m/s to greater than 420 for sediments. More so, the velocity obtained within the weathered and fractured basements are in agreement with Barrett and Froggatt (1978), the scholars established that the seismic velocities of some rocks like the basements from Victoria Land, Antarctica have 2200 to 4600m/s. Generally, the regions covered by the bluish colour within the velocity models possessed high velocity values compares to the low velocity regions with the reddish colour (Figure 9).

Table 3a: The summary of velocity Model Parameter in NDA (Dump site)

NDA Dumpsite	Velocity Range (m/s)			Average Depths (m)		
	V1	V2	V3	D1	D2	D3
A	1000	2000	2200	0.7	7.7	23
B	900	1400	2400	1.2	16.4	37.5
C	900	1400	2500	0.7	19.3	22.3
D	800	1200	200	14.7	21.4	25.6
Average	900	1500	1825	4.325	16.2	27.1

Table 3b: The summary of Velocity Model Parameter in Millennium City (Dump)

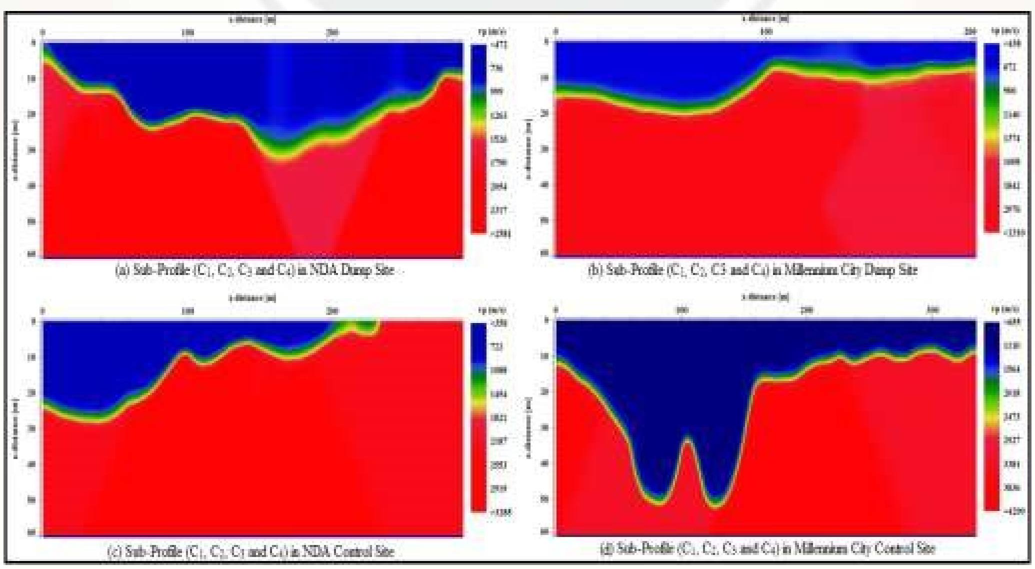
Millennium City Dumpsite	Velocity Range (m/s)			Average Depths (m)		
	V1	V2	V3	D1	D2	D3
A	1200	2000	2500	15.6	17.4	30.3
B	1400	2000	2400	2.3	16.4	36.7
C	900	1600	2000	0.7	19.3	8.9
D	1100	1600	2500	1.2	16.4	9.6
E	1200	2800	3000	1.2	18.3	9.9
Average	1160	2000	2480	4.2	17.56	19.08

Table 3c: The summary of Velocity Model parameter in NDA (Control site)

NDA Control site	Velocity Range (m/s)			Average Depths (m)		
	V1	V2	V3	D1	D2	D3
A	1400	2500	3300	1.3	13.5	12.4
B	1200	2000	3000	1.4	16.5	24.6
C	800	1300	1500	1.3	15	8.9
D	1400	2900	3000	1.1	14.9	22.8
Average	1200	2175	2700	1.275	14.975	17.175

Table 3d: The summary of Velocity Model Parameter in Millennium City (Control site)

Millennium City Control site	Velocity Range (m/s)			Average Depths (m)		
	V1	V2	V3	D1	D2	D3
A	1500	2800	3000	1.3	17.3	25.5
B	900	1500	2400	1.4	16.5	24.6
C	1400	2500	3300	1.7	15.7	19.6
D	1000	1500	3000	1.6	14.5	23.1
E	1600	3000	3700	0.9	16.9	22.4
Average	1280	2260	3080	1.38	16.18	23.04



(a) Sub-Profile (C_1, C_2, C_3 and C_4) in NDA Dump Site

(b) Sub-Profile (C_1, C_2, C3 and C_4) in Millennium City Dump Site

(c) Sub-Profile (C_1, C_2, C_3 and C_4) in NDA Control Site

(d) Sub-Profile (C_1, C_2, C_3 and C_4) in Millennium City Control Site

Figure 9: Velocity Models generated across the study area

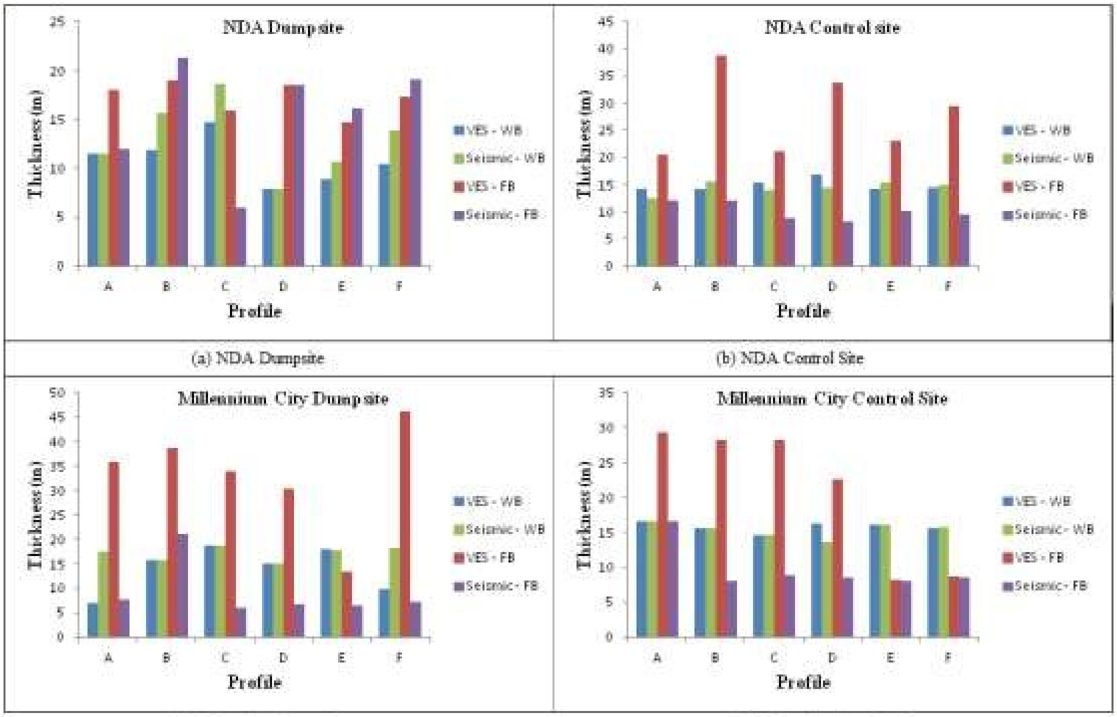
Comparison of VES and Seismic Refraction Tomography

Table 4 shows determination of thickness variations due to different physical properties measured by two geophysical methods used within the study area. The results obtained for different earth properties measured by two geophysical methods (vertical electrical sounding (VES) and seismic refraction tomography methods) were used to determine the level of leachate contamination of the subsurface structures and the aquifer potentials. Both the VES and seismic refraction tomography interpretations within the study area reveal that there are three to four distinct geologic units: overburden layer (topsoil), weathered layer, fractured and fresh basements. The interpreted geoelectric sections reveal that the first layer consists of contaminated area, weathered lateritic and sandy topsoil, the second layers then suggested the presence of weathered basement, the third layers constitutes fractured basement and the fourth layers are designated as fresh basement. Sometimes, second and third layers which comprise weathered and fractured basements are sandwiched together and this is also evident in the third and fourth layers. These are possible because these layers are in agreement with approximate resistivity ranges for both rocks and water types in the basement complex terrain as suggested by Keary *et al.* (2002).

Table 4: Variations of thickness obtained by VES and Seismic Methods Used

Specific Area	Geophysical method	Delineated layer	Average Thickness (m)						Total Average (m)
			A	B	C	D	E	F	
NDA Dumpsite	VES	WB	11.5	11.8	14.7	7.9	8.8	10.4	10.9
		FB	18	19	15.9	18.5	14.7	17.3	17.2
	Seismic Tomography	WB	11.5	15.7	18.6	7.9	10.6	16.2	13.4
		FB	12	21.3	6	18.5	13.9	19.1	15.1
NDA Control site	VES	WB	14.2	14.2	15.2	16.7	14.3	14.5	14.9
		FB	20.4	38.8	21.1	33.7	23.1	29.5	27.8
	Seismic Tomography	WB	12.5	15.5	14.1	14.5	15.2	14.8	14.4
		FB	12	12.1	8.9	8.3	10.1	9.4	10.1
Millennium City Dumpsite	VES	WB	7	15.7	18.6	15.2	17.9	9.9	14.1
		FB	35.8	38.8	33.9	30.3	13.5	46.2	33.1
	Seismic Tomography	WB	17.4	15.7	18.6	15.2	17.6	18.2	17.1
		FB	7.7	21.1	6	6.7	6.6	7.1	9.2
Millennium City Dumpsite	VES	WB	16.5	15.5	14.6	16.3	16	15.5	15.7
		FB	29.3	28.2	28.2	22.6	8.2	8.8	20.9
	Seismic Tomography	WB	16.5	15.5	14.6	13.6	16	15.7	15.3
		FB	16.6	8.1	8.9	8.6	8.1	8.5	9.8

Key: WB – Weathered basement; FB – Fractured basement.



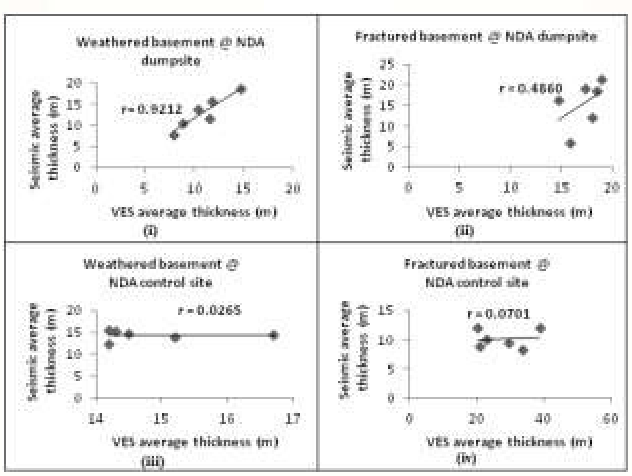
(a) NDA Dumpsite (b) NDA Control Site

(c) Millennium Dumpsite (d) Millennium Control Site

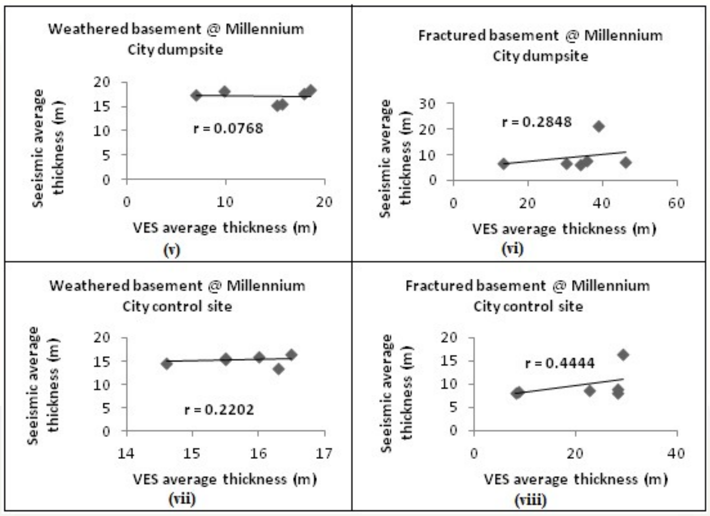
Figure 15: A bar chart representation of VES and Seismic Methods within the area

Geostatistical Deductions

There are positive relationships between the seismic and VES thicknesses with the correlation coefficient range of 0.00265 to 0.9212 for weathered basement layer while the fractured basement ranged from 0.0701 to 0.4860 across the area (Fig. 16). Considering the strength of the relationship in Fig. 16, it shows that about 12.5% of the entire delineated thicknesses possess a very strong positive relationship (Fig. 9i), which signifies that increase in VES thicknesses causes increase in seismic thicknesses, whereas, the 50% belongs to weak relationship, which depicts that the thickness points closely clinch on the correlation lines (Fig. 9ii, Fig.vi-viii). Also, 37.5% of the correlation coefficient which range from 0.026 – 0.077 signifies no linear relationship between VES and seismic thicknesses within the area (Fig. 9iii-v). According to Kleinbaum *et al.*, (1988), the correlation test of about 62.5% of the VES and seismic thicknesses within the study area is indicative of a statistically significant correlation.



(a) NDA site



(b) Millennium site

Figure 16: Graph showing the relationship between the seismic and VES thicknesses in the area

Hydrogeological and Environmental Implications of the Interpreted Results

Considering the entire results obtained, it can be deduced that most VES and seismic refraction points on both NDA and Millennium city dump sites are hydraulically very active. These are due to the fact that the study area is situated within the basement terrain where the aquifer is associated with fractured zones and shallower depths which is not beyond 15m as delineated from the interpretations. Specifically, within the study area, there are very good aquifer potentials that are not contaminated for now despite occurring within the dumpsite regions. For instance, at NDA dump site the VES points A_3, A_4, B_3, and C_5 with average depth to aquifer as 20 m are not contaminated, likewise at Millennium City dump site, the VES point B_{16} with depth to aquifer as 22 m is not contaminated.

Nevertheless, there are similar areas with overburden thickness above 10 m and low resistivity values less than 100 **Ω**m that had leachate contamination and invasion on both NDA and Millennium city dump sites. As such, the results of delineated leachate plume zones within the area signify that the zones are mainly associated with low resistivity values which range from 15 to 33**Ω**m at NDA dumpsite while at Millennium City area, the resistivity values of the dump site ranges from 26**Ω**m to 38**Ω**m. Actually, over 70% of the total VES points have some level of contamination which may be attributed to the thickness nature of the dump sites and the length of time of the dump sites. Therefore, the rate of leachate contaminants migration on both NDA and Millennium city dump sites has been calculated to be 0.5 meter per year and the waste had been deposited at both sites for at least 25 years now (Ministry of Environment and Natural Resources, Kaduna State (2015) and Shaibu *et al.*, 2018).

Notably, the study area is underlain by Basement Complex with distinct geological structures such as fractures, which were identified on most of the four layered geologic formations with the A, KH, and H – curve types at most of the VES points on both NDA and Millennium city dump sites and in returns pave ways for further leachate infiltration into the aquifer system. This implies that the vertical movement of leachate (contaminate) will be fast across the area, thereby allowing physical (filtration), chemical and biochemical processes to aid contaminants down to the groundwater zone. This deduction aligns with the extreme relative vulnerability to pollution by hydrologic setting after Montgomery (2000).

Generally, both the second and third layers which are designated as weathered and fractured basements across the study area, have low to moderate resistivity values at most of the VES points at the dumpsites compared with the resistivity values of the VES points at the control sites which are relatively high. This indicates that leachate contaminations are likely to be present in second and third layers of the dumpsites. Actually, the leachate contaminations within the NDA dumpsite range from 4.5 to 17.1m, whereas, at Millennium City dumpsite, the depth ranged from 7.7 to 12.7 m depict that the rate of contamination will relatively be high due to the shallow depth delineated. Also, the consistency of low resistivity values of the second layers in the control sites are likely caused by leachate contaminations up to depth of about 10.3m to 24.8m at NDA, while at Millennium City, the depth ranged from 0.8 to 16.5m. These deductions are in consistent with Mohammed *et al*. (2007) and Osazuwa and Abdullahi, (2008).

Seismic refraction tomography method also delineated three to four velocity layers with different thickness and various compositions of lithology. The velocity then increases down the depth. The correlations between seismic refraction tomography and electrical resistivity geo-electric sections indicates that even though the same number of layers is delineated, variations in thickness also exists due to different properties measured by both methods used.

CONCLUSIONS

The survey of groundwater contamination level in selected dumpsites in Kaduna, Nigeria using resistivity and seismic tomography methods has been carried out. Few contaminated zones from the NDA dumpsite is yet to affect the groundwater sources compared to the Millennium dumpsite, where barely all the contaminated zones have contaminated the groundwater sources thereby making the groundwater unfit for the dwellers in this region.

REFERENCES

Adegbola, R.B., Oyedele, K.F., Adeoti, L., and Adeloye, A.B. (2016). Multichannel analysis of the surface waves of earth materials in some parts of Lagos State, Nigeria. De Gruyter Open RMZ–M&G, Vol. 6, pp. 81-090.

Aliyu, N.S., Aminu, A.L., and Chiemeke, C. (2014). Geophysical Investigation of Weathered Basement, Using Electrical Resistivity Method in Zainawa Village, Kano State, Nigeria. The International Journal of Engineering and Science, Vol. 3 (01), pp. 23-29.

Amadi, S.C., Onwuemesi, A.G., Anakwuba, E K., Chinwuko, A.I., and Okeke, H.C. (2017). Estimation of Aquifer Hydraulic Characteristics from Surface Geo-Electrical Sounding of Affa And Environs Southeastern, Nigeria. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG), Vol. 5 (4), pp. 14-25

Anakwuba, E. K., Chinwuko, A.I., Onuba, L N. and Obiadi, I.I. (2012**)**. Integrated geophysical approach in Groundwater Exploration of Walla B, Gwoza Local Government Area of Borno State, Nigeria. Nigerian Journal of Physics. vol. 23, pp. 109-120.

Anakwuba, E.K., Nwokeabia, C.N., Chinwuko, A.I., and Onyekwelu, C.U. 2014. Hydrogeophysical assessment of some parts of Anambra basin, Nigeria. International Journal of Advanced Geosciences, Vol. 2 (2), 72-81.

Barrett, P.J., and Froggatt, P.C. (1978). Densities, porosities, and seismic velocities of some rocks from Victoria Land, Antarctica. New Zealand Journal of Geology and Geopbysics, vol. 21 (2), pp. 175-187.

Benson, A. K., Pane, K. L., and Stubben, M. A. (1997). Mapping groundwater contamination using DC Resistivity and VLF geophysical methods – A case study. Geophysics, vVol. 62 (1), pp. 80-86.

Brown, M. C., & Donnelly, O. T. (1999). Electrical and Seismic imaging surveys for Environmental and Engineering studies. A practical guide to 2-D and 3-D surveys.

Buselli., G Bareber, C., Davis, G B., & Saama, R. B.(1992). Detection of Groundwater contamination near waste disposal sites with Electromagnetic methods. Geotechnical Environmental Geophysics, vol. 11, pp. 73-79.

Chinwuko, A.I., Anakwuba, E.K., Okeke, H.C., Onyekwelu, C.U., Usman, A.O., Osele, C.E., and Iheme, O.K. (2016). Assessment of Hydrogeophysical and Geotechnical Properties in Central Part of Anambra State, Nigeria. International Journal of Geophysics and Geochemistry, Vol. 3 (2), pp. 6-13.

Chinwuko, A.I., Anakwuba, E.K., Okeke, H.C., Usman, A.O., Ovwasa, M.O., Okoye, I. F. (2015). Geoelectric Investigation for Groundwater Potential in Awka Anambra State, Nigeria. International Journal of Science for Global Sustainability, Vol. 1(1), pp. 85-95.

Fatta, D., Naomi, C., Karlis, P., & Loizidou, M. (2000). Numerical Simulation Of flow sand contaminant migration at a municipal landfill.Journal of Environmental hydrology, vol. 8 (6), pp. 1-10.

Dahlin, T. & Bing, Z. (2003). A numerical comparison of 2D Resistivity imaging with ten electrode arrays. Revised version for Geophysical Prospecting, vol. 1, pp. 43-47.

Ijila, P., Kolebaje, O., and Ojo, A. (2018). Geophysical Characterization of the Basement Rocks and Groundwater Potential Zones Using Electrical Resistivity Sounding Technique. Journal of Environment and Earth Science, vol.8 (7), pp. 21-33.

Jegede, S.I., Osazuwa, I.B., Ujuanbi, O., & Chiemeke, C.C. (2011). 2D electrical imaging survey for situation assessment of leachate plume migration at two waste disposal sites in the Zaria basement complex. Advances in Applied Science Research, vol. 2 (6), pp. 1-8.

Karlik, G, & Kaya, A.M. (2000). Investigation of groundwater contamination using electric and electromagnetic methods at an open waste disposal site: a case study from Isparta, Turkey. Environmental Geology, vol. 40 (6), pp. 725-731.

Kearey, P., Brooks, M., & Ian, H. (2002). An Introduction to Geophysical Exploration, Third Edition. Blackwell publishing, UK, 281p.

Kleinbaum, D.G, Kupper, L.L., & Muller, K.E. (1988). Variable Reduction and Factor Analysis in Applied Regression Analysis and Other Multivariable Methods. PWS Kent Publishing Co., Boston, USA, pp. 595-640.

McCurry, P. (1979). The Geology of Precambrian to lower Paleozoic rocks of Northern Nigeria–A review in: Kogbe, C.A. (Ed) Geology of Nigeria-Elizabeth and Published co. Lagos. 436p.

Mohammed, L. N., Aboh, H.O., and Emenike, E.A. (2007). A Regional Geoelectric Investigation For Groundwater Exploration In Minna Area,North West Nigeria. Science World Journal, vol. 2 (3), pp. 15-19.

Montgomery, C. L.(2000). Environmental Geology. 5th Edition, McGraw Hill. Higher Education Publication.

Mukhtar, A., Ibrahim, S., Abdullatif, P., & Hanafi, M. (2000). Detection of groundwater pollution using Resistivity imaging at Seri Petang landfill, Malaysia. Journal of Environmental hydrology, Vol. 8, pp. 1-8

Ministry of Environment and Natural Resources, Kaduna State, 2015.

Obiabunmo, O.C., Umego, M.N., Obiekezie, T.N., & Chinwuko, A.I. (2014). Application of Electrical Resistivity Method for Groundwater Exploration in Oba and Environs, Anambra State, Nigeria. Advances in Physics Theories and Applications, vol. 37, pp 19-29

Osele, C.E., Onwuemesi A.G., Anakwuba, E.K., & Chinwuko, A.I. (2016). Hydrogeophysical assessment of some parts of Anambra basin, Nigeria. International Journal of Advanced Geosciences, vol. 4 (1), pp. 1-7.

Osazuwa, I. B., & Abdullahi, N. K. (2008). 2-D Electrical Resistivity and Induced Polarisation Investigation at an open solid Waste Dumpsite: Case Study from Kaduna, North Central, Nigeria. Journal of Environmental Hydrology, Vol. 16 (29), pp. 1-11.

Porsani, L. Filho, W.M. Elis, V.R., Shimlis, J.D., & Moura, H.P. (2004). The use of GPR and VES in delineating a contamination plume in a landfill site: A case study in SE Brazil. Journal of Applied Geophysic, vol. 55, pp. 199-209.

Rosqvist, H. Dahlin, T.,Foune, A., Rohrs, L., Bengstsson, A., & Larsson, M. (2003). Mapping of Leachate plumes in two landfill sites in South Africa using Geo-electric imaging techniques. Proceedings Ninth international Waste Management and landfill symposium. Calgary, Italy, Sardina.

Russ, D. M. (1980). The Generalised Reciprocal Method of Seismic Refraction Interpretation. Society of Exploration Geophysicists, Vol. 53, pp. 345 – 352.

Sampat, P. (2001). The hidden threat of groundwater pollution. USA Today Magazine, 130p.

Shaibu, I.,Udensi, E.E., Chinwuko, A.I.,Usman, D. A., Adetona, A.A., and Omale, M.E. (2018). Geophysical Investigation of Groundwater Potential in Millennium City Housing Estate Kaduna, Nigeria using Electrical Resistivity Method. Kada Journal of Physics, vol. 2 (1), pp 14-22.

Udensi E E and Salako K A (2005), 'Vertical Electrical Sounding (VES) Investigation of Western Part of the Federal University of Technology Minna, Gidan Kwano Campus' 1st Annual S.S.S.E Conference, FUT, Minna, Book of Reading, Vol. 1, pp. 69-75.

Udoh, A.C., Chınwuko, A.I., Onwuemesı, A.G., Anakwuba, E.K., Oyonga, A.O., & Usman, A.O. (2020). Impact of solid waste on groundwater quality in selected dumpsites in Akwa Ibom State, Nigeria using resistivity and hydrochemical data. Bulletin of the Mineral Research and Exploration, vol. 163 (163), pp. 1-22.

Zhang, J., & Toksoz, M. N. (1998). Nonlinear refraction travel-time tomography. Geophysics, Vol. 63, pp. 1726–1737.

Zohdy, A.A.R., & Jackson, D.B. (1969). Application of deep electrical soundings for groundwater exploration in Hawaii. Geophysics, Vol. 40, pp. 584-600.