GEOELECTRICAL INVESTIGATION FOR LEACHATE PLUME MIGRATION ON MAITUMBI DUMP SITE, MINNA, NIGER STATE, NIGERIA.

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ABSTRACT

Leachate contamination due to poor solid waste management causes serious negative effects on the environment and human health. In this work, resistivity method was employed at an old dumpsite in Maitumbi, Minna, Niger State, Nigeria to study the ingress of leachate contamination into groundwater. The study area is mostly characterized by three (3) layered geologic sections, which include topsoil, weathered basement and Fresh basement. The Results indicate the ingress of leachate into the subsurface up to the depth of about 13 m. It was observed that the subsurface is contaminated by leachate migration. At the surface of the dump site, the resistivity value ranges from 20 Ωm to 40 Ωm as compared to that of the control site which ranges from 380 Ωm to 820 Ωm at the same depth. This indicates that the topsoil has been contaminated by leachate from the dump site. At 10 m depth, the resistivity value ranges from 20 Ωm to 60 Ωm at the dumpsite and that of the control site ranges from 260 Ωm to 580 Ωm. The low resistivity at this depth on the dumpsite compared to the control site further indicates the presence of leachate. At the depth of 13 m, the resistivity value at the dump site ranges from 100 Ωm to 850 Ωm and that of the control site ranges from 200 Ωm to 850Ωm. The similarity in resistivity value at this depth is indicative that the migration of leachate ends at the depth of 13 m. However, considering the weathered/fractured layer thickness map, the aquiferis observed to be promising at the depth of 20 m. This suggests that the groundwater is currently not affected by the leachate contamination. Nonetheless, the continuous migration of the leachate at the current rate of 1.63m/year, is estimated to result in the eventual contamination of the groundwater in 12.3 years.

Keywords: Leachate contaminant, resistivity, landfill, aquifer, solid waste.

INTRODUCTION

Landfilling of municipal solid waste (MSW) is a common waste management practice and one of the cheapest methods for organized waste management in many parts of the world (Jhamnani and Singh, 2009; Dsakalopoulous*et al*., 1998; El-Fadel*et al*., 1997). In most low to medium income developing nations, almost 100 percent of MSW generated goes to landfills. Landfill operations are most feasible in these countries as land is vastly available and moderately inexpensive. Even in many developed countries where land is scarce and where policies of reduction, reuse and diversion from landfills are strongly promoted, a great percentage of their generated MSW is still landfilled. For instance, in 2006, out of the 251 million tons of MSW generated in the United States of America, 138.2 million tons representing 55% was disposed of in landfill (United States Environmental Protection Agency (USEPA, 2007). In England, of the 29.1million tons of municipal solid waste generated between 2003 and 2004, 72% was land-filled (Department of Environment Food and Rural Affairs (DEFRA), 2005). The scenario is similar in Northern Ireland and Scotland where 82.9% and 85.4% of their generated MSW were land filled in 2005 and 2007 respectively (Environmental Health and Safety (EHS, 2005; Scottish Environmental Protection Agency (SEPA, 2007).Today, however, there is a progressive decrease in the volume of MSW being land filled in these developed countries yearly as great efforts in solid waste management are today directed towards waste reduction and recycling programs which is a real giant step in environmental improvements (USEPA, 2007; 2008). Disposal of refuse occurs all over the world and proves to be a major problem. Careless dumping of refuse and poor management can greatly affect one's health. Pollution from solid wastes always begins with precipitates carrying the leachates into land surface and ends with the water reaching surface water or groundwater.

Priscillia*et al*. (2019) assessed the leachate contamination level of groundwater resource at a dumpsite, in Minna, Nigeria using resistivity method. The depth of contamination in the study area is 7 meters but water bearing formation beyond this depth was safe from contamination. In the Urban centers in Nigeria, the management of solid waste has been a major problem as such wastes are indiscriminately dumped in rivers and lands depending on the proximity of the dumpsites to the settlements. The landfill constituents are predominately household waste. Other waste comes from shops, offices, hospitals and chemical and manufacturing industries. These wastes may contain toxic substances as they are decomposed or biodegraded, with the preference of infiltrating water, to produce an organic liquid known as leachate.

THE STUDY AREA

Maitumbi disposal site is located between latitudes 09 40’37.17 to 09 41’37.15 N (Figure 1) and longitudes 06 29’51.66’’ to 06 30’51.55 E. The area lies within the south western part of Minna metropolis.

Figure 1: Maitumbi Dumpsite-Study Area

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

Minna occupies the central portion of the Nigerian basement complex which lies on a batholith, (Udensi*etal*.,1986). The Minna area falls within the larger northwestern Nigerian Basement Complex. The rocks of the area are mostly crystalline rocks consisting of Gneisses and Migmatites, and Meta-Sedimentary Schist (Mohammed *et al*., 2008). The area is thus underlayed by two lithological units of Granites and Gneisses with Pegmatite’s and quartz veins as minor intrusive. The Granites, which cover about 80% of the area, are mostly exposed in the western part of the town. They mostly form high batholiths, which are extensive in size. The Granitic outcrops are highly jointed, fractured, foliated and in some places appear as boulders (Adeniyi, 1985). The second lithological unit, the Gneiss, covers about 20% of the area and occurs to the east of the city. They are fine-grained with gneissose banding defined by the alternating lighter colored minerals (quartz and feldspars) and the dark-coloured ones (biotite micas) (Figure 1).

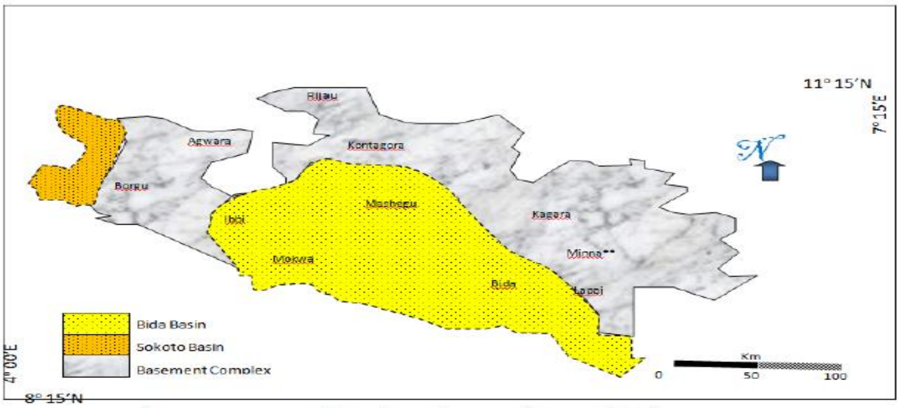


Figure 2: Map showing the Geology of Niger State

They are intruded by the granitic rocks and in most cases are highly fractured and weathered. Some of the Gneisses contain augen structures, banding and bounding ages. Apart from these two major rock types, there are other rock types in form of minor intrusive such as pegmatites and quartz veins. They are closely associated with the granitic rocks and the gneisses. These cut across one another and are generally characterized by coarse textures. Geometrically, they occur as Dykes, Sill lenses and Phenocrysts. The width of Pegmatite on average ranges from15 to 35cm and several meters long. Mineralogically, they mostly contain quartz, feldspars and some minerals of precious quality such as tourmaline, emerald, aquamarine and epidotite (Walton,2010). The quartz veins are generally less in dimension and in most cases barren while some may be mineralized.

MATERIALS AND METHODOLOGY

ABEM SAS 4000 model was used for the data collection in the study area. Other accessories were Metal electrodes, Hammer, Light insulated wires wound on portable reels, connecting cables and crocodile clips, tape rule, GPS, WinRESIST version 1.0 software and Surfer 10. The area under review was inspected, measured and gridded into six profiles (A – F). The length of each profile is 100m, and the distance between one profile and the other is 20m. The control site which is about100m away from the dump site and separated by an express road from the study area was also gridded into profiles A' – C'. The length of each control profile is 40m and the inter profile spacing is 20m.Vertical Electrical Sounding (VES) method was used to survey the study area to achieve the set aims and objectives. The method has the advantage of delineating the depth to surface resistivity variation of the subsurface, which makes it most suitable for the study. Vertical electrical sounding was carried out on thirty-six (36) points marked with pegs using Schlumberger spread of electrode configuration on the dumpsite which is the study area, while another nine (9) VES points was carried out using the same Schlumberger spread of electrode on the control area.

GENERAL PRINCIPLE OF ELECTRICAL RESISTIVITY

The fundamental physical law used in resistivity surveys is Ohm's Law which governs the flow of current in the ground. The equation for Ohm's Law in vector form for current flow in a continuous medium is given as (Kearey, 2002):

$$J = \sigma E \qquad (1)$$

where σ is conductivity of the medium, J the current density and $\boldsymbol{E}$ the electric field intensity.

In practice, what is measured is the electric field potential. In geophysical surveys, the medium resistivity ρ, which is equal to the reciprocal of the conductivity, is more commonly used. The relationship between the electric potential and the field intensity is given as (Kearey, 2002):

$$E = -\nabla\Phi \qquad (2)$$

Combining equations (1) and (2):

$$J = -\sigma\nabla\Phi \qquad (3)$$

Current sources are in the form of point sources. In this case, over an elemental volume ∇V surrounding the current source I, located at (x_s, y_s, z_s,).

The relationship between current density and current is given as (Dey and Morrison 1979):

$$\nabla * J = \left(\frac{I}{\Delta V}\right)\ \delta(x - x_s)\delta(y - y_s)\delta(z - z_s) \qquad (4)$$

Where δ is the Dirac delta function. Equation (4) can be rewritten as:

$$\nabla \bullet [\sigma(x,y,z)\nabla\phi(x,y,z)] = \left(\frac{I}{\Delta V}\right)\ \delta(x - x_s)\delta(y - y_s)\delta(z - z_s) \qquad (5)$$

Equation (5) is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. This is the “forward” modeling problem, which is to determine the potential that would be observed over a given subsurface structure. Fully analytical methods have been used for simple cases, such as a sphere in a homogenous medium or a vertical fault between two research with a constant resistivity. For an arbitrary resistivity distribution, numerical techniques are more commonly used. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method is commonly used (Koefoed, 1979). For 2-D and 3-Dcases, the finite-difference and finite-element methods are the most versatile.
Resistivity measuring instruments normally give a resistance value $R = \Delta\phi / I$. In practice, the apparent resistivity value is calculated from (Kearey, 2002):

$$\rho_a = kR \qquad (6)$$

The calculated resistivity value is not the true resistivity of the subsurface, but an “apparent” value. It is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the “apparent” resistivity and the “true” resistivity is a complex relationship. To determine the true subsurface resistivity from the apparent resistivity values is the “inversion” problem.

RATE OF PERCOLATION

Investigation reveals that the dump site has been in operation since about 8 years ago. Therefore, if percolation is assumed to be consistent annually, the rate of percolation can be estimated using (Aarne*et al.*, 1994):

$$\text{PPA} = \frac{D}{T} \qquad (7)$$

where PPA is Percolation per Annum, D is the Depth of contaminant and T the Year of operation.
Using equation (7), the rate of percolation in the area is 1.63m/year. However, the dumping of refuse in this dumpsite had stopped over the years and is now used for forming purposes.

RESULTSAND DISCUSSION

The VES Analysis Along Profiles (Dump Site)

Table 1 shows the general results obtained from the VES plots. The summary of the resistivity results for profiles A, B C, D, E and F shows three layers model. The profiles show two distinct curve types including H (VES A4, B2, C6, D1, E2, F6) and A (VES A5, B1, C4, D5, E4, F2). The first layer in profile A has a resistivity value ranging from 18.6 Ωm to 349.3 Ωm. The lowest resistivity value of 18.6 Ωm is found at VES A5 while the highest resistivity value of 349.3Ωm is found at VES A2. As for the second layer, the resistivity value ranges from 69.82 Ωm to 413.5 Ωm. the lowest resistivity value of 69.82Ωm is located at VES A3 while the point with the highest resistivity value of 413.5 Ωm is at VES A6. The layer has thickness ranging from 3.0 m at VES A6 to 50m at VES A5. Layer three is characterized by resistivity values ranging from 802.65 Ωm to 1748.7 Ωm. the lowest resistivity value of 802.65 Ωm is located at VES A2 while the highest of 1748.7 Ωm is at VES A5. The layer's thickness is to infinity depth.

The summary of profile B is shown in Table 1. The profile shows three layers model except for VES B1 and B6 which are characterized by two layers model. The profile shows three distinct curve types which are A (VES B1, B5 and B6), H (VES B2) and K (VES B3 and B4). The first layer has a resistivity value ranging from 0.6 Ωm to 42.2 Ωm. the lowest resistivity value of 0.6 Ωm is found at VES B1 while the highest resistivity value of 42.2 Ωm is found at VES B5. The layer has the highest thickness of 30.0m at VES B4 while the lowest thickness of 0.3m is located at VES B1. The second layer is typified by resistivity ranging from 7.35 Ωm to 1925 Ωm. The lowest resistivity of 7.35 Ωm is located at VES B2 and the highest is located at VES B6 respectively (1925 Ωm) The layer has the highest thickness of 47.0m at VES B3 and the lowest thickness of 2.6 at VES B5.As for the Third layer, the resistivity ranges from 112.2 Ωm to 873.7 Ωm. The lowest resistivity of 112.2 Ωm is located at VES B3 while the highest of 873.7 Ωm is located at VES B5 respectively. The layer's thickness is to infinity depth.

The summary of profile C is shown in Table 1. A three Layer model is observed along this profile except at VES C1 and C6 with two-layer model. The profile shows a singular curve type of type A. The first layer has a range of resistivity values from 0.9 Ωm to 248.8 Ωm with the lowest resistivity at VES C4 (0.9 Ωm) and the highest at VES C1 (248.8 Ωm). At VES C6 and VES C4. is seen the highest and lowest thickness of 15.0m and 0.3m respectively. The second layer is characterized by resistivity values ranging from 27.23 Ωm to 2446.6 Ωm. the layer's resistivity is lowest at VES C5 with 27.23 Ωm while it is highest at VES C1 with 2446.6 Ωm. The layer has the highest thickness of 54.0 m at VES C5 and the lowest thickness of 4.1 m at VES C4. The third layer has a range of resistivity values of 112.0 Ωm to 23619.5 Ωm. The layer has the lowest resistivity of 112.0 Ωm at VES C3 and the highest value of 23619.5 Ωm at VES C4. The layer's thickness is to infinity depth.

Profile D is a two-layer model; the profile is characterized by three layers model. The profile shows a singular curve type of type A. The first layer has a resistivity value ranging from 1.2 Ωm at VES D2 to 85.6 Ωm at VES D6. The layer has the lowest thickness of 0.8 m at D2 and D6 and the highest thickness of 20.0 m at VES D4. The second layer has the lowest resistivity value of 43.7 Ωm at VES D1 and the highest value of 18693.8 Ωm at VES D4. The layer's thickness is lowest at VES D2 and D3 with 3.4m and highest at VES D6 at 38.0m. With the third layer's thickness tending to infinity, the layer has a resistivity value ranging from 414.7 Ωm at VES D3 to 31832.9 Ωm at VES D6. The summary of profile E is shown in Table 1. The profile shows three layers model except for VES E5 which is characterized by two layers model like is the case in profile D. The profile shows two distinct curve types including A (VES E3, E4 and E5) and H (VES E1, E2 and E6).

Table 1: Summary of the VES Analysis Along Profiles (Dump Site)

VES Points	Curve Type	No of Layers	Depth (m)	Thickness (m)	Resistivity (Ωm)
A4	H	1	0.0	0.8	227.00
		2	0.8	8.9	100.83
		3	9.7	∞	1653.65
A5	A	1	0.0	20.0	18.60
		2	20.0	50.0	409.40
		3	70.0	∞	1748.70
B1	A	1	0.0	0.3	0.60
		2	0.3	47.0	463.10
		3	20.0	∞	1456.20
B2	H	1	0.0	3.0	7.35
		2	3.0	12.0	181.80
		3	15.0	∞	660.0
C4	A	1	0.0	0.3	0.90
		2	0.3	4.1	380.00
		3	4.4	∞	23619.10
C6	A	1	0.0	15.0	7.10
		2	3.2	8.5	42.00
		3	15.0	∞	1619.00
D1	A	1	0.0	2.3	7.10
		2	2.3	14.2	42.00
		3	0.0	∞	1619.00
D5	A	1	0.0	5.0	8.50
		2	5.0	35.0	61.70
		3	40.0	∞	740.50
E2	H	1	0.0	30.0	15.25
		2	30.0	10.0	1.80
		3	40.0	∞	321.30
E4	A	1	0.0	3.0	0.60
		2	3.0	27.0	50.05
		3	30.0	∞	1008.60
F2	A	1	0.0	5.6	8.9
		2	5.6	27.3	429.93
		3	32.9	∞	3391.1
F6	H	1	0.0	2.6	819.15
		2	2.6	3.0	0.7
		3	5.6	∞	364.1

Layer one is characterized by resistivity values ranging from 0.6 Ωm at VES E4 to 19.5 Ωm at VES E1. The layer has the lowest thickness of 2.0m at VES E6 while the highest thickness of 30.0m is at VES E2. Layer two has a resistivity value ranging from 0.2 Ωm at VES E6 to 233.9 at VES E5. The layer has the lowest thickness of 3.0m at VES E1 and the highest thickness of 27.0m at VES E4. The third layer is characterized by resistivity values ranging from 48.35 Ωm at VES E6 to 529.4 Ωm at VES E3. The depth of the layer is to infinity.

Profile F shows three layers model except for VES F5, which is characterized by a two-layer model. The profile shows a singular curve type of type A. The resistivity of the first layer ranges from 0.1 Ωm at VES F6 to 8.9 Ωm at F2. The layer has the lowest thickness of 1.3 m at F5 and the highest thickness of 10.0 m at VES F4. Layer two has resistivity values ranging from 0.7 Ωm at VES F3 to 711.2 Ωm at F5. The layer has the lowest thickness of 1.9m at F3 and the highest thickness of 67.0 m at VES F1. The third layer is characterized by resistivity values ranging from 60.4 Ωm at VES F1 to 3391.1 Ωm at F2. The layer's thickness is to infinity. The summary of the resistivity result for profile F is shown in Table 1

Vertical Geoelectric Section

The vertical section of profile A is shown in Figure 2 (a and b). The map is contoured at the interval of 100 Ωm. This map can be divided into three-layer structure, with each layer comprising different lithologies. The first layer has a relatively high resistivity value range of 18.6 Ωm – 349.3 Ωm which indicates absence of contaminant. The layer suggests a region of dry sandy soil. The first layer is an indication of dry sandy soil which is free from pollution. The second layer suggests a weathered basement with resistivity valuesrangingfrom69.82 Ωm – 413.5 Ωm. the third layer has a resistivity value ranging from 802.65Ωm to 1748.7Ωm which is an indication of a fresh basement.

DEDUCTIONS FROM WEATHERED/FRACTURED LAYER THICKNESS MAP

The weathered layer thickness map as shown in Figure 3 was produced from the thickness of the second layer of all VES points. It is contoured at an interval of 2m. The thickness of the weathered basement layer ranges from 4-46m with an average thickness of about 18.18m. The area shaded with orange, yellow and green represents the thickest region of the site which indicates the most probable region of water bearing (VES A3, B4, C4, D5, E4 and F2). The area has a thickness of 20-46m and resistivity values ranging from 27.2-409.4 Ωm.

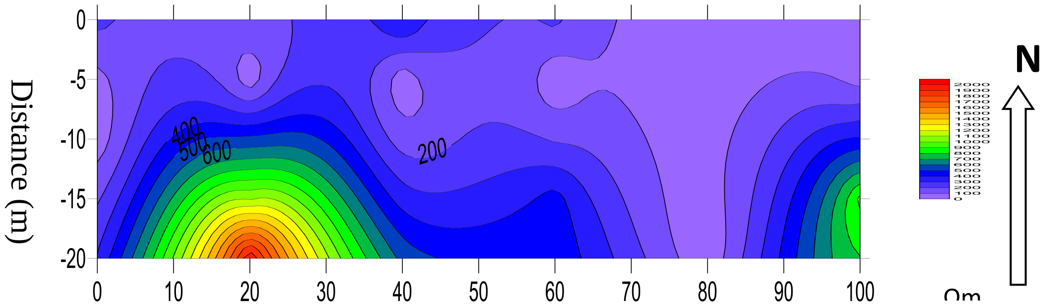


Figure 3a: Vertical Geoelectric Section on Profile A

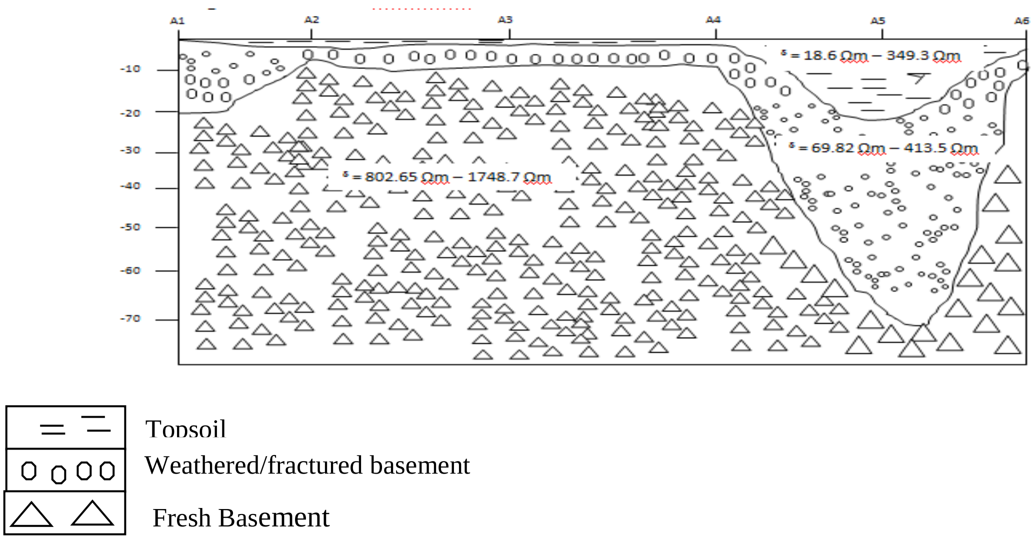
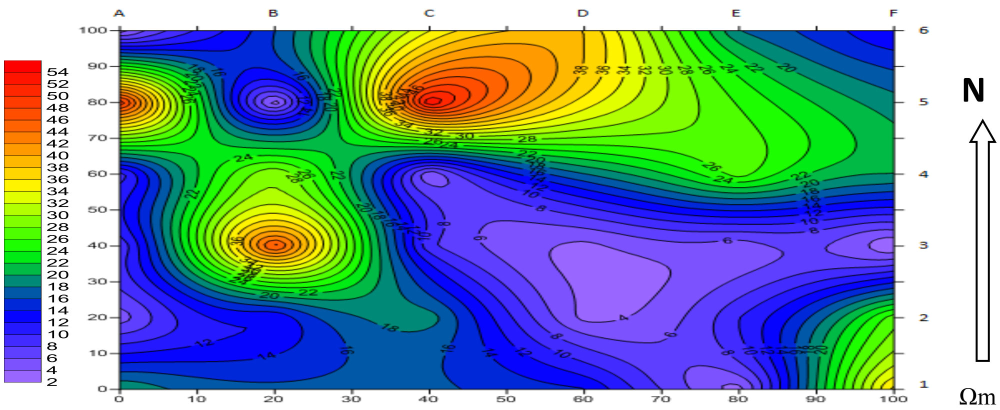


Figure 3b: Vertical (geologic) Section on Profile A



Deductions From 3-D Wireframe Model
The depth values corresponding to the last layer for all the VES points wereused to generate this map. Figure 4 gives the depth ofthe basement map. It iscontoured at an interval of 2 m and gives the depth to the basement from the ground surface. The map shows that the basement varies from 10m to 50 m. VES points A3, B4, C5, D5, E4 and F2 are relatively deep with depths between 30-50 m while other VES points are relatively shallow.

AQUIFER LOCATION

The results presented in the weathered/fractured layer thickness map (Figure 3) indicate that VES points A5, B4, C5, D5, F1 and F4 have a promising aquifer potential. The fractured layer has a thickness of 20-46m and resistivity values ranging from 27.2-409.4 Ωm. According to (Ogungbe*et al*., 2012) reported by Abdullahi and Udensi (2008), the electrical resistivity of this layerwhich forms the water bearing zone, depends on the sand-to-clay ratio and degree of saturation. The zone with resistivity above 100 Ωm indicates a good aquifer potential zone as it is made up of clayey sand and sand with high porosity. Regions with resistivity below 100 Ωm are poor aquifer potential zones as it is made up of clay with low water bearing capacity.

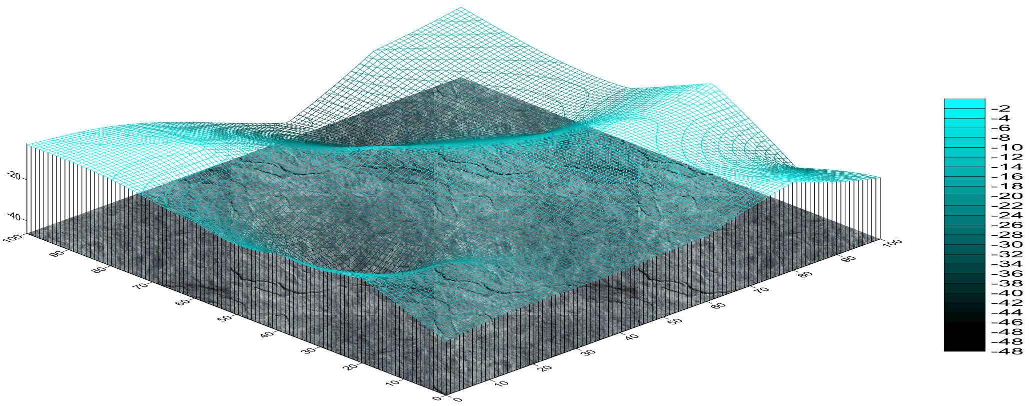


Figure 4: 3D Wire frame for weathered/fractured layer thickness map.

CONCLUSION AND RECOMMENDATIONS

Results from the VES graph and vertical geo-electric section maps in previous chapters indicate the ingress of leachate into the subsurface up to the depth of about 13 m. The study area is mostly characterized by three (3) layered geologic sections which include, topsoil, weathered basement, and fresh basement. Based on the findings which are evident in the iso-resistivity contour map presented, we suspect the subsurface at a depth of about 13 m to be contaminated by leachate migration. At the surface of the dump site, the resistivity value ranges from 20 Ωm to 40 Ωm as compared to that of the control site which ranges from 380 Ωm to 820 Ωm at the same depth. This indicates that the topsoil has been contaminated by leachate from the dump site. At 5 m depth, the resistivity value of the dump site ranges from 5 Ωm to 45 Ωm as against that of the control site at the same depth which is between 60 Ωm to 200 Ωm indicating migration of contaminants to that depth. The resistivity value for 10 m depths further indicates the presence of leachate as the dump site ranges from 20 Ωm to 60 Ωm and that of the control site ranges from 260 Ωm to 580 Ωm.At 13 m depth, the resistivity value at the dump site ranges from 100 Ωm to 850 Ωm and that of the control site ranges from 200 Ωm to 850 Ωm.This similarity in resistivity value at this depth influences the conclusion that the migration of leachate ends at 13 m. However, considering the weathered/fractured layer thickness map in Figure 4, the aquifer is observed to be promising at the depth of 20 m. this suggests that the groundwater is not contaminated. But if the migration continues at the current rate of 1.63m/year, the groundwater will be contaminated in 12.3 years.

Towards the control of groundwater vulnerability to pollution through landfills, there is need for adequate and proper planning, design and construction, and strategic management of waste disposal. Government at all levels should consider facing out the ordinary landfill system and provide modern sanitary landfills to ameliorate the incessant ground water contamination.

Detailed analysis of hydrogeology and ground water flow direction in proposed dump sites is required to safeguard the ground water system from pollution. Agencies such as Niger State Environmental Protection Agency (NISEPA) should engage in more research to monitor contaminant levels and plan mitigation strategies. To forestall the continuous contamination of ground water through disposal of domestic and industrial waste, the governments need to consider alternative management method such as recycling.

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