Nigerian Journal of Physics (NJP)

ISSN: 1595-0611

Volume 32(3), September 2023

Geophysical and Physico-Chemical Evaluation of Leachate Plumes and Groundwater Pollution in Minna, Niger State, Nigeria

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ABSTRACT

A geophysical research was carried out in parts of Minna which includes Rafin-Tofa, FM maitumbi and Albishiri respectively to determine the extent of groundwater contamination through the infiltration of the leachate plume. Three methods were adopted and their results were correlated. The Vertical Electrical Sound (VES) indicates the area is characterized by 3-layers, H-type curve with low resistivity values >100 Ohm-metre, (Ωm) on the 2-layer. The 2D results also correlates with the VES results with Albishiri zone showing more migration of the leachate plume at station 140 to 150 with resistivity value ranging from 9.0 - 33.0 Ωm and depth of 3.0 m -25.0m. The water sample results from Fm-maitumbi and Albishiri revealed pH range of 6.65 – 6.92 which is within the WHO (6.5 - 8.5) standard for drinking. The Electrical Conductivity (EC) showed a high EC range from 571-926.8 μS/cm which is above WHO standards for EC value which should not exceeded 400 μS/cm. The high EC value observed which could be as a result of the migration of the leachate plume. The (TDS) values range from 169.3 - 454.1 mg/l which was within WHO standard. The turbidity of Albshiri1 and Albishiri Control showed values above 1 NTU such as 11 NTU and 45 NTU respectively, which is not ideal according to WHO standard and FM-maitumbi showed values below the recommended value which ranged from, 0.75-0.95 NTU. The Nitrate level 2.6 -5.5 mg/kg was below WHO standard of 50 mg/l. The heavy metals tested were Iron (Fe), Zinc (Zn), Copper (Cu) and Cadmium (Cd) were within WHO permissible standard for drinking water. The Very Low Frequency Electromagnetic (VLF-EM) results with 5 Profile collected in NE-SW of the landfill and show high current density values spreading around the location which was at a distance of 100m for each profile at the dumpsite. The soil samples analyzed showed a high concentration of 173.6 Mg/kg of Cu in S2 beyond the WHO maximum allowed limits of 30 mg/kg and no trace (Pb and Cd).while the Fe, Zn, Ni falls below the WHO maximum allowed limits except for Mn.

Keywords:
The Vertical Electrical Sound (VES),
Groundwater,
Electrical Conductivity (EC),
Total Dissolved Salt (TDS),
Leachate,
Contamination.

INTRODUCTION

Groundwater is an important natural resource that supports life on earth. Over the past century, the enormous expansion of industrial and agricultural activities has led to increasing environmental pressure on groundwater systems. according to (Adeyemo et al., 2015), groundwater is important because it represents a large part of our freshwater and water resources in many developing countries like Nigeria, where public clean water production is rare or non-existent, people must work hard on their own to get clean water for their homes and businesses. However, other human activities such as agriculture, industry and the disposal of domestic and commercial waste in open spaces can contaminate and contaminate these invaluable groundwater resources. Open-air landfills, agricultural wasteland pollution, ponds and lakes, rock pollution, and subsoil pumping are just some of the many methods of solid waste disposal (Ismail and Hashin, 2006). Due to the generation of leachate and its movement in the waste, landfills are a source of groundwater and soil contamination (Christensen et al., 1993). Niger State lies between latitudes 8°15'–11°15'N and longitudes 4°00–7°15' E. It is bordered in the north by Kaduna and Kebbi states and in the south by Kogi state. It shares borders to the west with Kwara State and Benin

Republic and to the east with the Federal Capital Territory and Kaduna State. It is composed of 25 local governments that cover an area of roughly 80,000.00 square kilometers and a population of 3,920,000 (2006 census). The climate is like much of West Africa comprising of a rainy season and a dry season. The seasonal rainfall regime gives rise to a longer wet season of about seven months with an average rainfall of 250mm, and a dry season of about five months with little or no rains at all. About half of the land area of Niger State is covered by complex basement rocks while the other half is occupied by Cretaceous sedimentary rocks of the Bida basin and parts of Sokoto (Iullemeden basin). Similar research on assessment of leachate contamination of groundwater at some waste disposal site in Minna –North Central using Geoelectrical (VES and IP) and physico-chemical method. The results acquire show that this area is generally distinguished by three geological formations, infiltration and contamination of leachate streams at different moisture levels and depths, with significant IP effects, permeability and thickness of the over lying mantle (i.e.15 m or more) are determined towards the northeast, northwest and the south of the Fm site and the area east of the Albishir site according to Omale (2016)

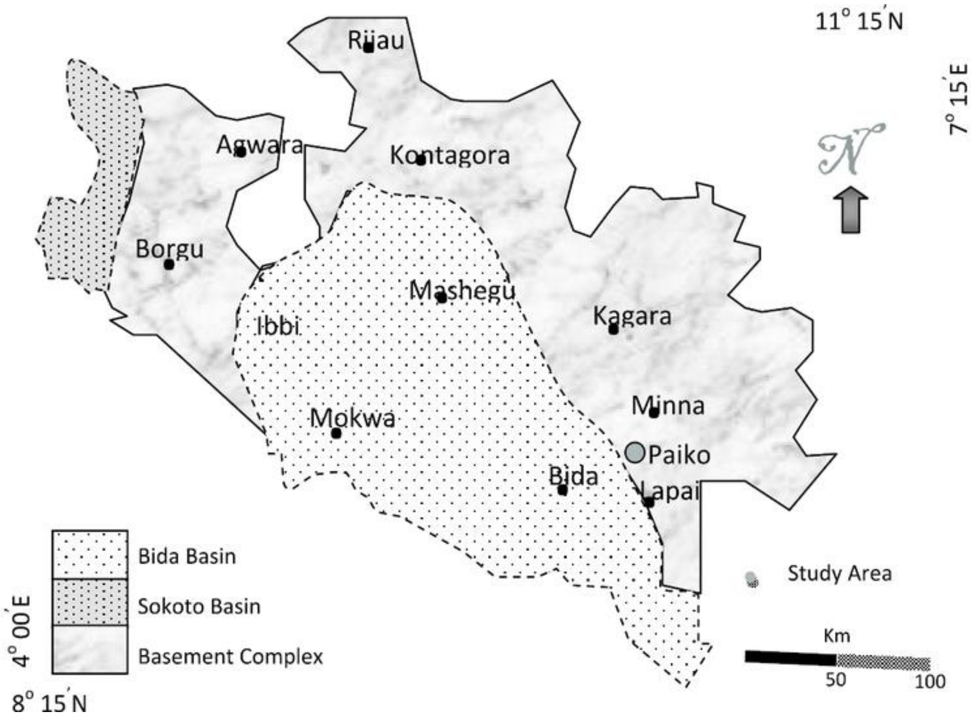

Figure 1: Geological map of Niger State basement complex and sedimentary basins (Amadi et al., 2012)

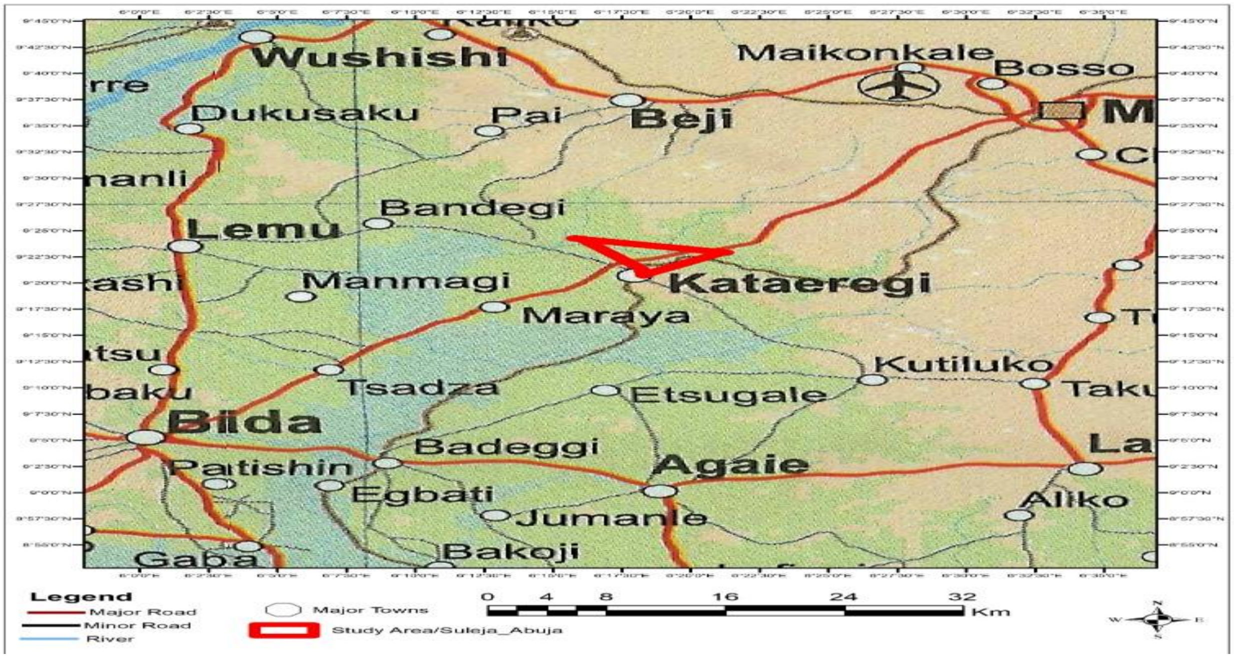

Figure 2: Location map of the Study Area

MATERIALS AND METHODS

In geophysical surveys, the SAS 4000 terrameter can measure natural or induced signals at extremely low levels, with excellent penetration and low power consumption, and can be used in Many applications require poor signal-to-noise discrimination. The strength of SAS 4000 lies in its ability to distinguish geological formations with similar resistivity (ABEM AB instruments, 1999).

Field procedure

The field investigation began with a reconnaissance survey using the "GPS" system of visual inspection, measurement and global positioning. The purpose of the reconnaissance survey was to identify the best locations and also identify the landfill sites in Niger state. Three soundings and one profiling survey were conducted inside the landfill and one sounding outside the landfill as a control.

Vertical Electrical sounding

The Schlumberger method was applied for this study because field work is faster, easier, and economically cost-effective (Selvam et.al 2010).This configuration is commonly used because it will provide information about a penetration depth ranging from 1⁄3 to ¼ of the total electrode distance present according to (Mallam and Ajayi, 2000).The resistivity values of the layers were measured using ABEM SAS 4000 Terrameters. Schlumberger surveys were performed with current electrode spacing (AB/2) ranging from 1 to 60 m per discharge. The distance used for the potential distance (MN/2) varies from 0.5 – 5.0 m.

Wenner Profiling

For 2D imaging, this were performed along a profile at each of 3 field locations, this technique is accomplished by sending a direct current down ground through a pair of current electrodes, while the voltage drop is measured through another set of potential electrodes. For each profile, a constant electrode spacing of 1a, 2a, 3a, 4a, 5a and 6a each for both current and potential electrode were used consecutively depending on nature of the location. For an electrode spacing of 1a, the spacing distance of current and potential electrodes are equal and are shifted successive readings along the spread of a maximum of 200m. The same procedure was repeated for each of the electrode spacing of 1a, 2a, 3a, 4a, 5a, and 6a separately, where represent 'a' is the electrode spacing which is equal to 10m (Agu and Mallam, 2023)

Very Low Frequency Electromagnetic (VLF- EM) ABEM WADI

Very low frequency electromagnetic (VLF-EM) geophysical methods involve the use of electromagnetic frequencies between 3 and 30 kHz to study subsurface features. In this method, the electromagnetic frequency is utilized to generate a VLF signal that is transmitted back to the ground. The signal is affected by subsurface geology, such as the conductivity of different rock layers and the presence of underground structures. By measuring the VLF signal at different locations of the study area, it is possible to create a map of surface geology and detect features such as buried metal objects or cavities. VLF electromagnetic methods are commonly used in a variety of applications, including mineral exploration, archaeological prospecting, and military detection of buried munitions. Instruments commonly used for electromagnetic geophysical methods include VLF transmitter, receivers, and antennas. The transmitter generates the VLF signal, which is then transmitted into the ground using antenna .The receiver is used to detect the VLF signal that is reflected back from the subsurface , and this signal is then used to create a map of the surface geology . The specific type of equipment used will depend on the specific application and the characteristics of the area being surveyed .for example, a handheld VLF transmitter and receiver may be used for small –scale survey, while a vehicle –mounted system may be used for a larger-scale survey.

Physiochemical Analysis

Three soil samples were collected from one of the location at 3 different depth first at the surface ,0.5m and finally at 1.0 m respectively. Water samples were collected from existing hand dug wells around the vicinity of the dumpsites, a water sample within the dumpsite and another sample 500km outside the dumpsite to serve as a control. Global positioning system were used to measure latitude, longitude and the elevation of each sample collected and analyzed

RESULTS AND DISCUSSION

VES Results

The inspection of the sounding curves in figure (3) and table (1) revealed the different geoelectric layers in terms of their resistivities and depths in the study area. A total of three geoelectric layers of H- curve type ($\rho_1 > \rho_2 < \rho_3$) were delineated reflecting litho logical variations with depth. The topsoil comprises has resistivity ranging from 30 -1331.9 Ωm with thickness and depth of 0.5 -2.5 m .This low resistivity is attributed to contamination of topsoil due to accumulation of leach ate (Shevin, 2005). This layer is preceded by clay formation at the second layer with resistivity values 5.8 -100.9 Ωm and depth 2.3 – 11.9 m indicating the migration of the leachate from the topsoil, thereby contaminating the groundwater due to leachate inversion (Ugwu and Nwosu, 2009). The third layer suggested as the fresh basement with resistivity range of 177.9- 2750.1 Ωm with limitless depth.

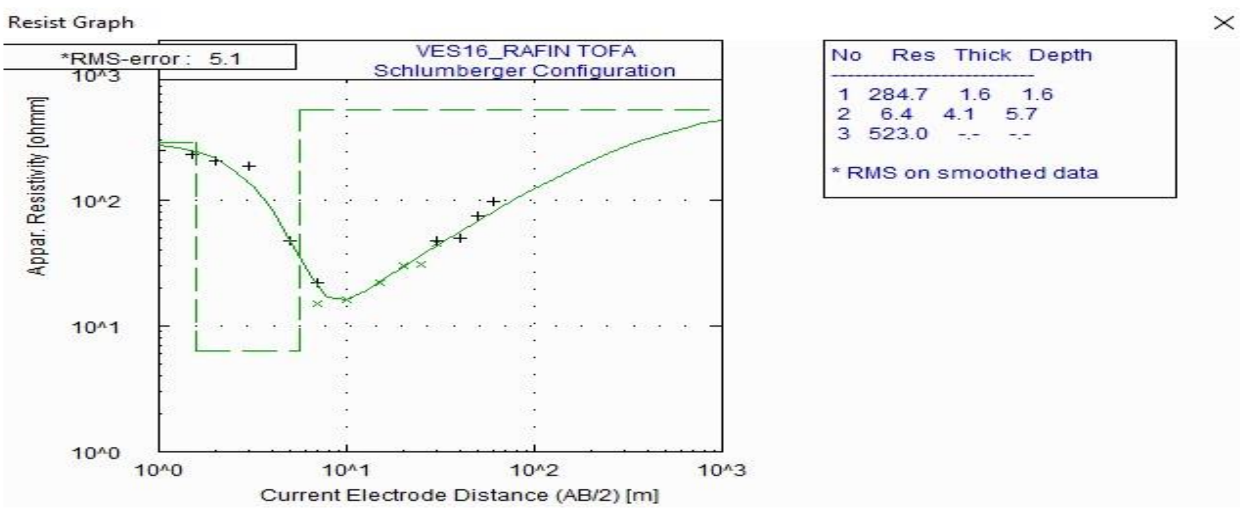

Figure 3: A typical H-Type Curve

Table 1: Summary of 1D interpretation

Location /coordinate	Number of layers/ curve Type	Resistivity values (Ωm)	Thickness (m)	Depth (m)	Lithology
Fm Maitumbi1	3- layers	1331.9	0.5	0.5	Topsoil
9 38’19.11’’N	$\rho_1 > \rho_2 < \rho_3$	12.2	2.4	2.8	Weathered
6 35’45.55’’E	H- Type	1061.6	-	-	Basement
Fm Maitumbi2	3- layers	219.7	0.5	0.5	Topsoil
9 38’17.85’’N	$\rho_1 > \rho_2 < \rho_3$	23.2	3.8	4.4	Weathered
6 35’39.92’’E	H- Type	2750.1	-	-	Basement
Fm Maitumbi 3	3- layers	302.0	0.9	0.9	Topsoil

9 38'16.55''N	$\rho_1 > \rho_2 < \rho_3$	92.1	3.3	4.2	Weathered
6 35'37.93''E	H- Type	1144.3	-	-	Basement
Fm Maitumbi	3- layers	172.5	1.0	1.0	Topsoil
Control	$\rho_1 > \rho_2 < \rho_3$	52.5	5.4	6.5	Weathered
9 38'19.75''N	H- Type	1202.0	-	-	Basement
6 35'21.61''E					
Albishiri1	3- layers	485.9	0.6	0.6	Topsoil
9 34'59.71''N	$\rho_1 > \rho_2 < \rho_3$	43.5	5.4	6.0	Weathered
6 30'44.21''E	H- Type	2008.1	-	-	Basement
Albishiri 2	3- layers	566.4	0.7	0.7	Topsoil
9 34'56.96''N	$\rho_1 > \rho_2 < \rho_3$	34.4	8.3	9.0	Weathered
6 30'46.06''E	H- Type	407.3	-	-	Basement
Albishiri 3	3- layers	438.7	1.1	1.1	Topsoil
9 34'54.25''N	$\rho_1 > \rho_2 < \rho_3$	38.4	11.9	13.0	Weathered
6 30'47.71''E	H- Type	1297.9	-	-	Basement
Albishiri	3- layers	473.8	1.2	1.2	Topsoil
Control	$\rho_1 > \rho_2 < \rho_3$	100.9	8.8	10.0	Weathered
9 35' 6. 11''N	H- Type	1578.0	-	-	Basement
6 30 33.39''E					
Rafin –Tofa	3- layers	180.3	0.8	0.8	Topsoil
9 40'43.54''N	$\rho_1 > \rho_2 < \rho_3$	16.5	2.3	3.1	Weathered
6 26 27.09''E	H- Type	233.0	-	-	Basement
Rafin –Tofa	3- layers	284.7	1.6	1.6	Topsoil
9 40' 40.6''N	$\rho_1 > \rho_2 < \rho_3$	6.4	4.1	5.7	Weathered
6 26' 6.86''E	H- Type	523.0	-	-	Basement
Rafin –Tofa	3- layers	30.0	1.0	1.0	Topsoil
9 40'43.54''N	$\rho_1 > \rho_2 < \rho_3$	5.8	3.0	3.0	Weathered
6 26 27.09''E	H- Type	177.9	-	-	Basement
Rafin –Tofa	3- layers	594.4	2.5	2.5	Topsoil
Control	$\rho_1 > \rho_2 < \rho_3$	27.7	6.8	9.3	Weathered
9 40'38.90''N	H- Type	2388.8	-	-	Basement
6 26 44.50''E					

Wenner Profiling Results

Rafin-Tofa Dumpsite Minna,Niger State(latitude 9. 40' 40'' 48° N and Longitude .6 26' 6'' 80° E)

In figure 4, the resistivity model shows low resistivity zone < 54.0 Ωm at a depth of (1- 5 m), this very low resistivity zones coded (blue) at the surface, depicts clay formation, this were observed at edge of the SE zone of the topsoil, between station 170 and 180 are suspected contamination zones since it was closer to the dumpsite. Leachate plumes with low resistivity contain organic matter and dissolved solids (Ugwu and Nwosu, 2009). The high resistivity zone (101.0 - 359.0 Ωm) spreads along NW-SE direction at the depth 10 -30 m, interpreted as clay/sandy. The high resistivity value indicates that the migration of the leachate plume has not affected the groundwater in this area. The red area at the bottom indicates fine sand lithology.

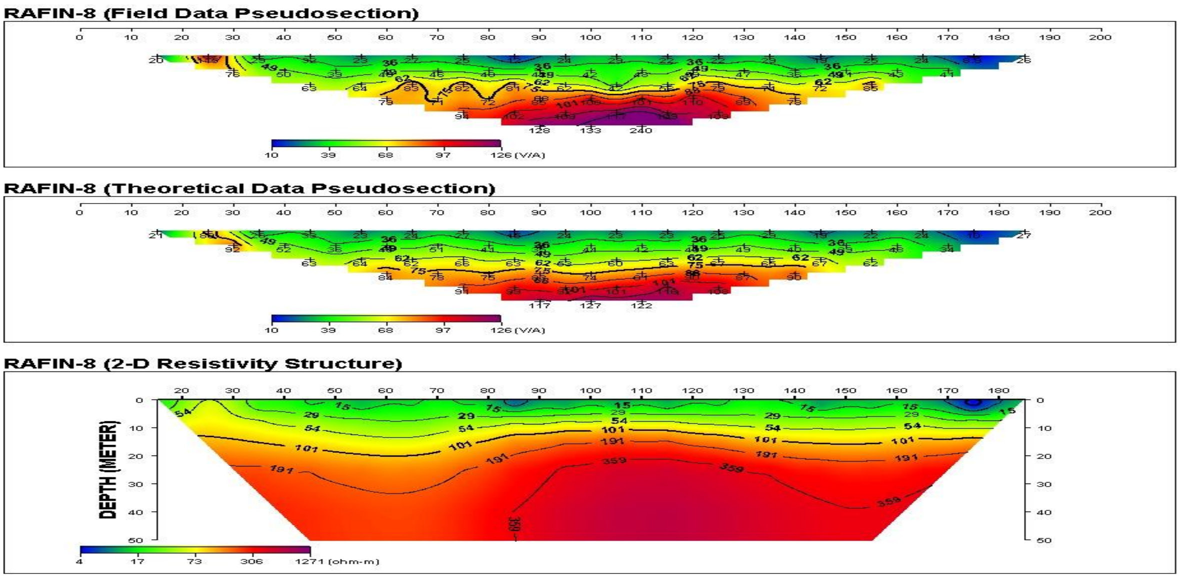

Figure 4: 2D Pseudo-section

FM maitumbi Dumpsite Minna, Niger State (latitude 9. 40' 40'' 48° N and Longitude .6 26' 6'' 80° E)

Figure 5 shows a low resistivity zone < 44.0 Ωm at the depth of 1 m at the edge of NW direction at of the transverse at station 20, which depicts clay topsoil, which is an indication of saturated conducting materials suspected to be leachate plume at this zone. The high resistivity zone (350.0 - 1383.0 Ωm) coded red at the depth of 20 -60 m, this indicates that the leachate plume has not infiltrated this zone and has not contaminated the groundwater in this area. The red coloured zone found at the base indicates fine sand lithology.

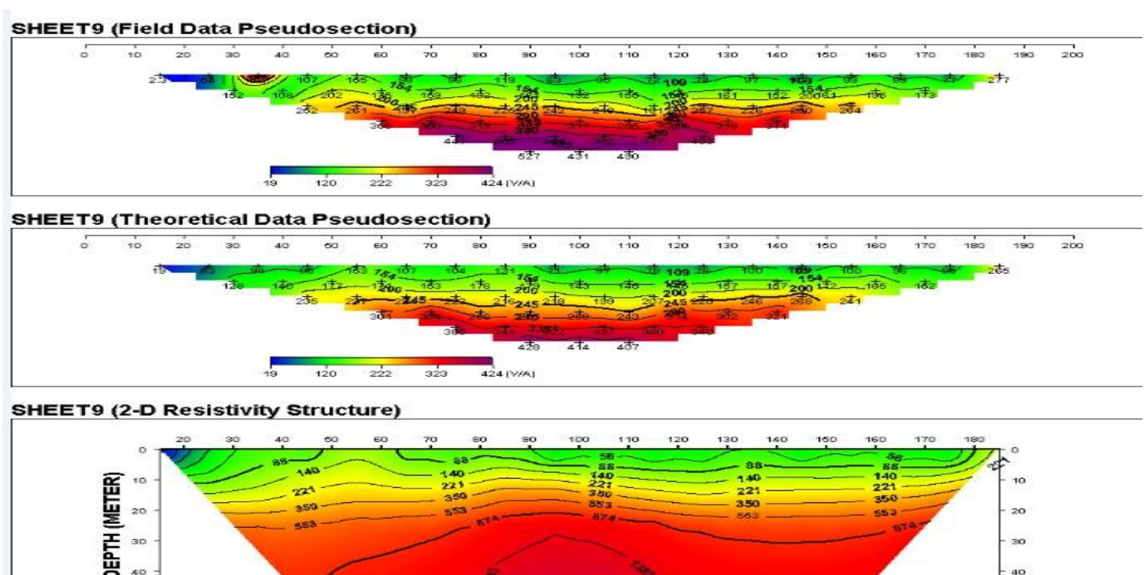

Figure 5: 2D Pseudo-section

Albishiri Dumpsite Dumpsite Minna, Niger State (latitude 9. 34' 57'' 68° N and Longitude 6. 30' 45'' 77° E)

Figure 6, shows that the traverse line is a high resistivity zone underlain predominantly by a sandy formation. Three distinct resistivity layers were delineated. Clayey sand with low resistivity values ranging from 9.0 – 33.0 Ωm was found at a depth range of 3.0 - 25 m, at station 120-150, revealed the presence of leachate contaminants significantly attributed to the low resistivity responses at the south eastern zone of the dumpsite. This layer is underlain by sand with resistivity values varying from 50.0 to 112.0 Ωm. Underlying this is also a sand layer with minor intrusions, the lateral increase in the north west direction is responsible for high resistivity of surface rocks to about 166.0 – 2831.0 Ωm at depth of 5-10 m, coded in red. The groundwater here 1s free from contamination since the resistivties are much higher here is because the profile is not underlain by refuse (Adeoti et al., 2012).

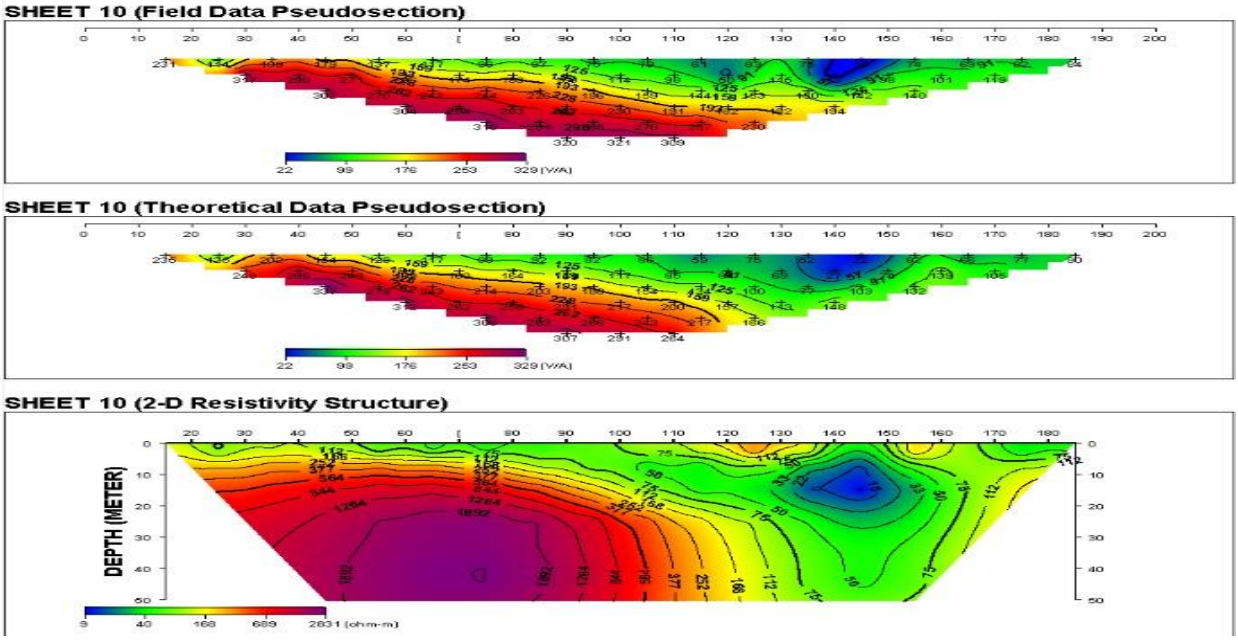

Figure 6: 2DPseudo-section.

Physio-chemical Results of Water Samples

The study area showed a pH range of 6.65 – 6.92), which is within the WHO permissible standard (6.5 - 8.5) for drinking water. The Electrical Conductivity (EC) of 3 samples showed high EC range from 571-926.8 µS/cm which is above WHO standards for EC value which should not exceeded 400 µS/cm. High electrical conductivity is usually attributed to contaminant fluids rich in dissolved salts (Abdullahi et al., 2010). Total Dissolved Solids (TDS) level of less than about 500 mg/l is generally considered to be good, the (TDS) values range from 169.3 - 454.1 mg/l which falls within WHO standard. Water with high TDS (>500 mg/dm³) is undesirable for consumption as it may taste, bitter, salty and may have unpleasant odors (Aweto, 2012). WHO (World Health Organization) determines that the turbidity of drinking water should not exceed 5 NTU and ideally should be less than 1 NTU. According to the result, two of the locations showed turbidity values above 1 NTU such as 11 NTU and 45 NTU respectively. Which is not ideal according to WHO standard and 2 others showed values below the recommended value which ranged from, 0.75-0.95 NTU. The Nitrate level 2.6 -5.5 mg/l was below WHO standard of 50mg/l the heavy metals tested (i.e Iron (Fe), Zinc (Zn),Copper (Cu), and Cadmium (Cd) all fall under the WHO standard permissible standard for drinking water expect for Manganese (Mn) which is slightly above. This results when correlated with the geophysical results confirmed that the leachate has infiltrated and contaminated the groundwater around active and abandoned landfills.

Table 2: Physico-chemical for water samples Analysis

Parameter	UNIT	FM1	FMC	AL1	ALC	WH0 STANDARD
PH		6.65	6.90	6.77	6.92	6.5 – 8.5
EC	µS/CM	517.3	550.7	344.7	926.8	400
TDS	Mg/l	253.3	269.6	169.3	454.1	500
TURBIDITY	NTU	0.75	0.95	45.0	11.0	5
NITRATE	Mg/l	3.0	5.5	2.6	NIL	50
Fe	Mg/l	0.003	NIL	NIL	0.102	0.3
Mn	Mg/l	0.551	NIL	NIL	0.115	0.4

Cu	Mg/l	NIL	NIL	NIL	NIL	2
Pb	Mg/l	NIL	NIL	NIL	NIL	0.01
Zn	Mg/l	NIL	NIL	NIL	NIL	3

Physico-Chemical Results of Soil Samples

Soil pollution can be caused by many different pollutants, but heavy metals (especially Cu, Ni, Cd, Zn, Cr and Pb) are considered the main sources (Hinojosa et al., 2004). The content of organic matter, clay minerals and pH in soil has a direct influence on the impact of heavy metals on the biochemical properties of soil organisms (Speira et al., 1999). The toxic effect of heavy metals on soil organisms is to disrupt biological processes, reducing their activity and quantity. Some heavy metals disrupt enzyme activity and their chemical effects in oil in different ways. Cd has a more toxic effect on enzymes than Pb due to its greater mobility and lower adhesion to soil particles (Karaca et al., 2010).The samples analyzed showed a high concentration of 173.6 Mg/kg of Cu in S2 beyond the WHO maximum allowed limits (ppm) of 30 mg/kg and no trace (Pb and Cd).while the Fe, Zn, Mn, Ni falls under the WHO maximum allowed limits.

Table 3: Physio-chemical analysis summary for soil sample.

Parameter	**UNIT**	**S1**	**S2**	**S3**
PH	-	7.31	7.02	7.05
EC	µS/CM	28.02	74.80	44.80
NITRATE	ppm	133.0	34.2	6.4
Cu	ppm	NIL	173.6	NIL
Fe	ppm	1263.6	1304.9	1273.1
Pb	ppm	NIL	87.91	NIL
Zn	ppm	NIL	264.9	NIL
Mn	ppm	1.17	3.03	137.8
Ni	ppm	NIL	2.81	NIL
Cd	ppm	NIL	NIL	NIL

Table 4: The maximum permissible heavy metal concentration in soil designated by the world health organization (WHO, 1996)

Toxic metal WHO maximum allowed limits (ppm)	**Maximum allowed concentration limits of some toxic metals in soil (mg/kg or ppm).**
Ni	80
Cu	30
Cd	3
Cr	100
Pb	100
Zn	300
Mn	≤100
Fe	50,000-100,000

VLF-EM Results

A Karous Hjelt filter is used to obtain relative current density pseudo-sections. Lower values of relative current density are associated with higher values of resistivity (Benson et al., 1997). In the figures below, the areas of high current density flow correspond to positive values (red ones). Profile 1- 5 were collected in NE-SW of the landfill and show high current density values spreading around the location which was at a distance of 100 m for each profile at the dumpsite located at Rafin Tofa , Albishiri and Fm-mutumbi all in Minna Niger State.

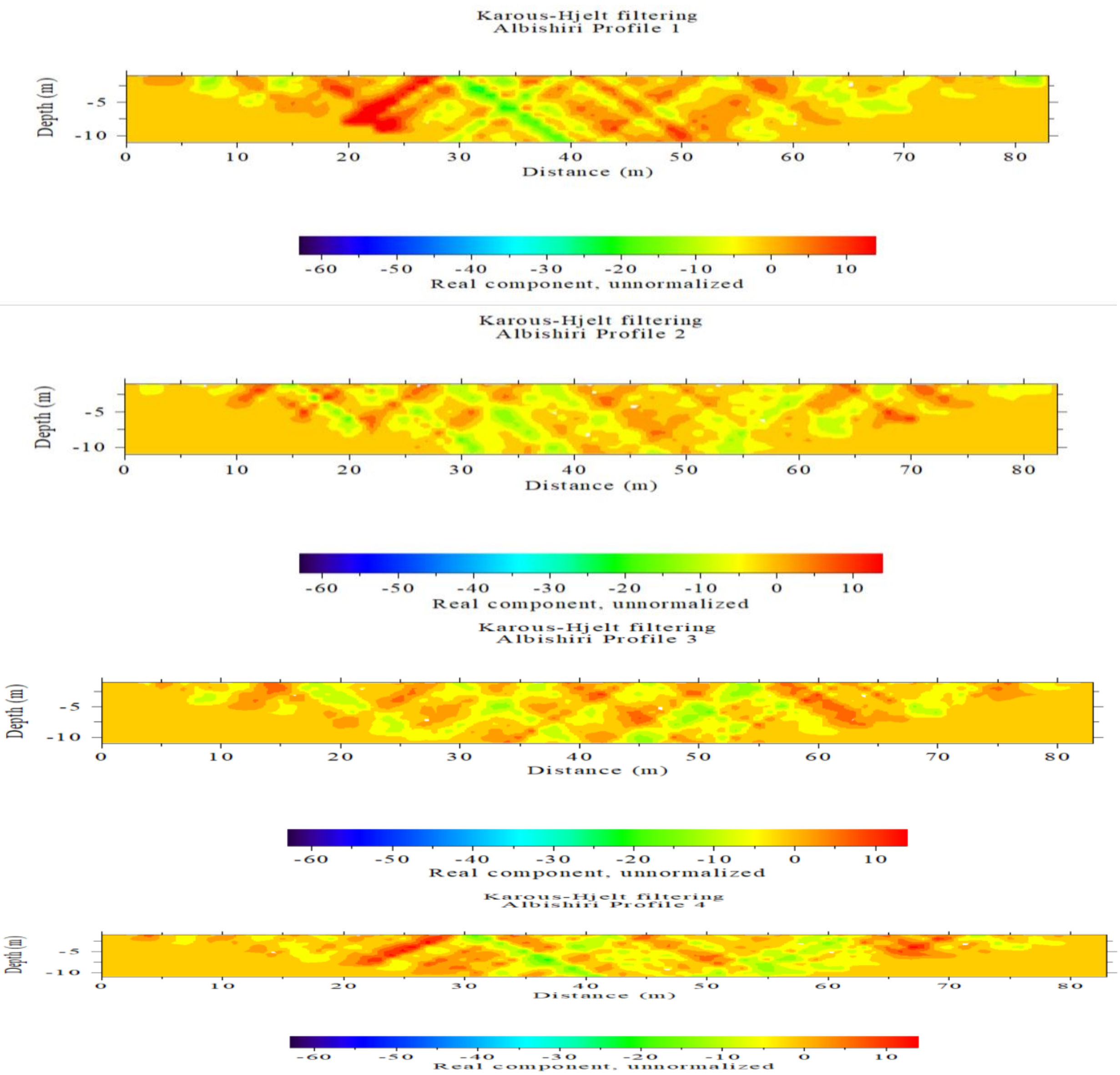

Figure 6: Albirishi VLF Results

CONCLUSION

Three major subsurface layers of H-type curve were delineated with a low resistivity value <100 Ωm were discovered in the second layer of the Vertical Electrical Sounding. The 2D Wenner profiling reveals the lateral and vertical variation of the subsurface strata with the resistivity of high conductive zone value < 100 Ωm and depth < 10m. Very Low Frequency Electromagnetic survey reveals the near surface fracture. The high conductive zone was visible in all the profile which shows the migration of leachate plumes in the surrounding area of the dumpsite the 2D and VLF-EM resistivity structure complements the VES results. The water samples with high EC and Mn and soil samples results with high Mn when correlated with the geophysical results confirmed that the leachate has infiltrated and polluted the groundwater around active and abandoned landfills.

REFERENCES

Abdullahi, N.K. Osazuwa, I.B and Onuga A. (2010). Detecting Municipal solid waste Leachate Plumes through Electrical Resistivity survey and Physio-chemical analysis of groundwater samples *Journal of American Science 6(8).*

Adeyemo, I.A, Akande, V.D., Aremo F.F and Ajayi G.O (2015). Geophysical Investigation of Impact of Geologic Structures on Preferred Percolating Paths of an oil based Leachate within a Migmatite –Gneiss

Environment: A Case Study of FUTA, Akure Campus (Nigeria). *Journal of Environment and Earth Science Vol.5, No.14, 2015*

Adeoti, L., Alile O.M., and Adegbola, R.B.(2012). Geoelectrical Investigation of the Groundwater Potential in Mowe, Ogun State, Nigeria. British Journal of Applied Science and Technology 2 *(1): 58 -71*, ScienceDomain international www.sciencedomain.org

Amadi, A. N., Olasehinde, P. I., Okoye, N. O., Momoh, O. I., and Dan-Hassan, M. A. (2012).Hydrogeophysical Exploration for Groundwater Potential in Kataeregi, Northern-Central Nigeria. Int. J. Sci. Res., 2, 9-17.

Agu, C. Rita and Mallam, Abu. (2023). Investigation of Leachate Plume and Groundwater Pollution using Geophysical and Physio-chemical Methods in an Open Dumpsite at Idugosa, Federal Capital Territory (FCT), Abuja, Nigeria. Physics Access. 03. 15-21. 10.47514/phyaccess.2023.3.2.004

Benson ,A.K., Payne, K. L. and Stubben, M.A (1997), Mapping groundwater contaminationusing DC resistivity and VLFgeophysical methods – A casestudy , Geophysics, 62, 80-86

Christensen, J. B., Jensen,D. L., Gron, C., Filip, Z. and Christensen, T.H.,(1993). Characterization of the dissolved organic carbon in landfill leachate-polluted groundwater, *Water research*, 32,125-135.

Hassanein, Khaled. (2019). Chemical analysis and environmental impact of heavy metals in soil of wadi jazanarea southwest of saudiarabia. Applied Ecology and Environmental Research. 17. 7067-7083. 10.15666/aeer/1703_70677084

Ismail , Z & Hashim R. (2006). Seepage of contaminants from waste containment. *Journal of Environmental hydrology 14:2*

Karaca, A. Cetin, S. C., Turgay, O. C., Kizilkaya, R. (2010): Effects of Heavy Metals on Soil Enzyme Activities. – In: Sherameti, I., Varma, A. (ed.) Soil Heavy Metals (Soil Biology). Springer, Heidelberg, pp. 237-265.

Mallam, A. and Ajayi C.O., (2000). Resistivity Method for groundwater investigation in sedimentary area. *Nigeria Journal of Physics, 12*

Selvam, S., Sseshunarayan T., Manimaram G., Sivassubramanian P., and Manimaram D., (2010).Groundwater investigation using Geoelectric survey : a case study from Kanukuna Village , Andhra Pradesh , India Journey of outreach , 4, pp 59-61

Ugwu, S.A. and Nwosu, J.I., (2009). Effect of Waste Dumps on Groundwater in Choba using Geophysical Method. Journal of Applied Sciences and Environmental Management. 13(1): 85-89.

WHO (1996): World Health Organization Report. – WHO, Geneva. [40] Woo, S., Yum, S., Park, H. S