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Vulnerability Assessment of Groundwater to Contamination Using Electrical Resistivity Method at the Open Dumpsite in Gosa, Abuja, Nigeria

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Abstract

Electrical resistivity method was used to investigate the open dumpsite at Gosa, Abuja in order to determine the vulnerability of the groundwater in the area as well as the surrounding environment to leachate contamination. A total of sixteen (16) vertical electrical sounding points with maximum current electrode of 100 m were investigated. The data were analyzed and used to establish the parameters required to fulfil the objectives of this research. A maximum of four geoelectric sections were identified in the area. They included sandy topsoil, clayey sand, weathered basement and fractured/fresh basement. Apparent resistivity values obtained for the four layers delineated were between 64.6 Ωm and 215.5 Ωm for the first layer; 19.0 Ωm and 295.6 Ωm for the second layer; 66.9 Ωm and 1003.7 Ωm for the third layer; and 438.0 Ωm and 1719.9 Ωm for the fourth layer. Furthermore, the ranges of the thickness of the layers were found to be 0.7 m and 12.9 m for the first layer; 1.3 m and 9.8 m for the second layer; and 1.6 m and 11.6 m for the third layer. The depths of water table in the area were estimated to range between 2.1 and 21.6 m. The parameters used in characterizing the aquifer protective capacity of the overburden units were layer thickness and their corresponding resistivity values. Accordingly, the total longitudinal layer conductance of the overburden of the area was generally found to be low, ranging between 0.014 mhos and 0.063 mhos, implying that the aquifer protective capacity of the area is poor. The 1D resistivity cross section for the three profiles investigated exposed the movement of contaminants toward the aquifer, further validating the fact that the aquifer is not protected. The low protective capacity of the area aided the conclusion that the water aquifer in the area was highly vulnerable to leachate contamination from the dumpsite.

Keywords: Electrical resistivity; Groundwater; Environment; Contamination; Vertical electrical sounding; Apparent resistivity; Aquifer; Longitudinal layer conductance; Overburden

Introduction

Contamination of groundwater under and near waste disposal site happens as a result of infiltration of contaminants through the soil. Pollutants are aqueous liquid called leachate. It is formed when rain falls on the dump, sinks into the waste and picks up contaminants as it seeps downwards [1]. Meanwhile, the earth materials act as natural filter to percolating fluids; therefore, its ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity [2]. The often shallow aquifer in the basement complex terrains is usually exposed to surface and near-surface contamination [3]. It has been asserted that once an aquifer is excessively depleted or contaminated, the damage is essentially permanent and efforts to reduce the contamination are extremely costly [4]. In the study area and the surrounding neighbourhood, there are palpable concerns over remediation costs in the event of full-blown contamination since groundwater tapped from hand dug wells and boreholes at depths that are sometimes as shallow as 6 m is the main source of water used for domestic, agricultural and industrial activities in the area [5]. The Gosa dumpsite was neither properly designed nor constructed as landfill site. Population explosion accompanied by astronomical increase in domestic, commercial, and industrial activities in the city has led to an increase in the generation of various categories of waste in the Federal Capital Territory (FCT) over the years. The system of waste disposal at the Gosa open dumpsite is open dumping, hence the indiscriminate distribution of wastes observed at the site during reconnaissance visit.

Wastes dumped at the dumpsite over the years are expected to have biodegraded and generated leachate which could have become a point source of pollutant into the soil and groundwater. It is therefore important that the aquifer vulnerability capacity of the layers underlying the dumpsite is assessed to determine the possible impact of the dumpsite on groundwater in the area [6]. Predictably, this mode of waste disposal makes the area and the surrounding environment highly vulnerable to groundwater contamination. In order to guarantee a continuous supply of safe and potable water in the area, there is need to investigate the vulnerability of the aquifers to contaminants emanating from the various categories of wastes dumped at the site [7].

Electrical resistivity methods are generally classified according to the energy source involved i.e. natural or artificial. For example, self-potential (SP) and telluric current come under natural source methods, while resistivity, electromagnetic (EM) and induced polarization (IP) are examples of artificial source methods [8]. This research employed artificial energy source from ABEM terrameter (SAS 300). Vertical electrical sounding technique has been used by different researchers as an efficient and economical technique in the investigation of contaminated sites [1,9,10]. It has also been deployed to determine several subsurface geologic parameters such as the thickness of the bedrock, salt water intrusion, the vertical extent of certain types of soil, the spread of groundwater contamination, among others [11]. The procedure utilizes direct current of low frequency (preferably less than HZ) rather than alternating current because direct current allows

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greater depth of penetration than alternating current. Another reason for using this procedure was to avoid electromagnetic coupling.

VES method was chosen for this research because of its simplicity and reliability [12]. Further, the method was preferred to ensure easy resolution, interpretation of results as well as determination of geoelectric parameters [11]. The combination of layer resistivity and thickness can be used to compute the Dar Zarrouk parameters L_c(longitudinal conductance) and R_T (transverse resistance) which are employed in aquifer protection studies and evaluation of hydrologic properties of aquifers [13].

The Study Area

Gosa is one of the main suburbs of Abuja. The open dumpsite in Gosa is located in the Idu Industrial Area of the FCT. The dumpsite is accessed either through the Nnamdi Azikiwe International Airport Road or Idu Karimu axis of Abuja. The Gosa dumpsite was provided in the Abuja Masterplan for location of an integrated waste management facility in the FCT [14]. It has a landmass of 891,200 m^2 (89.12. The FCT administration started using the dumpsite for waste disposal in the early 80s. During the period, there was basic infrastructure necessary for operation as a landfill site. After the internal road network collapsed, the site was abandoned and immediately, the waste disposal activity was moved to Mpape [15]. The waste disposal site was re-located back to Gosa in 2005 when the Mpape site was filled up. The system of waste disposal at Gosa is open dumping, hence the indiscriminate dumping prevalent at the dumpsite. The increasing population of Abuja has made Gosa an important settlement for the middle class and low income earners working and living in the capital city. Many residents of the area embark on the development of private boreholes and hand dug wells to augment public water supplies which are inadequate. Boreholes developed in the area are abortive and hence does not meet the expectations of their owners [13].

Geology and Hydrogeology of Gosa

Gosa forms part of the Basement Complex of north central Nigeria with lithologic units falling under three main categories which include undifferentiated migmatite complex of Proterozoic to Archean origin, metavolcano-sedimentary rocks of late Proterozoic age, and older granite complex of late Precambian – Lower Paleozoic Age, also known as Pan-African granites [16,17]. All these rocks have been affected and deformed by the Pan-African thermotectonic event [18]. In other words, the concealed basement rocks may contain highly faulted and folded area, joint and fracture systems which resulted from multiple tectonic events they have experienced [19]. The rocks are generally weathered into reddish micaceous sandy clay to clay minerals, capped by laterite. The hydrogeology of basement areas is simple since there is an inherent limitation to the occurrence of groundwater. However, where the regolith is thick, and there is a dense network of fractures, the potentials for the accumulation of groundwater in the basement complex rocks may increase. Ideally, the area can be divided into two units, namely, the aquiferous zone within the weathered overburden overlying the fresh basement rocks and the aquiferous zone within the intense fracture joint system in the partially weathered basement. [7]. A combination of thick regolith, high rainfall and favourable temperature pattern in the FCT offers a conductive condition for occurrence of groundwater [20]. Geological and hydrogeological studies contracted out by the Abuja Environmental Protection Board (AEPB) show that the site consists of clay-sandy soil such that the incorporation of bentonite would make it an ideal location for an engineered landfill [21]. The geological map of the study area showing the location of Gosa is presented in Figure 1.

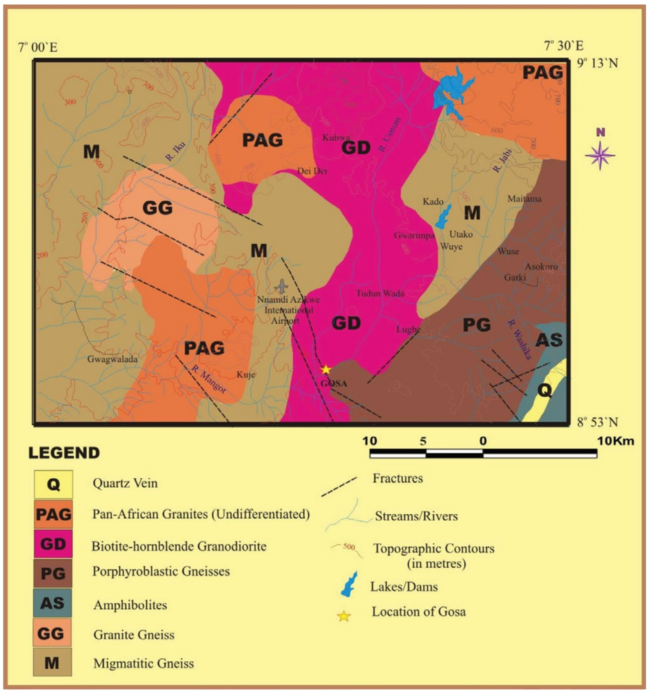

Figure 1: Geological map of the study area showing the location of Gosa (adapted from Omeje [16]).

Materials and Methods

The following equipment were used in carrying out this research: ABEM Terrameter SAS 300 C Resistivity Meter; four steel electrodes (two electrodes used as the potential electrodes and the other two electrodes for the current electrodes); four cable reels with metal clips attached to the wires; two measuring tapes; and hand held Global Positioning System (GPS) - Garmin 75 Model. The geologic features observed during reconnaissance visits to the site included undulating land forms, flood plain, rock outcrop, and water body. The information gathered during the reconnaissance visits was used in carrying out the field work which was performed during the dry season.

Electrical resistivity method which employs the Schlumberger electrode configuration with maximum current electrode separation (AB/2) of 100 m was used in acquiring VES data at the site. Overburden in the basement area is not as thick as to warrant large current electrode spacing for deeper penetration [8]. Therefore, the largest current electrode spacing AB=100 m used in this research was sufficient to achieve research objectives. Electrical resistivity surveys are usually designed to measure the electrical resistivity of subsurface materials by making measurements at the earth surface [22]. VES works on the principle of electrical resistivity which involves injecting a specified amount of electric current into the ground through a pair of current electrodes and then with the aid of potential electrodes, measure the potential difference between two points at the surface caused by the flow of the electric current in the subsurface. From the measured current (I) and the voltage (V) values, the ensuing resistivity is determined. Figure 2 shows a simplified diagram of the Schlumberger array

All the three profile lines were laid in N-S direction within the

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dumpsite. The choice of profile lines were informed by convenience and potential for contamination. The first profile was close to the boundary of the dumpsite while the other two were laid sequentially toward the centre of the dumpsite. Each profile was separated by a distance of 10 m. Accordingly, five (5) sounding points, each separated by 5 m were established on each profile. One VES dataset (VES 16) was acquired along the road leading to the Open Dumpsite for use as control in the analysis. The distance between VES 1 at the Gosa Open Dumpsite and the control point (VES 16) was 1.6 km. The GPS coordinates of each sounding point was captured and recorded against each point (Figure 3).

Data analysis

VES data were processed to determine the geoelectric parameters (overburden units, thickness and resistivity) as well as the hydrogeological characteristics of the subsurface [23]. The apparent resistivity values calculated for each geoelectric layer were plotted on bi-log (log-log) graph against the half current electrode separation AB/2. From the qualitative values, geoelectric parameters such as the resistivity of the top (first) layer as well as the thickness/depth of each layer were determined. The first quantitative interpretations were carried out using partial curve matching method in which the curves generated were matched segment by segment with the suitable master curves and auxiliary curves. The results from the modelling were finally iterated to the lowest Root Mean Square (RMS) percentage error with the aid of the win RESIST Version 1.0 Software (which uses the fixed layer interpretation method). The iteration process was conducted for each sounding point until the root mean square (RMS) error of about 5 percent was obtained. Selected graphs of apparent resistivity plotted against half current electrode spacing for each sounding point (VES station) are presented in Figures 4-12.

The total longitudinal layer conductance (S) of the overburden at each station was calculated [1]. Total longitudinal layer conductance (S) is one of the Dar Zarrouk parameters. Summary of the VES

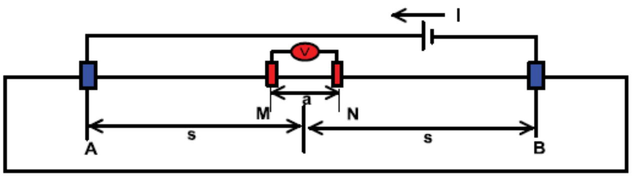

Figure 2: Simplified diagram of the Schlumberger Array.

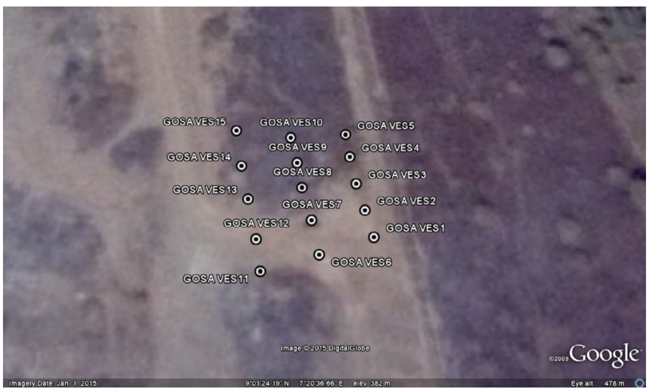

Figure 3: Google Earth map showing the VES points for the open dumpsite in Gosa, Abuja.

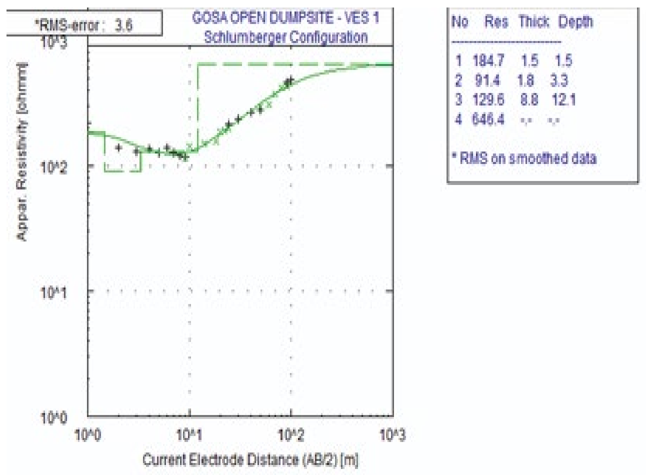

Figure 4: VES 1; GPS coordinates: 318003.99E, 997727.08N.

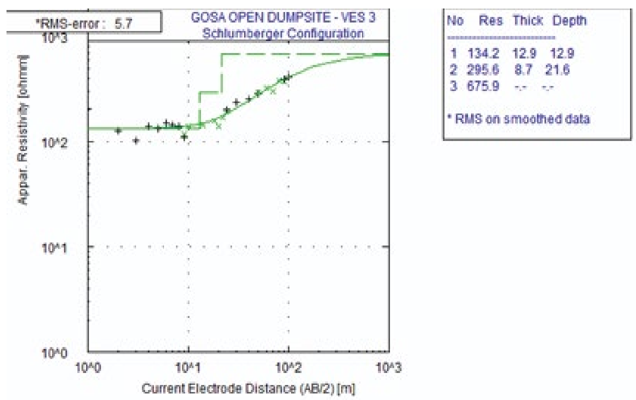

Figure 5: VES3; GPS coordinates: 317997.61E, 997735.10N.

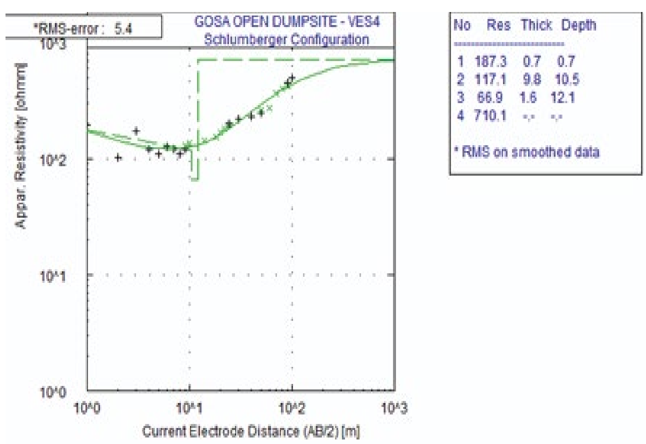

Figure 6: VES 4; GPS coordinates: 317995.18E, 0997739.41N.

number/GPS coordinates, geoelectric parameters, total longitudinal conductivity of protective layers, and the aquifer protective capacity rating of the study area is presented in Table 1. A standard used in assessing longitudinal conductance/aquifer protective capacity of an

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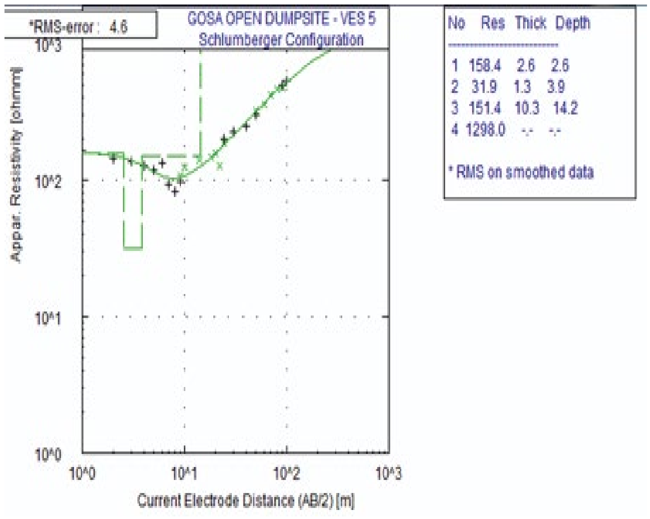

Figure 7: VES 5; GPS coordinates: 317993.06E, 997743.11N.

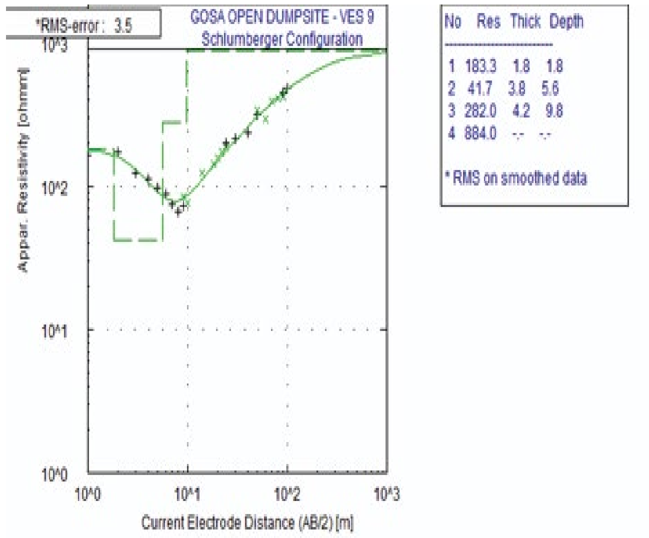

Figure 9: VES 9; GPS coordinates: 317986.61E, 997735.15N.

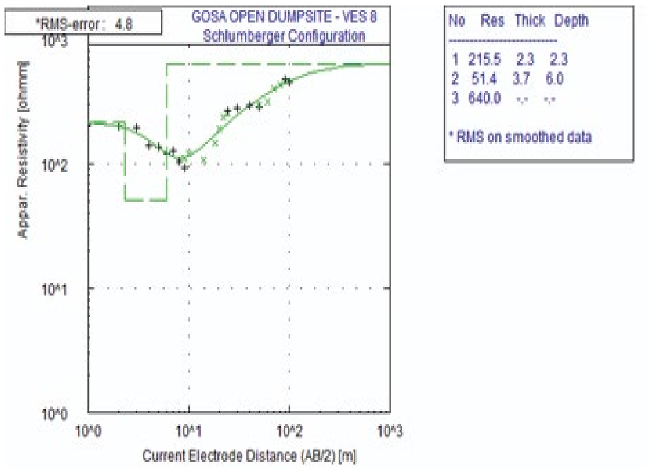

Figure 8: VES 8; GPS coordinates: 317989.04E, 997731.14N.

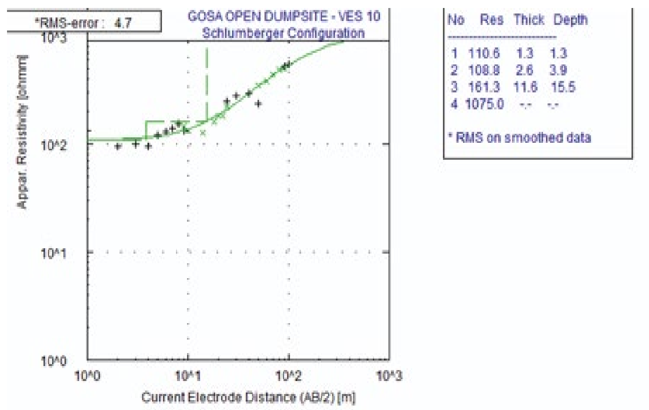

Figure 10: VES 10; GPS coordinates: 317983.86E, 997735.30N.

area is presented in Table 2. It is on the basis of this classification that the aquifer protective capacity of the dumpsite was characterized [2].

Geoelctric Sections

Figures 13-15 show the geoelectric sections for the three profiles at Gosa open dumpsite. To a large extent, the results show a degree of correlation in terms of the number of layers when compared with an existing borehole log (Figure 16). The first layer is mainly Sandy Topsoil. The resistivity of the layer ranges between 64.6 Ωm and 215.5 Ωm, while the layer thickness ranges between 0.7 m and 12.9 m. The second layer is the Clayey Sand with resistivity ranging between 19.0 Ωm and 118.5 Ωm. The thickness of the second layer ranges between 1.3 m and 10.5 m. The second layer (Clayey Sand) shows low resistivity values possibly due to the accumulation of leachate or because of the charged surfaces (characteristic of clay) and associated boundary layers of attracting ions. The third layer (Weathered Basement) shows decreasing trend of resistivity in some VES points and increasing trend of resistivity in others. The decreasing trends of resistivity are

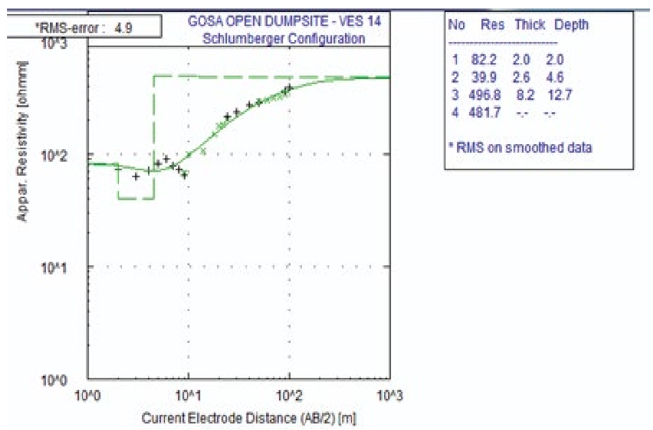

Figure 11: VES 14; GPS coordinates: 317977.43E, 997731.19N.

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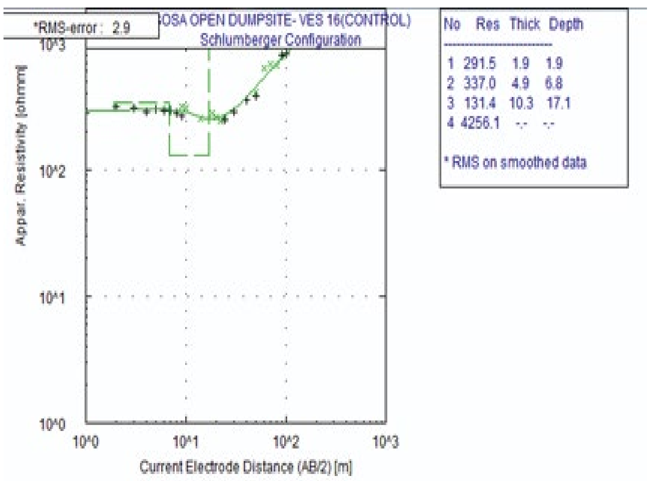

Figure 12: VES 16 (Control); GPS coordinates: 318003.01E, 999329.92N.

indications of contamination. The trend could also be caused by water saturation. The thickness of the third layer ranges between 1.6 m and 11.6 m. The fourth layer which constitutes the bedrock layer (Fractured or Fresh Basement) exhibited resistivity values ranging between 438.0 Ωm and 1752.2 Ωm. The bedrock at some VES points, for example VES 2, demonstrated varying degree of fracturing with resistivity values ranging between 438.0 Ωm and 888.0 Ωm. The low resistivity values at the basement level could also be caused by contamination. Accordingly, the bedrock formations of some VES points, for example VES 5 with resistivity values equal to or greater than 1000 Ωm are highly resistive fresh basements.

Figure 17 shows the geoelectric section for the control point. Summary of the layers and their corresponding resistivity values is presented in Table 3. The first three layers showed higher resistivity values compared with the resistivity values for their equivalent in the VES points measured along the three profiles at the dumpsite. The fresh basement exhibited much higher resistivity value of 4,256.1 Ωm. The relatively lower resistivity values recorded across all the VES points at the dumpsite, particularly for the first three layers are attributable

S/N	VES Number/GPS Coordinates	Layer	Resistivity, ρ (Ωm))	Thickness, (m)	Total Longitudinal Layer Conductance (S)	Total Longitudinal Conductivity of Protective Layers (mhos)	Aquifer Protective Capacity Rating
1	318003.99E, 997727.08N	1	184.7	1.5	0.008	0.032	Poor
		2	91.4	1.8	0.020		
		3	129.6	8.8	0.068		
		4	646.4	-	-		
2	318000.95E, 997731.09N	1	202.6	0.8	0.004	0.017	Poor
		2	75.2	1.3	0.017		
		3	118.7	11.3	0.095		
		4	438.0	-	-		
3	317997.61E, 997735.10N	1	134.2	12.9	0.096	0.063	Poor
		2	295.6	8.7	0.029		
		3	675.9	-	-		
4	317995.18E, 0997739.41N	1	187.3	0.7	0.004	0.037	Poor
		2	117.1	9.8	0.084		
		3	66.9	1.6	0.024		
		4	710.1	-	-		
5	317993.06E, 997743.11N	1	158.4	2.6	0.016	0.042	Poor
		2	31.9	1.3	0.041		
		3	151.4	10.3	0.068		
		4	1298.0	-	-		
6	317996.02E, 997720.97N	1	143.1	2.2	0.015	0.039	Poor
		2	118.5	4.4	0.037		
		3	131.8	8.6	0.065		
		4	829.8	-	-		
7	317992.68E, 997726.21N	1	151.0	2.3	0.015	0.038	Poor
		2	35.6	3.0	0.084		
		3	297.0	4.5	0.016		
		4	769.8	-	-		
8	317989.04E, 997731.14N	1	215.5	2.3	0.011	0.042	Poor
		2	51.4	3.7	0.072		
		3	640.0	-	-		
9	317986.61E, 997735.15N	1	183.3	1.8	0.010	0.038	Poor
		2	41.7	3.8	0.091		
		3	282.0	4.2	0.015		
		4	884.0	-	-		
10	10 317983.86E, 997735.30N	1	110.6	1.3	0.012	0.036	Poor
		2	108.8	2.6	0.024		
		3	161.3	11.6	0.072		
		4	1075.0	-	-		

11	317987.44E, 997714.87N	1	97.5	2.0	0.021	0.054	Poor
		2	49.6	4.3	0.087		
		3	1003.7	-	-		
12	317984.71E, 997719.79N	1	95.9	1.7	0.018	0.014	Poor
		2	19.0	2.2	0.012		
		3	201.9	2.6	0.013		
		4	1719.9	-	-		
13	317980.77E, 997725.96N	1	64.6	0.8	0.012	0.036	Poor
		2	24.0	2.1	0.088		
		3	662.6	4.7	0.007		
		4	487.7	-	-		
14	317977.43E, 997731.19N	1	82.2	2.0	0.024	0.035	Poor
		2	39.9	2.6	0.065		
		3	496.8	8.2	0.017		
		4	481.7	-	-		
15	0317974.09E, 0997735.20N	1	104.1	1.2	0.012	0.034	Poor
		2	37.4	2.5	0.067		
		3	366.6	7.9	0.022		
		4	1752.2	-	-		
16	318003.01E, 999329.92N (Control)	1	291.5	1.9	0.007	0.033	Poor
		2	337.0	4.9	0.015		
		3	131.4	10.3	0.078		
		4	4256.1	-	-		

Table 1: Summary of the VES Number/GPS Coordinates, Geoelectric Parameters, Total Longitudinal Conductivity of Protective Layers, and the Aquifer Protective Capacity Rating of the Study Area.

S/N	Longitudinal Conductance (mhos)	Protective Capacity Rating
1	>10	Excellent
2	5-10	Very good
3	0.7-4.9	Good
4	0.2-0.69	Moderate
5	0.1-0.19	Weak
6	<0.1	Poor

Table 2: Longitudinal conductance and aquifer protective capacity rating (adapted from Ogungbemi et al.).

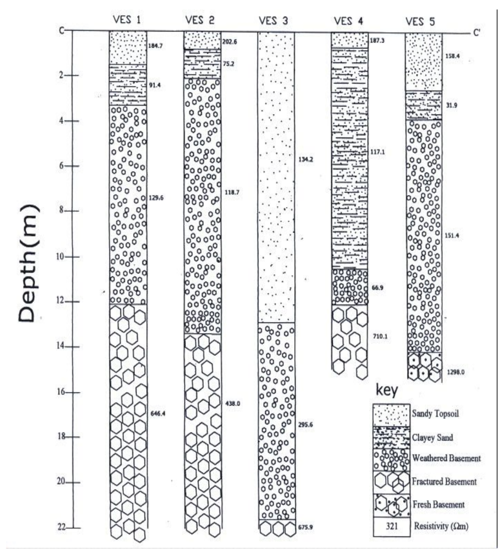

Figure 13: Geoelectric sections for profile 1 at Gosa open dumpsite.

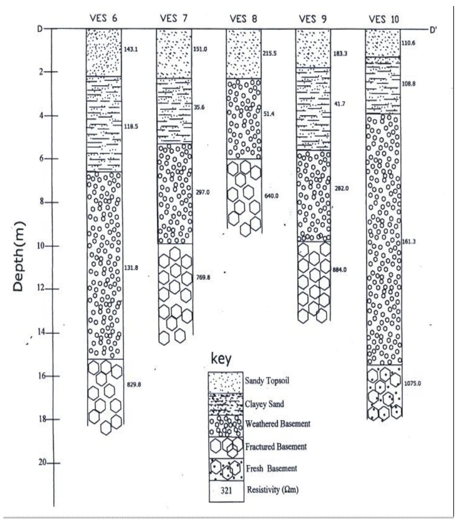

Figure 14: Geoelectric sections for profile 2 at Gosa open dumpsite.

to the various degrees of contamination that have taken place at the dumpsite following years of open and indiscriminate dumping of various categories of wastes.

Discussion

The total longitudinal conductance of the study area is low, ranging from 0.014 mhos (at VES 12) to 0.063 mhos (at VES 3). By implication, the aquifer protective capacity of the area is poor. Geoelectric sections generated for the overburden units show that the topmost layers at all the VES points are mostly sandy, while the second layer are occupied by clayey sand. The clay content in the second layer is minimal while the thickness of the layer is generally thin at all the VES points, thus providing little or no protection to the aquifer beneath them [3]. In geological terms, clayey overburden which is characterized by

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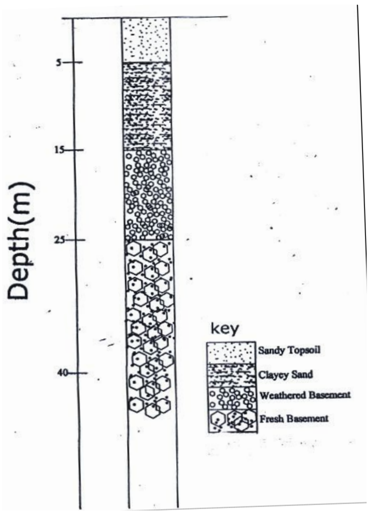

Figure 15: Geoelectric sections for profile 3 at Gosa open dumpsite.

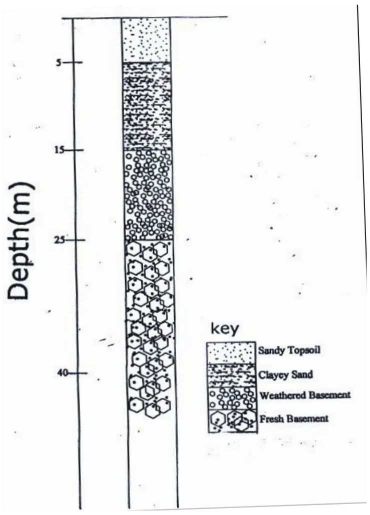

Figure 16: Typical borehole log of Gosa (Modified by Omeje et al.).

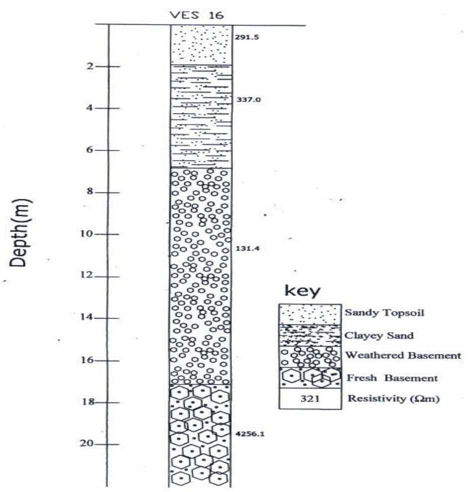

Figure 17: Geoelectric section for the control point (VES 16).

S/N	Layer Number	Geoelectric Layer	Resistivity Value (Ωm)
1	1	Sandy Topsoil	291.1
2	2	Clayey Sand	337.0
3	3	Weathered Basement	131.4
4	4	Fresh Basement	4256.1

Table 3: Table Showing layers and their corresponding resistivity values for the control point (VES 16).

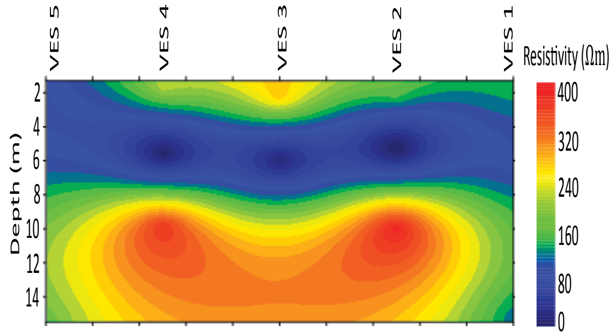

Figure 18: Resistivity cross section for profile 1 at the Gosa open dumpsite.

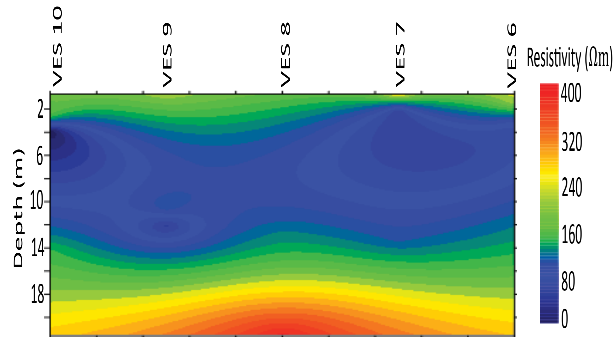

Figure 19: Resistivity cross section for profile 2 at the Gosa open dumpsite.

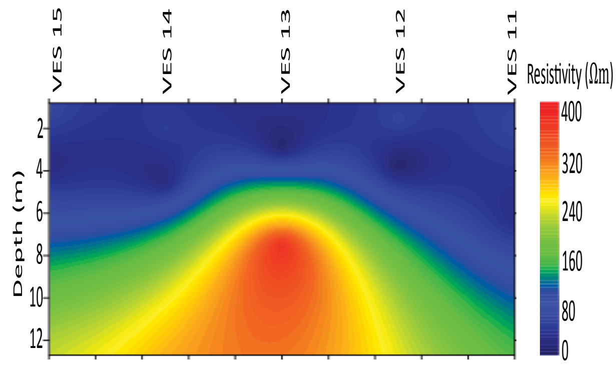

Figure 20: Resistivity cross section for profile 3 at the Gosa Open Dumpsite.

relatively high longitudinal unit conductance offers protection to the underlying aquifer. It has been reported that materials such as sand and gravel have low longitudinal conductance resulting from their higher resistivity values as a result of having low aquifer protective capacity [24]. The low value of the protective capacity is as a result of the absence of significant amount of clay as an impermeable material in the study area. This condition enhances the percolation of contaminants into the aquifer. From the foregoing, it is seen that the aquifer in the dumpsite area is prone to contamination [1]. Evidently, the shallow aquifer (perched aquifer) in the area can be easily polluted/contaminated by contaminated surface runoff water in the area [25]. The 1D imaging pseudo resistivity cross sections at the three profiles indicate possible occurrence of leachate across all the VES stations. It also confirms shallow occurrence of groundwater level which invariably implies the possibility of leachate entering into the groundwater level within short human and geological time [26].

Profile 1 (Figure 18) at the Gosa open dumpsite was taken at the north western axis of the site, close to the perimeter margin (boundary). The resistivity model for this profile (Figure 18) shows an uneven distribution of resistivity on the surface, particularly between VES 2 and VES 4, with the highest value of about 240 Ωm observed at VES 3. The reason for the uneven distribution of resistivity values is because waste disposal is minimal at the boundary but increases in intensity towards the centre of the dumpsite. At VES 1 and VES 5, there are indications of saturated zones represented by low resistivity of between less than 10 Ωm and 80 Ωm, starting at the ground surface down to 8 m depth. The colour scaling changing from deep blue to light blue reflects the changes in the concentration of leachate as it seeps down due to filtration by sediments. As observed in the model, there is evidence of lateral and vertical migration of the leachate plume. The approximately 240 Ωm resistivity observed at VES 3 is representative of sandy topsoil. The model reveals resistivity values of between 240 Ωm and 280 Ωm at the cross over zone at the depth of between 10 m and 14 m. This portion can be inferred to be a fracture in the crystalline basement rock. The zone with resistivity values upwards of 400 Ωm observed at VES 2 and VES 4 with varying depths is interpreted as fractured basement rock with varying degrees of water content.

Profile 2 (Figure 19) was laid parallel to and 10 m from Profile 1. The seemingly uniform and relatively lower resistivity at the surface of Profile 2, compared to Profile 1 reflects the presence of thin layer of surface contamination, with apparent resistivity values ranging from 80 Ωm to 120 Ωm. The prominent feature in the model is the horizontal low resistivity zone of between less than 10 Ωm and 90 Ωm which indicate an overburden saturated with leachate plumes. Further comparison between Profile 1 and Profile 2 shows that there is lateral and vertical migration of the contaminants along the profiles with Profile 2 showing higher rate of migration as seen in the contaminated zone (blue colour) extending down to the depth of about 14 m, while the equivalent contamination in Profile 1 is at the depth of about 8 m. Evidently, the rate and intensity of contamination increases as one moves towards the centre of the dumpsite.

Profile 3 (Figure 20) was taken at the same interval maintained throughout the investigation process i.e. 10 m from and parallel to Profile 2. The migration of the contaminant leachate downward towards the bottom implies that either the leachate is heavy and highly concentrated or that the surrounding media are porous [27]. The trend of very low resistivity values observed from the surface of the profile down to the depth of about 5 m is indicative of the degree of contamination along the profile. It also portrays the extent of groundwater contamination as a result of accumulation of leachate. At a depth of about 10 m at VES 11, leachate plume indicative of very low resistivity and thus high level of contamination follows a diagonal path upward up to a depth of about 5 m. From this point, the plume follows the same pattern (diagonal trend) and terminates at a depth of about 9 m at the western flank of the profile, thus creating a hemispherical zone of inverse resistivity which ranges between about 200 Ωm and over 400 Ωm downward. The high resistivity zone at greater depth could be interpreted as the weathered regolith underlying the dumpsite [28,29].

Conclusion

The results obtained from this research shows that the Open Dumpsite in Gosa is underlain by materials of poor aquifer protective capacity. By implication, the aquifer systems in the area are highly vulnerable to contamination from infiltration of leachate from decomposed wastes dumped at the site. This study has validated the opinion of previous researchers (Omeje et al, 2014) and (Omeje et al, 2013) that the subsurface in the area is characterized by low clay content and unconsolidated sand. This combination offers minimal impedance to fluid movement required to filter and also increase the residence time of percolating contaminants arising from leachate. From the pseudo resistivity cross sections constructed for the three profiles sampled at the dumpsite, it is seen that up to the depth of 14 m which is within the aquiferous zone in the basement complex environment where the dumpsite is located is already contaminated. This reinforces the inference that the materials underlying the site are of poor aquifer protective capacity. Being that the Gosa Open Dumpsite consists of clay-sandy soil, the incorporation of bentonite using multi-membrane would make the site ideal for the location of engineered landfill (Ayuba et al, 2013)

The results and data generated from this study should be taken into consideration when planning development projects that engages the subsurface within and outside the dumpsite. Such projects include water borehole, residential and commercial facilities, health facilities, roads, railways, farms, etc. Specifically, it is recommended that pre-drilling geophysical investigations should be carried out before embarking on any water borehole project within and around the dumpsite. Indeed, this research has reiterated the need for the introduction of modern engineered landfills with bottom liner for safe and sustainable waste disposal and management in Nigeria.

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