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Preliminary Investigations for Landfill Siting in Lafia, Nasarawa State of Central Nigeria

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Abstract: Waste management has taken the front purview in recent years due to the evident and attendant effects of indiscriminate disposal of wastes to the environment. This led to the preliminary investigations for the proposed siting of a landfill facility in Lafia and environs of Nasarawa State in Central Nigeria, with the aim of providing valuable information on the suitability for location for the disposal of Municipal Solid Waste (MSW). The combined use of geo-resistivity, geological and hydrogeological investigations were carried out for the study. Ten Vertical Electrical Soundings (VES) of the Schlumberger array was used to investigate the properties of the subsurface lithologies to determine their properties especially, clay, for siting a landfill. Clay, an attenuating material, is significant for siting a landfill facility because it tends to isolate potentially toxic wastes from the environment by slowing down the movement of leachates into groundwater and the environmental. Quantitative interpretation of data of the VES survey using the IPI2win computer software revealed the presence of four to five geologic layers comprising of sandy top soil (247 – 1964Ωm), silty sand (98 – 3488Ωm), clayey-shally/sand (68 – 3922Ωm), saturated clayey sand (31 – 3226Ωm) and loose sand (478Ωm). Clay was found to be abundant in the area and found at depths ranging from 30m to infinity. Geologically, structures like lineaments abound and were analysed; they show a dominant trend in the NW – SE direction from the Rosette Diagram. Lineaments are useful for studies because they are possible conduits where decomposed wastes in liquid form, such as leachates, get transported to pollute groundwater. Hydrogeological studies surveyed Static Water Levels (SWL) measurement from 51 hand dug wells in the study area. The SWL ranges between 5.8m and 37.1m. The data from the SWL was used to construct the absolute water level map in a 3D form to show the flow direction of the groundwater. The study revealed the presence of impermeable clays at VES 1, 2, 3, 9 and 10. This is significant for selection for landfill due to its pollution-prevention properties of groundwater pollution. The investigations carried out in this study show that Shabu, a town located about 8km from Lafia, is likely suitable for siting a landfill facility; because of the abundance of clay at a shallow depth of 30m and with limited preponderance of lineaments.

Keywords: Clay, Landfill, Leachates, Lineaments, Municipal Solid Waste, Resistivities, Vertical Electrical Sounding, Shabu

1. Introduction

1.1. Background to the Study

Waste management, especially in a developing country like Nigeria, is a challenge that is ravaging and affecting the environment adversely. Waste in the form of Municipal Solid Waste (MSW), comes in different forms which comprise of mixed metals, kitchen waste, paper, food scraps, plastics and glass [1]. Urban wastes constitute a wide range of materials such as food fragments, papers, rags, vegetable remains as well as dust and soil swept from streets and buildings [2]. This study was undertaken because waste management is one of the major challenges faced by municipality officials, public health officials, civil engineers and engineering geologists in their quest to safeguard the environment. MSW is defined as unavoidable and unwanted materials in solid, liquid and/or gaseous form which may be hazardous or non-hazardous [3]. Reasons for the huge volumes of MSW generation from households today may be related to the growth in the sizes of most Nigerian towns and cities leading to population explosion in leaps and bounds. As a result, households resort to indiscriminate disposal of MSW on streams, roadsides, vacant pieces of land, or borrow pits thereby leading to air pollution, groundwater and soil pollution, within Lafia metropolis of Nasarawa State [4, 5]. MSW has brought about environmental problems such as bad odours of wastes that attract flies, mosquitoes, snakes and rodents thereby serving as vectors, carrying infectious diseases. One of the ways to contain the menace of MSW disposal majorly utilized in the world today is the landfill. The construction and operation of an engineered sanitary landfill ensures proper and adequate waste management by disposing MSW in a way that safeguards the environment by laying the wastes in thin layers and subsequently compressing them into smaller volumes possibly by covering them with compacted soil after each working day. A number of developed countries have adequately managed and curbed their wastes as a result of proper planning and effective waste management policies [6]. Landfills in years to come will become the major mode of waste disposal because cheap equipment and machines are required to operate them.

Site selection suitable for landfills however, has become one of the greatest problems because several factors are taken into consideration such as the geology, proximity to residential houses, river/stream channels, structural geology (lineaments), etc. Lineament structures are crucial in site selection because their knowledge will help to curtail pollution of groundwater. However, the use of geophysical methods, especially by geo-electrical means, have proven their credibility in landfill-related studies, and become standard tools over the past decades in the determination of credible sites locations for landfills [7-10].

1.2. Literature Review

Research studies are available on MSW generation and management in developing countries such as Nigeria with each country having peculiar ways of handling their own waste. Among the studies are those that reveal how MSW defied several governments' laws and policies at different points in time [11]. The use of geophysical methods in landfill site investigation was carried out in Ibadan, Southwest Nigeria [12]. The work was carried out to provide detailed information on the suitability or otherwise the location for disposal of waste with utmost priority of preventing groundwater pollution. In their subsurface probe, 62 Very Low Frequency-Electromagnetic (VLF-EM) and 36 Vertical Electrical Soundings (VES) were used to determine the presence of linear structures, layer resistivity, bedrock depth, depth and characteristics of unsaturated zone, identification of any confined perched water bearing strata and subsurface features. Remote sensing (RS) and geographic information system (GIS) was used to delineate Karu metropolis to suitably site a landfill in the area for disposing MSW [13].

However, few publications are available in the use of geo-resistivity method for the purpose of landfill site selection for MSW disposal. This paper intends to bridge a gap to further add to the existing knowledge bank for site selection of landfills for future references. This forms the main objective of this paper which we believe will trigger further and detailed investigations in the years to come.

2. Location, Geology and Hydrogeology

2.1. Location

The study area is located in Lafia Local Government Area of Nasarawa State in Central Nigeria. It lies between between latitudes 8°30′00″N to 8°36′10″N and longitudes 8°30′00″E to 8°35′40″E, having an area extent of about 100 Km^2 (Figure 1). The mean annual temperature and mean annual rainfall of Lafia are 28.5°C and 1250 mm respectively [14]. The surrounding topography is almost flat to a great extent, slightly high in the south-eastern parts of the study area than in the north-western. Table 1 shows comprehensive information on the locations the VES and water level surveys from hand dug wells.

2.2. Geology

The study area which is characterized by ferruginized sandstones, red loose sands, flaggy mudstones and clays, is made up of two formations (Figure 1): the older Awgu Formation of Late Turonian – Early Santonian is coal-bearing while the younger Lafia Formation which is Maastrichtian in age ended the sedimentation in the Middle Benue Trough [15]. Awgu Formation was reviewed to be deposited in a marine environment and it consists of shale clays, siltstones and shelly limestones with some coals while the Lafia Sandstone which was deposited in a continental environment consisting of coarse grained, friable and feldspathic [16].

Being part of a larger sedimentary terrain, this area falls within the Middle Benue Trough of the Benue Valley of North-central Nigeria (Figure 2). The Benue Valley is widely believed to have evolved from a kind of rift structure due to a major fault along it [17]. Some authors postulated that what gave rise to the Benue Valley was sea floor spreading occasioned by the opening of the rift in the Cretaceous. This Benue Valley has rich documentations that are interesting and is worth studying in details.

2.3. Hydrogeology

The hydrogeology of the study area also follows that of the entire Benue Trough. The Lafia Formation is hydrogeologically viable because it is composed of majorly fine to coarse grain sandstones that are porously permeable for aquifers. The Middle Benue and other parts of the valley present difficult hydrogeological situations [16]. These ugly conditions become worrisome because most of the aquifers are either limited in capacity, thinly developed with constant clay and shale interbeddings or highly indurated formations that only secondary voids created by fractures, joints and solution openings can be hydrogeologically viable. Groundwater disposition of the Lafia Formation and other associated attributes was reviewed and there it revealed the presence of groundwater divides, like that of the Agyaragu Divide which separates the Lafia sub-basin from the main centre of the Giza basin [18]. It was observed that the groundwater flow recharges the Lafia sub-basin directly thereby making the bulk of the flow to emerge in the form of many springs at the contact with the impervious clays/shale beds of the Awgu Formation. The clay/shale formation in this study area poses great threats to hydrogeological potentials of Lafia and environs as it limits groundwater exploration of the area.

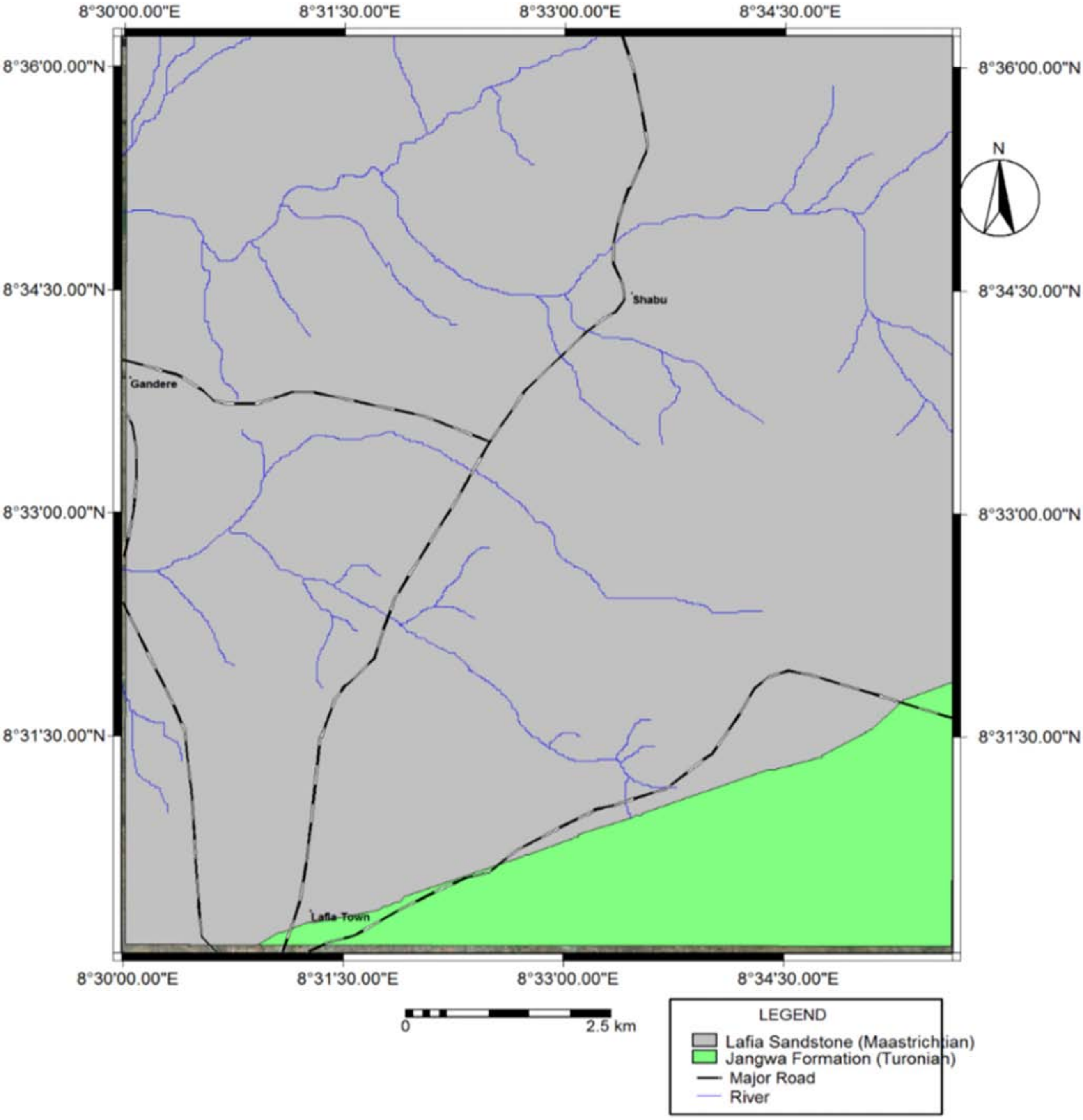

Figure 1. Geological Map of Study Area Showing the Two Formations.

Table 1. *Location of Vertical Electrical Sounding (VES) and Static Water Level (SWL) Measurement.*

Location	Survey Type	VES and HDW No.	Latitude (N)	Longitude (E)	Elevation (m)
Azuba	Vertical electrical sounding	VES 1	8°35’43.7”	8°34’11.5”	190
Kwandare II	VES	VES 2	8°35’03.8”	8°30’57.8”	140
Kwandare I		VES 3	8°33’57.2”	8°30’35.0”	154
Akurba I		VES 4	8°31’40.9”	8°34’27.5”	228
Akurba II		VES 5	8°30’45.3”	8°34’43.1”	226
AgwanRere		VES 6	8°31’12.8”	8°35’34.5”	258
AkurbaSanya		VES 7	8°33’06.2”	8°35’12.1”	191
Shend. Road		VES 8	8°30’54.3”	8°33’01.8”	202
Polytechnic		VES 9	8°32’30.2”	8°32’46.4”	190
Shabu		VES 10	8°34’41.7”	8°33’47.0”	164
Azuba-Bashayi	Hand dug well (HDW)	HDW 1	8°35′20.4"	8°33′25.1"	165
		HDW 2	8°35′32.8"	8°33′40.7"	166
		HDW 3	8°35′40.6"	8°34′3.7"	171
		HDW 4	8°35′43.8"	8°34′10.9"	172
		HDW 5	8°35′44.6"	8°34′9.6"	172
		HDW 6	8°35′45.1"	8°33′54.4"	161
		HDW 7	8°35′37"	8°33′33.7"	158
		HDW 8	8°35′28.0"	8°33′15.4"	157
		HDW 9	8°35′24.5"	8°33′10.2"	162
Shabu		HDW 10	8°34′27.4"	8°33′35.8"	155
		HDW 11	8°34′26.0"	8°33′40.1"	160
Coll. of Agric.		HDW 12	8°33′47.6"	8°32′29.6"	163
		HDW 13	8°33′43.7"	8°32′29.3"	158
		HDW 14	8°33′44.0"	8°32′23.8"	173
Danka Sarki		HDW 15	8°33′47.8"	8°31′10.0"	162
Kwandare		HDW 16	8°34′0.5"	8°30′21.6"	157
Polythecnic		HDW 17	8°33′1.2"	8°32′3.7"	182
		HDW 18	8°33 ′1.4 "	8°32′4.3"	178
		HDW 19	8°32 ′51.7"	8°32′18.5"	189
		HDW 20	8°32 ′51.5"	8°32′21.1"	183
Kurkyo		HDW 21	8°31 ′52.1"	8°32′57.6"	187
Akurba		HDW 22	8°31 ′42.8"	8°34′25.6"	220
		HDW 23	8°31 ′35.9"	8°34′25.4"	222
AngwanRere		HDW 24	8°31 ′26.3"	8°35′32.8"	243
AkurbaSanya		HDW 25	8°33 ′8.4 "	8°35′15.3"	191
BukanSidi		HDW 26	8°31 ′50.6"	8°31′26.9"	163
		HDW 27	8°31 ′45.7"	8°31′27.7"	162
		HDW 28	8°31 ′45.5"	8°31′17.3"	169
		HDW 29	8°31 ′46.4"	8°31′07.4"	171
		HDW 30	8°31 ′37.3"	8°31′04.9"	174
		HDW 31	8°31 ′25.3"	8°31′29."	173
		HDW 32	8°31 ′29.5"	8°31′28.0"	175
		HDW 33	8°31 ′29.1"	8°31′25.8"	181
		HDW 34	8°31 ′28.3"	8°31′32.3"	178
		HDW 35	8°31 ′19.2"	8°31′46.6"	184
		HDW 36	8°31 ′20.4"	8°31′42.7"	182
Kurkyo		HDW 37	8°31 ′45.8"	8°32′45.8"	180
		HDW 38	8°31 ′47.0"	8°32′44.6"	180
		HDW 39	8°31 ′47.8"	8°32′48.8"	177
		HDW 40	8°31 ′49.4"	8°32′49.1"	180
		HDW 41	8°31 ′49.6"	8°32′53.8"	188
		HDW 42	8°31 ′45.1"	8°32′46.4"	188
BukanSidi		HDW 43	8°31 ′39.9"	8°31′47.9"	184
		HDW 44	8°31 ′43.8"	8°31′36.1"	170
		HDW 45	8°31 ′39.7"	8°31′34.6"	168
Akurba		HDW 46	8°31 ′49.3"	8°34′16.1"	212
		HDW 47	8°31 ′52.2"	8°34′16.2"	201
		HDW 48	8°31 ′58.9"	8°34′17.8"	198
AngwanRere		HDW 49	8°31 ′27.8"	8°35′40.4"	243
		HDW 50	8°31 ′24.7"	8°35′44.8"	244
		HDW 51	8°31 ′24.5"	8°35′48.5"	246

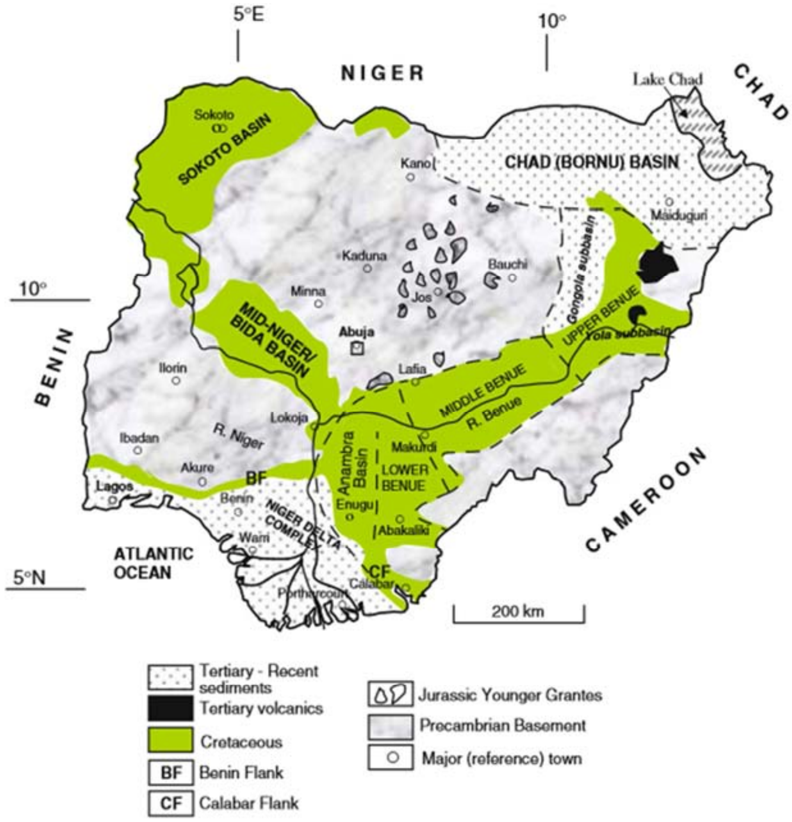

Figure 2. *Geological Map of Nigeria Showing the sub-divisions along the Benue Trough (after [19]).*

3. Materials and Methods

A total of ten Vertical Electrical Sounding (VES) stations were selected for the survey in the study area (Figure 4). The VES data for this study was obtained from using Schlumberger electrode array (Figure 3). Two electrodes each of potential and current were inserted and arranged such that the potential electrodes were positioned between the current electrodes. A measuring tape was used to rightly position both potential and current electrodes. The Avant Garde Resistivity meter was used to collect the data of the survey; this instrument generally measures the apparent resistivity of the subsurface lithology. The potential electrodes and current electrodes were connected to the potential terminal and current terminal respectively on the resistivity meter via the insulated copper cable wires.

During the survey, an artificially generated low frequency Direct Current (DC) was injected into the subsurface through a pair of current electrodes. The current electrodes half spacing (AB/2) ranges from 1.0 m to 200.0 m in successive manner and the potential difference that was generated between a pair of potential electrodes (MN/2) was measured. Coordinates of each VES station were written down together with their individual elevations using the Garmin Global Positioning System (GPS) device. Data that was generated from the survey was later plotted on a log-log graph sheet, placing the apparent resistivity (ρ_a) values on the *y-axis* while the current electrodes spacing (AB/2) on the *x-axis*. Plotted curves were interpreted quantitatively through partial curve matching. The results were further iterated using the iPi2win computer software. Pseudo resistivity cross-sections connecting more than two VES stations were later plotted and interpreted to a give a visual presentation of the subsurface of the preferred line of interest (Figure 4). The penetration depth of the current injected into the subsurface is proportional to the separation between the electrodes inserted in the homogeneous underlying layers while changing the current electrodes distance provides information about the distinct layers of the ground [20].

The geological mapping was carried out purposely to delineate and expose the major structural features in the study area. Lineament structures were identified and their direction orientations were also noted. Satellite image of the study area was obtained and subsequently, the lineament structures were traced and super-imposed on the topographical map to produce the lineament map. Lineaments are naturally occurring alignments of soil tones, topography, stream channels, vegetation or combinations of these fractures that are visible on remotely sensed imagery and aerial photographs. Presumably, the geomorphic expressions observed from lineaments features on satellite imageries are due to differential weathering with the fractures zones being readily susceptible to both mechanical and chemical weathering than unfractured rocks [21]. After producing the lineament map, it was further sub-divided into four parts so that each lineament structure in each quadrant is analysed in terms of the amount of degrees and direction of orientation by the use of a protractor and compass respectively. The main assumption inherent in performing any lineament analysis is that these alignments represent fracture zones (areas of intense, closely spaced fracturing) or other discontinuities (faults, geologic contacts) in the bedrocks that may be capable of transmitting groundwater or leachates to landfills as in the case of this paper. Data from the analysis was plotted on a rosette diagram to give a vivid picture of the structural trend generally.

The hydrogeological investigation involved the mapping of a total of fifty-one Hand Dug Wells (HDW) within the study area. The Static Water Level (SWL) of each HDW was measured by using a measuring tape with a dipper tied to the end measuring tape in meter. Once the measuring tape is lowered into the HDW and the dipper touches the water, the SWL is established. The coordinates and elevations above sea level of each of these wells were recorded. Absolute Water Level (AWL) of awell was calculated by subtracting the SWL from the elevation of that particular well. It is a dimensionless quantity. One of the uses of the hydrogeological investigation using the HDW is to determine water flow direction in the study area aside other uses that it has. Data generated from this survey were used to construct a water flow direction in a 3D presentation to grasp the pictorial and vivid presentation of the hydrogeological mapping of the study area.

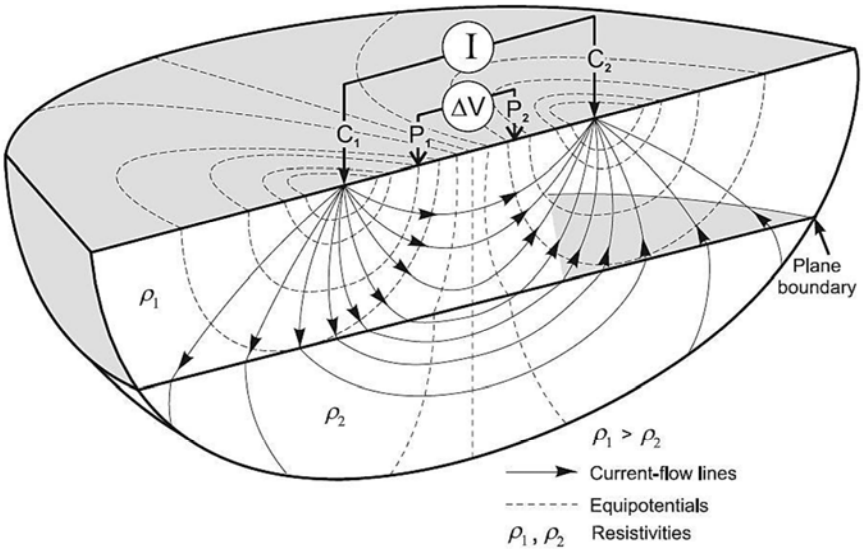

Figure 3. *Schematic Diagram of Electrical Resistivity Using the Schlumberger Array (after [22]).*

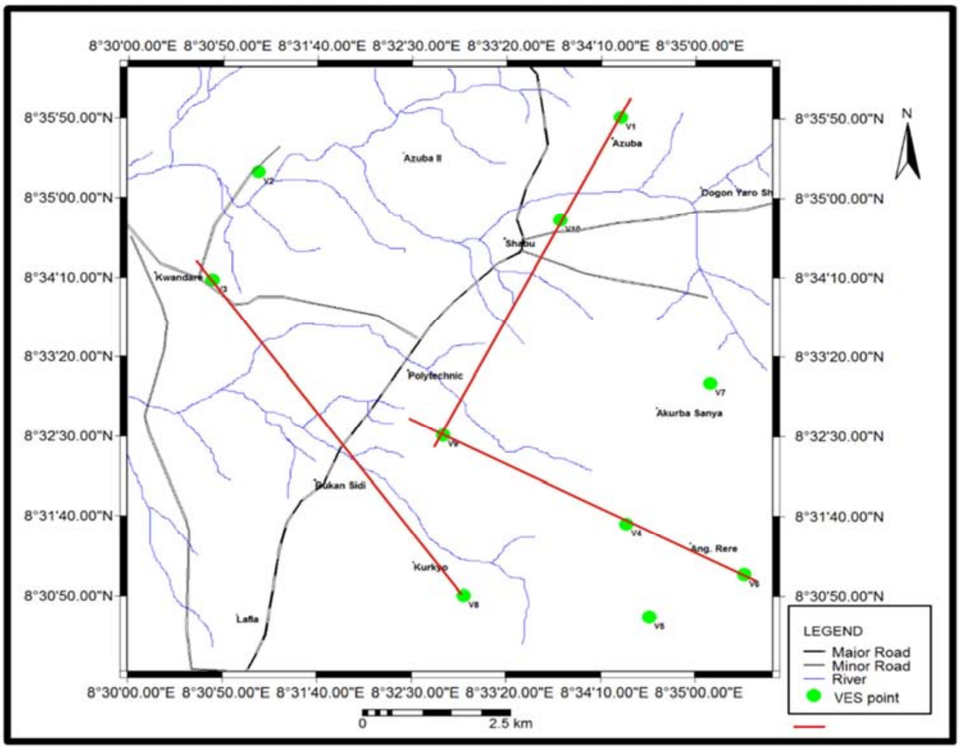

Figure 4. *Map of Study Area Showing Locations ofVES Points with profile Lines for Pseudo-Sections.*

4. Results and Discussion

4.1. Electrical Resistivity

Table 2 shows data generated from the ten VES stations of the study area. Quantitative interpretations of the VES show curve types that indicate 4 – 5 distinct geo-electric layers. The curve types are KQ, QH, AK, KH and HK, with a representative shown in figure 5. Analyses of the resistivity results layer by layer are as follows: (i) The resistivity of the sandy topsoil layer varies from 247 – 1964 Ωm with thickness ranging from 3.5 – 10.5 m; (ii) the second layer which is composed of silty sand has its resistivity varying from 98 – 3488 Ωm and thickness ranging from 7.0 – 24.0 m; (iii) the third layer is composed of clayey/sand whose resistivity varies from 68 – 3922 Ωm and the thickness ranges from 33.0 – 63.0 m; (iv) the saturated clayey sand comprise the fourth layer and has resistivity varying from 31 – 3226 Ωm and thickness ranges from 37.0 m - ∞; and (v) loose/shaley sand is the fifth layer whose resistivity value is 478Ωm with thicknesses placed at infinity which is peculiar of VES 8 only.

Since emphasis is placed on clay as key to siting a landfill, some of the VES stations such as VES 1, 2, 3, 9 and 10 revealed from the survey, to have abundant clay (Table 1). Clay present in VES 1 has resistivity value of 31 Ωm and a depth at infinity; at VES 2, the resistivity of clay is 21 Ωm and it lies at infinity depth; at VES 3 clay was also found to be at infinity depth but has a resistivity value of 23 Ωm; clay layer found at VES 9 has a resistivity value of 58 Ωm also at infinity depth; however, clay found at VES 10 located at Shabu, has a resistivity value of 98 Ωm and slightly buried at a shallow depth of 25.5 m. This is good for a landfill facility.

The pseudo-resistivity sections of some profile lines were plotted in 2D, were generated from the data in figure 4 above. Three profile lines were able to be extracted from figure 4 as shown by the red lines running joining points on the map. These lines include profile line through VES 1, 10 and 10; VES 9, 4 and 6; VES 3 and 8. The best profile line of interest is that that connects VES 1, 10 and 9. This profile line clearly shows the pseudo-resistivity section of the litho-stratigraphy of the subsurface (Figure 6). This pictorial presentation shows clay layer (black/blue coloration layer) that stretches throughout the line, and interestingly, at a depth of about 30 m substantial layer of clay was encountered which is ideal for siting a landfill.

Table 2. *Results of VES.*

VES No	Layer No.	Resistivity, ρ (Ωm)	Thickness, h (m)	Depth, d (m)	Inferred Geology	Type of Curve
VES 1	1	732	3.5	3.5	Sandy top soil	KQ
	2	887	19	22.5	Silty sand	
	3	326	36	55	Shaley sand/Aquifer	
	4	31	∞	∞	Clay	
VES 2	1	654	3.5	3.5	Sandy top soil	KQ
	2	916	12	15.5	Lateritic clay	
	3	186	33	45	Sandy clay/Aquifer	
	4	21	∞	∞	Clay	
VES 3	1	668	3.5	3.5	Lateritic sand	QH
	2	277	7	10.5	Sandy clay	
	3	44	33	40	Clay sand/Aquifer	
	4	23	∞	∞	Clay	
VES 4	1	1516	3.5	3.5	Lateritic top soil	KQ
	2	2237	24	27.5	Sandstone	
	3	1679	36	60	Sandstone/Aquifer	
	4	1500	∞	∞	Saturated sandstone	
VES 5	1	342	5.5	5.5	Shaley top soil	AK
	2	1178	17	22.5	Loose sand	
	3	1677	33.5	50.5	Sandstone/Aquifer	
	4	2291	∞	∞	dry sandstone	
VES 6	1	1964	10.5	10.5	Lateritic top soil	HK
	2	3488	33	43.5	Dry Sandstone	
	3	3922	47	80	Sandstone/Aquifer	
	4	3226	∞	∞	Sandstone	
VES 7	1	756	3.5	3.5	Clayey top Soil	KH
	2	1448	7	10.5	Loose sand	
	3	510	63	70	Shaley sand/Aquifer	
	4	303	∞	∞	Shaley sand	
VES 8	1	247	3.5	3.5	Silty top soil	AK
	2	799	7	10.5	Fine sand	
	3	1154	63	70	Loose sand	
	4	1202	37	100	Sandstone/Aquifer	

VES No	Layer No.	Resistivity, ρ (Ωm)	Thickness, h (m)	Depth, d (m)	Inferred Geology	Type of Curve
	5	478	∞	∞	Shaley sand	
VES 9	1	421	4.5	4.5	Sandy top Soil	KH
	2	794	18	22.5	Fine Sand	
	3	258	62	80	Sandy clay/Aquifer	
	4	58	∞	∞	Clay	
VES 10	1	673	6.5	6.5	Sandy top soil	QH
	2	98	19	25.5	Clay	
	3	68	51	70	Clay/Aquifer	
	4	91	∞	∞	Clay	

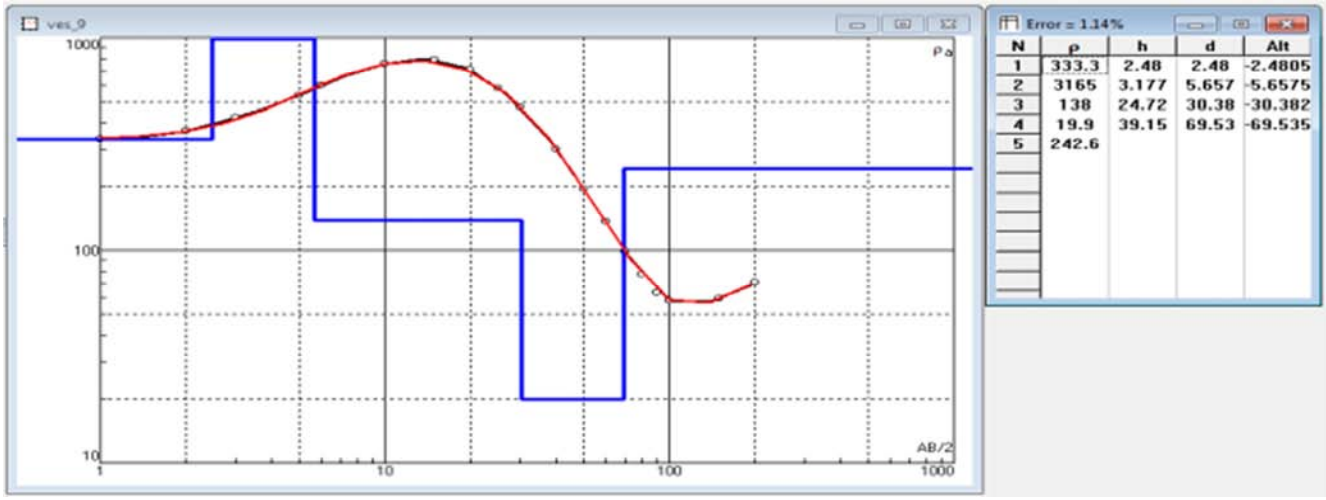

Figure 5. *Representative Resistivity curve (KH curve).*

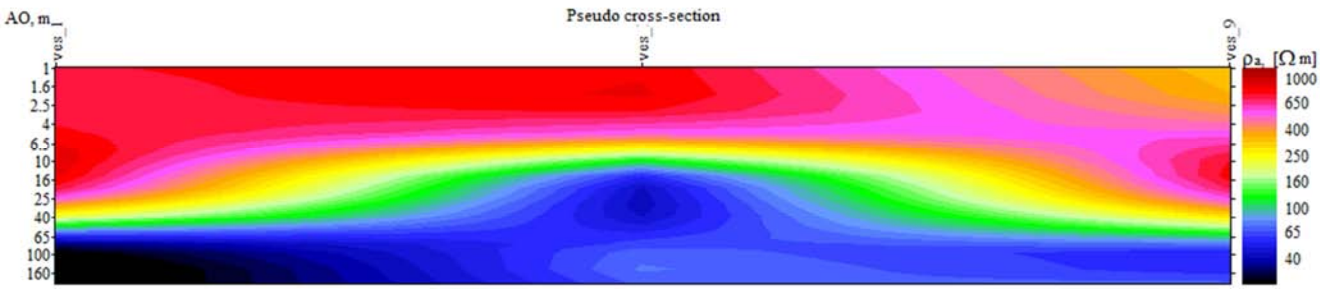

Figure 6. *Pseudo-resistivity Section for Profile line through VES 1, 10 and 9.*

4.2. Geological (Lineament) Studies

Data from lineament studies in table 3 indicate that the study area is underlain with geological structures (Figure 7) which may include fractures, faults, geologic contacts etc. The northern parts of the study area is highly characterized by many structures while the southern parts of the mapped area was observed to have a few number of lineament structures. Some trends of the lineaments measure N105°W, N145°W, N100°E, N105°E, N180°E, N130°W, etc with the use of a protractor. The analysis reveals the dominant trend to be NW – SE when plotted on the Rosette diagram (Figure 8). This dominant trend describes tectonically the effects of the lineaments to the flow patterns of streams and rivers systems in the study area. Notably, Shabu area lacks clusters of lineaments which make it good for landfill siting.

Table 3. *Lineaments Trend Analysis.*

S/No.	Trend Direction	Number of Lineaments	Percentage (%)
1	NE – SW	35	23
2	NW – SE	57	38
3	NNW – SSE	26	17
4	ENE – WSW	15	10
5	NNE - SSW	16	11

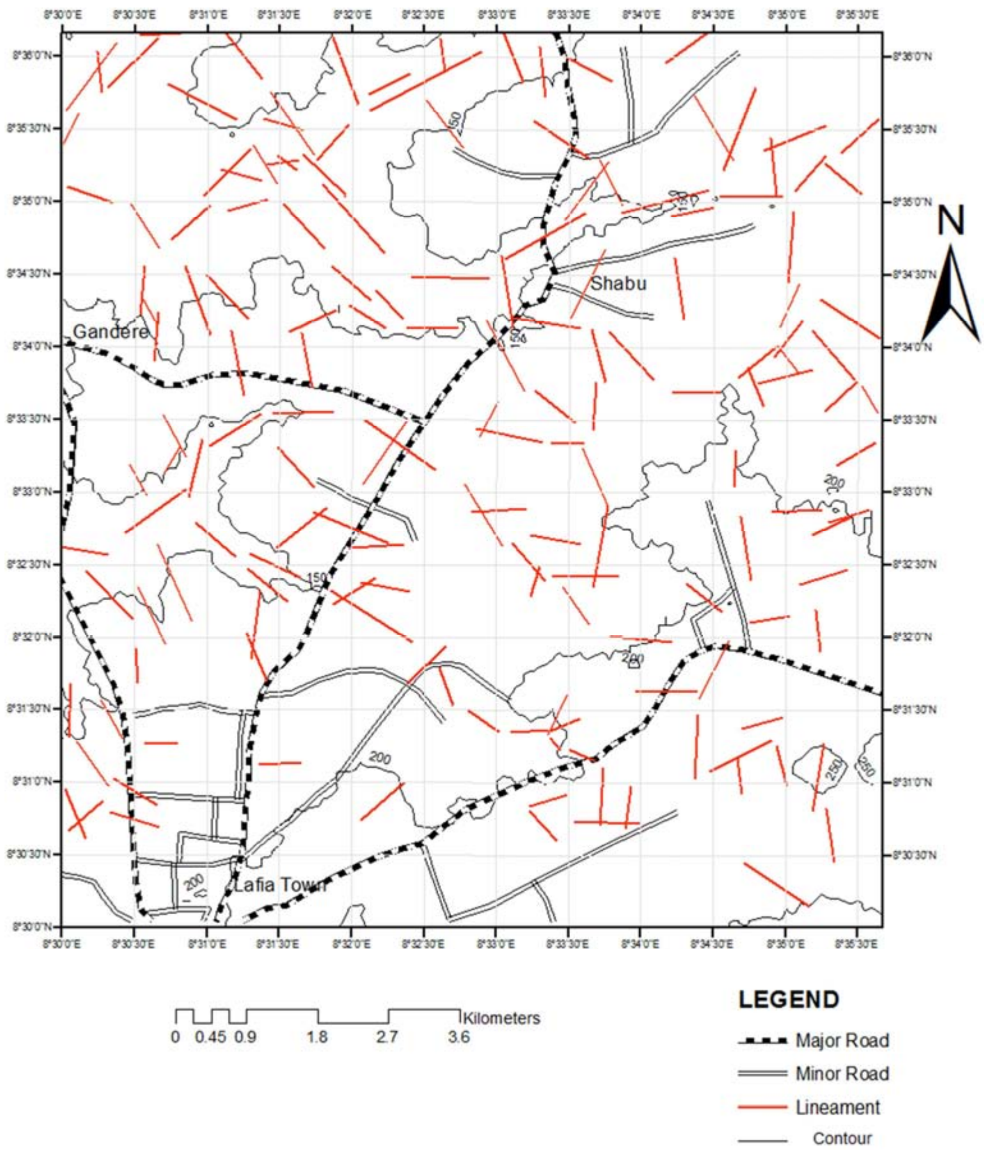

Figure 7. *Map Showing Lineament Structures.*

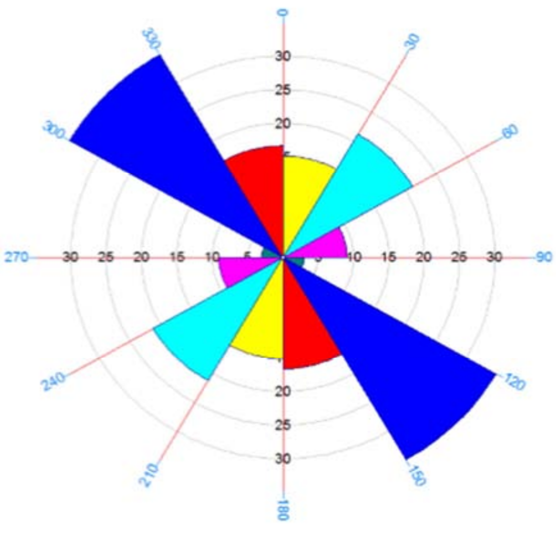

Figure 8. *Rosette Diagram for Lineament Structures.*

4.3. Static Water Level (SWL)

Table 4 shows the results of SWL obtained from 51 HDW of the study area. The mean SWL in the study area is measured at 12.3m depth. These wells vary in depths due to their locations with respect to their elevations above sea level. Consequently, data from the table were used to construct the AWL map in figure 9.

The SWL map in figure 9 shows the groundwater distribution flow pattern of the study area. The groundwater flows from the eastern and southeastern parts (blue coloration area) of the map towards the western and northwestern parts (greenish area) of the map. This is particularly true as a result of the difference in elevation pattern of the area. It is evidently clear that the eastern and southeastern parts of the map have higher elevation coefficients than other parts of the map. Since groundwater flows in accordance with the surface topography and hydraulic head, it is forced to flow accordingly as represented by the arrows on the 3D map of the HDW below. This flow pattern is possible because the hydraulic head values were observed to be higher than 190 in these areas, which consequently implies that these areas are the recharge zones. On the other hand, western and northwestern parts of the map are lower in hydraulic head values and so the groundwater flows towards the area.

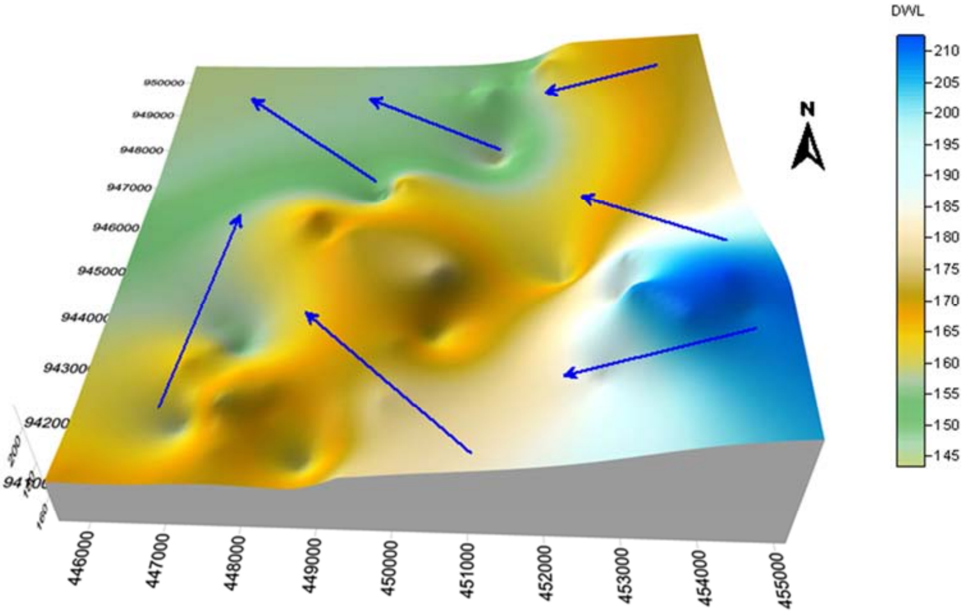

Figure 9. *Map showing 3D Presentation of AWL the study Area.*

Table 4. *Results of Static Water Level (SWL) and Absolute Water Level (AWL)*

HDW No	Elevation (m)	SWL (m)	AWL (m)
HDW 1	165.0	9.8	155.2
HDW 2	166.0	18.2	147.8
HDW 3	171.0	7.7	163.3
HDW 4	172.0	9.0	163.0
HDW 5	172.0	8.0	164.0
HDW 6	161.0	7.7	153.3
HDW 7	158.0	7.6	150.4
HDW 8	157.0	9.1	147.9
HDW 9	162.0	11.7	150.3
HDW 10	155.0	12.0	143.0
HDW 11	160.0	8.6	151.4
HDW 12	163.0	5.8	157.2
HDW 13	158.0	7.5	150.5
HDW 14	173.0	9.0	164.0
HDW 15	162.0	9.8	152.2
HDW 16	157.0	9.8	147.2
HDW 17	182.0	13.2	168.8
HDW 18	178.0	13.5	164.5
HDW 19	189.0	18.0	171.0
HDW 20	183.0	11.0	172.0
HDW 21	187.0	11.1	175.9
HDW 22	220.0	10.8	209.2
HDW 23	222.0	16.2	205.8
HDW 24	243.0	32.3	210.7
HDW 25	191.0	9.8	181.2
HDW 26	163.0	8.9	154.1
HDW 27	162.0	6.0	156.0
HDW 28	169.0	7.3	161.7
HDW 29	171.0	13.5	157.5
HDW 30	174.0	8.5	165.5
HDW 31	173.0	9.2	163.8
HDW 32	175.0	8.2	166.8
HDW 33	181.0	8.1	172.9
HDW 34	178.0	8.3	169.7
HDW 35	184.0	16.9	167.1
HDW 36	182.0	14.2	167.8
HDW 37	180.0	11.2	168.8
HDW 38	180.0	10.4	169.6
HDW 39	177.0	17.5	159.5
HDW 40	180.0	11.5	168.5
HDW 41	188.0	11.7	176.3
HDW 42	188.0	11.9	176.1
HDW 43	184.0	13.2	170.8
HDW 44	170.0	8.1	161.9
HDW 45	168.0	7.5	160.5
HDW 46	212.0	14.6	197.4
HDW 47	201.0	14.5	186.5
HDW 48	198.0	11.6	186.4
HDW 49	243.0	30.4	212.6
HDW 50	244.0	33.0	211.0
HDW 51	246.0	37.1	208.9

5. Summary and Conclusion

With the prevalence of waste generation, it is pertinent to also find a way of adequately manage their disposal in a way that will protect the environment. The preliminary investigations of this study, which involve geo-resistivity data collection, geological (lineament) and static water level from HDW, were integrated and used to delineate Lafia and environs for the purpose of suitably siting a landfill to curb the indiscriminate disposal of MSW. Ten VES points were randomly sited to collect geo-resistivity data using the Schlumberger array. Computer software, IPI2win, was used for the quantitative interpretation. Four to five geo-electric layers were revealed in the survey of the VES stations. Curve types from the interpretation show KQ, QH, AK, KH and HK curve types. Since clay is vital to siting a landfill because of its roles in attenuating leachate flow, VES VES 1, 2, 3, 9 and 10 were found to contain abundance of clay however; clay was not discovered at VES 4, 5, 6, 8 and 7. Clay's resistivity values ranges between 21Ωm to 68Ωm and thickness is between 19 m and 51m. Of all the sounding stations, VES 10 located in Shabu particularly, gives a better result when it comes to depth of clay in the survey. The depth was the shallowest at about 25.5 m and will likely be reasonable to site a landfill there.

Geological investigation in the form if lineament studies revealed that the area is underlain with many structures which may include faults, fractures, folds, etc. Analysis of lineaments indicates a trend dominant in the NW-SE direction when plotted in the Rosette diagram. It also describes the control of the flow pattern of the rivers and streams systems in the study area. Their studies are important because they help to uncover the geological structures that lie beneath the surface which are channels that pollute groundwater quality by contaminating leachates pollution from landfills. Though lineaments were abundant in the study area, interestingly, Shabu was found to have less of the lineaments. This attribute makes Shabu a likely area suitable to site the facility.

The hydrogeological investigation revealed that most of the HDW studied in thearea only utilized shallow aquifers. The SWL found in the areas with rich-clay deposits range between 7.6 m and 18.2 m.

In conclusion, this paper found out that Shabu, a town about 8 KM located north of Lafia, is suitable for siting a landfill having taken into consideration the results from electric resistivity, geological and hydrogeological investigations.

6. Recommendations

These recommendations were deduced from the studies undertaken from the paper;

(i) Municipal Solid Waste management in Nasarawa State, especially in Lafia the state's capital, is poor because wastes disposal facilities, like landfills are not available for use.

(ii) Shabu, located at 8°34′41.7″N, 8°33′47.0″E, 8Km and NE from Lafia, is recommended for a landfill based on the findings of the geo-resistivity, geological, hydrogeological and structural investigations.

(iii) The combined parameters used for this study are inadequate for a detailed investigation because the findings here merely are preliminary ones: a detailed investigation should be conducted to review and validate the claims of the study.

(iv) Nasarawa State Government, corporate bodies and wealthy individuals can collaborate to find a lasting solution to this environmental menace by sponsoring scientific researches that have direct bearing on the lives of people and the environment.

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