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HYDROGEOPHYSICAL ASSESSMENT OF AQUIFER POTENTIAL ZONES USING HYDRAULIC PARAMETERS IN LOKOJA AND ITS ENVIRONS, NORTH-CENTRAL NIGERIA

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Abstract: This research is aimed at delineating the groundwater potential in Lokoja and environs using Dar Zarrouk parameters. The study area is part of the Basement Complex of South-western Nigeria and the Lokoja sub-basin of the middle Niger sedimentary basin, on area coverage of about 400km2. Thirty-five (35) vertical electric soundings (VES) using Schlumberger array method with the aid of ABEM Signal Averaging System (SAS) Terrameter were used for the data acquisition. The result of the interpretation shows four geo-electric layers. The resistivity soundings results revealed that about 4 curve types were identified in the study area namely AA, HA, A and H type with the lithologic layers varying from 3 to 4 and consisting of varying resistivity and thicknesses across each VES point. The geo-electric sections revealed that the major aquifer systems in the study area are weathered basement and weathered/fractured basement. The longitudinal conductance computed that range from 0.00904951 to 0.7814713 **Ω-1**indicates that the aquifers in the area have poor to moderate protective capacity whereas transverse resistance that range from 24.5841 to 7290.15**Ω** indicates very low groundwater development class. Hydraulic conductivity with a range of 0.36757M/day to 56.86754M/day and transmissivity values with a range of 4.4548 to 917.273M2 /day indicate very low to moderate aquifer capable of sustaining moderate communities.

Keywords: Hydraulic conductivity, Transmissivity Vertical electrical sounding, transverse resistance

S1.0 Introduction

The importance of water as a basic resource for human activities cannot be over-emphasized. It is needed for cooking, washing, cleaning, construction activities, manufacturing etc. The qualitative and quantitative assessments of its sources are therefore necessary to ensure its availability in the study area. Lokoja has witnessed an upsurge in human and infrastructural growth since it became the capital of Kogi State in 1991. The demand for potable water supply for various needs has grown significantly. The State Water Board is currently supplying about 2.7 million gallons of water per day to Lokoja and its environs as against the 10 million gallons needed per day (Omali, 2012). Successive governments in Kogi state, the United Nation Children Emergency Fund (UNICEF), Water and Environmental Sanitation (WES) and private developers have provided a number of boreholes to augment the water supply in the area. The major source of water for domestic and industrial uses in the study area is groundwater. The methods of exploration are grouped into surface geological, subsurface geological, surface geophysical and subsurface geophysical methods. The techniques of water resources evaluation require an understanding of the concept of groundwater yield, the quantity and quality of groundwater in the hydrogeological environment. The method of exploitation of groundwater involves the drilling and installation of pumps and piezometers and abstraction of water from the subsurface.

The concept of Dar Zarrouk parameters can be used to assess the groundwater potential of an aquifer, such that, when the thickness and resistivity of subsurface layer are known, its transverse resistance and longitudinal conductance can be estimated (Egbai and IserhienEmekeme, 2015; Bello *et al.*, 2019). According to Egbai and Iserhien-Emekeme (2015) and Bello *et al.* (2019), the concept of Dar Zarrouk parameters can be used to assess the groundwater potential of an aquifer, such that, when the thickness and resistivity of subsurface layer are known, its transverse resistance and longitudinal conductance can be estimated. Over the years, the Dar Zarrouk Parameters primarily derived from layer resistivity and thickness, have proven to be important in understanding the spatial distribution of aquifer's hydraulic parameters, assessment of contaminated landfills and subsurface investigation of engineering structures (Udoinyang and Igoekwu, 2012; Okiongbo and Oborie, 2015) which can be obtained from surface geo-electric soundings, have proven to be important in understanding the spatial distribution of aquifer hydraulic parameters. Dar Zarrouk parameters of an aquifer including transverse resistance, reflection coefficient and coefficient of anisotropy can be established with resistivity measurement of an aquifer (Heigold *et al.*, 1979; Nwosu *et al.,* 2014; Kwame *et al.*, 2019). Nwosu *et al.* (2014) derived analytical relations between aquifer transmissivity and transverse resistance. In the same vein, Kwami et al. (2019) were able to delineate groundwater potential zones in Gombe and its environs using Dar Zarrouk parameters. There are several water boreholes in Lokoja metropolis and environs. However, majority of these boreholes are not functioning as expected due to low yield and poor maintenance. There are several boreholes scattered throughout the Lokoja metropolis and environs however, majority of these boreholes are not functioning as expected due to low yield and poor maintenance. Some of the physical properties of an aquifer such as hydraulic conductivity and transmissivity that control the flow and yield of groundwater can be adequately estimated using Dar Zarrouk parameters (Bello *et al.*, 2019). The aim of this work therefore, is to use Dar Zarrouk parameters to assess the groundwater potential of the aquifers and ascertain aquifers of good yield and productivity in the Basement Complex rock of Lokoja metropolis.

1. Study area

The area is located between latitudes $7^{o}\ 44^{1}\ 33^{11}$N and $7^{o}\ 52^{1}$N and longitudes $6^{o}\ 38^{1}\ 6^{11}$E and $6^{0}\ 48^{1}$E. It lies on part of the Basement Complex of South-western Nigeria and the Lokoja subbasin of the middle Niger sedimentary basin, on area coverage of about 400 km^2 as shown in Figure 1. The major settlements in the area include Lokoja, Adankolo, Lokongoma, Kabawa, Ganaja, Zangodaji, Sarkin Noma and Felele. The study area is accessible through a trunk "A" road from Abuja to Lokoja and Okene to Lokoja and a trunk "B" road from Ajaokuta to

Lokoja. It is also accessible by ferry via the River Niger from Shintaku. The area is populated by several ethnic groups and it is thus very typical of the middle Belt region of Nigeria.

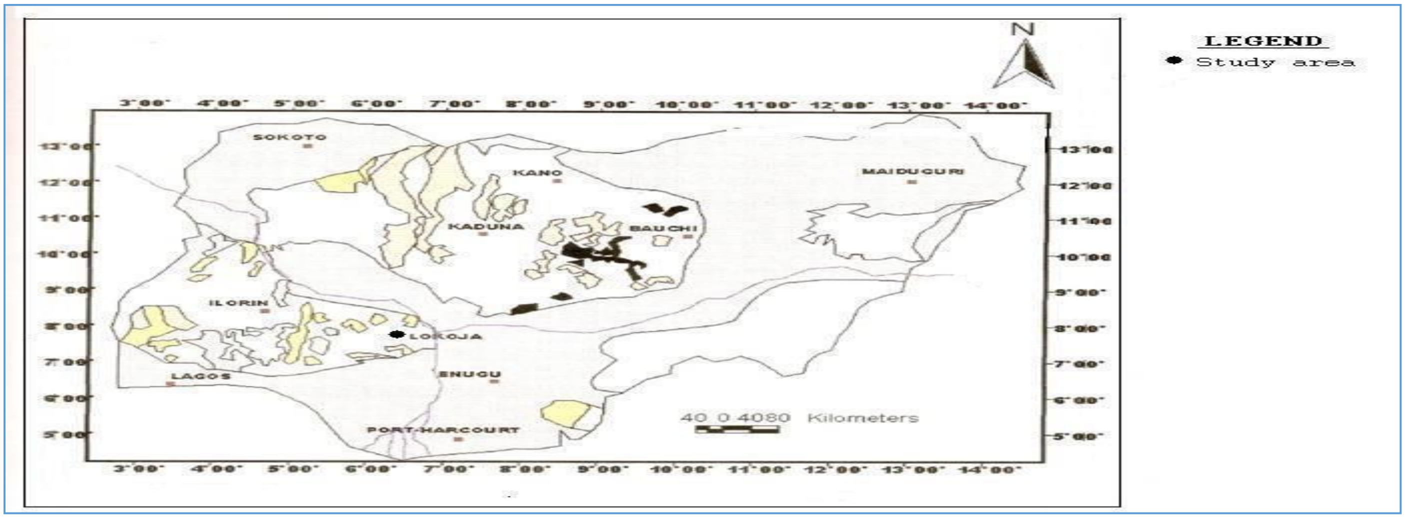

Figure 1: Map of Nigeria showing Lokoja, the study area

2.1 Geology and hydrogeology of the study area

The study area falls into two geological domains, viz, the Basement Complex of South-western Nigeria and the Lokoja Sub-basin of the mid Niger-basin. The North-Western, western and South-western parts of the study area are pred ominantly covered by Migmatite, whereas the Northern part is composed of biotite hornblende gneiss. In addition, the South and Southeastern part are dominated by undifferentiated older granite, mainly Porphyroblast granite, granite gneiss with porphyroblast gneiss while the South also composed of outcrops of fine-grained biotite granite. The central portion of the area is made of feldspathic sandstone and siltone. However, thick alluvium deposits trend from the Northeast to South of the area along the Benue and Niger drainage system (Figure 2). The study area falls into two geological domains, viz, the Basement Complex of South-western Nigeria and the Lokoja Sub-basin of the mid Niger-basin (Abimbola, 1997; Akande *et al.*, 2005). The North-Western, western and South-western parts of the study area are predominantly covered by Migmatite, whereas the Northern part is composed of biotite hornblende gneiss. In addition, the South and Southeastern part are dominated by undifferentiated older granite, mainly Porphyroblast granite, granite gneiss with porphyroblastic gneiss while the South also composed of outcrops of fine-grained biotite granite as shown in Figure 2, the central portion of the area is made of feldspathic sandstone and siltone. However, thick alluvium deposits trend from the Northeast to South of the area along the Benue and Niger drainage system (Udenzi and Osazuwa, 2004).

Hydrogeologically, the area is drained by river Benue and river Niger in addition to the Meme River, which is a tributary of river Niger. Groundwater in the study area is recharged by these drainage systems and from meteoric water during rainfall. Prolific aquifers are sourced from weathering of the Basement rocks and fractures of the rock (Omali, 2014).

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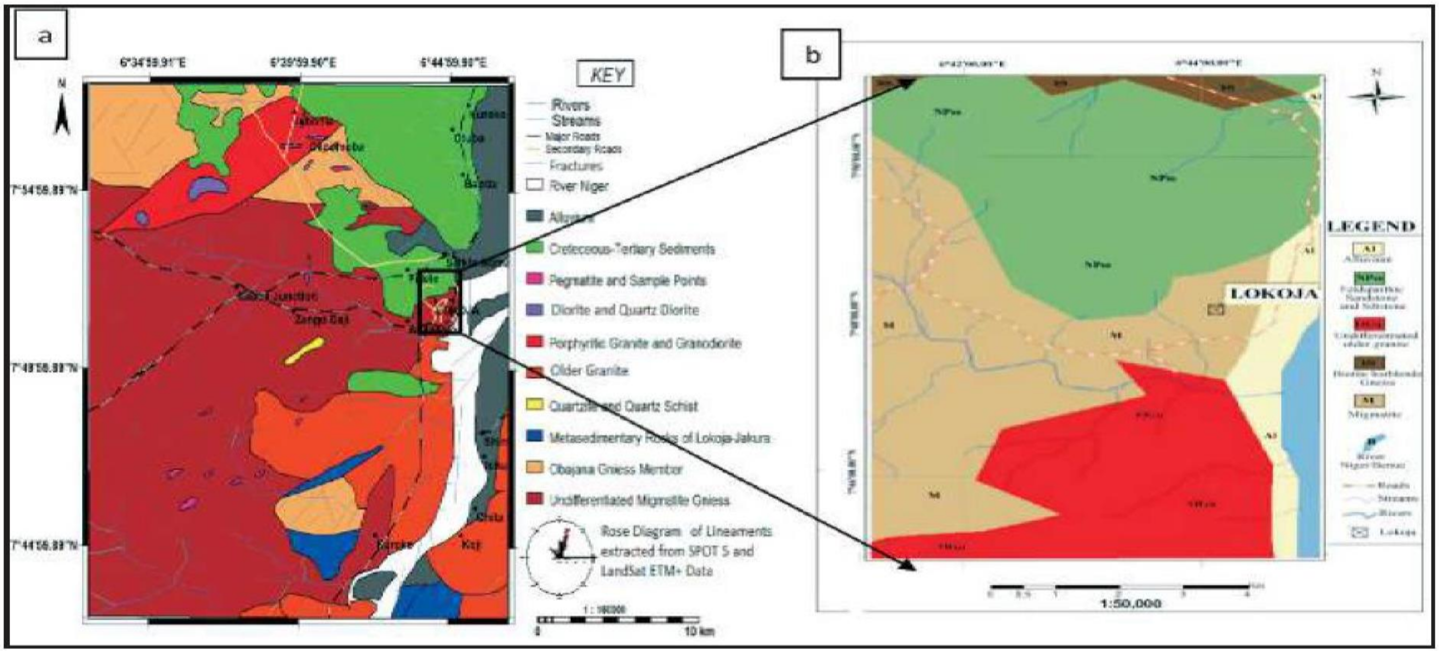

Figure 2: (a) Generalized geological map of Lokoja area (Omada *et al.,* 2015) (b) Detailed geological map of the study area (Omali, 2014)

3. Materials and Methods

A total of thirty-five (35) vertical electrical soundings (VES) were carried out in this study. Terrameter SAS 300C was used to carry out the resistivity measurement in the field.

Schlumberger configuration was adopted with maximum half-current electrode spread (AB/2) of 60m while the half potential electrode separation (MN/2) was maintained between 0.5m and 7.5m. The VES curves were quantitatively interpreted by partial curve matching and computer iteration techniques, using resound, a computer programme based on linear filter theory (Zohdy, 1989). The principle of the resistivity method is that electric current is passed into the ground through two outer electrodes, and the resultant potential difference is measured across two inner electrodes that are arranged in a straight line, symmetrically about a centre point The potential difference to the current ratio is displayed by the terrameter as resistance. A geometric factor in meters (m) is calculated as a function of the electrode spacing. The resistance readings obtained from the Terrameter is multiplied by this factor to give an apparent resistivity value. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. The electrical resistivity survey was carried out to determine aquifer types.

3.1 Hydraulic parameters

The term Dar Zarrouk parameters has been used to describe the relationship between the longitudinal unit conductance and transverse resistance.

Longitudinal conductance (S_i) $=\sum_{i=1} hi/\rho i$ (1)

hi = layer thickness measured in meters (m) pi= aquifer resistivity in measured in ohms meter (Ωm)

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Transverse resistance (R) = $\sum_{i=1} hi\ \rho i$ (2) The longitudinal conductance (Si) in equation (1) is a measure of the impermeability of a rock layer (Billing, 1972; Mbonu *et al.,* 1991).
Transmissivity (Tr) = K.hi (3)
Tr is measured in meter square per day (m^2day)
K is the Hydraulic conductivity measured in metes per day (m/day) hi is the layer thickness of the aquifer measured in meters (m)
Hydraulic conductivity (K) = $386.40R_{rw}^{-0.93283}$ (4)
R_{rw} is the layer resistivity measured in ohms meter
An n-layer DZ curve is composed of n branches, each of which terminates at a point whose coordinates, Lm and pm, represent the thickness and resistivity of a fictitious layer that replaces all the overlying layers. According to Eqns. (3) and (4), the coordinates of any given point on a DZ curve are a function of the thicknesses and resistivity of layers that exist above a given depth, D, but they are not related to the thicknesses and resistivity of layers beneath that depth. In contrast, on a VES (vertical electrical sounding) curve, the coordinates of a given point are calculated from an integral expression (Stefanesco et al., 1930) that involves all the thicknesses and resistivity in the section, and, therefore, they are not related to particular depth. The longitudinal conductance (S) is a measure of the impermeability of a rock layer (Billing, 1972). Electrical anisotropy is a measure of stratified rock which is generally more conductive in the parallel plane than in the perpendicular plane (Malick et al., 1973; Cihan et al., 2014).
For a sequence of horizontal, homogeneous and isotropic layers of resistivity $e1$ and thickness hi. Eqs. (v) and (vi) defined the Dar Zarrouk parameters (longitudinal conductance S and transverse resistance TR) as follows:
Equation 1, 2, 3 and 4 are only true for a sequence of horizontal, homogeneous and isotropic layers of resistivity $e1$ and thickness hi (Malick et al., 1973; Cihan *et al*., (2014) and Kwami *et al.*, 2019).
The methods discussed above were employed to generate Vertical electrical sounding data.

4. Results

The results of the analyses are as presented in Tables 1-9 and Figures 3-6

Table 1: Vertical Electrical Sounding Data

VES No.	Location	Coordinates	Layer No.	Resistivity(Ohm-m)	Thickness (m)	Inferred Layer	Remark
1	Ganaja BH1	N 070 4433” E0060 44’ 33”	1	161.45	1.09	Topsoil (clay/laterite	
			2	17.87	10.83	Weathered basement(aquifer)	Aquiferous unit
			3	5721.11	-	Competent basement	
2	500 unit (BH1)	N 070 44’ 56.6" E0060 44’ 24.7”	1	538.83	1.07	Topsoil (clay/laterite	
			2	83.19	12.07	Weathered basement(aquifer)	Aquiferous unit

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			3	6928.32	-	Competent basement	
3	500 unit (BH2)	N 070 45’ 24.7” E060 44’ 24.7”	1	190.66	2.76	Topsoil (clay/laterite	
			2	48.35	8.89	Weathered basement(aquifer)	Aquiferous unit
			3	1230.23	-	Competent basement	
4	200 unit (BH1)	N 070 45’ 33.1" E060 44’ 21.1”	1	648.47	2.9	Topsoil (clay/laterite	
			2	18.35	14.34	Weathered basement(aquifer)	Aquiferous unit
			3	1298.98	-	Competent basement	
5	200 Unit (BH2) N 070 45’ 48” E060 44’ 15.5”		1	485	3.87	Topsoil (clay/laterite	
			2	15.57	12.23	Weathered basement(aquifer)	Aquiferous unit
			3	7724.31	-	Competent basement	
6	Phase I (BH1)N 070 47’ 24.7” E 060 43’ 22.3”		1	20	8	Topsoil (clay/laterite	
			2	41.5	7.5	Clay/laterite	
			3	277.6	3.7	Weathered basement(aquifer)	Aquiferous unit
			4	491.89	-	Competent basement	
7	Phase I (BH2)N 070 47’ 29.3” E 060 43’ 33”		1	75	14	Topsoil (clay/laterite	
			2	166.23	3.6	Weathered basement(aquifer)	Aquiferous unit
			3	260.4	-	Competent basement	

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8	Phase II (BH1)N 070 48' 4.7" E060 41' 55.2"		1	111.99	3.09	Topsoil (clay/laterite	
			2	6.81	3.61	Weathered basement(aquifer)	Aquiferous unit

VES No.	Location	Coordinates	Layer No.	Resistivity(Ohm-m)	Thickness (m)	Inferred Layer	Remark
			3	1109.59	-	Competent basement	
9	Phase II (BH2)	N 070 47' 44.3" E 060 42' 18.6"	1	1092.09	3.25	Topsoil (clay/laterite	
			2	50.44	12.51	Weathered basement(aquifer)	Aquiferous unit
			3	4432.72	-	Competent basement	
10	Otokiti Estate (BH)	N 070 48' 18.5" E 060 41' 7"	1	25.92	2.86	Topsoil (clay/laterite	
			2	7.8	16.13	Weathered basement	Aquiferous unit
			3	330.45	-	Competent basement	
11	Army Barrack (BH)	N 070 48' 9.4" E060 40' 34.5"	1	157.61	9.62	Topsoil (clay/laterite	
			2	55.61	12.54	Weathered basement(aquifer)	Aquiferous unit
			3	819.94	-	Competent basement	
12	Roja Table Water (BH 1)	N 070 48'32.6" E060 38'41.3"	1	144.33	0.6	Topsoil (clay/laterite	
			2	8.48	3.39	Weathered basement(aquifer)	Aquiferous unit
			3	2875.1	-	Competent basement	

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13	Zangodaji (BH 2)	N 070 48’ 40.6” E 060 38’ 26.1”	1	58	6	Topsoil (clay/laterite	
			2	100.65	7	Clay/laterite	
			3	750.04	5	Weathered basement(aquifer)	Aquiferous unit
			4	1930.2	_	Competent basement	
14	Adankolo (BH 1)	N 070 47’ 15.6” E 060 44’ 16”	1	79.4	10	Topsoil (clay/laterite	
			2	99.35	4	Clay/laterite	
			3	317.5	3	Weathered basement(aquifer)	Aquiferous unit
			4	521.93	-	Competent basement	
15	Adankolo (BH 2)	N 070 47’23.5” E060 44’ 28.6”	1	664	7.8	Topsoil (clay/laterite	
			2	66.84	8.8	Clay/laterite	
			3	316.62	5.7	Weathered basement(aquifer	Aquiferous unit
			4	505.53	-	Competent basement	
16	Adankolo (BH 3)	N 070 47’ 21.6” E 060 44’ 17.5”	1	39.7	11.8	Topsoil (clay/laterite	
			2	79.86	6.14	Weathered basement(aquifer)	Aquiferous unit
			3	507.56	-	Competent basement	
17	Adankolo (BH 4)	N 070 47’ 33.9” E 060 44’ 29.9”	1	372	15	Topsoil (clay/laterite	
			2	389.49	3.3	Clay/laterite	
			3	469.4	6.7	Weathered basement (aquifer)	Aquiferous unit
			4	690.3		Competent basement	

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VES No.	Location	Coordinates	Layer No.	Resistivity(Ohm-m)	Thickness (m)	Inferred Layer	Remark
			4	690.3		Competent basement	
18	Marine Road (BH)	N 070 48' 7.1" E060 44' 54.4"	1	79.4	10	Topsoil (clay/laterite)	
			2	198.2	13.5	Weathered basement(aquifer)	Aquiferous unit
			3	409.16	-	Competent basement	
19	Kenwo Hotel (HDW)	N 070 47' 50" E060 43' 55.9"	1	99.35	7.5	Weathered basement	
			2	123	12.2	Weathered basement(aquifer)	Aquiferous unit
			3	1734.9	15.7	Fractured basement	Aquiferous unit
			4	678	-	Competent basement	
20	Kasuwa Hotel (BH)	N 070 48' 28.9"	1	317.5	3.7	Weathered/fractured basement	
		E 060 44' 55.5"	2	311.2	19	Weathered basement(aquifer)	Aquiferous unit
			3	1212.5	11.6	Fractured layer	Aquiferous unit
			4	1456	-	Competent basement	
21	GRAJ(GRA) (HDW)	N 070 48' 24.5" E 060 43' 44.5"	1	521.93	4.6	Topsoil/clay/laterite	
			2	233.14	5.7	Weathered basement(aquifer)	Aquiferous unit
			3	895.8	-	Competent basement	
22	New Layout (HDW)	N 070 48' 37.8" E	1	49.3	1.04	Topsoil (clay/laterite)	

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		060 44' 12.7"					
			2	253.7	3.59	Clay/laterite	
			3	547.2	12.03	Weathered basement(aquifer)	Aquiferous unit
			4	$7^{80.2}$	-	Competent basement	
23	New Layout (HDW 2)	N 070 48' 37.2" E 060 44' 32.8"	1	23	2.1	Topsoil (clay/laterite)	
			2	179.3	3.7	Clay/laterite	
			3	234.1	9.6	Weathered basement(aquifer)	Aquiferous unit
			4	1267.8	-	Competent basement	
24	Megiri (HDW)	N 070 48' 45.1" E 060 44' 42.1"	1	56.9	1.8	Topsoil (clay/laterite)	
			2	89.1	3.37	Clay/laterite	
			3	135.7	10.6	Weathered basement(aquifer)	Aquiferous unit
			4	230	-	Competent basement	
25	Kabawa (HDW)	N 070 49' 8.5" E060 44' 54.7"	1	112.7	2.4	Topsoil (clay/laterite)	
			2	65.8	6.2	Clay/laterite	
			3	124.7	11.8	Weathered basement(aquifer)	Aquiferous unit
			4	569.2		Competent basement	
26	SarkinNoma (HDW)	N 070 50' 31.3" E060 44' 50"	1	354	7.01	Topsoil (clay/laterite)	
			2	213	13.09	Weathered basement(aquifer)	Aquiferous unit
			3	678	-	Competent basement	

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VES No.	Location	Coordinates	Layer No.	Resistivity(Ohm-m)	Thickness (m)	Inferred Layer	Remark
27	Felele (HDW 1)	N 070 51' 6.2" E060 43' 31.7"	1	301	2.03	Topsoil (clay/laterite)	
			2	226.1	11.2	Weathered basement(aquifer)	Aquiferous unit
			3	429.5	-	Competent basement	
28	Felele (HDW 2)	N 070 51' 15.8" E 060 43' 21.8"	1	29.4	5.6	Topsoil (clay/laterite)	
			2	79.5	9.17	Weathered basement (aquifer)	Aquiferous unit
			3	96.1	-	Competent basement	
29	Felele (HDW 3)	N 070 51' 6.6" E060 43'24.5"	1	45.8	3.6	Topsoil (clay/laterite)	
			2	67.23	13.6	Clay/laterite	
			3	156.9	7.9	Weathered basement(aquifer)	Aquiferous unit
			4	1273.1	-	Competent basement	
30	Behind Secretariat (HDW)	N 070 45' 47" E 060 43' 32.8"	1	564.6	13	Tosoil	
			2	234.67	10.4	Clay/laterite	
			3	1472.4	12.4	Weathered basement (aquifer)	Aquiferous unit
			4	96.1		Competent basement	
31	LGEA Primary school Zango 1	N 070 50' 56" E060 45 34"	1	45.8	14.6	Topsoil (clay/laterite)	

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			2	76.8	17.9	Weathered basement (aquifer)	Aquiferous unit
			3	1076	-	Competent basement	
32	LGEA Primary school Zango 2	N 070 48' 37.2" E060 41' 21"	1	18.8	12.8	Topsoil (clay/laterite	
			2	26.8	9.4	Weathered basement (aquifer)	Aquiferous unit
			3	79	-	Competent basement	
33	LGEA Primary school Zango	N 070 47' 30.2" E060 3	1	29	8.9	Topsoil (clay/laterite	
			2	45	24.8	Weathered basement (aquifer)	Aquiferous unit
			3	86	-	Competent basement	
34	Mami Market	N 070 46' 41" E060 51' 26"	1	41	9.4	Topsoil (clay/laterite	
			2	42	12.6	Weathered basement (aquifer)	Aquiferous unit
			3	53	-	Competent basement	
35	Model nurs. and prim. Sch. Aneibo quarters	N 070 46' 35" E 060 48' 05"	1	123	5.7	Topsoil (clay/laterite	
			2	12	8.9	Weathered basement (aquifer)	Aquiferous unit
			3	201	-	Competent basement	

Table 2: Dar Zarrouuk Parameters

VES	Location	Layer resistivi	Layer thick	Aquifer conductivity (σ)	Longitudinal	Hydraulic	Transmissivity

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N o.		ty(Rrw)	ness (h)		conductance (s)	Transverse conductivity resistance (R) M/day	(k)	(Tr)M2/day)
1	Ganaja BH1	17.87	10.83	0.05624296	0.60604364	193.53	26.24325	284.21
2	500 unit (BH1)	83.19	12.07	0.01202067	0.14508955	1076.53	6.250823	75.447
3	500 unit (BH2)	48.35	8.89	0.02068252	0.18386763	429.8	10.37	92.189
4	200 unit (BH1)	18.35	14.34	0.05449591	0.78147138	256.29	25.60232	367.137
5	200 Unit (BH2)	15.57	12.23	0.06422607	0.78548491	190.42	29.84245	364.973
6	Phase I (BH1)	277.6	3.7	0.0036023	0.01332853	1027.12	2.03115	7.5152
7	Phase I (BH2)	166.23	3.6	0.00601576	0.02165674	598.43	3.27712	11.797
8	Phase II (BH1)	6.81	3.61	0.14684287	0.5301028	24.5841	64.54349	233
9	Phase II (BH2)	50.44	12.51	0.01982553	0.24801744	631	9.96867	124.708
10	Otokiti Estate (BH)	7.8	16.13	0.12820512	2.06794872	125.81	56.86754	917.273
11	Army Barracks (BH)	55.61	12.54	0.01798237	0.22549901	697.35	9.10135	114.13
12	Roja	8.48	3.39	0.11792452	0.39976415	28.75	52.60192	178.32
13	Table Water (BH 1) Zangodaji (BH 2)	750.04	10	0.00133326	 0.01333262	 750	 0.80365	 8.0365
14	Adankolo (BH 1)	317.5	3	0.0031496	0.00944882	952.5	1.79198	5.3759

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15	Adankolo (BH 2)	316.62	5.7	0.00315836	0.01800379	1804.73	1.79663	10.24
16	Adankolo (BH 3)	79.86	6.14	0.01252191	0.07688454	490.34	6.49362	39.8708
17	Adankolo (BH 4)	469.4	6.7	0.00213937	0.01427354	3144.98	1.24434	8.337
18	Marine Road (BH)	1734.9	15.7	0.0005764	0.00904951	2723 7.9	0.36757	5.7708
19	Kenwo Hotel (HDW)	1212.5	11.6	0.00082474	0.00956701	1406 5	0.51343	5.9557
20	Kasuwa Hotel (BH)	233.14	5.7	0.00428926	0.02444883	1328.9	2.3903	13.6247
21	GRAJ(GRA) (HDW)	198.2	13.5	0.00504541	0.068113	2675.7	2.78118	37.5459
22	New Layout (HDW)	547.2	12.03	0.00182749	0.0219846	6582.82	1.07848	12.9741
23	New Layout (HDW 2)	234.1	9.6	0.00427168	0.0410081	2247.4	2.38115	22.859
24	Megiri (HDW)	89.1	3.37	0.00112233	0,0378227	300.267	5.86317	19.7588
25	Kabawa (HDW)	124.7	11.8	0.00801924	0.0946271	1471.46	4.28499	50.5628
26	Sarkin Noma (HDW)	213	13.08	0.00469483	0.06140845	2786.04	2.60048	34.0142
27	Felele (HDW 1)	226.1	11.2	0.00442282	0.0495356	2531.3	2.45965	27.548
28	Felele (HDW 2)	79.5	9.17	0.01257862	0.11534591	7290.15	6.52105	59.798
29		156.9	7.9	0.00637349	0.05035054	1239.5	3.45855	27.3225

Original Article

	Felele (HDW 3)							
30	Behind Secretariat (HDW)	226.1	11.2	0.00442282	0.0495356	2531.3	2.45965	27.548
31	LGEA Primary school Zango 1	124.4	12.1	0.0080385	0.0923406	1505.24	2.60048	23.7623
32	LGEA Primary school Zango 2	167	8.9	0.005988	0.1287423	1504.1	1.48076	15.3225
33	LGEA Primary school Zango 3	76.9	13.3	0.0130039	0.2244317	1027.39	2.56871	34.3067
34	Mami Market	205.6	13.9	0.0048638	0.0872312	2796.16	3.24587	12.4326
35	Model nurs. and prim. Sch. Aneibo quarters	157.1	11.34	0.006365	0.11439123	1781.5	1.84089	69.0012

The aquifer protective rating (Protection against contamination) of any aquifer can be established using Table 3 below (Oladapo and Akintorinwa, 2007).

Table 3: Rating of protective Capacity of Aquifers (After Oladapo and Akintorinwa, 2007).

Longitudinal conductance (Ω—1)	Protective capacity rating
>10	Excellence
5–10	Very good
0.7–4.9	Good
0.2–0.69	Moderate
0.1–0.19	Weak
0.1	Poor

According to Offodile (1983), the aquifers in the study area were classified in terms of their yielding capacity using Transmissivity. This is as shown in Table 4.

Table 4: Aquifer classification based on Transmissivity values (Offodile, 1983).

Transmissivity (m^2/day) Classification of well

Original Article

>500	High Potentials
50–500	Moderate Potential
5–50	Low Potential
0.5–5	Very low Potential
<0.5	Negligible potential

Table 5 shows the protective capacity of the aquifers within study area obtained using their longitudinal conductance

Table 5: Longitudinal conductance and protective capacity of the study area

VES No.	Locations	Longitudinal conductance (s)	Protective capacity rating
1 2	Ganaja BH1	0.60604364	Moderate
3	500 unit (BH1)	0.14508955	Weak
4	500 unit (BH2)	0.18386763	Weak
5	200 unit (BH1)	0.78147138	Good
6	200 Unit (BH2)	0.78548491	Good
7	Phase I (BH1)	0.01332853	Poor
8	Phase I (BH2)	0.02165674	Poor
9	Phase II (BH1)	0.5301028	Moderate
10	Phase II (BH2)	0.24801744	Moderate
11	Otokiti Estate (BH)	2.06794872	Good
12	Army Barracks (BH)	0.22549901	Moderate
13	Roja Table Water (BH 1)	0.39976415	Moderate
14	Zangodaji (BH 2) Adankolo (BH 1)	0.01333262	Poor
15	Adankolo (BH 2)	0.00944882	Poor
16	Adankolo (BH 3)	0.01800379	Poor
17 18	Adankolo (BH 4)	0.07688454	Poor
19	Marine Road (BH) Kenwo Hotel	0.01427354	Poor
20	(HDW) Kasuwa Hotel (BH)	0.00904951	Poor
21		0.00956701	Poor
22	GRAJ(GRA) (HDW)	0.02444883	Poor
23	New Layout (HDW)	0.068113	Poor
24	New Layout (HDW 2)	0.0219846	Poor
25	Megiri (HDW)	0.0410081	Poor
26	Kabawa (HDW)	0,0378227	Poor
27	SarkinNoma (HDW)	0.0946271	Poor
28	Felele (HDW 1)	0.06140845	Poor
29	Felele (HDW 2)	0.0495356	Poor
30	Felele (HDW 3)	0.11534591	Poor
31	Behind Secretariat (HDW)	0.05035054	Weak
32	LGEA Primary school Zango 1	0.0070633	Poor Poor

Original Article

33	LGEA Primary school Zango 2	0.09234012	Poor
34	LGEA Primary school Zango 3	0.1287434	Weak Poor
35	Mami Market	0.2241145	Poor
	Model nurs. and prim. Sch. Aneibo quarters	0..087234 0.1143912	

Figure 3 is one of the geo-sections (station 16) obtained from the vertical electrical sounding carried out in the study area. It is one the station where three (3) geo-electric layers were encountered during the study.

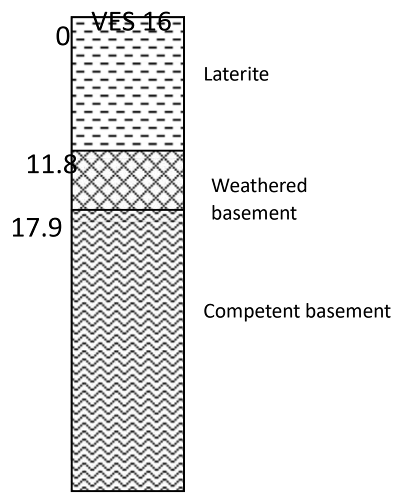

Figure 3: Geo-electric section of station 16 in the study area.

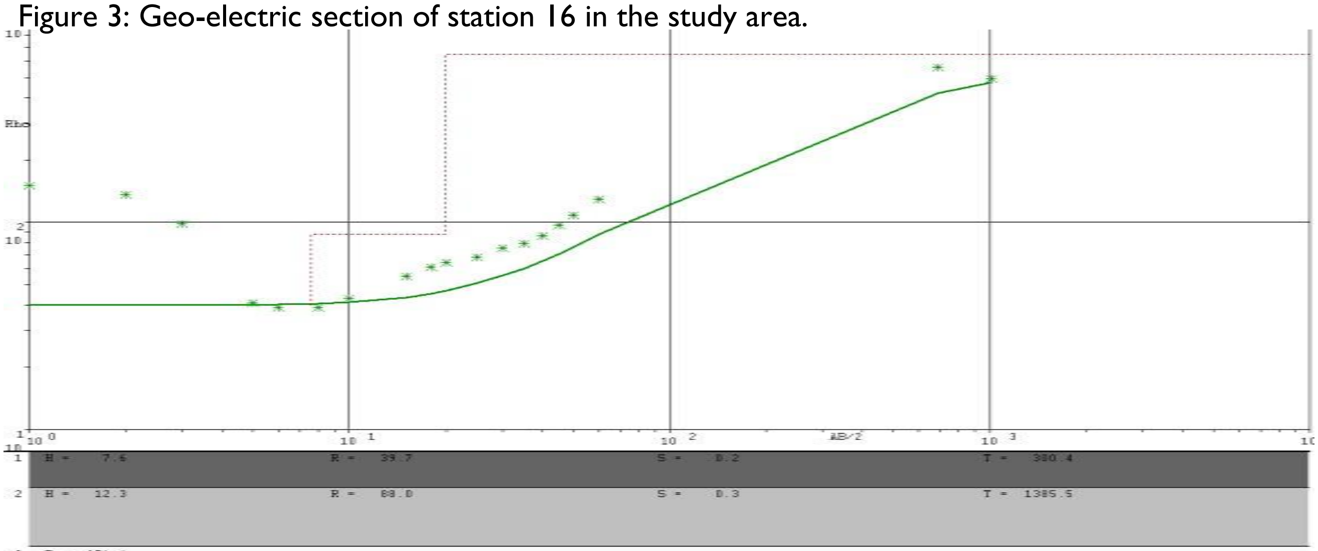

Table 6: Vertical Electrical Sounding Station 16 (3 layers)

Depth(m)	Thickness(m)	Resistivity(ohm-m)	Inferred lithology

Original Article

0-11.8	11.8	39.70	Laterite
11.8-17.94	6.14	79.86	Weathered Basement
>18	-	507.56	Basement

Figure 4 is one of the geo-sections (station 17) obtained from the vertical electrical sounding carried out in the study area. It is one the station where four (4) geo-electric layers were encountered during the study.

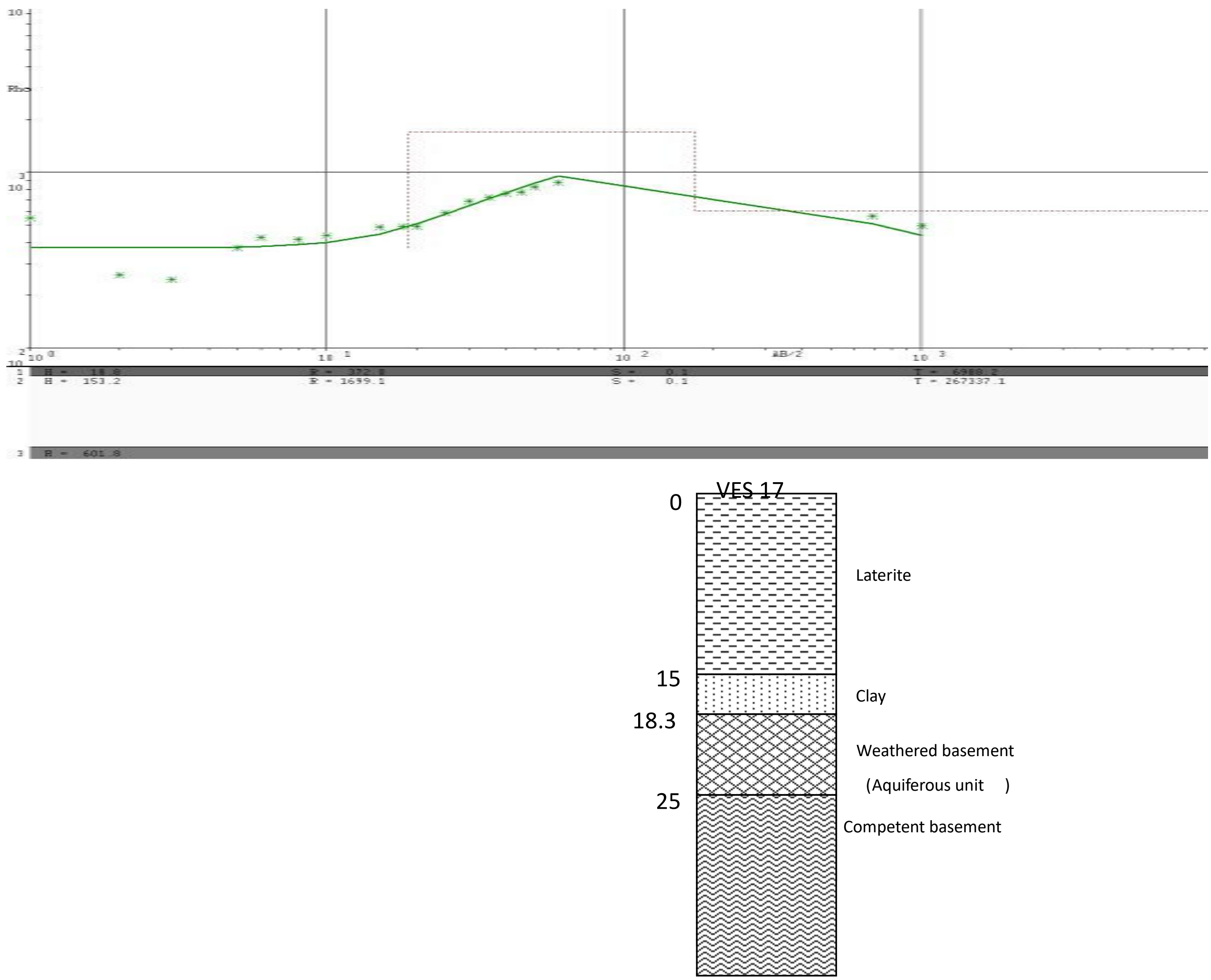

Figure 4: Geo -electric section of station 17 in the study area

Table 8: Hydraulic conductivity of the aquifers in the study area

Original Article

VES No.	Locations	**Hydraulic conductivity (k) M/day**
1	Ganaja BH1	26.24325
2	500 unit (BH1)	6.250823
3	500 unit (BH2)	10.37
4	200 unit (BH1)	25.60232
5	200 Unit (BH2)	29.84245
6	Phase I (BH1)	2.03115
7	Phase I (BH2)	3.27712
8	Phase II (BH1)	64.54349
9	Phase II (BH2)	9.96867
10	Otokiti Estate (BH)	56.86754
11	Army Barracks (BH)	9.10135
12	Roja Table Water (BH 1)	52.60192
13	Zangodaji (BH 2)	0.80365
14	Adankolo (BH 1)	1.79198
15	Adankolo (BH 2)	1.79663
16	Adankolo (BH 3)	6.49362
17	Adankolo (BH 4)	1.24434
18	Marine Road (BH)	0.36757
19	Kenwo Hotel (HDW)	0.51343
20	Kasuwa Hotel (BH)	2.3903
21	GRAJ(GRA) (HDW)	2.78118
22	New Layout (HDW)	1.07848
23	New Layout (HDW 2)	2.38115
24	Megiri (HDW)	5.86317
25	Kabawa (HDW)	4.28499
26	SarkinNoma (HDW)	2.60048
27	Felele (HDW 1)	2.45965
28	Felele (HDW 2)	6.52105
29	Felele (HDW 3)	3.45855
30	Behind Secretariat (HDW)	0.42835
31	LGEA Primary school Zango 1	2.60048
32	LGEA Primary school Zango 2	1.48076
33	LGEA Primary school Zango 3	2.56871

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34	Mami Market	3.24587
35	Model nurs. and prim. Sch. Aneibo quarters	1.84089

Table 9 shows the aquifer potential of the aquifers in the study area using transmissivity data obtained.

Discussion

From the result of the vertical electrical sounding (Table 1), two types of aquifers were delineated, namely; the weathered basement aquifer and weathered/fractured aquifer. The weathered basement aquifer was shown by VES 1 to 18, 21, 22 to 35 while weathered/fractured aquifer was revealed by VES stations 19 and 20. Thirteen (13) out of the thirty five (35) VES curves revealed a 4–layer geo-electric model (VES 6, 13 to 15, 17, 19, 20, 22 to 25, 29 &30) and the characteristic geo-electric signatures are AA- and HA- type curves, while the remaining twenty two (22) indicated a 3–layer geo-electric model and the characteristic geo-electric signatures are H- and A–type curves.

The A – type curve represents a subsurface condition in which there is an increase in resistivity values from the topsoil to the bedrock ($\rho1 < \rho2 < \rho3$). The H – type curve represents a subsurface whereby the resistivity of the first layer is greater than the second layer while the resistivity of the second layer is less than the third layer ($\rho1 > \rho2 < \rho3$). The AA – type curve represents a subsurface which is composed of four layers in which there is an increase in resistivity from the first layer to the competent basement ($\rho1 < \rho2 < \rho3 < \rho4$). The HA – type curve shows a subsurface in which the resistivity of the first layer is greater than the second layer while the second layer is less than the third layer and the resistivity of the third layer is less than the fourth layer ($\rho1 > \rho2 < \rho3 < \rho4$).

The topsoil generally comprises clay and laterite and constitutes the zone of aeration (phreatic zone). This zone contributes to groundwater development as it serves as a conduit through which meteoric water infiltrates the subsurface to form groundwater (Table 1).

The weathered basement aquifer in the study area formed the second layer for the 3–layer formations. The depth of the layer ranges from 3.0m to 16.13m and the thickness ranges from 3.1m to 6.14m. The resistivity is of the range of 6.81Ωm to 166.23Ωm (Tables 1 and 2). For the four-layer formations, the weathered layer aquifer forms the third layer. The depth of the layer varies from 18m to 25m, while the thickness ranges from 5m to 6.7m with a resistivity range of 316.62Ωm – 750.20Ωm. The groundwater yield of this aquifer type is determined by the degree of shaliness of the weathered zone. Low yield is encountered when the aquifer unit is clayey. This is because clay is not permeable to allow the flow of water. Sources of clay in Lokoja can be attributed to weathering of feldspar of the Lokoja Formation and the Basement rocks in the area.

The weathered/fractured aquifer forms the third layer in the four-layer geo-electric model. The depth of the layer ranges from 17m – 9.2m, a thickness range of between 3m and 3.7m and a resistivity varying from 277.6Ωm – 317.5Ωm (Table 1 and 2). This zone underlies the weathered zone directly. The groundwater yield from this aquifer type could be high if the density of the fractures in the fractured column is high. The fresh Basement Complex forms the last layer in the geo-electric section. The resistivity values of the competent basement for both aquifers vary from 33.45Ωm – 7724.31Ωm.

The layer resistivity of the aquifers together with the thickness of the layer as shown in Table 2 were used to compute the various Dar Zarrouk parameters as shown in Table 2. The rating of the aquifer protective capacity according to Oladapo and Akintorinwa, 2007 is shown in Table 3. This rating was used as standard for the data

obtained from the study area. The classification of aquifers based on their discharge ability/yielding ability according to Offodile, 1983 is shown in Table 4. This classification was used as standard for the data obtained from the study area.
The longitudinal conductance was used to evaluate the protective capacity of the aquifers in the study according to Oladapo and Akintorinwa, 2007. The longitudinal conductance ranges from 0.00915Ω to 2.063Ω with an average of 1.068Ω (Table 5). The results show that most of the aquifers in the area have poor to moderate protective capacity. This is an indication that most of the aquifers in the study area are adequately protected. Wells located in this area are therefore susceptible to surface contamination-because of the proximity of the aquifer to the surface.
Tables 6 and 7 show the geo-electric properties of some of the aquifers (Location 16 and 17). The results were obtained from vertical electrical sounding (VES) done with the aid of ABEM Terrameter using Schlumberger array.
The hydraulic conductivity obtained ranges from 0.36757m/day to 56.86725m/day with a mean value of 21.34m/day (Table 8). The results show that the aquifers have low to moderate yielding potentials. The spatial distribution of hydraulic conductivity across the study area (Figure 4) that the southern part of the study has good yield that the northern area.
The Transmissivity of the aquifer in the area ranges from 4.4543m^2 to 912.273m^2/day with a mean value of 213.34m^2/day. This was used to compute the aquifer potential of the study area as shown in Table 9. The spatial distribution of Transmissivity across the study area shows poor to moderate potentials (Figure 5)
The transverse resistance obtained ranges from 28.75Ωm^2 to 7290Ωm^2 with an average value of 1120 Ωm^2
This result indicates very low groundwater development class (Ezeh, 2012). The spatial distribution as shown in Figure 6 indicate that the Northeastern part of the study has the least groundwater development.

4. Conclusion

The result of the vertical electrical sounding two types of aquifers was delineated, namely; the weathered basement aquifer and weathered/fractured aquifer. Thirteen (13) out of the thirty-five (35) VES curves revealed a 4–layer geo-electric model and the characteristic geo-electric signatures are AA- and HA- type curves, while the remaining twenty-two (22) indicated a 3– layer geo-electric model and the characteristic geo-electric signatures are H- and A–type curves.
The results obtained revealed that the aquifers within the study area have poor to moderate protective capacity and very low to moderate yielding/discharge potentials.
The resistivity soundings results revealed that about 4 curve types were identified in the study area namely AA, HA, A and H type with the lithologic layers varying from four 3 to 4 consisting of varying resistivity and thicknesses across each VES point. The geo-electric sections revealed that the major aquifer systems in the study area are weathered basement and weathered/fractured basement. The longitudinal conductance computed indicates that the aquifers in the area have poor to moderate protective capacity whereas transverse resistance indicates very low ground water development class. Hydraulic conductivity and transmissivity values indicate very low to moderate aquifer potentials.

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