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Resistivity Prospecting for Groundwater Potential at the Proposed Ibrahim Badamasi Babangida University Teaching Hospital, Lapai, Niger State

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ABSTRACT
Resistivity methods have been increasingly used for aquifer characterisation due to their high level of effectiveness. In this study, electrical resistivity survey was carried out at the Proposed Ibrahim Badamasi Babangida University Teaching Hospital Lapai Niger State Nigeria in order to study the groundwater potential with a view of determining the depth to the bedrock and thickness of the overburden protective capacity. Vertical Electrical Sounding (VES) using Schlumberger array was used to occupy thirty (30) VES stations using ABEM Terrameter (SAS 300) for the acquisition of apparent resistivity data. The field data obtained was analysed using computer software (*IPI2win*) which gave the secondary geoelectric parameters of depth, layer thickness and layer resistivities. The results revealed heterogeneous nature of the subsurface geological sequence comprising top soil (clayey-sandy and sandy-lateritic), weathered layer, partly weathered (fractured basement) and fresh basement. The resistivity value for the topsoil layer varied from 20Ωm to 600Ωm with thickness ranging from 0.5 to 7.2 m. The weathered basement had resistivity values ranging from 15Ωm to 593Ωm while the thicknesses varied between 2.75 and 33.04m. The fractured basement had resistivity values ranging from 201Ωm to 835Ωm and thicknesses having values between 11 and 20.4m. The fresh basement (bedrock) had resistivity values ranging from 1161Ωm to 3115Ωm with infinite depth. The depth from the earth's surface to the bedrock surface varied between 2.5 to 47.75m. The VES 10, 11 and 19 had very good overburden protective capacity and can serve as good sites for borehole drilling.

Keywords:
Groundwater,
Resistivity,
Aquifer protectivity,
Dar-Zarrouk parameters.

INTRODUCTION

The accessibility of quality water assets has forever been the essential worry of social orders in Semi-Bone-dry and Dry locales (Yusuf, 2020). Indeed, even in areas of more plentiful precipitation, the issue of acquiring a sufficient stock of potable water is for the most part turning out to be more intense because of truly expanding populace and industrialization. Accordingly, surface water cannot be trustworthy consistently, thus, the need to search for different choices to enhance surface water. This makes the world to rely upon the biggest accessible wellspring of water which lies underground and this is alluded to as groundwater. It is the water held in the subsurface inside the zone of immersion under hydrostatic strain beneath water table (Yusuf, 2020).

Groundwater can be in sedimentary territory where it is less hard to take advantage of with the exception of its synthetic organization. It can likewise be in the translucent storm cellar complex territory where it may be challenging to find, particularly in regions underlain by glasslike un-cracked or un-endured rocks (Yusuf, 2018). The examination for groundwater today has become fundamental, because of its affordability and the possibility of getting quality water from the bedrock, information on the event and development of groundwater where it is required.

Hydrogeology alludes to the investigation of the event and development of groundwater, its science and connection to the geologic climate (Charles 2018). Groundwater prospecting and investigation helps in finding groundwater and seeing some spring properties. Hence, the use of geophysical techniques to the fruitful investigation of groundwater requires a legitimate comprehension of its hydrogeological trademark. Proof has shown that geophysical techniques are the most dependable methods for looking over strategy for subsurface primary examinations and rock variety (Yusuf et *al*., 2016).

A few techniques utilized in groundwater investigation incorporate electrical resistivity, gravity, seismic, attractive, remote detecting and electromagnetic methods, out of which the electrical resistivity strategy is the best for finding useful well as it estimates the resistivity dissemination of the subsurface. Various materials in the subsurface have different electrical resistivity values that can help in distinguishing the groundwater. It is a non-damaging and practical technique for finding the spring. This strategy is ordinarily being utilized to identify spring, as it can enter further. The resistivity technique is likewise pertinent in the distinguishing proof of subsurface developments, groundwater zones, groundwater saltiness and anthropogenic tainting (Khaki, 2014). Vertical Electrical Sounding (VES) technique can give data on the upward variety in the resistivity of the ground with profundity and the Constant Separation Traversing (CST) gives a method for deciding stretch variety in the resistivity of the ground (Ariyo, 2003).

Although, many geophysical techniques could be employed for groundwater characterization, the electrical and electromagnetic methods are better, in mapping and monitoring contaminated and clean groundwater. The knowledge of the aquifer characteristics is important in determining groundwater potential. The electrical resistivity method is suitable for subsurface study and has the capability of exploring and identifying aquifer characteristics (Lashkapour, 2005).

Electrical resistivity method is used to investigate the nature of subsurface formations while studying the variations in their resistance to flow of electrical current and hence determining the occurrence of groundwater. The objectives of this method in the field of groundwater exploration are to locate groundwater bearing formations, estimate the depth to the water table, thickness and lateral extent of aquifers; depth to bedrock, delineation of weathered zones, structures and stratigraphic conditions such as fractures and dykes. Among the geophysical methods commonly employed in subsurface investigations, the electrical resistivity method has particular advantage in hydrology because it reacts to changes in the conductivity of groundwater. Electrical resistivity method has gained considerable importance in the field of groundwater exploration because of its low cost, easy operation and efficacy to detect the water bearing formations.

Resistivity of geological formations varies significantly between their dry and saturated states. Resistivity values of rocks are controlled by chemical composition of the minerals, density, porosity, water content, water quality and temperature. The value of formation resistivity also depends on the direction of electrode spread and the nature of the top layer in hard rock area (Tsepav, *et al.*, 2021). Resistivity varies to a large extent in different rocks. Igneous and metamorphic rocks show a range of 10^2 and 10^6 ohm-meter, and the sedimentary rocks show 10^0 to 10^5 ohm-meter. However, in the porous formation such as highly weathered and fractured rocks, and unconsolidated sediments, the resistivity is controlled more by the amount and quality of water present, than the external rock resistivity.

This research utilizes the application of vertical electrical sounding method employing the Schlumberger configuration to identify viable sites, with good overburden protective capacity and solid bedrock at the proposed site of the Ibrahim Badamasi Babangida University Teaching Hospital, Lapai for the construction of productive boreholes.

MATERIALS AND METHODS

Location and Geology of the Study Area

The Proposed Ibrahim Badamasi Babangida University Teaching Hospital, Lapai, is situated along Lapai – Minna Road, is about 10 km from Lapai town, Lapai town is the headquarters of Lapai Local Government Area of Niger State (Fig 1.). The study area is located between Latitude 9^0 06′ 05.53″N and 9^0 05′ 06.22″N, and Longitude 6^0 32′ 05.53″ and 6^0 33′ 38.47″E along Minna road. (Tsepav *et al*., 2014)

The area falls within the guinea savannah vegetation comprising various species of shrubs and high forest plants along the streams and depressions. The area also consists of short grasses of height ranging from 3 to 4m and trees of up to 15m high. There are two climatic seasons associated with the area, the rainy and dry seasons. The total annual rainfall in this area is between 1086 and 1309 mm, spread over the months of April to November. The highest amount of rainfall is recorded in the month of August (Tsepav *et al*., 2014).

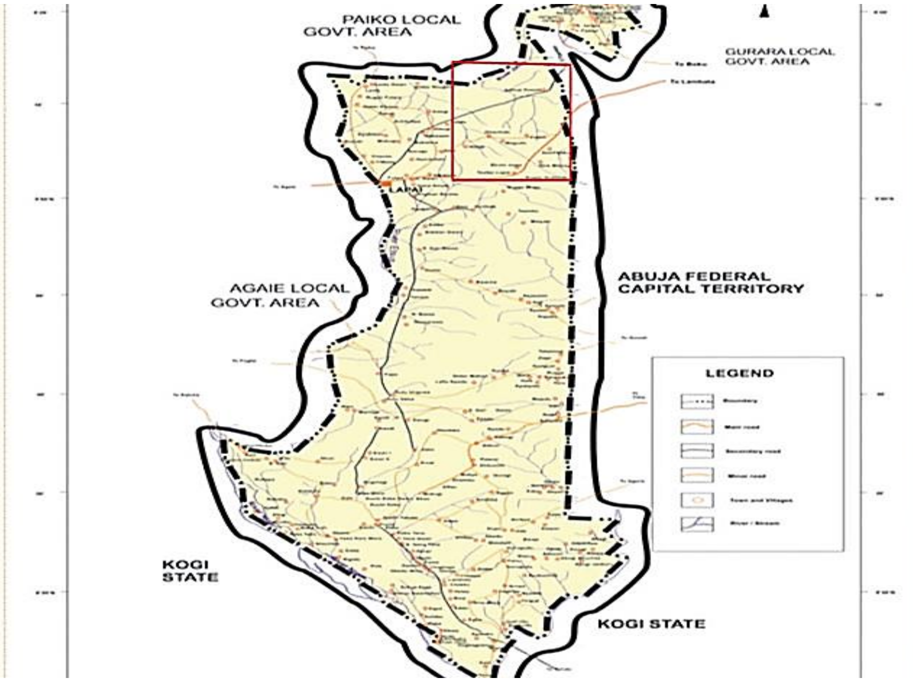


Figure 1: Map of Lapai Local Government Area, Niger State (Amadi, et al, 2011).

Lapai, like other areas on the same zone, has two major rock formations (Nigeria: Physical Setting – Niger State (1996)). The sedimentary rocks to the south, characterized by sandstones and alluvial deposits, particularly along the Niger valley and in most parts of Gulu, Muye and the eastern parts of Lapai town. These areas contain extensive flood plains of the River Niger and that has made the local government one of the most important and productive agricultural lands in the state (Tsepav *et al*., 2014)

To the north is the basement complex, characterized by outcrops of the Migmatite-Gneiss complex, the Schist Belts and the Older Granites of Precambrian age which can be found in the vast topography of rolling landscape. Such outcrops dominate the landscape in areas bounding Paikoro Local Government area in the northern part of Lapai Local Government.

Ibrahim Badamasi Babangida University, Lapai is located in an area that is made up of the older granitic rocks of the basement complex as can be seen from the granitic intrusions that form a suite of batholiths which is composed mainly of gneisses and schist (Tsepav *et al.,* 2015).

The instrumentation used for this survey consists of the Campus Geopulse Terrameter SAS 300,

Theory of Electrical Resistivity

It is well known that the resistance R, in ohms, of a wire is directly proportional to its length L and inversely proportional to its cross-sectional area A. That is:

$R \propto L/A$ or $R = \rho \frac{L}{A}$, (1)

where ρ, the constant of proportionality, is known as the electrical resistivity or electrical specific resistance, a characteristic of the material which is independent of its shape or size. According to Zohdy (1989), the resistance is given by

$R = \Delta V / I$, (2)

where ΔV is the potential difference across the resistance and I is the electric current through the resistive material. Substituting equation (1) in equation (2) and rearranging we get

$\rho = \frac{A}{L}\frac{\Delta V}{I}$ (3)

Equation (3) may be used to determine the resistivity ρ of homogeneous and isotropic materials in the form of regular geometric shapes, such as cylinders, parallelepipeds, and cubes. In a semi-infinite material the resistivity at every point must be defined. If the cross-sectional area and length of an element within the semi-infinite material are shrunk to infinitesimal size then the resistivity ρ may be defined as:

$$\rho = \frac{\frac{lim}{L \to 0}(\frac{\Delta V}{L})}{\frac{lim}{A \to 0}(\frac{I}{A})}$$

or

$\rho = \frac{E_L}{J}$ (4)

where E_L is the electric field and J is the current density. To generalize, we write

$\rho = \frac{E}{J}$ (5)

Equation (5) is known as Ohm's law in its differential vectorial form (Zohdy, 1989). The resistivity of a material is defined as being numerically equal to the resistance of a specimen of the material of unit dimensions. The unit of resistivity in the mks (meter-kilogram-second) system is the ohm-meter. In other systems it may be expressed in ohm-centimeter, ohm-foot, or other similar units.

Dar-Zarrouk Parameters and aquifer protective capacity

The Dar-Zarrouk (D-Z) parameters were defined by Maillet (1947) as the resistance T normal to the face and conductance S parallel to the face for a unit cross section area. They play an important role in resistivity soundings and are sufficient for computing the distribution of surface potential and hence an electrical resistivity graphs (Henriet, 1976).

Suppose that a section consists of N fine layers with thickness h_1, h_2, ...,h_n and resistivity ρ_1, ρ_2, ρ_3,....,ρ_n for a block of unit square area and thickness

$$H = \sum_{i=1}^{N} h_i \quad (6)$$

The values of S and T are set equal to those for an anisotropic block with unit square area so that: Longitudinal Unit Conductance S, can be express as:

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \ldots\ldots + \frac{h_n}{\rho_n} \quad (7)$$

$$S = \sum_{i=1}^{N} \frac{h_i}{\rho_i} \quad (8)$$

and the Transverse Unit Resistance T as:

$$T = \rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3 + \ldots\ldots + \rho_n h_n \quad (9)$$

$$T = \sum_{i=1}^{N} \rho_i h_i \quad (10)$$

Longitudinal Resistivity R_S

$$R_s = \frac{H}{S} \quad (11)$$

Transverse Resistivity,

$$R_T = \frac{T}{H} \quad (12)$$

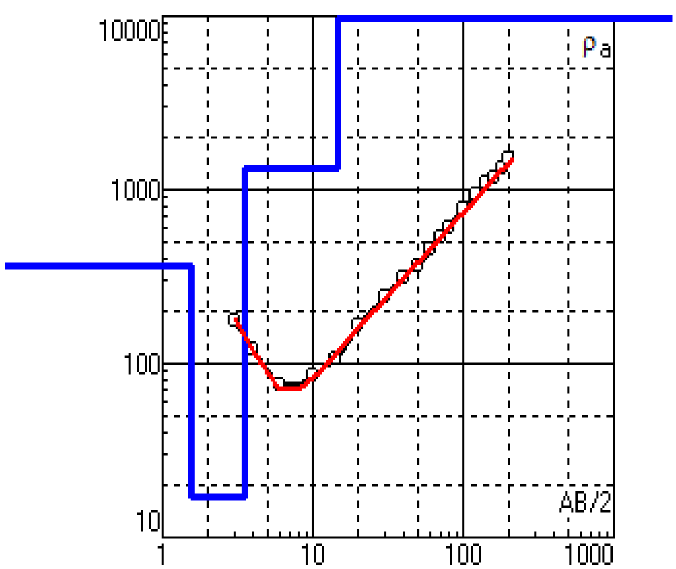
Oladapo and Akintoriwa (2007) brought up the values for rating the protectivity of overburdens using the longitudinal conductance values as shown in Table 1

Table 1: Longitudinal conductance/protective capacity rating (Oladapo and Akintoriwa, 2007)

Total longitudinal unit conductance (mhos)	Overburden protective capacity classification
<0.10	Poor
0.1-0.19	Weak
0.2-0.69	Moderate
0.7-4.9	Good
5-10	Very good
>10	Excellent

RESULTS AND DISCUSSION

The resistivity data obtained from the field was processed using IP2win software to generate parameters of interest in computing the Dar Zarrouk parameters. Figure 2 shows a representative VES model revealing the resistivities, depth and thicknesses of the layers while Table 2 shows the secondary parameters of thickness, depth and layer thickness obtained from the processed raw resistivity data from the field.



N	ρ	h	d	Alt
1	362	1.54	1.54	-1.543
2	17.1	1.93	3.48	-3.477
3	1312	11.1	14.6	-14.61
4	10750			

Figure 2: modelled VES parameters for VES 1

Table 2: Parameters from Geoelectric Resistivity Soundings of VES 1 to 30.

Coordinates	Thickness layer (m)			Depth (m)			Resistivity layer (Wm)			
	h_1	h_2	h_3	d_1	d_2	d_3	ρ_1	ρ_2	ρ_3	ρ_4
09°06’05.5N 006°33’05.4Es	1.03	8.72	40.8	1.03	9.75	50.5	192	1980	4924	9507
09°05'41"N 006°32'54"E	1.65	1.8	2.17	1.65	3.45	5.62	19.5	649	1223	2512
09°06'02.1"N 006°33'05.2"E	2.95	12.6	18.9	2.95	15.6	34.5	34.5	214	1029	3448
09°05'55"N 006°32'55"E	1.03	8.72	40.8	1.03	9.75	50.5	197	1980	4924	9507
09°05'58.7"N 006°33'05.2"E	1.59	9.11	16	1.59	10.7	26.7	13.8	177	944	3255
09°05'41"N 006°32'555"E	1.94	3.37	15.2	1.94	5.31	20.5	13.3	200	1995	9717
09°05'56"N 006°33'05.2"E	1.08	3.72	5.46	1.08	4.8	10.3	112	518	1931	4230
09°05'48"N 006°32'57"E	1.98	3.07	4.95	1.98	5.05	10	32.8	100	193	531
09°05'53.1"N 006°33'04.9"E	1.8	8.46	97.5	1.8	10.3	108	31.4	337	806	6939
09°05'5"N 006°32'58"E	1.93	7.58	11.3	1.93	9.51	70.8	0.018	0.11	0.48	0.975
09°05'50.6"N 006°32'00.1"E	0.232	1.75	8.02	0.232	1.98	60	0.022	0.022	0.193	0.492
09°05'51.1"N 006°33'00.1"E	0.972	1.08	2.96	0.972	2.05	5.01	2.59	86.6	244	631
09°05'48.04"N 006°33'03.5"N	1.53	3.52	7.18	1.53	5.05	12.2	17.4	49.2	193	193
09°05'48.04"N 006°33'03.5"E	1.83	0.053	7.29	1.83	1.88	9.17	9.44	410	398	2114
09°06'01.7"N 006°33'00.7"E	1.63	16.2	71.3	1.63	17.8	89.1	1.5	13.3	27.4	26.6
09°05'45.5"N 006°33'02.8"E	2.18	2.55	5.27	2.18	4.73	10	12.2	523	1939	31810
09°06'01.4"N 006°33'00.9"E	2.44	2.03	0.13	2.44	4.47	4.5	14.5	1413	1413	3548
09°05'42.8"N 006°33'01.4"E	2.03	7.97	40.5	2.03	10	50.5	10.3	95.1	203	975
09°06'02.4"N 006°33'00.9"E	0.162	3.6	6.83	0.162	3.76	10.6	0.248	0.562	6.31	30.7
09°05'39.6"N 006°33'02.5"E	1.98	2.94	15.4	1.98	4.92	20.3	242	650	3123	5312
09°06'06.7"N 006°33'01.5"E	1.03	3.84	14.5	1.03	4.87	19.4	1.78	9.72	48.7	97.2
09°05'58.7"N 006°33'05.2"E	1.65	1.8	2.17	1.65	3.45	5.62	19.5	649	1223	2512
09°05'45.5"N 006°33'02.8"E	0.187	1.31	1.58	0.187	1.5	3.08	18	18	230	3162
09°05'48.04"N 006°33'03.5"E	1.83	8.46	10.2	1.83	10.3	20.5	15	100	473	1939
09°05'56"N 006°33'05.2"E	2.15	28.8	4.98	2.15	30.9	35.9	724	417	10	119
09°06'01.4"N 006°33'00.9"E	1.03	8.72	40.8	1.03	9.75	50.5	197	1980	4924	9507
09°06’05.5N 006°33’05.4E	1	9	40.1	1	10	50.1	12.2	972	1995	11221
09°05'58.7"N 006°33'05.2"E	1.83	0.053	7.29	1.83	1.88	9.17	9.44	410	398	2114

09°05'48"N 006°32'57"E	1.03	3.84	14.5	1.03	4.87	19.4	1.78	9.72	48.7	97.2
09°06'01.4"N 006°33'00.9"E	0.187	1.31	1.58	0.187	1.5	3.08	18	18	230	3162

The values in Table 2 were then used in Equations 8 and 12 to compute the Longitudinal Conductance and Transverse Resistance as shown in Table 3.

Table 3: Longitudinal Conductance and Transverse Resistance.

VES NO.	Coordinates	Long. Conductance (Siemens)				Transverse Resistance (Ωm^2)			
		S_1	S_2	S_3	TLC	R_1	R_2	R_3	TTR
1	09°06’05.5N 006°33’05.4E	0.005	0.004	0.008	0.017	197.8	17266	200899.2	218363
2	09°05'41"N 006°32'54"E	0.085	0.003	0.002	0.090	32.18	1168	2653.9	3854.08
3	09°06'02.1"N 006°33'05.2"E	0.086	0.059	0.018	0.163	101.8	2696	19448.1	22245.9
4	09°05'55"N 006°32'55"E	0.005	0.004	0.008	0.017	202.9	17266	200899.2	218368.1
5	09°05'58.7"N 006°33'05.2"E	0.115	0.051	0.017	0.183	21.94	1612	15104.0	16737.94
	09°05'41"N 006°32'555"E	0.146	0.017	0.008	0.171	25.8	674	30324.0	31023.8
7	09°05'56"N 006°33'05.2"E	0.010	0.007	0.003	0.020	121	1927.0	10543.3	12591.3
8	09°05'48"N 006°32'57"E	0.060	0.031	0.026	0.117	64.94	307.0	955.4	1327.34
9	09°05'53.1"N 006°33'04.9"E	0.057	0.025	0.121	0.203	56.52	2851.0	78585	81492.52
10	09°05'5"N 006°32'58"E	104.891	68.909	23.542	197.342	0.036	0.8	5.4	6.27
11	09°05'50.6"N 006°32'00.1"E	10.498	79.186	41.554	131.238	0.005	0.0	1.5	1.544
12	09°05'51.1"N 006°33'00.1"E	0.375	0.012	0.012	0.399	2.517	93.5	722.2	818.247
13	09°05'48.04"N 006°33'03.5"N	0.088	0.072	0.037	0.197	26.62	173.2	1385.7	1585.52
14	09°05'48.04"N 006°33'03.5"E	0.194	0.000	0.018	0.212	17.28	21.9	2901.4	2940.57
15	09°06'01.7"N 006°33'00.7"E	1.087	1.218	2.602	4.907	2.445	215.5	1953.6	2171.545
16	09°05'45.5"N 006°33'02.8"E	0.179	0.005	0.003	0.187	26.6	1334.0	10218.5	11579.1
17	09°06'01.4"N 006°33'00.9"E	0.168	0.001	0.000	0.169	35.38	2868.0	183.7	3087.08
18	09°05'42.8"N 006°33'01.4"E	0.197	0.084	0.200	0.481	20.91	757.9	8221.5	9000.31
19	09°06'02.4"N 006°33'00.9"E	0.653	6.406	1.082	8.141	0.04	2.0	43.1	45.163
20	09°05'39.6"N 006°33'02.5"E	0.008	0.005	0.005	0.018	479.2	1911.0	48094.2	50484.4
21	09°06'06.7"N 006°33'01.5"E	0.579	0.395	0.298	1.272	1.833	37.3	706.2	745.353
22	09°05'58.7"N 006°33'05.2"E	0.085	0.003	0.002	0.090	32.18	1168.0	2653.9	3854.08

23	09°05'45.5"N 006°33'02.8"E	0.010	0.073	0.007	0.090	3.366	23.6	363.4	390.346
24	09°05'48.04"N 006°33'03.5"E	0.122	0.085	0.022	0.229	27.45	846.0	4824.6	5698.05
25	09°05'56"N 006°33'05.2"E	0.003	0.069	0.498	0.570	1557	12010.0	49.8	13616.8
26	09°06'01.4"N 006°33'00.9"E	0.005	0.004	0.008	0.017	202.9	17266.0	200899.2	218368.1
27	09°06’05.5N 006°33’05.4E	0.082	0.009	0.020	0.111	12.2	8748.0	79999.5	88759.7
28	09°05'58.7"N 006°33'05.2"E	0.194	0.000	0.018	0.212	17.28	21.9	2901.4	2940.57
29	09°05'48"N 006°32'57"E	0.579	0.395	0.298	1.272	1.833	37.3	706.2	745.353
30	09°06'01.4"N 006°33'00.9"E	0.010	0.073	0.007	0.090	3.366	23.6	363.4	390.346

Figure 3 shows the sketched geoelectric sections (not to scale) of some of the litho-sections in the study area for VES 1 to 10, indicating the layer resistivities, thicknesses and depth of each lithologic section.

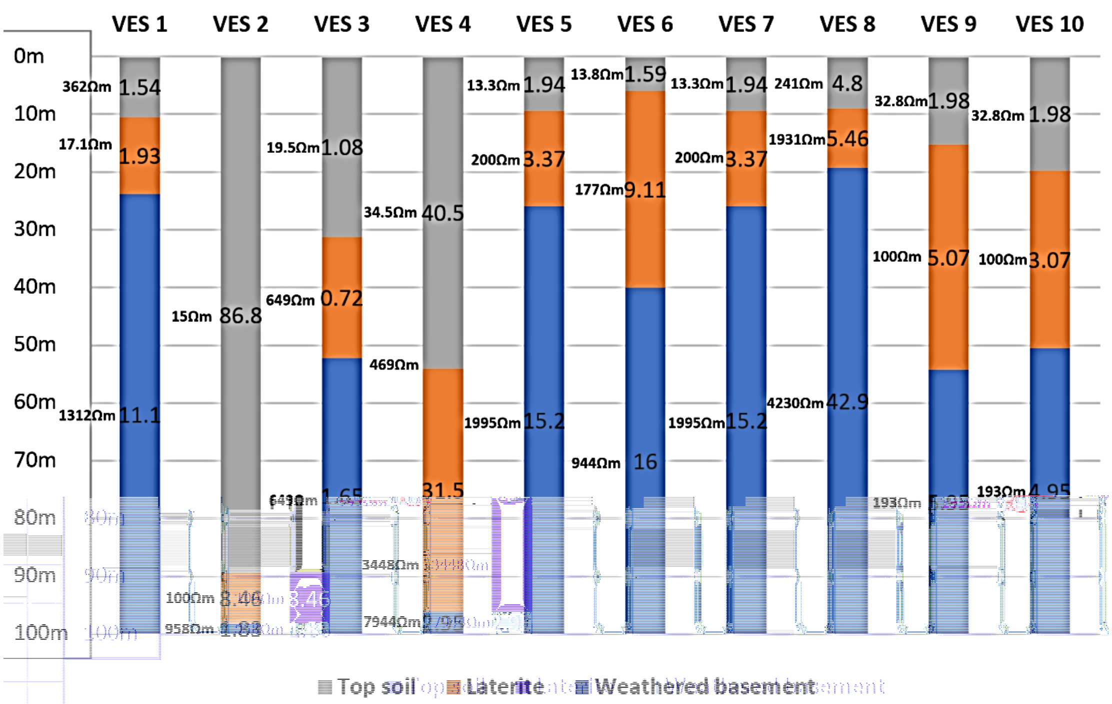


Figure 3: Sketched geoelectric sections showing the litho-sections in the study area

The geoelectric sections revealed basically four subsurface geo-electrical layers in VES 6, 9, 10, 14, 17, 19, 22, 23, 26, 28, 29, and 30, while three subsurface geo-electrical layers were revealed in VES 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 15, 16, 18, 20, 21, 24, 25, and 27.

The top layer which is the topsoil had resistivity values ranging from 10.7 to 1992 ohm-m, with mean resistivity of 611.267 ohm-m. Its highest value was observed at VES 14 and the lowest at VES 10. The top layer thickness ranged from 0.396 to 3.45m, with mean thickness of 1.872m. Its highest value was observed at VES 9 and the lowest at VES 4. The top soil contributes to the development of ground water, because it is the passage for the flow of surface water to the fractured layer. It is known as aeration area and water in this layer is called sub-surface water. The top soil generally consists of three parts: the belt of the soil water at the top, the intermediate vadose zone, and the capillary fringe at the bottom. The difference in compaction of the clayed sand is likely responsible for the variation in the resistivity values.

For VES 1, 6, 7, 8, 9, 10, 11 and 12 which have four layers, the second layer constitute the Lateritic clay and it had resistivity values ranging from 30.6 to 896ohm-m, with mean resistivity of 256.85ohm-m. Its highest value was observed at VES 12 and the lowest at VES 7. Its thickness ranged from 1.17 to 23.8m, with mean thickness of 6.249m. It highest value was observed at VES 9 and the lowest at VES 7. The second layer of VES 2, 3, 4 and 5, and the third layer of VES 1, 6, 7, 8, 9, 10, 11 and 12 were considered the weathered zones and had resistivities that ranged from 6.24 to 661 ohm-m, with mean resistivity of 187.287 ohm-m. Its highest value was observed at VES 8 and the lowest at VES 10. The weathered zone thickness ranged from 1.94 to 118m, with mean thickness of 32.0425m. It highest value was observed at VES 9 and the lowest at VES 3.

The third layer in VES 4 and the fourth layer in VES 5 constitute the Fresh basement and its resistivity is 14547Ωm in VES 4 and it is 70069Ωm in VES 6, while the mean resistivity 2308Ωm. The third layer of VES 10, and the fourth layer of VES 11, and 19, constitute the fractured basement which has resistivity that ranges from 20.5 to 509 ohm-m, with mean resistivity of 236.11 ohm-m.

From VES 9,12,14,18,24,25, and 28, the total longitudinal conductance which is the protective capacity of the overburden rock material had values ranging from 0.203 – 0.570 Siemens, it indicates that these particular VES points had a moderate level of overburden protective capacity. While VES 15, 21, had total longitudinal conductance values ranging from 1.272 – 4.907 siemens, and as a result of the range it shows that this VES have a good protective capacity of the overburden rock material according to Oladapo and Akintoriwa, (2007) rating.

CONCLUSION

This research has provided information on the depth to the groundwater and the thickness of the aquifer unit in the study area, as well as the overburden protective capacity. This information is relevant for the development of an effective water scheme for the area. Based on the findings made in the interpretation of the VES data, the following VES stations have been chosen as the most viable locations for the development of groundwater resources in the study area, they are: VES 10, VES 11 and VES 19. The thickness and resistivity of the aquifers at these VES stations indicates a high potential for groundwater, their aquifer protective capacity ranges from 131.238-197.342 siemens, which is very good. Although the study area has a relatively high potential for groundwater development, proper preliminary geophysical work is required before drilling of water bore holes to avoid failure due to the complex geology of the area.

On the basis of results generated in the study area, and a very good aquifer protective capacity, it is recommended that future borehole could be sunk at a depth of 60 m beneath VES 10, 11 and 19.

REFERENCES

Amadi, A., Nwawulu, C., Unuevho, C., Okoye, N., Okunlola, I., Egharevba, N., Ako, T. and Alkali, Y. (2011). Evaluation of the Groundwater Potential in Pompo village, Gidan Kwano, Minna Using vertical Electrical Resistivity Sounding. *Journal of Applied Science and Technology*,1 (3)**:** 53-66.

Ariyo, S.O. Oduwole, M.O and Mosuro, G.O. (2003): Hydro-geopghysical, evaluation of groundwater potentials of Awa-Ijebu, Southwestern Nigeria. Journal of the Nigerian Association of Hydrogeologist (NAH) 14: 31-36.

Charles, W. F. (2018). *Applied Hydrogeology*. Waveland Press.

Henriet J.P (1976) Direct Application of Dar-Zarrouk Parameters in Groundwater Surveys. Geophys Prospect 24:344–353

Khaki, (2014). Delineating the characteristics of saline water intrusion in the coastal aquifers of Tamil Nadu, India by analysing the Dar-Zarrouk parameters

Lashkapour, A. (2005). Electrical Imaging and Laboratory Resistivity Testing for Geotechnical Investigation of Pusan Clay Deposit. J Appl. Geophys.

Maillet, R. (1947) "The Fundamental Equations of Electrical Prospecting," *Journal of Geophysics,* Vol. 12, No. 4, 1947, pp. 529-556.

Oladapo M.I. and Akintorinwa O.J. (2007). Hydrogeophysical Study of Ogbese Southwestern, Nigeria. *Global Journal of Pure and Applied Science*, 13(1), 55-61.

Tsepav, M.T., Bello Abdullahi and A. A Gbedako, (2014): Geoelectric Investigation of Some Parts of Ibrahim Badamasi Babangida University, Lapai, Nigeria: *Physical Science International Journal* 4(4): 623-635.

Tsepav MT., Ibrahim SI. and Bayegun FA. (2015). Geoelectrical Characterization of Aquifer Precincts in Parts of Lapai, North Central Nigeria. *Journal of Apply Science Environmental Management*. 19, 295 – 301.

Tsepav, M. T., Aliyu, Y. B., Obaje, N. G.and Usman, Y. T. (2021). On the use of electricalresistivity method in mapping potential sources and extent of pollution of groundwater systems in Lapai Town, Niger State, Nigeria. *Journal of Physics: Theories and Applications.*

Vol. 5(1), pp. 18-36. Doi: 10.20961/jphystheor-appl.v5i1.51563

Yusuf, T. U. (2016). Overview of Effective Geophysical Methods used in the study of Environmental Pollution by Waste Dumpsites. *African Research Review: An International Multi-Disciplinary Journal, Bahir Dar, Ethiopia.* Volume 10, Number 2, pp. 124 – 143.

Yusuf, T. U., Udensi E. E., Rafiu A. A.,P. C. Eze and Aliyu M. (2018). Investigating groundwater quality and soil cultivation viability using geophysical and geochemical approach at a dumpsite in Mokwa, Niger State Nigeria. *Lapai Journal of Applied and Natural Sciences. Faculty of Natural Sciences, IBB University Lapai, Niger State Nigeria.* Volume 3, Number 1, 2018, pp. 20 – 35.

Yusuf, T. U. (2020). Location and Quality Assessment of Groundwater resources in Mokwa, Niger State Nigeria. *Nigerian Journal of Physics.* Volume 29(1), pp. 146 – 157.

Zohdy A.A.R., 1989. A new method for the automatic interpretation of Schlumberger and Wenner sounding curves: Geophysics, Volume 54, pp9-39.