ABUAD INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES
ISSN: 2955-1021
AIJNAS Volume 2, Issue 3, December 2022 pp 139–154
https://doi.org/10.53982/aijnas.2022.0203.02-j

https://journals.abuad.edu.ng/index.php/aijnas

The Application of Vertical Electrical Sounding for the Geophysical and Hydrogeological Investgation in University of Benin Area, Nigeria

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Abstract
The occurrence and distribution of ground water in sedimentary basin is localized and confined to the weathered sandy layer/zone. The study was carried out with the aim of demonstrating the vertical electrical sounding method of investigation in the exploration for groundwater in University of Benin, around VC's lodge. A total of six VES points were probed using the ABEM SAS 300C terrameter which was used to generate field data applying the Schlumberger Array with AB/2 of 1.5m, 215m. The results were simulated usingIPI-2WINsoftware. The results show an average of four geo-electric layers per VES point; superficial layer, duricrust, clay layer, alluvium, sand layer and the weathered sandy layer. For VES 1-6, the thicknesses of the water table are 11.6 m. 16.6 m, 22.5m, 30.5 m 51.4 m and 27.8 m respectively and the depth to water table as 124.4 m, 124.6 m, 78.4m, 55.2 m, 38.5 m, and 29.4 m accordingly. Going by the results, VES 1 & 5 ranked the highest water prospect due to the thickness of water table layer, the depth to water table and most importantly the weathered/fractured layers with resistivity as high as 15,188Ω and 76,432Ω for VES 1 & 5 respectively, which also increases the permeability and storage of the groundwater. VES 2, 3, 4, and 6 are also wet reservoirs but for their shallow thicknesses and depth to water table which will influence the purity of the water. However, further investigation is needed to ascertain the suitability of the water as portable drinking water by examining the physicochemical and hydrogeological characteristics of existing Borehole drilled in the vicinity of the study area. The findings of this study are a reminder of the essence of a geophysical survey prior to drilling exercises and the suitability of electrical resistivity as a tool for aquifer delineation.
Keywords: vertical electrical sounding, groundwater, water table, weathered layer, wet reservoir

INTRODUCTION

It is impossible to overestimate the role that groundwater plays in keeping the human race alive on Earth. Ground water is the liquid that lies beneath the earth's surface and fills the pore spaces between sedimentary rocks, clastic sedimentary rock, and fracture zones in basement complex rocks. The issue of finding an adequate supply of high-quality water is become more and more difficult as a result of the population growth, irrigation, and industrialization. This circumstance makes it impossible to rely solely on surface water throughout the year, necessitating the usage of additional sources to supplement surface water. The world depends on the supply of groundwater, which is the highest-quality water that can be found beneath the surface of the earth. It is the water that is retained under hydrostatic pressure in the subsurface's saturated zone under the water table. There are two types of terrain: basement complex terrain, which is more difficult to find, especially in areas with crystalline rocks, and sedimentary terrain, which is easier to exploit (Fadele *et al.*, 2013).

The use of geophysical techniques for groundwater exploration and water quality assessments has grown recently as a result of the quick development of computer software and other numerical modeling methods. Vertical electrical sounding (VES), which is simple to use, has gained a lot of traction in groundwater exploration. The electrical geophysical survey approach seeks to identify the surface affects of the flow. Examples of geophysical investigations that have used this method include mineral exploration, archeological research, engineering studies, geothermal exploration, permafrost mapping, and geological mapping (Fadele *et al.*, 2013).

Based on the sort of energy source used—natural or artificial—electrical processes are categorized. Examples of natural source methods include self-potential (SP), telluric current, and magnetotelluric, whereas examples of artificial source methods include resistivity, electromagnetic (EM), and induced polarization (IP). The ABEM (SAS 300) terrameter was the instrument used in this study's artificial approach, the electric d.c. resistivity method, and a Schlumberger array was used to gather the data. Marrison and Gasperikova (2012) performed a comparable experiment to investigate the presence of groundwater in the coastal plain region of southern Virginia and North Carolina. Their findings are based on 45 Vertical Electrical Soundings (VES). These recordings were made using a Schlumberger array with current electrodes that may be up to 8000 feet apart. The VES data outputs were analyzed using the curve-matching method and an automatic computer interpretation system.

Ariyo and Banjo (2008) investigated the groundwater zone in a sedimentary terrain in Ilara-Remo, southwest Nigeria, using a similar technique. In their investigation, they utilized a Schlumberger array system and the vertical electrical sounding (VES) approach. implemented in ten (10) stations, with the spatial curve-matching approach and computer-assisted iteration technique used to analyze the results.

In order to investigate the groundwater in the area of the Nigerian College of Aviation Technology in Zaria, Kaduna State, Nigeria, Fadele et al. (2013) also used vertical electrical sounding (VES). In fifteen (15) VES stations, the data was assessed using computer software (IPI2win), which offers an automatic evaluation of the apparent resistivity. Many previous groundwater investigations have used Vertical Electrical Sounding (VES) and found it to be quite beneficial.

The electrical resistivity approach is used to describe the subsurface both vertically and laterally. Vertical sounding (VES) is used to measure the vertical properties of the subsurface whereas resistivity profiling is used to measure lateral variations. In the electrical method of geophysical investigation, vertical sounding (VES) using Schlumberger array is a technique used to investigate the resistivity construct between lithological layers or geoelectric horizons. It offers detailed information on the vertical succession of various conducting zones and their individual thickness and apparent resistivity (Anizoba *et al.*, 2015; Anakwuba *et al.*, 2014; Hardianshah and Abdul, 2013). As a result, inferences on the hydrogeological, stratigraphic, engineering, and geological features of soil and subsequent archaeological problems of the subsurface can be drawn (Al-Garni, 2009; Alisiobi and Ako, 2012; and Anudu *et al.*, 2013). As a result, inferences on the hydrogeological, stratigraphic, engineering, and geological characteristics of soil and subsequently archaeological issues with the subsurface can be drawn (Al-Garni, 2009; Alisiobi and Ako, 2012; and Anudu *et al.*, 2008). Electrical technologies are therefore frequently used in geotechnical probing as well as groundwater inquiry. This study intends to measure the depth to the water table zone, the thicknesses of the water table, the geo-electric layers, and the resistivity of a typical sedimentary terrain in the University of Benin and its surroundings using the vertical electrical sounding (VES) method for borehole drilling.

Location of Study Area

The University of Benin, in the vicinity of the Post graduate hostels.. It is located between latitude N06°23' and longitude E06°37', with six (6) Vertical Electrical Sounding points identified as N 6⁰ 24' 00.4", E 5⁰ 37' 39.3" ; N 6⁰ 23' 55.4", E 5⁰ 37' 44.5" ; N 6⁰ 24' 09.5", E 5⁰ 37' 34.2" ; N 6⁰ 23' 55.1", E 5⁰ 37' 36.4" ; N 6⁰ 24' 12.4", E 5⁰ 37' 37.0 figure I, is the VES points in the sample location map.It is located in the Bini formation, a sedimentary basin in south-western Nigeria that is largely made of sand and sandstone with a few interspersed pockets of clay or shale. The most frequent types of rocks in this region are sedimentary rocks and an abundance of sediments, which are produced by weathering and erosion of sedimentary rocks that already exist. The geophysical investigation was carried out in a sag sedimentary basin that is peripheral to the University of Benin and suitable to the research region. The region's geomorphology is reflected in the drainage system. Just a few kilometers from the survey location, in the vicinity of the University of Benin, the Ikpoba River, a tributary of the Ekosodin River, drains the area of this village.

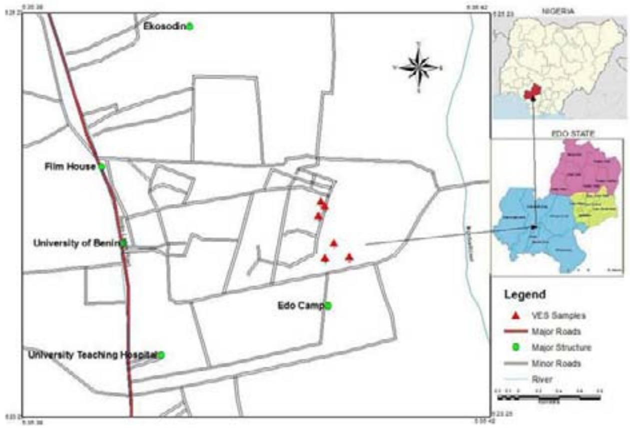

Figure 1: Map of study area showing VES sampling location

Regional Setting

A failing arm of a triple junction system (aulacogen) that developed during the late Jurassic separation of the South American and African plates is where the clastic wedge of the Niger Delta formed (Burke *et al.*, 1972; Whiteman, 1982). The three failed arms generated the Benue Trough, while the two arms that followed the southwesterly and southeasterly coasts of Nigeria and Cameroon produced the passive continental margin of West Africa. Additionally, numerous depo-centers around the African Atlantic coast helped with deltaic build-ups (figure 2). The oldest dated sediments come from the Albian period, and synrift sediments accumulated from the Cretaceous through the Tertiary periods.In a sequence of transgressive and regressive phases, the thickest successions of syn-rift marine and marginal marine clastics and carbonates were deposited (Doust and Omatsola, 1989). The Synrift phase of the Santonian came to an end with basin inversion (late Cretaceous). New subsidence occurred as the continents split apart and the sea reached the Benue trough. The Niger Delta's clastic wedge prograded into a depocenter near the triple junction during the middle Cretaceous, which is when the continental margin collapsed. Most of the sediment was supplied by the rift arms that failed, the Benue and Bida Basins. Periodic incursions hampered sediment progradation in the Late Cretaceous.

During the Tertiary era, sediment was primarily imported from the north and east via the Niger, Benue, and Cross Rivers. The Cross and Benue Rivers began to supply substantial amounts of volcanic rubbish from the Cameroon volcanic zone in the Miocene. The Niger Delta clastic wedge prograded at a steadily increasing rate into the Gulf of Guinea in response to the development of these drainage zones and ongoing basement subsidence. Regression rates increased in the Eocene as more sediment had been deposited since the Oligocene. The shape of the Niger Delta changed as it developed from an early stage that spanned the Paleocene to early Eocene to a later stage that spanned the Miocene. During the Tertiary era, sediment was primarily imported from the north and east via the Niger, Benue, and Cross Rivers. The Cross and Benue Rivers began to supply substantial amounts of volcanic rubbish from the Cameroon volcanic zone in the Miocene. The Niger Delta clastic wedge prograded at a steadily increasing rate into the Gulf of Guinea in response to the development of these drainage zones and ongoing basement subsidence. Regression rates increased in the Eocene as more sediment had been deposited since the Oligocene. The shape of the Niger Delta changed as it developed from an early stage that spanned the Paleocene to early Eocene to a later stage that spanned the Miocene.

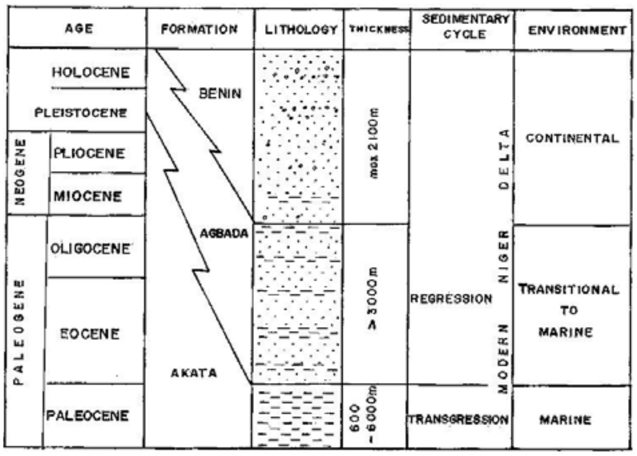

Figure 2: Generalizedlithostratigraphy of Niger Delta (from Nwangwu, 1990)

Stratigraphy of Niger Delter Basin

The majority of the stratigraphic schemes in the Niger Delta Basin continue to be owned by the major oil companies operating concessions, despite the fact that the stratigraphy of the Niger Delta clastic wedge has been documented throughout oil exploration and production. Short and Stauble talk about the Tertiary Niger Delta's stratigraphic history and the lower Cretaceous layers (1967). The petroleum geology of the Niger Delta is described by Tuttle *et al.* (1993), Doust and Omatsola (1990), and Evamy *et al.* (1978). (1999). Stacher (1995) developed a hydrocarbon habitat model for the Niger Delta using sequence stratigraphic techniques. The depositional settings, sedimentation, and physiography of the current Niger Delta were thoroughly described by Allen (1965) and Oomkens (1974).

Despite the fact that the stratigraphy of the Niger Delta clastic wedge has been documented, the three major lithostratigraphic units defined in the subsurface of the Niger Delta (Akata, Agbada, and Bini Formations, figure II) decrease in age basinward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. The formations reveal a progradational clastic wedge that was deposited in marine, deltaic, and river environments (Short and

Stauble, 1967). (Weber, 1986; Weber and Daukoru, 1975). The Akata 1 Well, 80 kilometers east of Port Harcourt, is where the type portion of the Akata Formation was found (Short and Stauble, 1967). In the Akata 1 well, a total depth of 11,121 feet (3, 680 m) was reached without coming into contact with the formation's base.The apex of the formation is marked by the deepest occurrence of deltaic sandstone strata (7,180 feet in Akata well). The formation is thought to be 21,000 feet thick in the clastic wedge's center (Doust and Omatsola, 1989). The predominant lithologies are dark gray shales and silts, with a few streaks of sand from a turbidite flow (Doust and Omatsola, 1989). Up to 50% of the microfauna collection are marine planktonic foraminifera, suggesting shallow shelf deposition (Doust and Omatsola, 1989).

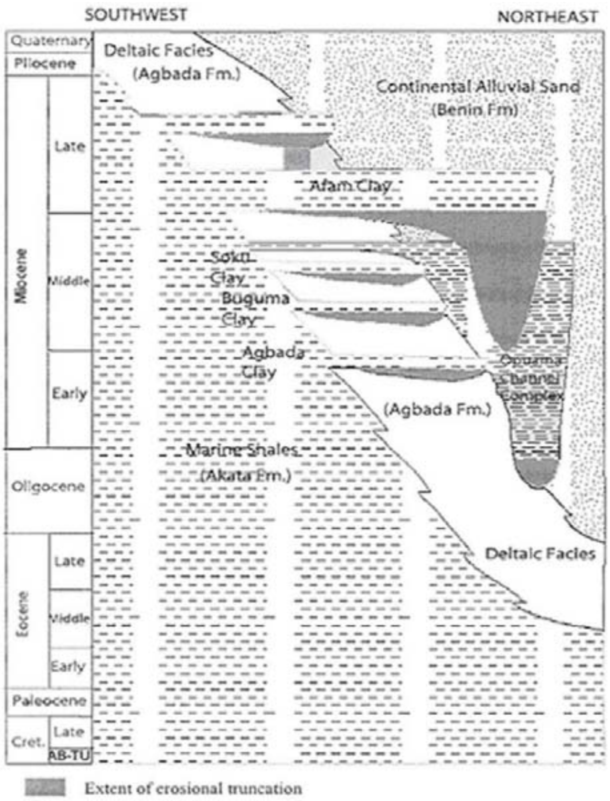

Figure 3: Stratigraphic column showing the formations of the Niger Delta (Tuttle et al., 1999).

Table 1: Showingformations within the Niger Delta area, Nigeria. (modified after Short and Stauble (1967).

Subsurface			Surface Outcrops		
Youngest		Oldest			
known Age		known Age	Youngest Known Age		Oldest Known Age
	Benin Formation			Benin	
Recent	(Afam clay member)	Oligocene	Plio/Pleistocene	Formation	
				Ogwashi-	
				Asaba	
				Formation	
			Miocene	Ameki	Oligocene
Recent	Agbada Formation	Eocene	Eocene	Formation	Eocene
				Imo shale	
Recent	Akata Formation	Eocene	Lower Eocene	Formation	Paleocene
				Nsukka	
Unknown			Paleocene	Formation	Maestrichtian
				Ajali	
			Maestrichtian	Formation	Maestrichtian
				Mamu	
			Campanian	Formation	Campanian
				Nkporo	
			Campanian/ Maestrichtian	Shale	Santonian
				Awgu	
			Coniacian/ Santonia	Shale	Turonian
				Eze Aku	
			Turonian	Shale	Turonian
				Asu River	
			Albian	Group	Albian

The formation is between Paleocene and Recent in age (Table I) (Doust and Omatsola, 1989). The Benue and Bida Troughs, which were formed during the initial stages of Niger Delta progradation, are where the shales are the thickest. When this formation is exposed onshore in northeastern Nigeria, it is referred to as the Imo Shale. The formation can be seen offshore in diapirs along the continental slope. Where they are completely submerged, these marine shales are regularly over pressured. The Akata shales were deep-water lowstand deposits in Stacher's opinion (1995). The formation grades vertically into the Agbada Formation, which contains abundant plant remains and micas, in the transition zone (Doust and Omatsola, 1989). Crops are strewn around the offshore slope of the continental continent. The subterranean environment typically contains these marine shale formations. The Agbada - 2 well, which was dug 11 kilometers north of Port Harcourt, identifies the Agbada Formation (Short and Stauble, 1967). The well descended to a total depth of 9500 feet without breaking through the formation's base (the base was defined as the top of the Akata Formation in Akata - 1 well). The structure, which can be up to 13,000 feet thick, can be found all over the Niger Delta. Between Ogwashi and Asaba in southern Nigeria, it is known as the Ogwashi-Asaba Formation (Doust and Omatsola, 1989). Sands, silts, and shales alternate in the lithologies, which are grouped in ten to hundred foot layers.The strata are generally believed to have developed in fluvial-deltaic environments. From the Eocene to the Pleistocene, the formation's age ranges.

The Benin Formation makes up the upper portion of the Niger Delta clastic wedge from the Benin - Onitsha region in the north to beyond the present-day coastline (Short and Stauble, 1967). Its type section is Elele 1 Well, located about 38 kilometers north-northwest of Port Harcourt (Kazeem, 2007). The formation's base is 4600 feet deep, and its top is the delta top surface that was just recently exposed to the atmosphere. The base is defined by the newest marine shale. All of the non-marine sand deposited in alluvial or upper coastal plain environments during delta progradation makes up the formation's shallow portions (Doust and Omatsola, 1989).The formation is believed to be Oligocene to Recent in age, despite the fact that the lack of preserved fauna prohibits precise date dating (Short and Stauble, 1967). As it advances basinward, the formation becomes thinner and eventually comes to a halt close to the shelf's edge.

Sand/shale ratios taken from subsurface well logs were used by Short and Stauble (1967) to describe different formations. These unofficial classifications do not follow the international stratigraphic code and are based on subsurface well logs that only partially penetrate type sections. Local geologists define formation tops and bases in conflicting ways. The top of the Agbada Formation is frequently used to describe the base of fresh water sand. The top of the Akata Formation is typically described during drilling as the top of overpressured shale encountered. Doust and Omatsola (1989) acknowledge problems with their formation definitions (first thick sand defining the Akata - Agbada Formation boundary and last thick marine shale defining the Agbada - Benin Formation boundary which may arise due to local argillaceous intercalations of considerable thickness in sands of the Benin Formation) due to local argillaceous intercalations of considerable thickness in sands of the Benin Formation and the local presence. They recommended using colloquial language when using their stratigraphic terms. Adesida *et al.* (1977) proposed the segmentation of Niger delta deposits into regional lithostratigraphic mega sequences using an integration of log trends, biostratigraphy, and sequence stratigraphic surfaces observed in seismic data (their abstract does not provide details of the criteria used in the definition of their stratigraphic divisions).

MATERIALS ANDMETHOD

It made use of the ABEM Digital Terrameter SAS 3000 model. This was done using the electrical resistivity method that incorporates the VES methodology (Zonge *et al.*, 2005). By gathering data at ground level, electrical resistivity surveys are often used to calculate the electrical resistivity of subsurface materials (Abdel-Azim, *et al.,* 1996). For VES work, two common electrode arrays are those from Wenner and Schlumberger (Sharma, 1997). The Schlumberger array's potential electrode spacing shouldn't be greater than 40% of the spacing between the current electrodes (AB) (Adewumi, *et al.*, 2005). Schlumberger electrodes were used, and their maximum current electrode spacing (AB/2) was 100 m. The apparent resistivity and depth penetration of this array are both 0.125AB.This served as the primary tool. Both the receiver and transmitter circuitry are currently housed in the box. During data collection, extras such cable reels, stainless steel electrodes, and meter tapes were also used.

Principles

Electrical Resistivity Method

The electrical resistivity approach takes advantage of the resistance differential between various ground materials. The level of resistance a material exhibits to the passage of electrical current through it is measured as resistivity. In general, resistivity is the opposite of conductivity and is measured in Ohm meters. According to Ohm's rule, which states that the current flowing through the ends of a linear conductor with a uniform cross section is proportionate to the applied voltage, theoretically all conductive materials must abide by this law..

Therefore, I

V=IR (I) ……………………. (1)

Where R = Resistance of the medium.

I = Current.

V = Voltage

Therefore, $R = \frac{V}{I}$ …………..…… (2)

Resistance of a medium (R) is also proportional to its length (L) and inversely proportional to its cross — sectional area (A).

Therefore, $R = \frac{\rho L}{A}$ …………………. (3)

$\rho = \frac{RA}{L}$ …………………………….. (4)

Where is the resistivity constant substituting for R in equation (4)

$\rho = \frac{VA}{IL}$ …………………………..… (5)

Apparent Resistivity
The ratio of the measured voltage to the impressed current, multiplied by the geometric factor, is known as the apparent resistivity (a). Actual resistivity will only be tenable if the sampled earth is homogeneous, which is why it is called apparent because the sampled earth is typically homogeneous.

The potential Vc at an interval electrode C is the sum of the potential contributions VA and VB from the current source A and sink B if we take into account a scenario where current is introduced through the source A from the current sink B, which is at a finite distance from an as illustrated below.

Field Operation
The vertical electrical sounding is based on the four electrode principle as shown in figure4. The electrical current (I) is applied to A and B electrodes and the potential (V) is measured between M and N electrodes. The bulk soil electricalresistivity (ER) is calculated with

ER = $\frac{K\Delta U}{I}$ ………………… (1)

Where K, is the geometric factor.

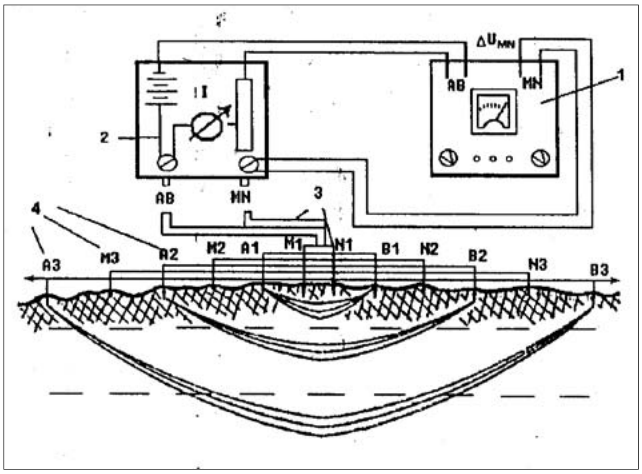

Fig 4: The electrode principle of Vertical electrical Sounding

There are some uncertainties in the soil literature when determining measurement depth with different arrays and computing K. (Ako and Olorunfemi 1989; Dan-Hassan and Olorunfemi, 1999). According to conventional geophysics, the geometry of the array, along with the electrical conductivity and layer organization of the medium, determines the depth of penetration of the electrical field in the media (Olayinka *et al.*,; Olorunfemi, 1993). Because of this, it is impossible to determine the depth of penetration using only the spacing between electrodes in an array. According to theoretical derivations and actual experiments, the penetration depth for the variety of Schlumberger and Wenner types used on a variety of soils and grounds can be roughly regarded as 1/6 of [AB]. (Daramola, 2006; Omosuyi *et al.*, 2008, Obaje et al.,2011). However, for the four electrodes profiling with Werner array and a depth approximation coefficient (1/3 of [AD]) has been misused (Emmanuel *et al.*, 2011; Garba, 2011).

While the depth of penetration for an array varies with different soils around 1/6 of [AB], the geometric factor (K) can be precisely derived from the array geometry based on the law of electrical field distribution. Using Laplace equation in polar coordinates, Hamil and Bello (1986), derived the electrical potential function around the source (A and B) and measuring (M and N) electrodes. The geometric factor K can be obtained for four — electrode array of AMNB

Configuration as K $= \frac{2\pi}{\frac{1}{[AM]} - \frac{1}{[BM]} - \frac{1}{[AN]} + \frac{1}{[BN]}}$ ……. (2)

Where [AM], [BM], [AN] and [BN] are the distances (m) between the respective electrodes. For central symmetric array, when [AM] = [BN] and [BM] = [AN], equation 2 can be simplified to;

K= $\pi \frac{[AM][AN]}{[MN]}$ ……………….....………….. (3)

The VES array consists of a series of the electrode combinations AMNB with gradually increasing distance among the electrodes. The K factors for the combination are calculated with equation (3) and used to obtain electrical resistivity for measured electric potential and current using equation (1).

The result of VES measurement with central — symmetric arrays is apparent (bulk) electrical resistivity as a function of half the distance between the current

Electrodes, i.e. ER = (Ako and Olorunfemi, 1989). Through computer interpretation, the link between ER and AB/2 can be transformed into a relationship between electrical resistivity and real soil depth. According to the approach, the electrical resistivity of the soil is correlated with its salinity, porosity, bulk density, saturation, and hydrogeological conductivity (Omosuyi *et al.*, 2008). In light of this, the VES profile can offer details about the geological structures, soil qualities, and hydrological conditions in a research area.

RESULTS

Data volume

The variation in resistivity with depth was examined at a total of six (6) places, namely VES 1 through VES 6. Along the transverses, an electrical sounding was taken vertically. Determining the thickness is the main goal of these electrical studies. The state of the ground limits the choice of a location. Despite these limitations, the VES sites were picked for their optimal distribution and outstanding coverage.

Generally speaking, resistivity rises with depth. In actuality, however, this is not the case because of the increase in induration and decrease in porosity. Tables 2 through 5 show the basic vertical profile that occurs at depth for various rock types and sediments.

Table 2: A typical vertical profile of depth

Regolith (0 – 40m)	Top soil Duricrust Clay layer
Weathering front (0 - 100m)	Weathered basement Fractured zone
Fresh basement	Fresh basement (usually massive)

Table 3: Vertical profile of resistvity of various rock types in dry and wet (moist) condition.

Type of material	Resistivity (Ω)	
	Dry	Wet
Top soil	200 – 2400	45 – 250
Duricrust	400 – 1600	270 – 380
Clay	-	1 – 100
Alluvium and sand	800 – 2500	100 – 800
Highly fractured	-	300 - 10^6
Massive bed rock	-	1000 - 10^6

Table 4: Resistivity of different rock types

Rock type	Resistivity Ω
Granite	> 10^2 - 10^6
Gabber	10^3 - 10^6
Schist	10 – 10^4
Sandstone	1 – 10^8
Shale	10 – 10^4
Alluvium	10 – 10^3

Table 5: Saturated Resistivity of different materials

Type of material	Resistivity at saturation (Ωm)
Clayey sand	100 – 175
Sandy clay	15 – 100
Coarse gravesly sand	350 – 415
Medium fluvial sand	200 – 250
Weathered bedrock	228 – 180

Plotting the collected data (Tables 6, 8, 10, 12, 14, and 15) in the field, followed by error correction and additional measurements as needed, provided a first interpretation of the data. After then, a set of software programs were used to evaluate and analyze the data (resistivity modeling and contouring software). The resistivity models' data and findings are shown in Tables 7, 9, 11, 13, 15 and 17, while the VES curves are shown in Figures 5–7.

Table 6: Resistivity, apparent resistivity, adjusted resistivity and line spacing for VES 1

S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	189.55	7.54	1429.21	1430
2	0.2	1.47	108.26	16.66	1803.61	1800
3	0.2	2.15	52.84	36.00	1902.24	1900
4	0.2	3.16	23.15	78.10	1808.48	1800
5	0.2	4.64	9.49	169.00	1601.91	1600
6	0.2	6.81	4.07	364.00	1481.48	1480
7		10.00				1330
8	2	14.70	8.53	167.00	1424.52	1420
9	2	21.50	4.86	360.00	1746.60	1750
10	2	31.60	2.85	781.00	2226.50	2230
11	2	46.40	1.81	1688.00	3055.28	3055
12		68.10				4150
13	10	100.00	3.13	1555.00	4868.06	4900
14	10	147.00	1.54	7246.00	5203.76	5200
15	10	215.00	0.58	14123.00	4202.82	5200
16	10	300.00	0.40	-	5649.32	4700

Table 7: Interpreted result for VES 1

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
1	817.73	0.30854	0.30854	99.691
2	2737.8	1.2374	1.5459	98.454
3	1077.4	5.1647	6.7106	93.289
4	931.46	3.3477	10.058	89.942
5	3038.3	8.5804	18.639	81.361
6	15188.0	34.231	52.870	47.130
7	4096.8	71.553	124.42	-24.423
8	2549.4			

The resistivity, thickness and depth to water table averages 3805Ωm, 15.6m and 26.8 m respectively. The geo-electric layer with the highest resistivity value is layer 5 as 15188Ωm at a depth of 52.9m and 34.0 m thickness (Table 7)

Table 8: Resistivity, apparent resistivity, adjusted resistivity and line spacing for VES 2

1S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	173.56	7.54	1308.64	1300
2	0.2	1.47	98.53	16.66	1641.51	1640
3	0.2	2.15	53.59	36.01	1929.78	1930
4	0.2	3.16	27.91	78.14	2180.89	2180
5	0.2	4.64	13.40	169.85	2262.59	2260
6	0.2	6.81	6.03	364.07	2195.34	2200
7		10.00				2130
8	2	14.70	12.77	166.64	2127.99	1900
9	2	21.50	6.16	360.05	2217.91	2220
10	2	31.60	3.47	781.44	2711.60	2700
11	2	46.40	2.13	1688.47	3596.44	3600
12	2	68.10	1.17	3640.00	4259.44	4260
13		100.00				5100
14	10	147.00	2.64	3379.99	8923.17	5040
15	10	215.00	0.78	7248.22	5653.61	5650
16	10	300.00	0.40	14123.29	5649.32	4000

Table 9: Interpreted Result for VES 2

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
1	709.69	0.36105	0.36105	101.64
2	3042.9	1.5407	1.9017	100.10
3	2583.4	2.4001	4.3018	97.698
4	974.81	4.7176	9.0194	92.981
5	2310.6	3.5657	12.585	89.415
6	7176.5	16.551	29.136	72.864
7	8711.2	95.607	124.74	-22.743
8	758.18			

From this table VES 2, the interpreted result reveals layer seven(7) with resistivity of 8711Ωmand a water table thickness of 95.6m and a depth to water table of 124.7m.

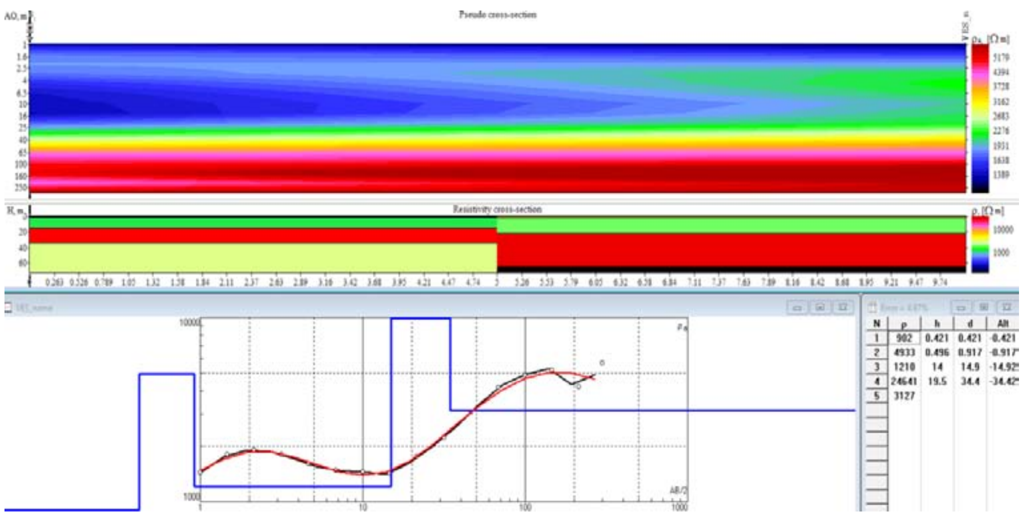

Figure 5: Apparent resistivity versus spacing for VES 1 & 2 with cross section

Table 10: Resistivity, apparent resistivity, adjusted resistivity and line spacing forVES 3

S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	83.02	7.54	625.97	630
2	0.2	1.47	41.82	16.66	696.72	700
3	0.2	2.15	21.14	36	761.04	760
4	0.2	3.16	09.55	78.1	745.86	750
5	0.2	4.64	04.53	169	765.57	650
6	0.2	6.81	02.21	364	804.44	800
7	0.2/2	10.00	1.08/18.06	785/75.4	847.80/1361.72	1100
8	2	14.70	08.81	167	1471.27	1470
9	2	21.50	04.66	360	1677.06	1680
10	2	31.60	02.84	781	2218.04	2220
11	2	46.40	01.70	1688	2869.06	2870
12	2	68.10	0.93	3639	3384.27	3380
13	2/10	100.00	0.46/03.89	7851/754	3611.46/2933.06	3600
14	10	147.00	1.68	1666	2798.88	2800
15	10	215.00	0.53	3599	1907.47	1900

The apparent resistivity from table 10, geo-electric layers 8-12 have values 1471Ωm, 1677Ωm, 2218Ωm, 2869Ωm and 3384Ωm respectively.

Table 11: Interpreted resulted for VES 3

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
	361.39	0.34534	0.34534	77.655
	1514.9	0.68776	1.0331	76.967
	261.55	1.4721	2.5052	75.495
	3048.5	13.512	16.017	61.983
	10724.0	22.466	38.483	39.517
	2683.0	22.701	61.184	16.816
	334.16			

The averages for Resistivity, thickness and depth to water table for VES 3 are 2705Ωm, 10.2 m and 19.9 maccordingly. A close look on the thicknesses of the water table (Table 11) shows that the thickest geo-electric layer is about 22m which is not advised for a water table.

Table 12: Resistivity, apparent resistivity, adjusted resistivity and line spacing for VES 4

S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	115.93	7.54	874.10	870
2	0.2	1.47	56.52	16.66	941.60	940
3	0.2	2.15	27.90	36.01	1004.70	1000
4	0.2	3.16	13.15	78.14	1027.50	1030
5	0.2	4.64	6.06	168.85	1023.20	1020
6	0.2	6.81	2.63	364.07	957.50	960
7	0.2⁄2	10.00	1.23⁄14.0	785.4⁄75.43	966.0⁄1056.0	970
8	2	14.70	7.07	166.64	1178.10	1180
9	2	21.50	3.83	360.05	1379.00	1380
10	2	31.60	2.19	781.44	1711.402313.20	1700
11	2	46.40	1.37	1688.47	2313.20	2300
12	2	68.10	0.78⁄3.81	3640.7⁄713.05	2839.70⁄2716.7	2800
13	2⁄10	100.00	2.71	1555.72	3375.90	3380
14	10	147.00	1.05	3379.99	3549.00	3430
15	10	215.00	0.473	7248.22	3428.40	

Table 13: Interpreted result for VES 4

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
1	767.15	0.30330	0.30330	91.697
2	992.50	11.751	12.054	79.946
3	2032.6	6.6239	18.678	73.322
4	8700.7	29.570	48.248	43.752
5	2987.3	30.483	78.731	13.269
6	2368.9			

From Table 13, the resistivity, thickness and depth minimum and maximum values are 767.2Ωm , 8700Ωm ; 0.3 m , 30.5m and 0.3 m, 78.7 m. The depth to water to water table are rather to shallow for borehole drilling where pure water is the target(VES 4).

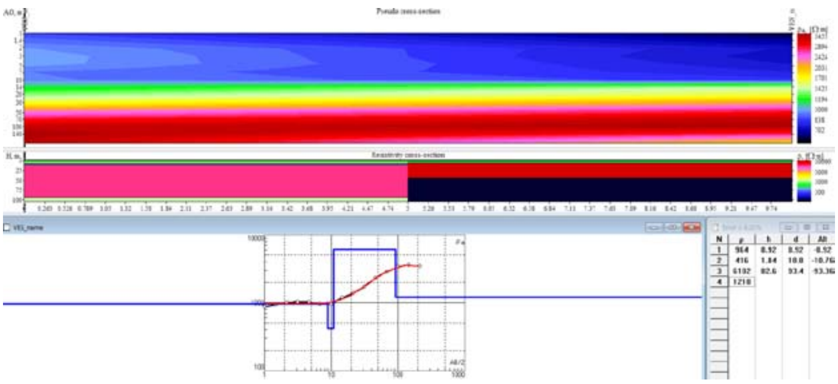

Figure 6: Apparent resistivity versus spacing for VES 3 & 4 with cross section

Table14: Resistivity, apparent resistivity, adjusted resistivity and line spacing for VES 5

S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	32.52	7.54	242.20	240
2	0.2	1.47	14.03	16.66	233.74	240
3	0.2	2.15	5.36	36.00	192.96	190
4	0.2	3.16	1.58	78.10	123.40	120
5	0.2	4.64	0.43	169.00	72.67	70
6	0.2⁄2	6.81	0.10⁄1.02	364.00⁄33.28	36.40⁄33.95	36
7	2	10.00	0.61	75.40	46.00	46
8	2	14.70	0.46	167.00	76.82	77
9	2	21.50	0.38	360.00	136.80	137
10	2	31.60	0.28	781.00	218.68	220
11	2⁄10	46.40	0.19⁄1.56	1957.00⁄322.00	372.21⁄502.32	370
12	10	68.10	1.03	713.00	739.39	740
13	10	100.00	0.84	1555.00	1300.39	1300
14	10	147.00	0.58	3379.00	1959.00	1960
15	10	215.00	0.27	3599.00	971.73	970

Table 15: Interpreted result for VES 5

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
	182.24	0.36741	0.36741	99.633
	536.83	0.54333	0.91074	99.089
	10.557	1.3616	2.2723	97.728
	355.36	1.6298	3.9022	96.098
	76431.0	129.26	133.16	-33.162
	2583.6	51.437	184.60	-84.599
	1110.2			

The geo-electric layers in VES 5 with thicknesses 129.26m and 51.44m and resistivity of 76431 Ωm and 2583.6Ωm (table 15) belonging to geo-electric layers 6&7 also shows that the depth to the water table is considerably high at 133.20m and 184.60m accordingly, which gives it preference over the other layers as the likely aquifer zone.

Table 16: Resistivity, apparent resistivity, adjusted resistivity and line spacing for VES 6

S/N	MN/2	AB/2	R(Ω)	G.F	(Ωm)	Adjusted (Ωm)
1	0.2	1.00	83.81	7.50	628.08	630
2	0.2	1.47	35.02	16.66	583.43	580
3	0.2	2.15	15.91	36.00	572.76	570
4	0.2	3.16	08.78	78.10	668.54	670
5	0.2	4.64	04.78	169.00	807.82	810
6	0.2	6.81	02.71	364.00	986.44	990
7	0.2/2	10.00	1.72/11	785/75.4	1350.20/889.72	1350
8	2	14.70	5.98	167.00	998.66	1000
9	2	21.50	2.90	360.00	1044.00	1040
10	2	31.60	1.57	781.00	1266.17	1270
11	2	46.40	0.73	1959.00	1430.07	1430
12	2	68.10	0.48	3639.00	1746.72	1750
13	2/10	100.00	0.23/2.01	7851.0/754	1805.73/1515.54	1650
14	10	147.00	0.58	1666.0	966.28	1200
15	10	215.00	0.35	3599.0	1259.65	1000

Table 17: Interpreted results for VES 6

S/N	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (m)
1	773.16	0.57532	0.57532	102.42
2	325.52	0.98290	1.5582	101.44
3	3567.0	2.1216	3.6798	99.320
4	471.08	2.2351	5.9149	97.085
5	399.69	4.4969	10.412	92.588
6	6127.90	16.929	27.340	75.660
7	661.91	27.828	55.169	47.831
8	549.65			

A detailed examination of the wells' thicknesses and depths to the water table reveals numbers that are far too low and shallow to be taken into account for groundwater exploitation (Table 17). The resistivity, apparent resistivity, and corrected apparent resistivity are shown in Tables 6, 8, 10, 12, 14, and 16. The apparent resistivity values for VES 1–6 range from 1429 m to 5549 m, 1308 m to 8923 m, 625 m to 3384 m, 874 m to 3549 m, 242 m to 1959 m, and 573 m to 1746 m, respectively.

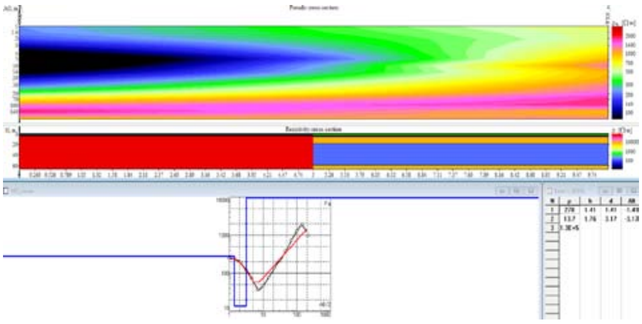

Figure 7: Apparent resistivity versus spacing for VES 5&6 with cross section

DISCUSSIONOF RESULTS

The geoelectric layers' VES curves were interpreted using resistivity models. Low resistivity levels suggest wet zones with a good subterranean water storage, while high resistivity values indicate dry zones. The following provides the interpretations for the various VES readings:

Analysis of VES 1

Seven geo-electric layers were identified after interpretation using computer software, the first four of which are superficial layers (Regolith materials) with average depth penetration of less than 15 meters.

The thickness here is still in the region of regolith materials, with (0-40m) as the benchmark, and is made up of alluvium and sand, with sandy becoming more predominate.The resistivity value of the sixth layer, which is approximately 53 meters deep, indicates an area or layer that may be the top of the water table's penetration.

Analysis of VES 2

Beyond layer five, the interpretation reveals seven (7) geo-electric layers with gradually increasing resistivity (5). The first five strata have depth penetrations that follow the surface regolith material.

A sandstone layer that is thick enough to serve as underground water storage begins in layer six (6), where there is a sharp increase in resistivity.

Analysis of VES 3

Six (6) geoelectric strata were identified by the interpretation. Following the resistivity values and depth of penetration, layers one through four are made up of regolith materials, while layers five and six, as indicated by their thickness and depth, are located close to a dense layer of sand and have the potential to serve as a ground water reservoir.

Analysis of VES 4

From the software, five (5) geo-electric layers were obtained. The resistivity of the first three layers gradually increased, and they mostly consisted of Regolith materials with resistivity and depth value ranges that matched those of the surface layer.The significant increase in layer four's resistivity value is suggestive of depth near the point when the water table's top began to penetrate. Its thickness and depth of penetration at layer five point to a layer with favorable groundwater reservoir properties.

Analysis of VES 5

According to the interpretation of the resistivity data, there are six subsurface geoelectric layers (6). The materials are regolith from the surface to a depth of 3.9 meters (i.e. from the first to the fourth layer). Layer five has a 129 m thickness and a top depth that suggests water table penetration. The thickness of layer six and the whole increase in resistivity value over layer five point to a zone with higher conductivity and water content.

Analysis of VES 6

There were discovered seven geo-electric strata. Layers 1 through 5 are composed of regolith, layer 6 indicates the depth of penetration to the top of the water table, and layer 7 is a very thick layer of sand (as indicated by the thickness value of 28 m), with a great potential for ground water research.

Table 18: Ranking of the prospects of the entire VES taken in the Surveyed area.

VES points	Thickness of water table layer (m)	Depth to water table (m)	Ranking
1	11.6	124.4	1
5	51.4	124.6	2
4	30.5	78.4	3
6	27.8	55.2	4
3	22.5	38.5	5
2	16.6	29.4	6

According to table 6, the water prospects VES 1 and VES 5 have the maximum water table layer thickness, whereas VES 2, VES 3, and VES 4 have a low water table layer thickness. When prospecting for ground water in sedimentary basin topography, it is crucial to take the thickness of the water table into consideration. High water table layer thickness indicates high ground water prospects, or aquifer systems, in a sedimentary basin topography. In the survey region, which is a reliable location for bore-hole sitting, VES 1 and 5 are therefore the most productive.However VES 2, VES 3 and VES 4 are areas with low values of thickness to water table but high with high over burden thickness, thus the productivity of ground water in these locations will be based on overburdened thickness for supply in the survey area. The findings of this study are similar with the contributions and studies of Mayange et al., (2018); Kasidi and Victor, (2019); and Abdulahiet al., (2014).

CONCLUSION

Based on the Geophysical investigation carried out in University of Benin, the conclusion may be drawn:

1. Thereare different geo-electric layers andthe varied lithology's which provides a natural subsurface filtration process for the water as it percolates through the different permeable lithological layers.
2. From the ranking of the prospect of the area for ground water VES 1 and VES 5 are the most productive points (wells) for ground water borehole drilling considering the thicknesses of water table layer.
3. The results further emphases on the relevance of a detailed geophysical investigation prior to drilling and the suitability of electrical resistivity as a tool for aquifer delineations.

RECOMMENDATION

Further investigation and study to determine the suitability of the water for domestic consumption by examining the Physicochemical and hydrogeological characteristics of the Borehole water in the vicinity studied.

REFERENCES

Abdel-Azim, M.E, Mahmoud, M.S.and Kamal, A.D. (1996). Geoelectrical and Hydrogeochemical studies for delineating Groundwater contamination due to Salt-water Intrusion in the Northern part of the Nile Delta, Egypt. Groundwater. 35(2): 218.

Abdulahi M.G., Toriman M.E., Gasim M.B. (2014). The Application of Vertical Electrical Sounding for Ground water Exploration in Tudun Wada kano State, Nigeria. International Journal of Engineering Research and Reviews, 2(4): 51-55

Ako, B. D. and Olorunfemi, M. O. (1989). Geoelectric Survey for Groundwater in the Newer Bassalts of Vom, Plateau State. Journal of Mining and Geology 25, pp.247-250.

Al-Garni, M. A. (2009). Geophysical Investigations for Groundwater in a Complex Subsurface Terrain, Wadi Fatima,

Alisiobi, A. R. and Ako, B. D. (2012). Groundwater Investigation Using Combined Geophysical Methods. Search and Discovery Article No. 40914, AAPG Annual Convention and Exhibition, Long Beach, California.

Allen, J.R.L., 1965, Late Quaternary Niger Delta, and adjacent areas-sedimentary environments and lithofacies: AAPG Bulletin, 49: 547-600.

Anakwuba, E.K., Nwokeabia, C.N., Chinwuko, A.I., and Onyekwelu, C.U.(2014). Hydrogeophysical assessment of some parts of Anambra basin, Nigeria. International Journal of Advanced Geosciences, 2(2): 72-81.

Anizoba, D. C. Chukwuma, G. O., Chukwuma, E. C., & Chinwuko, E. C. (2015). Determination of Aquifer Characteristics from Geo-electrical Sounding data in parts of Anambra State, Nigeria. Inter-national Journal of Innovation and Applied Studies, 11(4): 832-843.

Anudu, G.K., Onwuemesi, A.G., Ajaegwu, N.E., Onuba, L.N., and Omali, A.O. (2008). Electrical resistivity investigation for ground-water in the basement complex terrain: a case study of idi-ayunre and its environs, oyo state, southwestern Nigeria. Natural and Applied Sciences Journal, 9(2): 1-11.

Ariyo, S.O and Banjo, A.A (2008) Application of Electrical Resistivity Method for Groundwater Exploration in a Sedimentary Terrain: A case study of Ilara-Remo Southwestern Nigeria.

Burke, K., 1972, Longshore drift, submarine canyons and submarine fans in development of Niger delta: AAPG Bulletin, v. 56:1975-1983.

Dan-Hassan, M. A. and Olorunfemi, M.O. (1999). Hydro-geophysical Investigation of a Basement Terrain in the North-Central part of Kaduna state, Nigeria. Journal of Mining and Geology 35(2): 189-206.

Daramola, S.O. (2006). Research and statistical methods in education for students and researchers in tertiary institutions. Bamitex Printing and Publishing, Ilorin, Nigeria.

Doust, H. andOmatsola E., 1989. Niger delta: AAPG Memoir 48 p. 201-238.

Doust, H., and OmatsolaE., 1990, Niger delta: in J. D. Edwards and P.A. Santogrossi,eds., Divergent/passive margin basins: AAPG Memoir 48, p. 239-248.

Doust, H.,1989, The Niger delta: Hydrocarbon potential of a major Tertiary delta province, in coastal lowlands, geology and geo-technology in Proceedings of the Kon. Nederl. Geol. Mijnb. Genootschap, p. 203-212.

Emmanuel O. Joshua, Olayinka O. Odeyemi and Oladotun O. Fawehinmi (2011). Geoelectric investigation of the groundwater potential of Moniya Area, Ibadan. Journal of Geology and Mining Research Vol. 3(3), pp. 54-62, Available online http://www.academicjournals.org/jgmrISSN 2006 -9766©2011 Academic Journals

Evamy B.D., J. Haremboure, R. Kammerling, W.A. Knaap, F.A. Molloy, and P.H. Rowlands,1978. Hydrocarbon habitat of tertiary Niger Delta: AAPG Bulletin, 62:1-39.

Fadele S.I., SuleP.O.and Dewu B.B.M.,(2013). The use of Vertical Electrical Sounding (VES) for Groundwater Exploration around Nigerian College of Aviation Technology (NCAT), Zaria, Kaduna State, Nigeria. Pacific Journal of Science and Technology. 14(1):549-555.

Garba, A. A. (2011). Geology, Geochemistry and Rare-Metal Bearing Potentials of Pegmatite of Gbugbu, Lema and Bishewa Areas of North Central Nigeria. Unpublished Ph.D Thesis. University of Ilorin, Nigeria. 207 pp

Hamil, L. and Bell, O. (1986). Groundwater Resources Development. Britain Library Cataloguing in Publication Data London, pp. 151-158

Hardianshah Saleh and Abdul Rahim Samsudin,(2013). Application of Vertical Electrical Sounding (VES) in Subsurface Geological Investigation for Potential Aquifer in Lahad Datu, Sabah. Journal of AIP Conference Proceedings, 1571(1): 432-437.

Kasidi S. and Victor V. (2019). Groundwater Exploration using Vertical Electrical Sounding method in Musawa and Environs of Katsina State, Nigeria. Journal of Applied Geology and Geophysics. 7(6): 73-83

Kazeem, A. S. (2007). Lithostratigraphy of Nigeria. An Overview. Workshop on Geothermal Reservation Engineering, Stanford University, Stanford, California. (32): 1-4.

Marrison and Gasperikova (2012) D.C Resistivity and IP field systems, data processing and interpretation.

Mayange B. Claver N., Kubaya K. and Lama S. (2018). The Application of Vertical Electrical Sounding for the Hydrogeological and Geophysical Investigation in Kibuma, DR Congo. International Journal of Innovation and Applied Studies, 24(1): 9-16 Nwangwu, U.,1990, A unique, hydrocarbon trapping mechanism in the offshore Niger Delta, in Oti, M.N., and G. Postma, eds., Geology of Deltas: Rotterdam, A. A. Balkema, pp.269-278.

Obaje, N. G., Moumouni A, Goki N.G., and ChaandaM. S., (2011). Stratigraphy, Paleogeography and Hydrocarbon Resource Potentials of the Bida Basin in North-Central Nigeria. Journal of Mining and Geology 47(2): 97–114.

Olayinka, A. I. and Olorunfemi, M. O. (1992). Determination of Geoelectrical Characteristics in Okene Area and Implication for Boreholes Siting. Journal of Mining and Geology (28): 403- 412.

Olayinka, A. I.; E. J. Akpan and O. A. Magbagbeola, (1997). Geoelectric Sounding for Estimating Aquifer Potential in the Crystalline Basement Area around Shaki, South-Western Nigeria. Water Resources- Journal of Nigerian Association of Hydrogeologits 8(2): 71-81.

Olorunfemi, M. O. and Fasuyi, S. A. (1993). Aquifer Types and the Geoelectric/ Hydrogeologic Characteristics of Part of the Central Basement Terrain of Nigeria (Niger State). Journal of African Earth Sciences (16): 309-317.

Omosuyi, G. O.; J. S. Ojo and M. O. Olorunfemi (2008). Geoelectric Sounding to Delineate Shallow Aquifer in the Coastal Plain Sands of Okitipupa Area, South Western Nigeria. Pacific J. Sci. Technol., 9(2): 562-577.

Oomkens, E., 1974. Lithofacies relations in late Quaternary Niger delta complex: Sedimentology, 21:195-222.

Sharma, P. V. (1997). Environmental and Engineering Geophysics. Cambridge University Press. Cambridge. U.K. 474pp.

Short, K. C., and A. J. Stauble, 1967, Outline of Geology of Niger delta: American Association of Petroleum Geologists Bulletin 51: 761-779.

Tuttle, M. L. W., R. R. Charpentier and M. E. Brownfield, 1999, The Niger delta petroleum system: Niger delta province, Nigeria, Cameroon, and Equatorial Guinea, Africa: USGS Open-file report 99-50-H.

Weber, K.J. and Daukoru,E.M. 1975, Petroleum geology of the Niger delta:Proceedings of the 9th World Petroleum Congress, Tokyo, 2: 202-221.

Weber,K.J., 1986, Hydrocarbon distribution patterns in Nigerian growth fault structures controlled by structural style and stratigraphy: AAPG Bulletin, 70: 661-662.

Whiteman, A. J., 1982, Nigeria, its petroleum, geology, resources and potential. v. I and II, Edinburgh, Graham and Trotman.

Zonge, K.; J. Wynn and S. Urquhart (2005).Resistivity, induced polarization and complex resistivity. In: Near Surface Geophysics. Butler, D. K (ed.). Society of Exploration Geophysics, pp 265-300.