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Geoelectrical Assessment Of Groundwater Potentials Of Some Parts Of Makurdi Metropolis, Benue State Using The Dar Zarrouk Parameters

[1]D.T. Ayaakaa, [2]S.O. Ikogo,[3]G. Adagba, [4]S.M. Shiada, [5] T.T. Bem
[1,2,3,4,5]Benue State University Makurdi, Physics Department, Faculty of Science. Benue State, P.M.B. 102119, Nigeria.

ABSTRACT
A geophysical survey involving ten (10) vertical electrical soundings (VES) employing Schlumberger array method was carried out at Makurdi, Benue State Capital, using Dar Zarrouk Parameters with the aid of TPZ-02 resistivity meter for data acquisition. The results show that the area is characterized by 4–5 geoelectric subsurface layers, namely, topsoil, lateritic clay, weathered layer, fractured unit and fresh basement. The determined aquifer thickness ranges from 6 m (VES 8: Kanshio Makurdi) to 69 m (VES 5: New Kanshio Layout, Makurdi), with an average value of 36.7 m and the aquifer resistivity ranges from 7 Ωm (VES 8: Kanshio1 Makurdi) to 378 Ωm (VES 10: Kanshio2 Makurdi) with an average of 133.8 Ωm. The aquifer thickness and aquifer resistivity were used to compute the values of the Dar Zarrouck parameters: longitudinal conductance (S) which ranges from 0.07143 to 0.78006Ω^{-1}*with an average of 0.362916*Ω^{-1} *and minimum longitudinal conductance of VES 10 and a maximum of VES 5 and transverse resistance (T) which ranges from 162* Ωm^2 *(VES 8: Kanshio1 Makurdi) to 12351*Ωm^2 *(VES 3: Industrial Estate Makurdi) with average of 4923.9*Ωm^2*. The groundwater productivity potential in the area has been classified into three zones namely; high, intermediate and low, the area shows 20% (VES 4 and 8) are of low groundwater potential, 40% (VES 1, 9, 8 and 7) are of moderate ground water potential and 40% (VES 3, 5, 10 and 2) are of high groundwater potential. This study has revealed that no single index determines the groundwater productivity potential but a combination of two or more factors.*

Key words: *Aquifer thickness, Aquifer resistivity, Dar Zarrouk parameters, Ground water, geoelectric subsurface layers*

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I. Introduction

Water is one of the most important and useful natural resources occurring both as surface water and groundwater. Water is very much needed and paramount to all living things in the universe. The growth and development of our society depends on the availability and adequate water usage. This precious resource is sometimes scarce, sometimes abundant, but unevenly distributed, both in space and time. Groundwater represents the second most abundantly available freshwater resources and constitutes about 30% of the fresh water resources of the globe (Subramanya, 2008). Surface water was the major source of drinkable water since the beginning of mankind (since creation) and because of population growth and economic development, surface water in many parts of the world is pushed to their natural limits. Unfortunately, surface water reservoirs, which are historically safer and cheaper than groundwater as major potable water resources, have not been properly recharged and maintained to meet the population's needs. Hence, the search for groundwater which is strategically valuable because of its high quality and availability as it represents about 97% of the planet's fresh water (Singh *et al.*, 2006).

Groundwater is the largest available reservoir of fresh water, it comes from rain, snow sheet, and hail that infiltrate the ground and become the groundwater responsible for the springs, wells and bore holes (Oseji, Atakpo, and Okolie, 2005). Groundwater has been a popular resource of water in many tropical countries. It is easy to extract, and it remains well protected from the hazards of pollution that the surface water has to put up with. However, situations wherein we have encountered overexploitation of groundwater resources are not uncommon. Insufficient knowledge regarding the basics of groundwater is the primary reason why we have not been able to use groundwater resources to their full extent. Thus, there is a growing emphasis on groundwater management (Subramanya, 2008).

The growing demand for potable water supply has been the major problem of most urban centers in Nigeria. Potable drinking water is the basic need for any society to live a healthy and productive life and for industry and agriculture to flourish. It is estimated that approximately 100 liters per day of safe drinking water is the minimum amount of water required per person for good health (Falkenmark*et al*. 2010). This is however, in variance with what is obtained in most of our urban towns, where people are constrained to manage water because of inadequate supply.

Makurdi and its environment have witnessed rapid growth in economic activities and increased urbanization in recent years. This has made it difficult for the government to meet up with thewater needs of the town. Groundwater is expected to form a significant part of the water resources of Makurdi and its environment, considering the enormous tropical rainfall experienced each year. Unfortunately, some parts of Makurdi lack enough groundwater resources, because of its distinct location and geological complexity. The availability and quality of groundwater in Makurdi, the capital town of Benue State, North Central Nigeria, are determined from a number of composite factors such as porosity and permeability. The Public Water Works which supplied water to all parts of the town has become dysfunctional and moribund. Most residents of the town have adjusted to providing their own domestic supplies by use of shallow hand dug wells (approximately 10 m deep) which are often poorly completed (Davison *et al*., 1997). The Makurdi Sandstone, which is the main aquifer that supplies water into wells for abstraction, is frequently indurated to the extent that well failure is always recorded when it is encountered using manual digging as is the case with all shallow boreholes. The wells are neither cased nor are they properly capped after completion. The immediate surroundings of the wells are inadequately sequestered from unsanitary conditions. Since there was no professional prospecting for the location of water-bearing sediments, some of the boreholes have either failed entirely or partially because of uncoordinated drillings. When the rate at which a well is discharged is greater than the rate at which it is recharge, then the well may fail (Davison *et al*., 1997). The nature of the aquifer is a function of subsurface geological compositions that plays an important role in determining the circulation of water from the surface (infiltration) to subsurface water through recharge processes (Bashir *et al.,* 2014).

Geophysical surveys are the implementation of geophysical methods to indirectly determine the geological and structural as well as the physical and mechanical characteristics of the foundation soil. These methods are used to determine the layout, thickness and properties of individual layers below the terrain surface, on which the construction of a specific structure is planned.

Among these Geoelectrical methods, Vertical Electrical Sounding (VES) technique has been frequently used in Hydro-geophysical studies for groundwater in both porous and fissured media (Onuoha and Mbazi, 1988). This method is based on the response of the earth to the flow of a regulated input current source, it is efficient and cost effective, geoelectric method provides a one-dimension (1-D) electrical impedance of the ground based on surface measurements, from which water saturation and lithological information are obtained (Mbonu*et al.*, 1991; Fadele*et al.,* 2013). Recently, there has been a growing interest in understanding, characterizing, and mapping the spatial distribution of aquifers in an area. Characterization and distribution of aquifers in an area can be determined successfully with the accurate knowledge of the aquifer geohydraulic Parameters (specifically the Dar Zarrouk) in the area. Geohydraulic parameters are key parameters usually employed in investigating a wide range of hydrogeologic problems such as groundwater flow modeling, prediction, aquifer characterization, protection, management, and solution (OkiongboandoAkpofure, 2012; Baride, 2017). Porosity, permeability, fluid transmissivity, transverse resistance, formation factor, longitudinal conductance, hydraulic conductivity, and aquifer depth are fundamental properties describing subsurface hydrology. As a result, many investigation techniques are commonly employed with the aim of the estimation of the spatial distribution of the above-mentioned parameters (Ekwe*et al.,* 2006).

All rocks are porous to some degree – varying from joints in natural rock formations to micro cracks and tiny pores in some specimens. Porosity affects fluid transport in rocks and is important to many sciences and engineering problems, including earthquake and fault studies, oil and gas recovery, reservoir architecture, groundwater contamination control, and nuclear waste deposit monitoring. The key physical property that affects fluid transport in rock is permeability, or the ability of a rock to transmit fluid. However, to estimate the permeability is challenging, because it varies a great deal in different rocks. To make matters more complicated, Earth is a dynamic environment, which means that there are huge variations in pressure, temperature, fluid chemistry, and other Environmental conditions. Some geophysical researches have been carried out in the study area to delineate regions with good aquiferous layers, computing the aquifer parameters, investigating groundwater flow potential using vertical electrical sounding method, employing Schlumberger electrode and Wenner Configuration (Idoko *et al.,* 2017; Abdullahi *et al.,* 2018). For an effective groundwater survey in the area, this work will compute the Dar Zarrouk parameters of rocks in the study area, employing computer-enabled software in interpreting the variation of these Dar Zarrouk parameters using electrical resistivity data set. An aquifer is a layer of earth minerals that is capable of yielding useable quantities of water. It is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated material (gravel, sand, or silt) found in the earth layer. This means that an aquifer must be both permeable and porous. In order for a well or borehole to be productive, it must be drilled into an aquifer.This to estimate aquifer resistivity and thickness of geologic layers in the study area, to compute the Dar Zarrouk parameters in the study area and interpret the variations of the hydraulic parameters (Dar Zarrouk) for the effective ground water survey in the study area.

Dar Zarrouk parameters

Some parameters are generally essential in the understanding and interpretation of the geological models (Egbai and Iserhien-Emekeme, 2015), among these parameters are the Dar Zarrouk parameters. These parameters are related to the different combinations of a sequence of horizontal, homogeneous and isotropic layers of resistivity ρ_i and thicknessh_i of each geoelectric layers in the model (Braga *et al.*, 2006)

Longitudinal conductance (*S*)

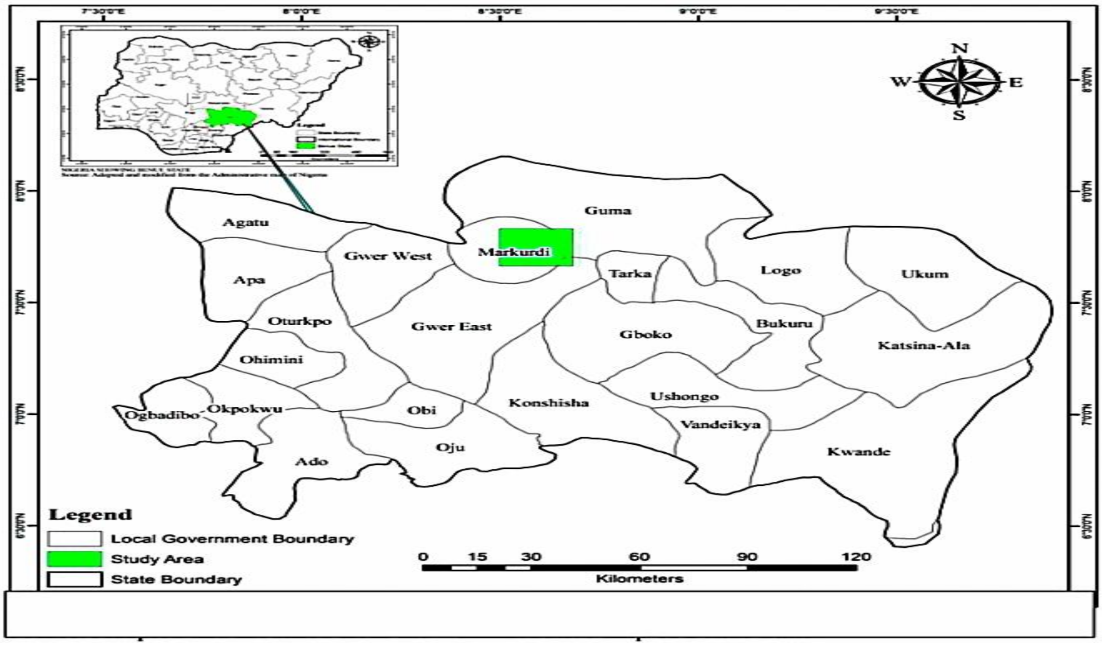
When the current flows parallel to the geoelectric boundaries, the parameter that influences the current flow is the longitudinal conductance (*S*) (Telford *et al*. 1978).

$$S=\sum_{i=1}\frac{h_i}{\rho_i} \qquad (1)$$

Transverse Resistance (*T*)

When the current flows normal to the bed boundaries, the transverse resistance (*T*) is significant (Telford *et al.*, 1978).

$$T=\sum_{i=1} h_i\rho_i \qquad (2)$$



II. Methodology

Location and Geology of the Study Area

The study area is Makurdi, the Benue State Capital, North Central, Nigeria (Figure 1). It lies between latitudes 7°40'N and 7°50'N of the equator and between longitudes 8°20'E and 8°40'E of the Greenwich Meridian, covering a total area of about 670 km². Makurdi lies within the Guinea savannah vegetation zone with a few patches of forest. The annual rainfall ranges between 1,500 to 2,000 mm with its peak rainfall in July (Offodile, 1976).

Temperatures in March and April are about 38 and 48°C, respectively, while in December/January, the temperature is 27°C Benue State Water Supply and Sanitation Agency (2008). Makurdi belongs to the Makurdi formation, which overlies the Albian Shale. It consists of thick current bedded coarse-grained deposits. The Makurdi sandstone has a thickness of about 900 m (Offodile, 1976). The southern part of the Benue valley is generally gently undulating and punctuated by a few low hills. However, to northeast, the relief is exaggerated by hills like the Lammuder and Ligri hills, which rise up to 600 m above sea level. The drainage consists of rivers which meander into the River Benue from the north and south directions. Geological, the Benue valley consists of a linear stretch of sedimentary basin running from the present confluence of the Niger and the Benue rivers to the north east, and is bounded roughly by the basement complex areas in the north and south of the River Benue. The elongated trough-like basin is continuous with the coastal basin, and in fact, has been correctly described as the longest arm of the Nigerian coastal basin (Offodile, 2002). The MAP of Benue State is shown in fig 1 and 2 respectively.

FIGURE 1: Map of Benue State showing makurdi metropolis (Daniel, O. and Johnson, I., 2015)

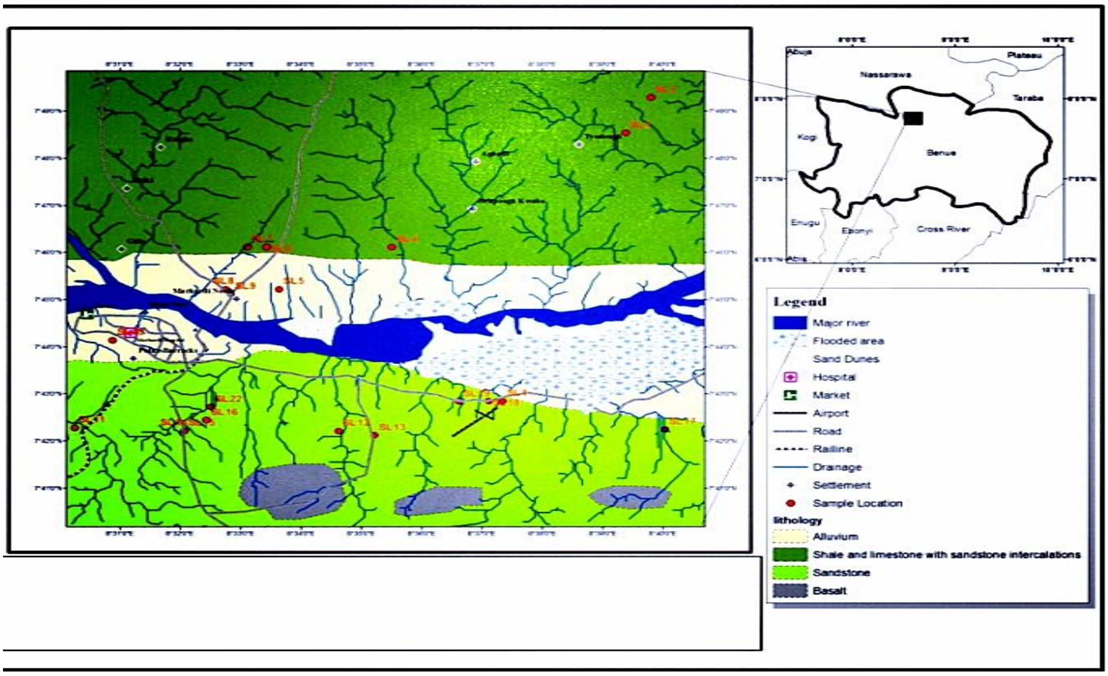


Figure 2: Geological map of Makurdi metropolis (Daniel, O. and Johnson, I., 2015)

Relief and Drainage

Makurdi Metropolis is collectively curvy and wavy with sparse hills and valleys. Elevations within this area range from 76 m on the flood plains of River Benue to about 182 m above mean sea level at the northern and southern parts of the study area. There are also some undulations which mark the main water sheds in the area. Makurdi metropolis is drained by the River Benue, which flows from the eastern to the western parts of the study area and its numerous seasonal tributaries (Daniel and Johnson (2015)

Data Acquisition and Method

Ten (10) vertical electrical sounding (VES) points were carried out in different locations within the study area using PZ-02 resistivity meter. The Arrangement of the electrode configuration was Schlumberger with Maximum half current electrode spacing (AB/2) of 100.0m and potential electrode spacing (MN/2) of 15.0m. The product of geometric factors K and R was then made to obtain the apparent resistivity (ρ_α) of the said earth material using Equations 1 and 2. Figure 3 shows the Schlumberger Array of Vertical Electrical Sounding used in this work.

$$k = \pi\left[\frac{\left(AB/2\right)^2 - \left(MN/2\right)^2}{MN}\right] \quad (3)$$

$$\rho_{\alpha} = \pi\left[\frac{\left(AB/2\right)^2 - \left(MN/2\right)^2}{MN}\right]R \quad (4)$$

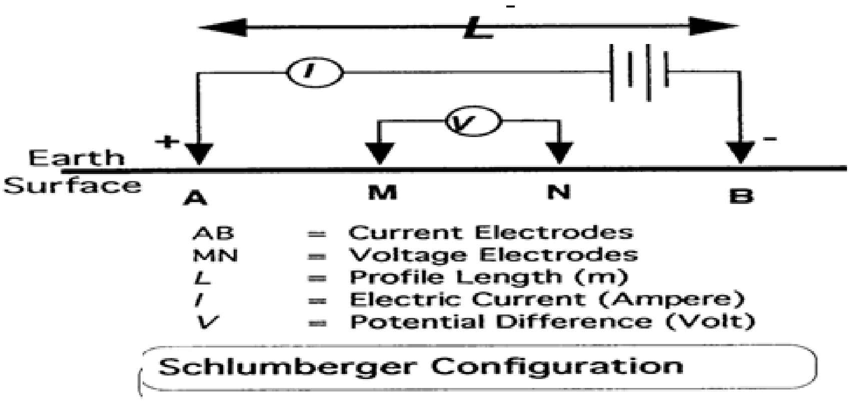


Fig 3: Schlumberger Array of Vertical Electrical Sounding

III. Results and Discussion

Results

Table 1.0 shows the variation of aquifer resistivity and thickness due to lithologic composition, from which the longitudinal conductance and transverse were computed. It also shows the variation of the thickness in the study area in which the minimum value is observed in point VES 4 and a maximum value in point VES 3 with the average of 36.7m. The groundwater potentials of the area are evaluated based on the following indices; Dar Zarrouk parameters (Aquifer resistivity, Aquifer thickness, longitudinal conductance, and transverse resistivity).

Table 1.0: The summary of the interpreted electrical resistivity survey

Ves Station	Location	Aquifer Resistivity	Aqifer Thickness	Longitdinal Conductance	Transverse Resistance	Latitude	Longitude	Curve Type	Groundwater Potential
1	Gboko Road Mkd	111.0	32.0	0.28828	3552.0	7.72241	8.56058	HK	Intermediate
2	Kwararafa quarters Mkd	256.0	29.0	0.11328	7424.0	7.73935	8.52446	QHA	High
3	Indstrial Estate Mkd	176.0	69.0	0.39205	12351.0	7.70466	8.48856	AK	High
4	Fed Low Cost Naka Road Mkd	79.0	7.0	0.08861	553.0	7.70932	8.49805	HA	Low
5	New Kanshio Layout Mkd	80.0	78.0	0.78006	6240.0	7.68794	8.52730	QHA	High
6	David Mark Bye-Pass, Mkd	98.0	22.0	0.22357	2156.0	7.71989	8.51439	HKH	Low
7	U.A.M	75.0	57.0	0.76000	4275.0	7.79285	8.62162	HAA	Intermediate
8	Kanshio1 Mkd	27.0	6.0	0.22222	162.0	7.68247	8.53725	HA	Intermediate
9	North Bank Mkd	58.0	40.0	0.68966	2320.0	7.75326	8.55861	HK	Intermediate
10	Kanshio2 Mkd	378.0	27.0	0.07143	10206.0	7.68338	8.53665	QH	High
	Average	133.8	36.7	0.362916	4923.9				

Discussion

Geo-electric parameters are interpreted from geoelectrical resistivity survey data. Interpretation of vertical electrical sounding data using winResist software led to the generation of geo-electrical layers. The information from these geo-electric layers enhanced the identification of layers and their apparent resistivities, thicknesses, depth, curve type and aquifer systems. The summary of the interpreted electrical resistivity survey is presented in Table 1.0 above. The VES analysis reveals that the area is characterized by 4 – 5 geoelectric subsurface layers with 4-layer types occurring more. The curve types obtained from the study area are HK, QHA, AK, HA, QHK, HAA and QH, which are also called the curve pattern. The 4-layer geoelectric section is characterized by HK, AK, HA, and QH. The 5-layer geoelectric section is characterized by QHA, QHK, and HAA. (Figures 4.2, 4.5 and 4.6). The high groundwater potential is observed at VES 3, 5, 10, and 2 because of the high values of longitudinal conductance, transverse resistivity, and aquifer thickness with low aquifer resistivity.

These VES points are zones of higher water bearing potential which is most likely to be of great regional importance which tends to be higher than (Nwachukwu *et al.*, 2019) values reported in Orogun Town, Ughelli North Local Government Area of Delta State but lower than Oladunjoye *et al.*, (2018**)** result obtained in Gbongudu community, Ibadan.

The low groundwater potential is observed at VES 4 and 6 due to the high value of aquifer resistivity and low value of the aquifer thickness,although some VES stations have high values of longitudinal conductance and transverse resistivity which discontinuously disagrees with (Nwachukwu *et al.*, 2019) similar research work conducted in Orogun Town, Ughelli North Local Government Area of Delta State but closely agrees with (Oladunjoye *et al*., 2018**)** result obtained in Gbongudu community, Ibadan, VES 1, 7, 8 and 9 shows moderate groundwater potential. These zones are most likely to provide local water supply for private consumption. Table 1.0 was also used to draw 2D contour maps for all groundwater potential indices used in the VES analysis.

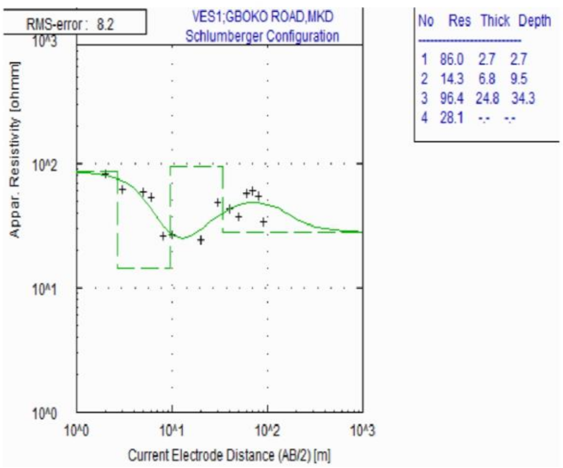


Figure 4: Typical HK curve.

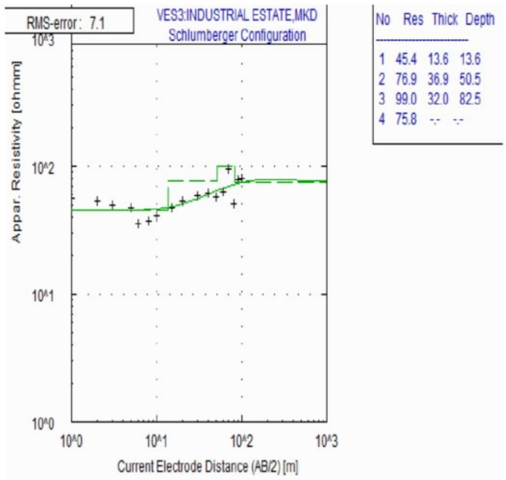


Figure 5: Typical QHK curve.

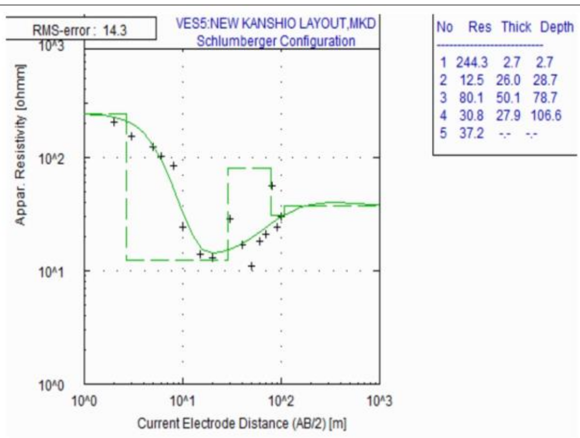


Figure 6: Typical AK curve.

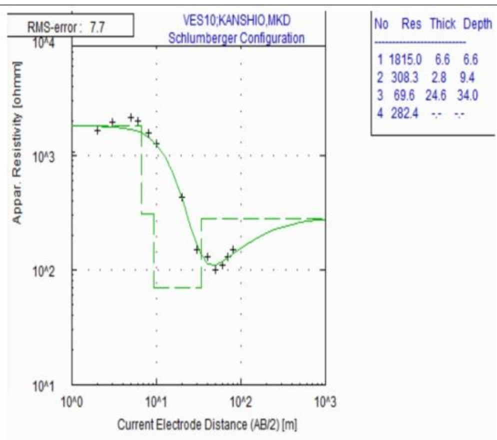


Figure 7: Typical HA curve

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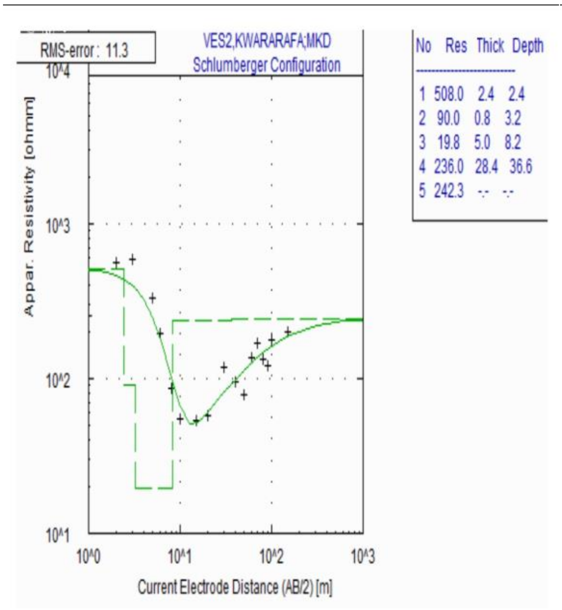

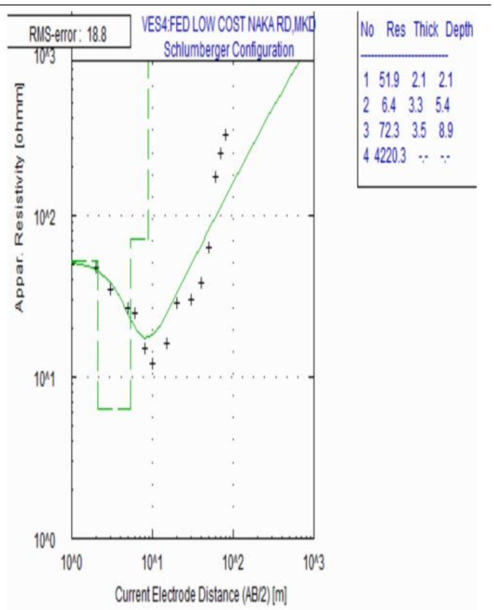

Figure 8: Typical QHK curve. **Figure 9:** Typical HAA curve.

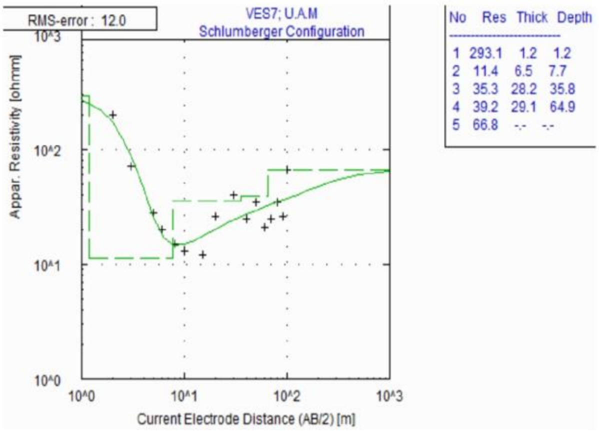

Figure 10: Typical QH curve.

Aquifer resistivity

The aquifer resistivity in the study area ranges from 25 to 378*m* with an average of 133.8*m* in which the minimum resistivity is observed in point VES 8, and a maximum resistivity is observed in point VES 10. This shows the spatial distribution of aquifer resistivity in the study area. This suggests that zones with low aquifer resistivity values will have high conductive geomaterials, such as poor groundwater quality

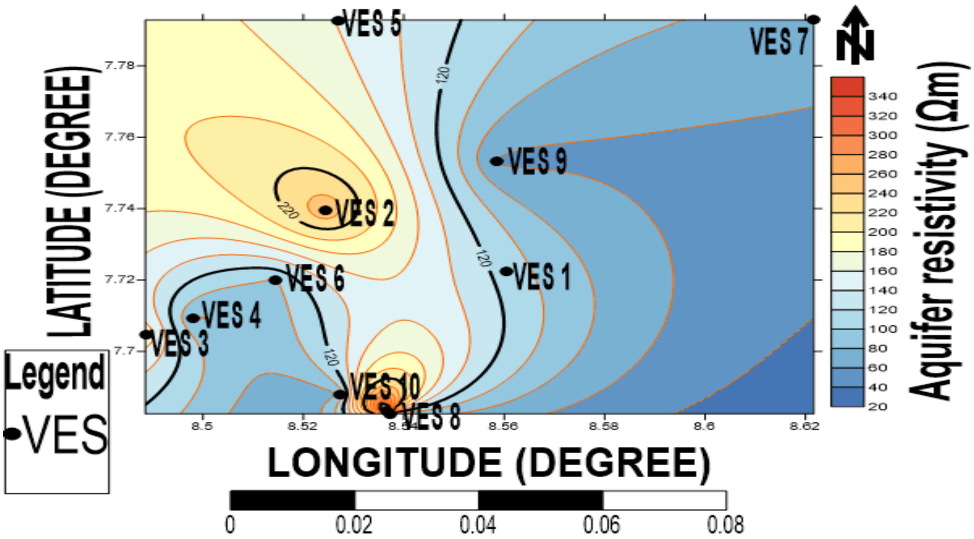

Figure11: Spatial distribution of Aquifer resistivity in the study area.

Aquifer thickness

The spatial distribution of aquifer thickness across the study area. It is observed that the aquifer thickness decreases from the northern part to the southern part of the study area and from the eastern part to the western part of the study area. The aquifer thickness in the study area ranges from 6.0*m* to 78.0*m* with an average of 36.7*m* in which the minimum thickness is observed in point VES 8, and a maximum is observed in point VES 5.

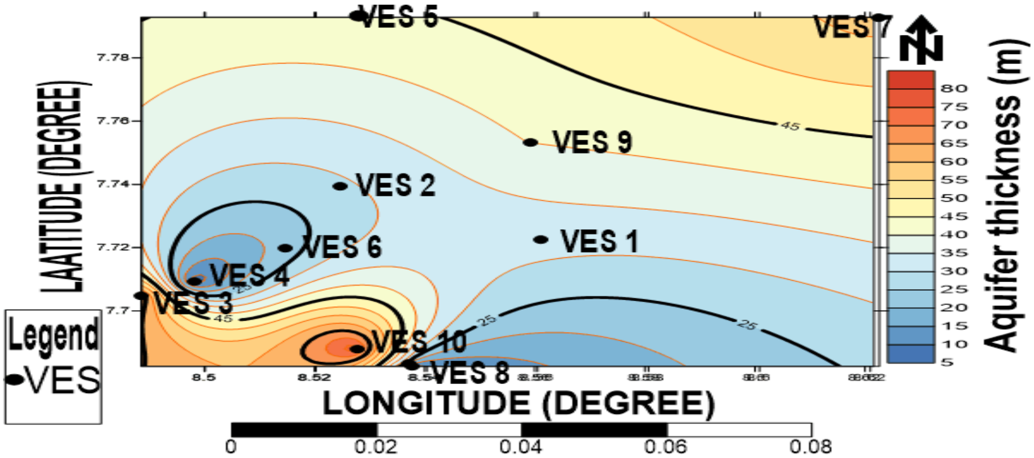

Figure 12: Spatial distribution of Aquifer thickness in the study area.

Longitudinal conductance

The total longitudinal conductance is one of the Dar-Zarrouk parameters used to define the target areas of groundwater potential. Figure 12 shows the spatial distribution and variation in the longitudinal conductance across the area investigated, which ranges from 0.07143 to 0.78006 $\Omega^{-1}$with an average of 0.362916Ω^{-1}in which the minimum longitudinal conductance is observed in VES 10, and a maximum is observed in VES 5, the average value of Longitudinal conductance as calculated from my work is observed to be higher than Nwachukwu *et al*., (2019) values reported in Orogun Town, Ughelli North Local Government Area of Delta State and slightly higher than Oladunjoye *et al*., (2018**)** result obtained in Gbongudu community, Ibadan. Note the changes in the total thickness of low resistivity materials found within the overburden. Increase in the value of longitudinal conductance may correspond to an increase in clay content and thus, a reduction in transmissivity (Khali, 2009), which can be observed in this work and in both (Nwachukwu *et al*., 2019) research in Orogun Town, Ughelli North Local Government Area of Delta State and (Oladunjoye *et al*., 2018**)** result obtained in Gbongudu community, Ibadan. The clay overburden, which gives relatively high longitudinal conductance, protects the underlying aquifer. Comparing figures 4.8 and 4.10. It was observed that the zone with high aquifer resistivity corresponds to zones with low to moderate longitudinal conductance, although some zones have similar properties in both contour maps, which indicate that S within a saturated zone is generally greater than that in the unsaturated zone due to the presence of enough water in the pore space, as observe in this work and in both (Nwachukwu *et* *al*., 2019) research in Orogun Town, Ughelli North Local Government Area of Delta State and (Oladunjoye *et al*., 2018**)** research in Gbongudu community of Ibadan. From this observation, it indicates that the northeastern part of the study area is dominated by resistive geo-materials; as such,the groundwater flow in the area is not simple but complex because of the geologic control of the confined aquifers.

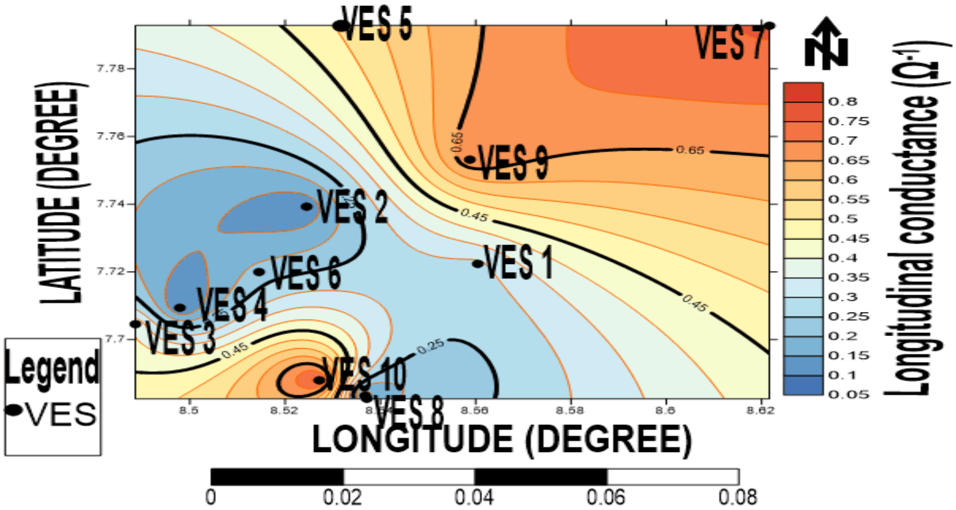

Figure 13: Spatial distribution of Aquifer thickness in the study area.

Transverse resistance

The total transverse resistance at the top of basement has direct relationship with transmissivity, and the highest transverse resistance value most likely reflects the highest transmissivity values of the aquiferous zone (Braga *et al*., 2006). Figure 13 shows the variation in the total transverse resistance of the area mapped and it ranges from 162 to 12351Ωm^2 with average of 4923.9 Ωm^2. The total transverse resistance can be classified as; less than 500 Ωm^2 to be poor with negligible transmissivity, then the transverse resistance of between 500 to 2000 Ωm^2 is said to be weak, while 2000 to 5000 Ωm^2 is said to be moderate with moderate transmissivity and above 5000 Ωm^2 is very good with good aquifer transmissivity. The total average transverse resistance value in this work is extremely lower than Nwachukwu *et al*., (2019) values reported in Orogun Town, Ughelli North Local Government Area of Delta State but higher than Oladunjoye *et al*., (2018**)** result obtained in Gbongudu community, Ibadan. From the map generated for the total transverse resistance, it can be observed that less than 50 % of the area investigated has poor to weak transmissivity based on their total transverse resistance values. The right part of the area has good transmissivity because of the high value of total transverse resistance as observed from the contour map of the total transverse resistance.

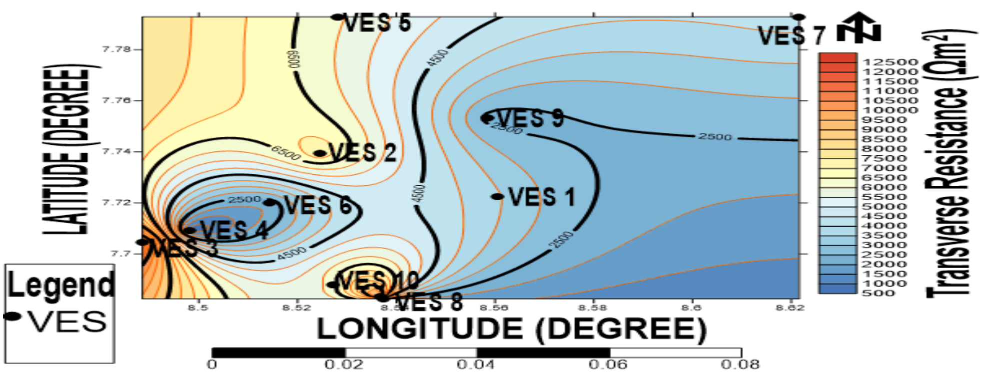

Figure 14: Spatial distribution of Aquifer thickness in the study area.

IV. Summary

The electrical resistivity sounding method using the Schlumberger array configuration was used to explore the study area, and this work evaluated the Dar Zarrouk parameters of some parts of Makurdi, Benue State to determine the groundwater potential. Ten (10) Vertical Electrical Sounding (VES) was carried out in the study area which was used to compute the Dar Zarrouk parameters of the survey area. The VES analysis reveals that the area is characterized by 4 – to 5- geoelectric subsurface layers, with four layers in VES 1, 3, 4, and 7, while VES

2, 5 and 6 revealed five geoelectric layers. The results provide data on the formation parameters which were evaluated, and the parameters evaluated include: longitudinal conductance and transverse resistance. The results from these evaluated parameters showed that the area has good groundwater potential. Most zones with the low longitudinal conductance have low transverse resistance, which gives the low groundwater potential. The empirical relationship established between longitudinal conductance and aquifer resistivity is a good tool for categorizing groundwater potential. Therefore, geoelectrical sounding technique is an inexpensive tool for calculating the Dar Zarroukparameters and categorizing the aquifer potential of the study area. Considering the calculated Dar Zarroukparameters in particular, the study area shows three different groundwater potentials. 20% are of low groundwater potential, 40% are of moderate ground water potential, and 40% are of high groundwater potential. From these ranges of values, the study area can be inferred to as having moderate to high groundwater potential with little to low potential.

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