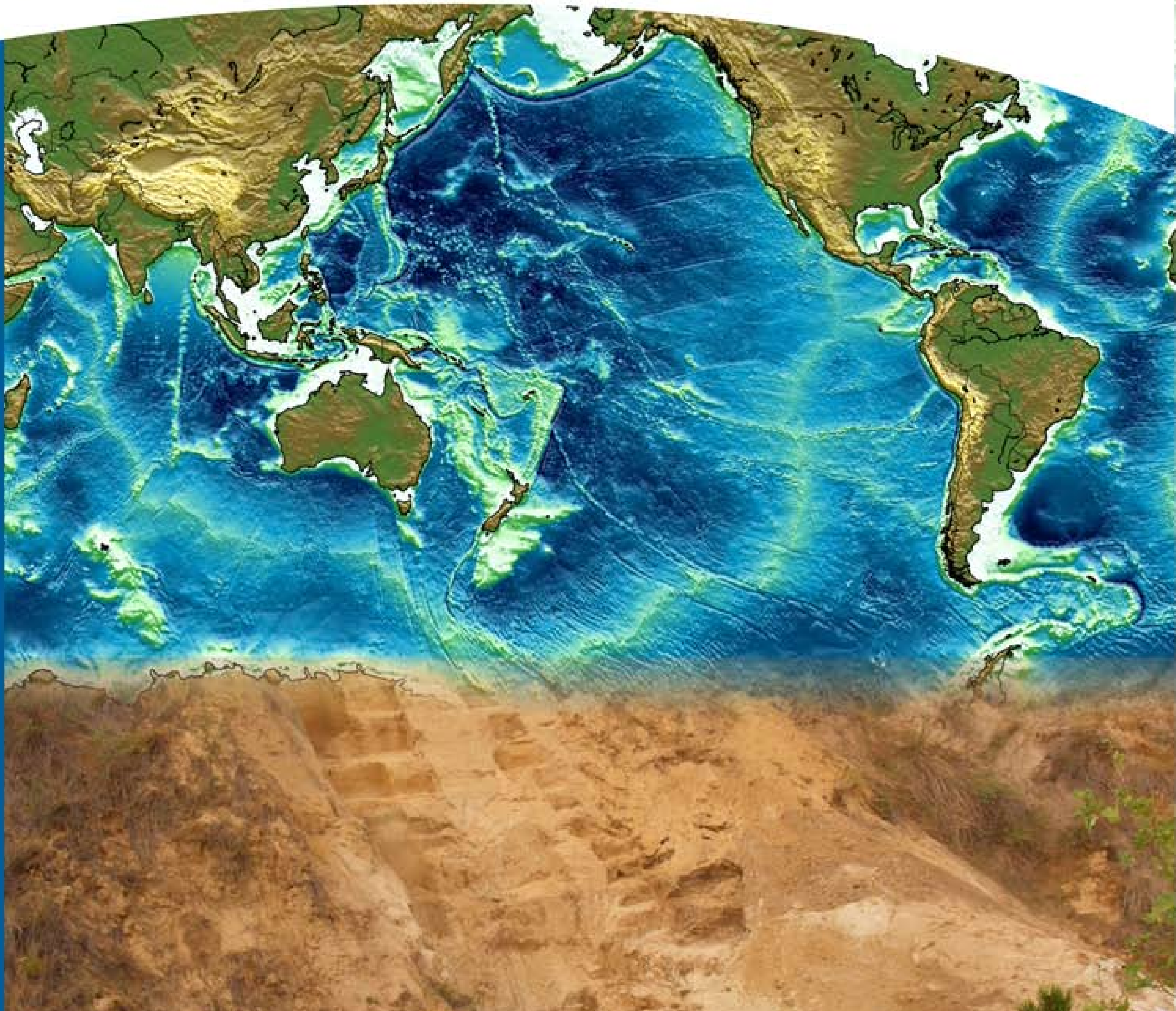
ISSN : 2395-647X

Vol. 3, No. 3, September 2017

International Journal of Geology and Earth Sciences



www.ijges.com

Email : info.ijges@gmail.com or editor@ijges.com

Int. J. of Geol. & Earth Sci., 2017

International Journal of Geology and Earth Sciences

ISSN 2395-647X www.ijges.com
Vol. 3, No. 3, September 2017

Research Paper

GEOELECTRIC AND HYDROELECTRIC PARAMETERS OF AQUIFERS IN SOUTHERN PARTS OF AKWA IBOM STATE

Inyang Namdie J[1]* and Akpabio Idara O[1]

*Corresponding Author: Inyang Namdie J ✉ namdie007@yahoo.com

Received on: 30th May, 2017 Accepted on: 22nd August, 2017

A Vertical Electrical resistivity Sounding (VES) survey was carried out, to study the geoelectric and hydroelectric parameters of aquifer in some locations in Part of Akwa Ibom State. A total of six (6) geoelectric soundings were acquired. The lithology of the aquifer layer can be said to compose of fine to gravelly sand, with sand and clay intercalation. The low resistivity values across most of the geoelectric layers can be attributed to conductive argillaceous geomaterials. Underlying aquiferous layer is likely unprotected from the surface contamination flow due to the fact that the protective capacity of most part of the study area is good as shown by this study. Contour maps generated using the results from the study shows bulk aquifer resistivity and water resistivity values, the formation factor calculated ranges from 2.3-50.45. Porosity ranges from 8.68-48.27% and hydraulic conductivity ranges from 0.671 m/day^2 from estimates. Porosity values obtained confirms that aquifer in the study area consist mainly of sandstone. It is also revealed that, areas with low resistivity have high porosity and the storativity as observed in the extreme south and central parts of the study area.

Keywords: Porosity, Formation factor, Hydraulic conductivity, Aquifer

INTRODUCTION

The discontinuous nature of the aquifer system makes detailed knowledge of the subsurface geology, its weathering depth and structural disposition through geologic and geophysical investigations difficult. According to Oluorunfemi and Fasuyi (1993) and Edet and Okereke (1997) weathering is an important factor that determines the presence of porosity and permeability.

Some researchers have used different techniques to estimate the spatial distribution of aquifer parameters such as hydraulic conductivity, transmissivity and aquifer depth (Allen *et al.*, 1997). The hydraulic characteristics of subsurface aquifers are important properties for both groundwater and contaminated land assessments and also for safe construction of civil engineering structures. Groundwater recharge is dependent on rainfall, high porosity and connectivity of the aquiferous layers as such the amount of groundwater in a formation is a function of porosity. The number of pores and crevices in a soil and rock and how well they are

1 Department of Physics, University of Uyo, Nigeria.

connected determines how easily groundwater moves through the ground and how much groundwater comes from a particular layer. Since groundwater has to move between pores and crevices in soil and rock, it moves much more slowly than surface water. The aquifer's electrical resistivity is mainly influenced by porosity and fluid resistivity in pores and the geoelectrical data recorded on the surface contain useful information about the aquifer which can be interpreted by experienced geophysicists for hydrogeological studies (Niwas and Celik, 2012).

The problem of estimating rock, fluid and hydraulic properties becomes more important as hydrologists are asked to solve problems related to groundwater flow in rock materials about which little is known (Jorgensen, 1989). Hydraulic and electric conductivities are dependent on each other since the mechanisms of fluid flow and electric current conduction through porous media are governed by the same physical parameters and lithological attributes. The poor knowledge of the geometry and nature of the aquifers have posed problem to groundwater exploitation as many boreholes have been drilled without any knowledge of the hydrogeophysical characteristics and distribution of aquifers in the Study area.

Transmissivities, formation factors and hydraulic conductivity can be estimated in a porous media using empirical/semi empirical correlation often using simple linear relations (Kelly, 1977; Heigold *et al*., 1979; Schimschal, 1981; Urish, 1981; Chen *et al.*, 2001; and Laouini *et al.*, 2017). The physical condition controlling the electric current flow also controls the flow of water in a porous media. Groundwater flow in fractured aquifers is very complicated, and accuracy in estimation of the hydraulic parameters depends on the hydraulic behavior in particular fractures, which is site specific (Singh, 2005). The choice of VES for the study is based on the fact that the electrical resistivity of most rocks depends on the amount of water in their pores, it also depends on the distribution of these pores and the salinity of the water (Todd, 2004). Also, the variation of conductivity within the earth's subsurface layers affects the distribution of electric potential. The degree of this effect depends on the size, shape, location and bulk electrical resistivity of the subsurface layers. The bulk electrical resistivity depends on the mineralogy of the rocks and it's containing fluids (Lowrie, 1997). This study is aimed at using the Schlumberger electrode configuration method to define the aquifer geometry and to model the variation of electric and hydraulic parameters in the study area.

The study was carried out in Akwa Ibom State in Nigeria, the state lies between Latitude $4^{0}30^{1}$ and $5^{0}30^{1}$N and Longitude $7^{0}50^{1}$ and $8^{0}20^{1}$E having a land area of 7249 Km^2 and a population of 5,272,029 people. It is bounded on the East by Cross River State, on the West by Rivers State, on the North by Abia State and on the South by the Atlantic Ocean. It has a shoreline 129 km and encompasses the Qua Iboe River Basin and the Eastern half of the Imo River Estuary. The region is flat and low-lying, exhibiting three major physiographic units which can be identified from the terrain. These are the alluvial plains (mangrove and flood plains), the beach ridge sands and the rolling sandy plains.

The alluvial plain comprises mangrove swamps and fresh water flood plains. The mangrove swamp, which are drained by tidal brackish water, are found in the estuaries of Imo River, Uta Ewa (Jaja), Shooter and Qua Iboe

Creeks and along the coastal fringes, separating the beach ridge sands from the upland coastal sandy plains. The fresh water flood plains are formed by the upper reaches of Imo River and a large network of creeks, the major ones being Essene, Uta Ewa (Jaja), Shooter and Qua Iboe Creeks.

The geological formations in the area consist of the Quaternary sedimentary deposits, and the Tertiary Coastal Plain Sands, generally referred to as Calabar Formation. The Quaternary sediments give rise to alluvial plains as well as the beach ridge sands. The alluvial plains include the mangrove mudflats, which are under the influence of tidal brackish waters along the coast and in the estuaries of rivers and creeks, and the fresh water flood plains and swamps which form the wetland environments found along the upper reaches of rivers, creeks, tributaries and meander belts. The beach ridge sands form some raised portion of land between the mangrove swamps and the shoreline. The mangrove mudflats contain strata of mixed inorganic matters and plant debris. The soils are deep, have loamy sand to sandy loam surface over clay loam to sandy clay subsoil. They have good physical attributes for seedbed preparation, but because of their sandy nature, they are fragile and highly susceptible to erosion. The study area is that of humid tropic with the temperature range of 26 °C and 28 °C, while the mean annual rainfall lies between 2,000-4,000 mm. The rainy season lasts from April to November and is characterized by high relative humidity and heavy cloud covers.

METHODOLOGY

Geoelectric Parameters

The relationship between the hydraulic conductivity (K) and geoelectrical resistivity (ρ) of an aquifer is strongly controlled by the nature of the aquifer substratum (Niwas and Singhal, 1985; and Niwas and de Lima, 2003). For a highly resistive substratum, both the current and the hydraulic flows are dominantly horizontal in a typical unit column of the aquifer, and the relationship between *K* and ρ, is inverse. If the substratum is highly conductive, the hydraulic flow will still be horizontal while the current flow in a characteristic unit column is dominantly vertical; thus, a direct relation exists between *K* and ρ. If the aquifer material is cut in the form of a vertical prism of the unit cross-section from top to bottom, fluid flow and current flow in the aquifer material obeys Darcy's law and Ohm's law respectively. Thus, for current and fluid flows in a lateral direction, the transmissivity of the aquifer is given as:

$$T = (K^{\circ})S \qquad ...(1)$$

where ° is the bulk resistivity and *S* given by $h/^{\circ}$ is the longitudinal unit conductance of the aquifer material with thickness *h.*

For hydraulic conductivity *K*, we have

$$K = 8 \times 10^{-6} e^{-0.0013^{\circ}} \qquad ...(2)$$

For a lateral hydraulic flow and current flowing transversely, the transmissivity of the aquifer becomes:

$$T = \left(K/^{\circ}\right)R \qquad ...(3)$$

where R is the transverse unit resistance of the aquifer material given by h° . If the aquifer is saturated with water with uniform resistivity, then the product K° or $K/^{\circ}$ would remain constant. Thus, the transmissivity of an aquifer is proportional to the longitudinal conductance for a highly resistive basement where electrical current tends to flow horizontally, and proportional to the transverse resistance for a highly conductive basement where electrical current tends to flow vertically (Sir Niwas *et al.*, 2011). The above equations may therefore be written as:

$$T = \sim S \text{ ; } \sim = K^{\circ} \qquad ...(4)$$

and

$$T = \quad R \text{ ; } \quad = K/^{\circ} \qquad ...(5)$$

where and ~ are constants of proportionality. From these relations, the model resistivity values obtained from the inversion process were used to estimate the longitudinal unit conductance and transverse unit resistance of the aquifer unit.

Hydroelectric Parameters

Since the electrical resistivity of most minerals is high (exception: saturated clay, metal ores, and graphite), the electrical current flows mainly through the pore water. According to the famous Archie law (Archie,1942), the resistivity of water saturated clay-free material can be described as

$$R_o = R_w \times F_i \qquad ...(6)$$

where R_o= specific resistivity of water saturated sand, R_w= specific resistivity of pore water, F_i= intrinsic formation factor.

The intrinsic formation factor (F_i) combines all properties of the material influencing electrical current flow like porosity u, pore shape, and digenetic cementation.

$$F_i = a \times ¤^{-m} \qquad ...(7)$$

Different definitions for the material constant (m) are used like porosity exponent, shape factor, and cementation degree. Factors influencing (m) are, e.g., the geometry of pores, the compaction, the mineral composition, and the insolating properties of cementation. The constant (a) is associated with the medium and its value in many cases departs from the commonly assumed value of one. The quantities (a) and (m) have been reported to vary widely for different formations. The reported ranges are exemplified in Table 1, which is based upon separate compilations of different investigators.

Equation (6) is called Archie's first law, where it is valid only in fully saturated clean formations (the grains are perfect insulators).

When the medium is not fully saturated, water saturation plays an important role, where the changing in degree of saturation changes the effective porosity (accessible pore space), the equation became Archie's second law.

Table 1a: Aquifer Geoelectrical Parameters

VES	Resistivity (t m)	Thickness (m)	Hydraulic Conductivity (m/s)	Hydraulic Conductivity (m/day^2)	Transmissivity (m^2/day)	Longitudinal Conductance (t -1)	Transverse Resistance (t m)	Longitudinal Resistivity	Transverse Resistivity
1	4.11	6.36	7.95E-06	0.687516767	4.372606638	1.547445255	26.1396	4.11	4.11
2	6.79	5.79	7.92E-06	0.670852176	3.884234098	0.852724595	39.3141	6.79	6.79
3	11.1	1.79	7.89E-06	0.667103902	1.194115984	0.161261261	19.869	11.1	11.1
4	0.506	1.72	7.99E-06	0.676354947	1.163330509	3.399209486	0.87032	0.506	0.506
5	5.52	10	7.94E-06	0.671960667	6.719606675	1.811594203	55.2	5.52	5.52
6	2.41	10.2	7.97E-06	0.674682904	6.881765618	4.232365145	24.582	2.41	2.41

Table 1b: Aquifer Geoelectrical Parameters

VES 1	Anisotropy	Protective Capacity	Soil Corrosivity	Transmissivity Designation
1	1	Good	Very Strongly Corrosive	Low
2	1	Good	Very Strongly Corrosive	Low
3	1	Weak	Moderately Corrosive	Low
4	1	Good	Very Strongly Corrosive	Low
5	1	Good	Very Strongly Corrosive	Low
6	1	Good	Very Strongly Corrosive	Low

$$F_i = \frac{R_o}{R_w} = a¤^{-m} S_w^{-n} \qquad ...(8)$$

where R_o is the formation resistivity, R_w is the pore water resistivity, ¤ is the porosity, S_w is the water saturation, a and m are constants related to the rock type, and n is the saturation index (usually equals 2).

Many studies concluded that Archie's law breaks down in three cases: (1) clay contaminated aquifer (Vinegar and Waxman, 1984; and Worthington, 1993), (2) partially saturated aquifer (Börneretal, 1996; and Martys, 1999), and (3) freshwater aquifer (Alger, 1966; and Huntley, 1987).

Table 2: Aquifer Hydroelectrical Parameters

VES 1	Resistivity (t m)	Rw	F	Porosity %
1	4.11	0.22	18.68182	15.07710927
2	6.79	0.22	30.86364	11.40752534
3	11.1	0.22	50.45455	8.681731067
4	0.506	0.22	2.3	48.27276116
5	5.52	0.22	25.09091	12.79831928
6	2.41	0.22	10.95455	20.28194621

RESULTS AND DISCUSSION

80% of the aquifers in the study area have good protective capacity and are strongly corrosive. Aquifers Transmissivity in the study area are generally low due to the low porosity, which ranges from 8% to 48% (Table 1). The underlying aquiferous layer is unprotected from the surface contamination flow due to the fact that the protective capacity of most part of the study area is good. The aquifer resistivity increases from northeast towards the south-western part of the study area as shown in

Figure 1: 2D Map Showing the Aquifer Porosity

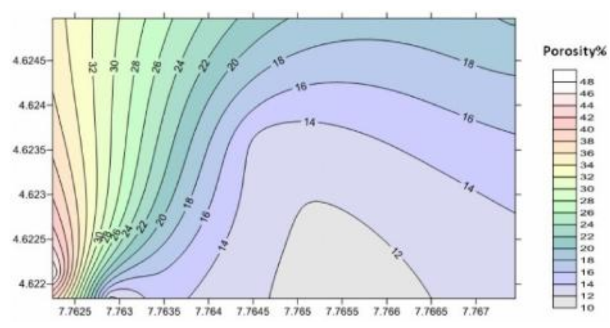


Figure 2: 2D Map showing the Aquifer Resistivity

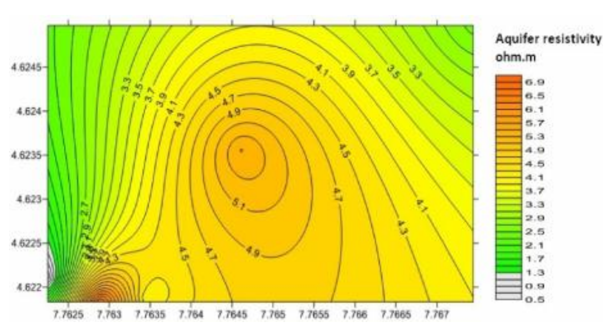


Figure 3: Aquifer Points Distribution

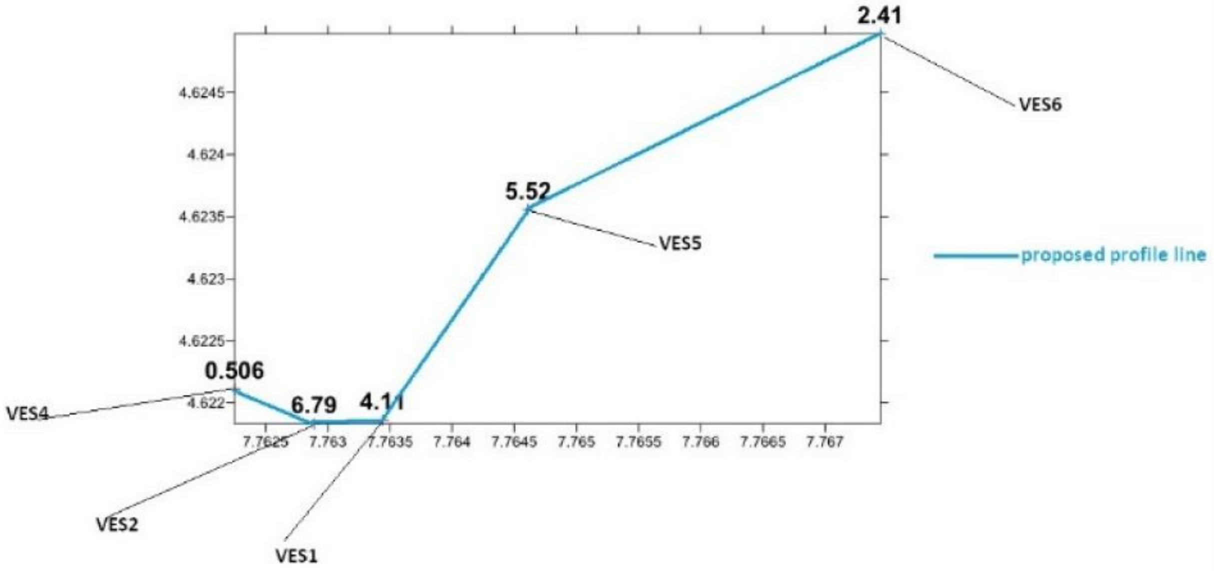


Figure 4: Aquifer Geoelectrical and Hydrogeological Parameters

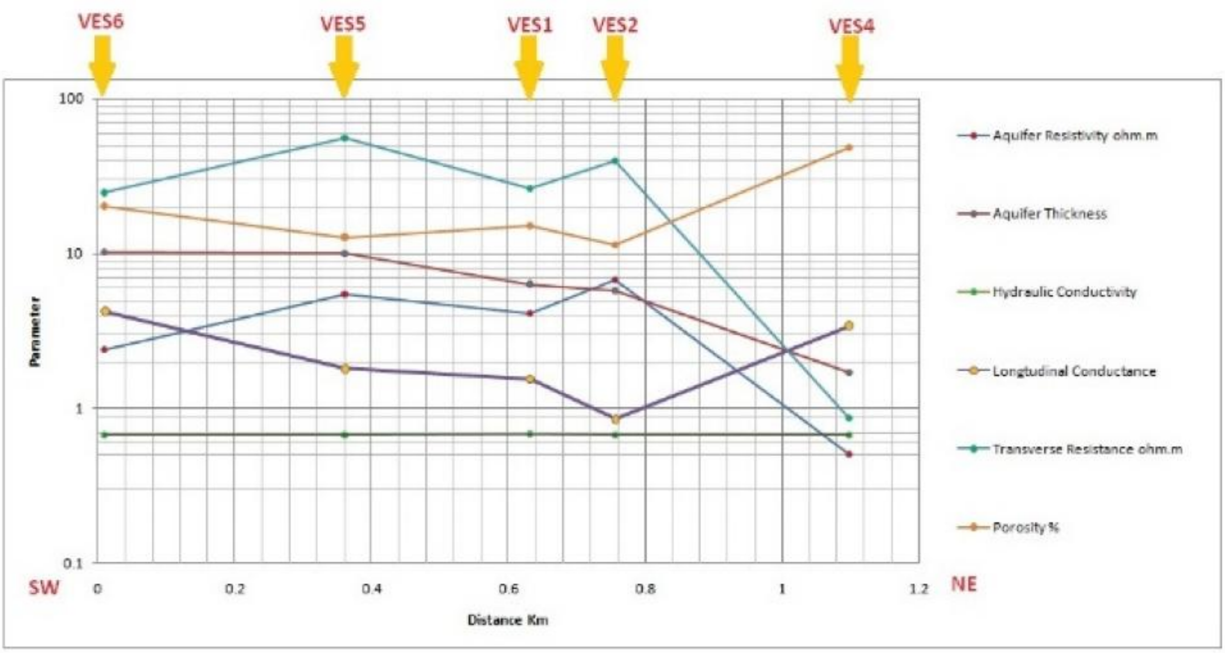


Figure 3. Places west of the study have high aquifer resistivity and can be said to have low conductive materials. High to moderate groundwater potential can be obtained from the area based on the aquifer thickness. Longitudinal conductance and transverse resistance of the study area were also computed using the aquifer geoelectric parameters. The result shows that most parts of the study area have unprotected aquifer as

Figure 5: Porosity Against Resistivity of the Aquifer

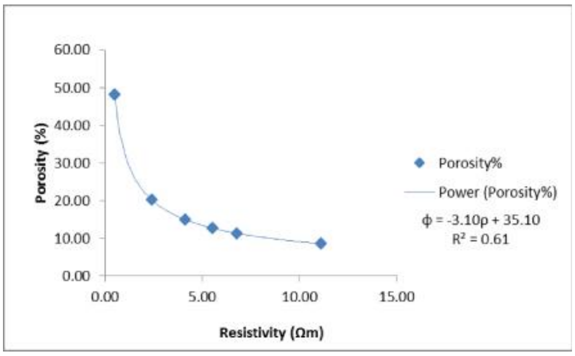


Figure 6: Hydraulic Conductivity Against Resistivity of the Aquifer

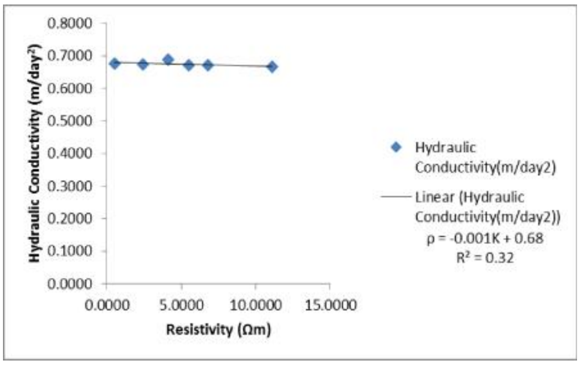


Figure 7: Formation Factor Against Porosity of the Aquifer

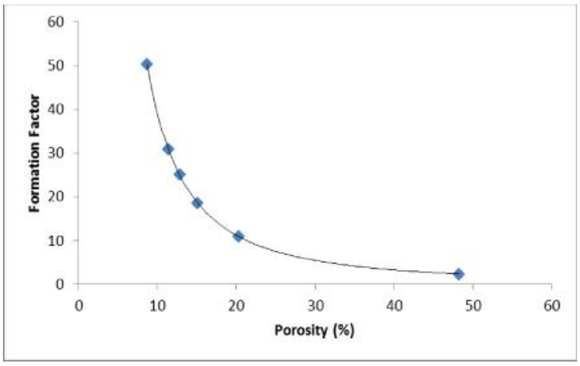


Figure 8: Porosity Against Hydraulic Conductivity of the Aquifer

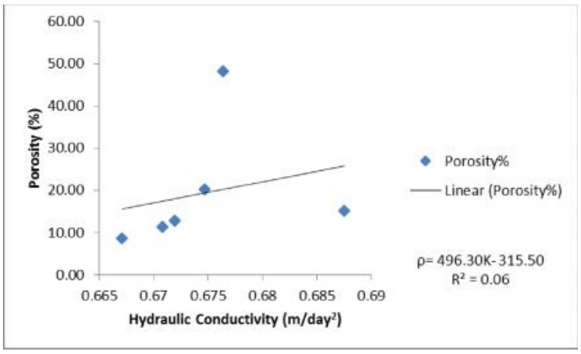


Figure 9: Transverse Resistance Against Transmissivity of the Aquifer

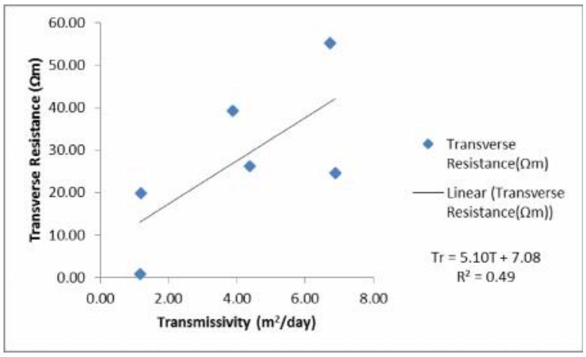
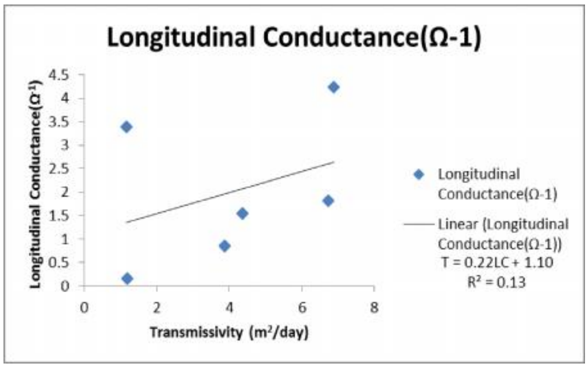


Figure 10: Longitudinal Conductance Against Transmissivity of the Aquifer



shown by the good longitudinal conductance. The low longitudinal conductance across the aquifers in study area indicates that aquifers in the study area is separated by clay intercalations (conductive substratum) characterized with high Formation Factor and hydraulic conductivity.

CONCLUSION

The study area shows the following curve types: HAA, KHKH, KHK and HKH. Groundwater potential of the area is high to moderate; the longitudinal conductance and transverse resistance (hydraulic parameters) were estimated from the geoelectric parameters. The longitudinal conductance shows that the area is vulnerable to contamination due to high permeability in the aquiferous layer, while the transverse resistance indicates high transmissivity and yield occasioned by the presence of impervious clay substratum. Values of Geoelectric and Hydroelectric parameters are presented in Table 1a, 1b and 2 respectively.

The calculated hydraulic conductivity was plotted against aquifer resistivity, where an inverse relationship was obtained between the two variables (Figure 6). The relationship between Porosity and hydraulic conductivity; Transverse Resistance and Transmissivity; Longitudinal Conductance and Transmissivity are all direct relationships as seen in Figures 8, 9 and 10 respectively.

The relationship between Porosity and the Resistivity in the aquifer is given as $\phi = -3.10\rho + 35.10$.

The variation of aquifer water resistivity is directly proportional to that of aquifer bulk resistivity. A decrease of the formation factor is observed with increasing aquifer bulk water resistivity. The range of porosity in the study area (Table 1) revealed the study area as sandstone, the mean value being 19.24%. Hydraulic conductivity increases in a north-south direction as shown on the contour map. The hydraulic conductivity controls the behavior of groundwater flow within an aquifer. It is observed from this study that, increase in resistivity lowers the hydraulic conductivity of the aquifer geomaterials. According to the present study, the relation between hydraulic conductivity and formation resistivity in the study area is generally a non-linear relation.

REFERENCES

1. Alger R P (1966), “Interpretation of Electric Logs in Fresh Water Wells in Unconsolidated Formations”, *Soc of Prof Well Log Analyst Trans*, Art CC, pp. 1-25.
2. Allen D J, Brewerton L J, Coleby L M, Gibb B R, Lewis M A, Mac Donald M A, Wagstaff S A and Williams A T (1997), “The Physical Properties of Major Aquifers in England and Wales”, British Geological Survey Technical Report WD/97/34.
3. Ameen A K (2008), “Aquifer Delineation and Evaluation of Hydraulic Parameters from Surfacial Resistivity Measurements in Sharazoor Basin”, North East Iraq. Ph.D. Thesis, College of Science, University of Baghdad, Iraq.
4. Archie G E (1942), “The Electrical Resistivity Logs as an Aid in Determining Some Reservoir Characteristics”, Transactions of the American Institute of Mineralogical and Metallurgical Engineers, Vol. 146, pp. 54-62.
5. Börner F D, Schopper J R and Weller A (1996), Evaluation of Transport and Storage Properties in the Soil and Ground Water Zone from Induced Polarization Measurements”, *Geophys Prospect*, Vol. 44, pp. 583-601, doi:10.1111/j.1365-2478.1996.tb00167.x.
6. Bear J (1972), “Dynamics of Fluids in Porous Media”, American Elsevier, New York.

7. Chandra S, Ahmed S, Ram A and Dewandel B (2008), "Estimation of Hard Rock Aquifers Hydraulic Conductivity from the Geoelectrical Measurements: A Theoretical Development with Field Application", *J Hydrol,* Vol. 357, pp. 218-227.

8. Chen J, Hubbard S and Rubin Y (2001), "Estimating the Hydraulic Conductivity at the South Oyster Site from Geophysical Tomographic Data Using Bayesian Techniques Based on the Normal Linear Regression Model", *Water Resources Research*, Vol. 37, No. 6, pp. 1603-1613.

9. Edet A E and Okereke C S (1997), "Assessment of Hydrogeological Conditions in Basement Aquifers of the Precambrian Oban Massif South-Eastern Nigeria", *Journal of Applied Geophysics*, Vol. 36, No. 4, pp. 195-204.

10. Heigold P C, Gilkeson R H, Cartwright K and Reed P C (1979), "Aquifer Transmissivity from Surficial Electrical Methods", *Ground Water*, Vol. 17, No. 4, pp. 338-345.

11. Hubbard S S and Rubin Y (2005), "Introduction to Hydrogeophysics", Springer, The Netherlands.

12. Huntley D (1968), "Relation Between Permeability and Electrical Resistivity in Granular Aquifers", *Groundwater*, Vol. 24, pp. 466-474.

13. Jorgensen D G (1989), "Using Geophysical Logs to Estimate Porosity, Water Resistivity and Intrinsic Permeability", US Geological Survey Water-Supply Paper 2321.

14. Kelly W E (1977), "Geoelectric Sounding for Estimating Aquifer Hydraulic Conductivity", *Ground Water*, Vol. 16, No. 6, pp. 420-425.

15. Laouini G, Etuk S E and Agbasi O E (2017), "Delineation of Aquifers Using Dar Zarrouk Parameters in Parts of Akwa Ibom, Niger Delta, Nigeria", *J Hydrogeol Hydrol Eng,* Vol. 6, p. 1, doi:10.4172/2325-9647.1000151.

16. Lowrie W (1997), "Fundamentals of Geophysics", Cambridge University Press, New York.

17. Martys N S (1999), "Diffusion in Partially-Saturated Porous Materials", *Mater Struct*, Vol. 32, pp. 555-562, Materiauxet Constructions.

18. Massoud U, Santos F, Khalil M, Taha A and Abbas M (2010), "Estimation of Aquifer Hydraulic Parameters from Surface Geophysical Measurements: A Case Study of the Upper Cretaceous Aquifer, Central Sinai, Egypt", *Hydrogeol J,* Vol. 18, pp. 699-710.

19. Mazac O, Kelly W E and Landa I (1985), "A Hydrogeophysical Model for Relations Between Electrical and Hydraulic Properties of Aquifers", *J Hydrol,* Vol. 79, pp. 1-19.

20. Niwas S and Celik M (2012), "Equation Estimation of Porosity and Hydraulic Conductivity of Ruhrtal Aquifer in Germany Using Near Surface Geophysics", *Journal of Applied Geophysics*, Vol. 84, pp. 77-85.

21. Offodile M E (1976), "A Review of the Geology of the Cretaceous of the Benue Valley", in *Geology of Nigeria*, Kogbe C A (Ed.), pp. 319-330, Elizabethan Publishing Company, Lagos, Nigeria.

22. Olorunfemi M O and Fasuyi S A (1993), "Aquifer Types and the Geoelectric/ Hydrogeologic Characteristics of Part of Central Basement Terrain of Nigeria (Niger

State)", *Journal of Afr. Earth Sciences*, Vol. 16, No. 3, pp. 309-317.

23. Okechukwu E Agbasi and Sunday E Edet (2016), "Hydro-Geoelectric Study of Aquifer Potential in Parts of Ikot Abasi Local Government Area, Akwa Ibom State, Using Electrical Resistivity Soundings", *International Journal of Geology and Earth Sciences*, Vol. 2, No. 4, pp. 43-54.

24. Orellana E and Mooney H (1966), "Master Tables and Curves for VES Over Layered Structures", Interciencia, Madrid, Spain.

25. Schimschal U (1981), "The Relationship of Geophysical Measurements to Hydraulic Conductivity at the Brantley Dam Site, New Mexico", *Geoexploration*, Vol. 19, pp. 115-125.

26. Sikandar P, Bakhsh A, Arshad M and Rana T (2010), "The Use of Vertical Electric Sounding Resistivity Method for the Location of Low Salinity Groundwater for Irrigation in Chaj and Rana Doabs", *Environ Earth Sci,* Vol. 60, pp. 1113-1129.

27. Singh K P (2005), "Nonlinear Estimation of Aquifer Parameters from Surficial Resistivity Measurements", *Hydrology and Earth System Sciences Discussions,* Vol. 2, pp. 917-993.

28. Todd D K (2004), *Groundwater Hydrology,* 2nd Edition, John Wiley and Sons, New York.

29. Urish D W (1981), "Electrical Resistivity-Hydraulicconductivity Relationships in Glacial Outwashaquifers", *Water Resource Res.,* Vol. 17, No. 5, pp. 1401-1408.

30. Vinegar H J and Waxman M H (1984), "Induced Polarization of Shaly Sands", *Geophysics*, Vol. 49, No. 8, pp. 1267-1287, doi: 10.1190/1.1441755.

31. Waxman M H and Smits L J M (1968), "Electrical Conductivities in Oil Bearing Sands", *Journal of the Society of Petroleum Engineering*, Vol. 8, pp. 107-122.

32. Worthington P F (1975), "Quantitative Geophysical Investigations of Granular Aquifers", *Surv Geophys*, Vol. 2, No. 3, pp. 313-366, doi: 10.1007/BF01447858.

33. Worthington P F (1976), "Hydrogeophysical Equivalence of Water Salinity, Porosity and Matrix Conduction in Arenaceous Aquifers", *Ground Water*, Vol. 14, No. 4, pp. 224-232, doi: 10.1111/j.1745-6584.1976.tb03107.x.

International Journal of Geology and Earth Sciences
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: info.ijges@gmail.com or editor@ijges.com
Website: www.ijges.com