Integrated Geophysical and Petrophysical Characterization of the Coastal Plain Sands: A Case Study from Upenekang, Akwa Ibom State

[1]CHINAKA A.I, [2]ONWUEGBUCHULAM C.O, [3]EZEBUNANWA A.C, [4]MBAGWU E.C, [5]NWUGHA V.N
[12345]Mathematics
[1]Physics Department, [3]Department of Management, [4]Department of Earth, Energy and Environment
[1]Alvan Ikoku Federal University of Education Owerri, Imo State Nigeria

***Abstract*—This study presents an integrated subsurface evaluation of a borehole located in Upenekang, Ibeno (Akwa Ibom State), utilizing a combination of Vertical Electrical Sounding (VES) and downhole geophysical logging to characterize the subsurface of Upenekang, Ibeno.The primary objective was to delineate the local lithostratigraphy and evaluate the petrophysical potential of the target aquifers within the Coastal Plain Sands.The lithological sequence reveals a transition from superficial clays to prolific sand aquifers extending from approximately 35 m to 90 m. Correlation with the spontaneous potential (SP) and resistivity logs confirmed this interval as a clean, permeable formation characterized by significant positive resistivity separation, indicating high permeability and active fluid invasion. Resistivity data at depth greater than 200m suggest a vulnerability to saltwater intrusion, while geotechnical analysis of the overburden identifies potential settlement risks in upper clay units. Petrophysical modeling using Archie's Law yielded estimated porosities ranging from 30% to 42% within the primary sand unit. A Pickett Plot analysis demonstrated that the data points align closely with the 100% water saturation line, suggesting a high-quality, freshwater-saturated reservoir. These findings confirm the depth interval of 35–90 m as the most viable target for high-yield groundwater abstraction, with a secondary, lower-permeability aquifer identified in the silty sand units below 118 m. Also, study reveals one of the weaknesses of VES known as principle of suppression. This integrated approach validates the accuracy of surface geoelectrical models against direct borehole measurements.**

***Index Terms*—ibeno, upenakang, VES, geotechnical**

I. Introduction

The coastal aquifers of the Niger Delta, particularly in Akwa Ibom State, serve as the primary source of potable water. However, these systems face dual threats: anthropogenic pollution and saltwater intrusion (Etie et al., 2021). Borehole geophysics plays a critical role in evaluating groundwater resources, delineating aquifers, and assessing water quality prior to well completion (Díaz-Curiel et al., 2022). Among the traditional wireline geophysical techniques, Spontaneous Potential (SP) and Resistivity logging remain foundational tools in hydrogeological investigations (Keys, 1988). Initially developed and heavily optimized for the petroleum sector, these electrical logging methods have been adapted to fresh-groundwater environments to provide continuous, in-situ profiles of subsurface formations intersected by a open borehole (Keys, 1988). Together, SP and resistivity logs offer a complementary approach to understanding subsurface geology, identifying permeable water-bearing zones, and evaluating the chemical properties of groundwater.

Vertical electrical sounding (VES) has been proved very effective for water content estimation, water quality assessment, evaluation of aquifer properties, geo-electric parameters and mapping of the depth to water table (Hubbard and Rubin, 2005). Eluwole and Oladimeji (2013) did a hydrogeophysical evaluation of the groundwater potential of the Afe Babalola University,Ado Ekiti, Southwestern Nigeria using electrical resisitivity method. Nwosu and Nwosu (2017) discussed the groundwater exploration for sustainable water supply development in the rural communities of Imo state in the Imo River basin, Nigeria. Ezebunanwa etal 2020 used it to delineate the suitability of utughugwu for dam construction Nwugha etal 2025 used it to detect marl deposits at Ibii community, Ezebunanwa etal 2021 used it to delineate dolerite intrusive at Achara Uturu. This study utilizes geoelectric sections and borehole logs from Upenekang (4° 34.473'N, 7° 58.574'E) to model the hydrogeological framework and assess the geotechnical integrity of the subsurface. Its objectives include a) To determine the depth to aquifers b) to delineate fresh water zone from saltwater c) to compare both geophysical method d) to show the weaknesses that occurs from using surface and subsurface methods.

II. GEOLOGY OF THE AREA

Upenakang Ibeno falls within the Benin Formation which is the youngest formation (Miocene-Recent) in the Imo River Basin. The Formation occupies the middle to lower region and directly overlies more than half of the Basin. The Benin Formation is made up of very friable sands with minor intercalations of clays. It is mostly coarse-grained, pebbly poorly sorted and contains pods and lenses of fine-grained sands, sandy-clays and clays (Whiteman,1982; Uma and Egboka, 1985). The formation is in part cross-stratified and the fore set beds alternate between coarse and fine-grained sands. Petrographic study on several thin sections (Onyeagocha, 1980) show that quartz makes up more than 95% of all grains but Asseez (1976) and Avbovbo (1978) indicated a possible presence of more percentage to other skeletal materials including feldspar. The dominance of sandy horizon in the Benin Formation is also indicated by the logs of boreholes drilled through the formation. The strata logs of more than 85% of the over 400 water wells examined indicated sand horizons of more than 90% with sandy clays making up the rest. The Benin Formation and the other formations are covered (at their exposed areas) to varied depths by red acid sandy soils and mangrove soils.

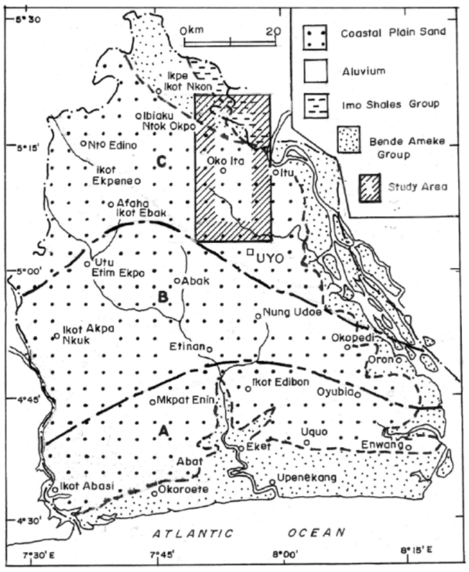


Figure 1 :Geology map of Akwaibom State

III. Methodology

The data was acquired using two primary geophysical methods:

1. Vertical Electrical Sounding (VES): Interpreted to produce a 1D geoelectric section.
2. Borehole Logging: Spontaneous Potential (SP) and Resistivity (2.5" and 10") measurements were captured to a depth of 260m

The integration of these methods allows for the "blind" interpretation of VES to be calibrated against the high-resolution "truth" of the borehole log (George et al., 2015).The Schlumberger array of the vertical electrical sounding technique was employed at maximum current electrode spacing of AB/2 of 400m for the location, Mohammed I. N., et al (2008). The theories of are well explained in standard texts such as Telford et al, (1976); Griffiths and King (1983), Dobrin M.S. and Savit (1988). Electrical resistivity data were acquired using the Vertical Electrical Sounding technique with the Schlumberger electrode configuration. The instruments employed for the data acquisition include: ABEM Terrameter SAS1000 resistivity metre, Etrex GPS, and Compass. An ABEM Terrameter (SAS) 300B with a liquid crystal digital read-out and automatic signal averaging microprocessors was used for logging exercise. The Terrameter System consists of a basic unit called the terrameter SAS Log 200. SAS stands for Signal Averaging System a method whereby consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is presented automatically on the display. This continues until the operator is satisfied with stability of the result. SAS results are more reliable than those obtained using Single-Shot Systems. The SAS Log 200 has capabilities for measuring spontaneous potential (SP), Resistivity (Short Normal 16”, Long Normal 64”, long Lateral 18’). Temperature and fluid resistivity of a hole.

IV. RESULTS PRESENTATION

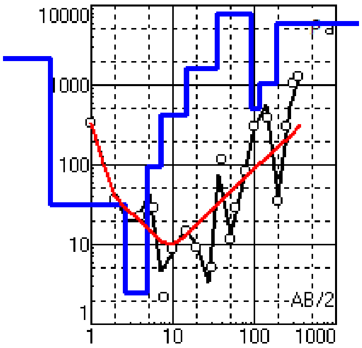
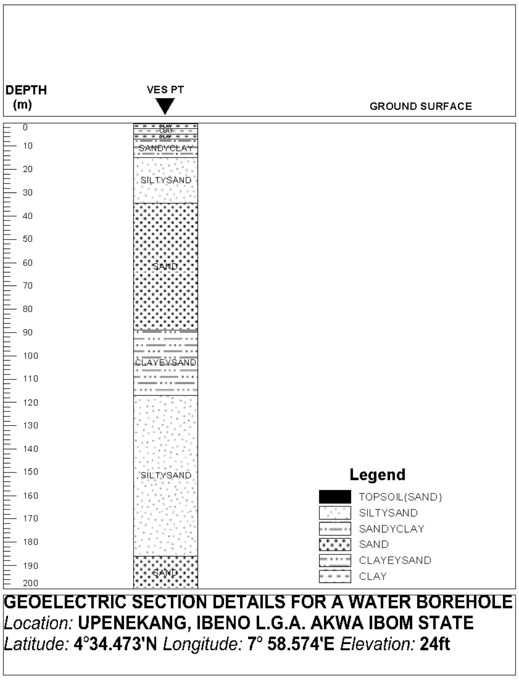


FIG 2 Model Curve

VES1 :4º34.473′ N, 7º58.574 ′E.*(24ft*)				
layer	resistivityℓ(Ω)	depth (m)	Thickness (m)	Lithology
1	2139	0.319	0.319	Top soil
2	32	2.58	2.26	clay
3	2.43	4.95	2.37	clay
4	96.4	7.06	2.12	clay
5	412	14.9	7.79	Sandy clay
6	1645	34.4	19.6	Silty sands
7	7733	89	54.6	sands
8	511	117	28	Clayey sand
9	1060	186	69	Silty sands
10	5826			sands

Fig 3 Geoelectric Lithology table



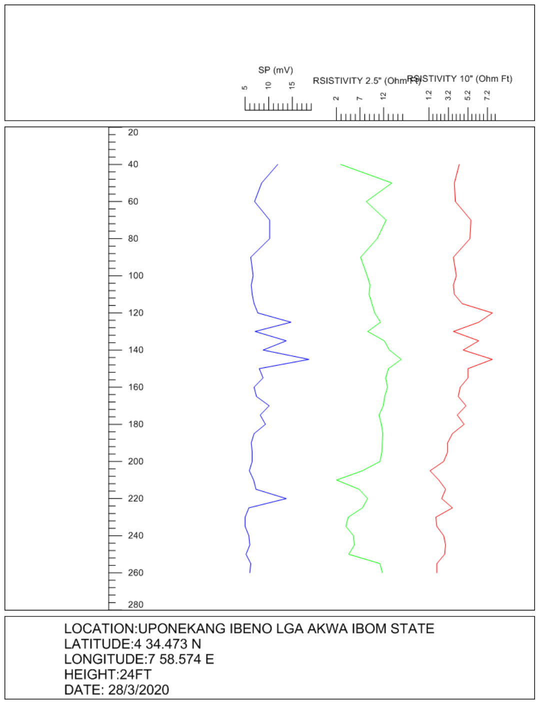


Fig 4

GEOELCTRIC SECTION

fig 5 SP and RESISTIVITY LOGS

Resistivity Trend	**Depth Range (m)**	**Character**	**Significance**
High (< 2000 ohm metre)	0 - 0.34	Dry Topsoil	Overburden/Surface layer/ Dry/Aerated zone
Moderate	0.34 - 4.36	High Clay Content	**Incompetent** rocks Poor for foundations; good for protection and Aquitard (Poor yield)
Stable High	24.9 – 90m	Sands / Silty Sands	**Primary Aquifer Target zone**
Very Low (<10 ohmmetre)	>150m	Silty Sand	Secondary Aquifer (Silt risk) and Saline Intrusion Zone

Table 1 Aquifer table interpretation

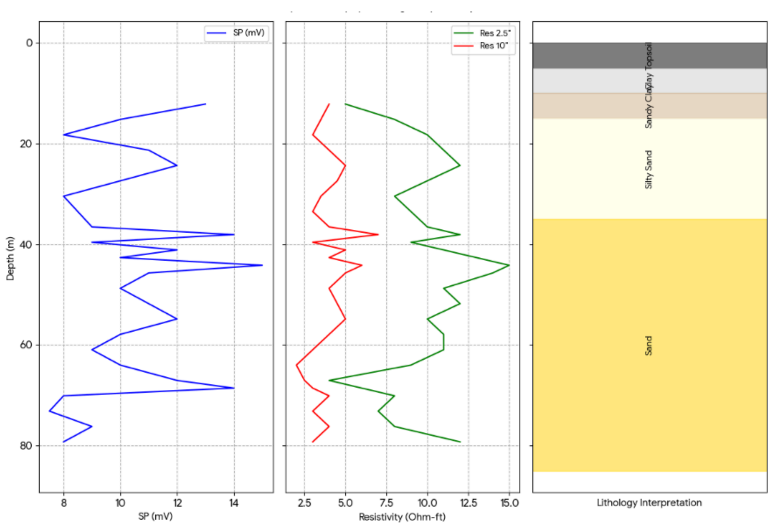


Fig 1

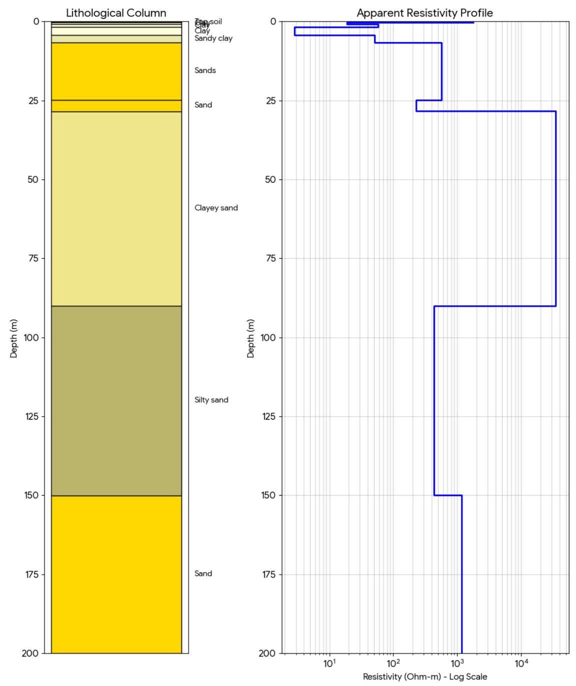


Fig 2

Fig 3

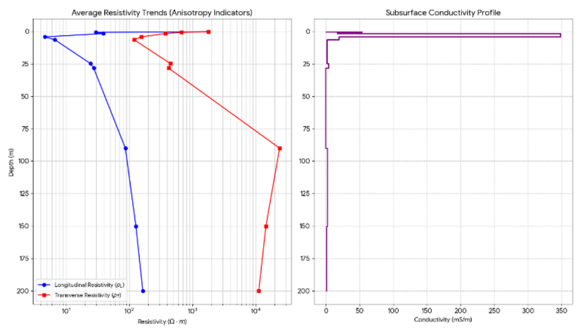
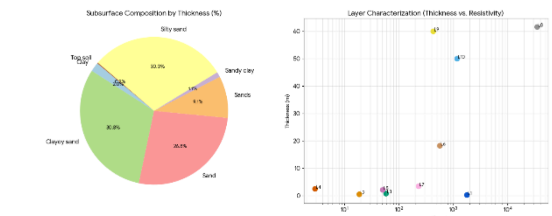


Fig 4



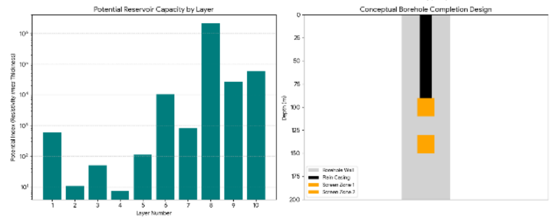
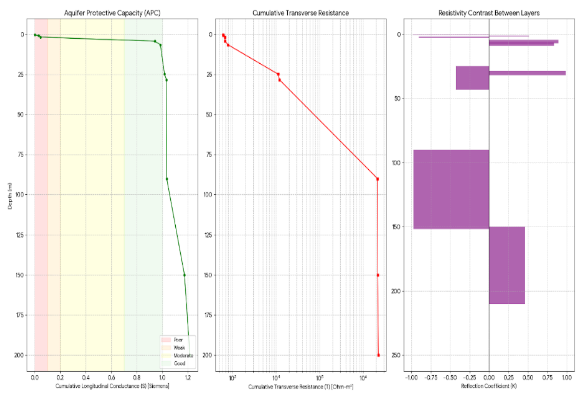


Fig5



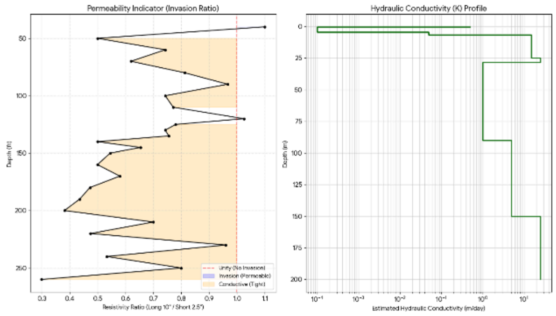


Fig 6

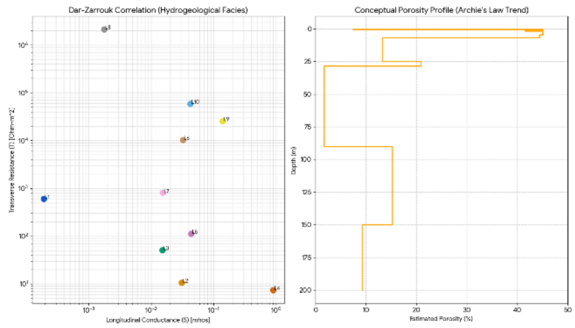


Fig7

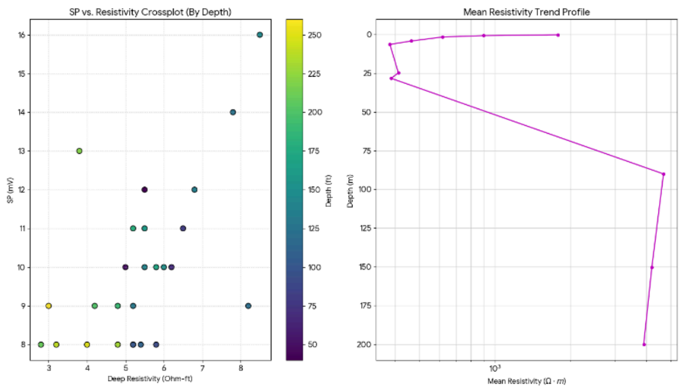


Fig8

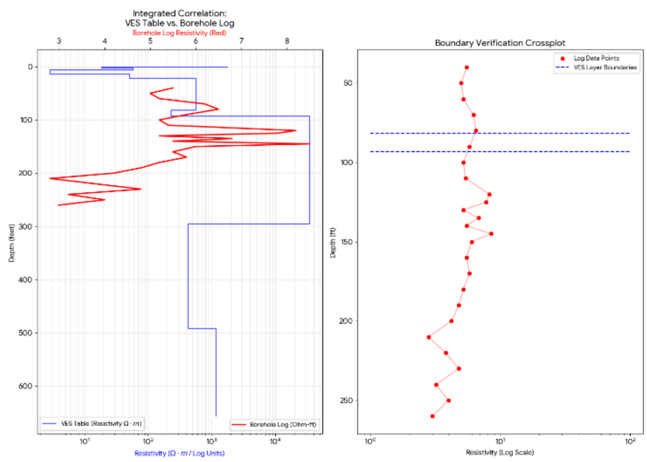


Fig9

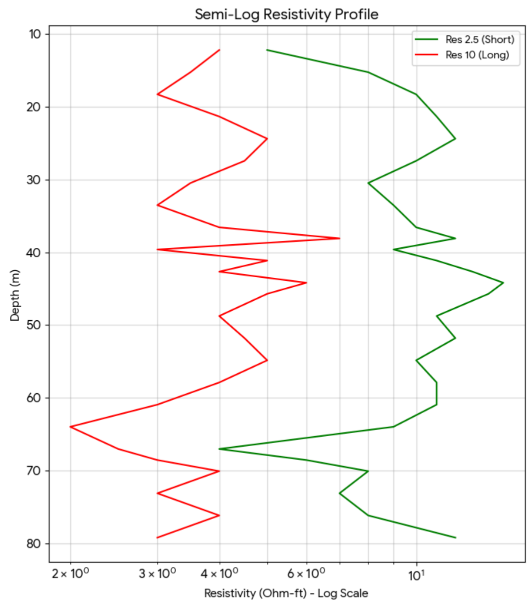


Fig10

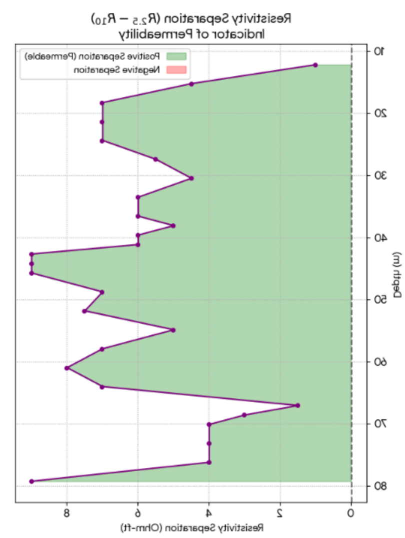


Fig11

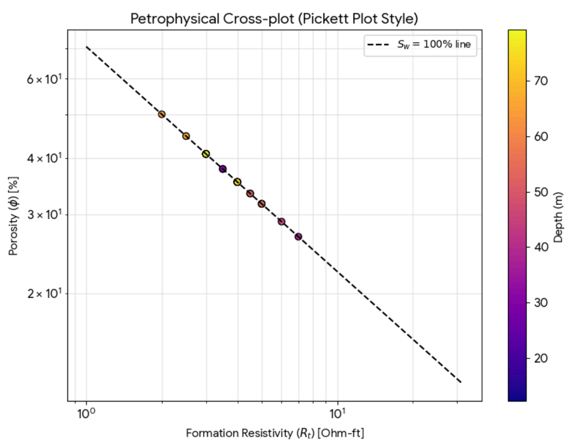


Fig12

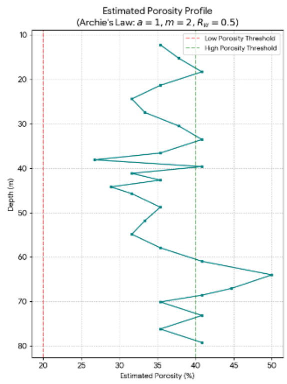


Fig13

V. DISCUSSION

From the results a number of facts came out

A) Topography is Low with elevation of 24ft, typical of coastal regions

B) Hydrogeological Characterization & Groundwater Potential: is the study of "science of water" within the earth. with view to determine which subsurface layer provides the best yield and highest quality of water. In Ibeno, finding clean water is often a challenge due to the complex layering of sediments. subsurface profile reveals a complex 10-layer geoelectric sequence and shows a transition from high-resistivity topsoil through a thick clayey section into a series of sandy units that likely host the local aquifer system. The subsurface can be divided into three main zones:
*Surface Zone (Layer 1): A high-resistivity topsoil (1781 Ωm) which is very thin (0.34m). This suggests dry, possibly lateritic or sandy surface conditions.

*Clay/Aquitard Zone (Layers 2–4): There is a significant drop in resistivity (18.7 Ωm to 2.87 Ωm) between 0.34m and 4.36m depth. This indicates a saturated clay sequence which acts as a "seal" or aquitard, preventing surface contaminants from easily reaching deeper layers.

*Transition & Aquifer Zone (Layers 5–10): Starting from about 6.59m, the resistivity begins to rise, signaling a change from clay to sandier materials hence Potential Aquifer Layers 6 through 10 represent the primary interest for water exploration. The resistivity values (229 Ωm to 1174 Ωm) are typical for freshwater-bearing sands. The most promising water-bearing zones begin at 24.9 meters (Layer 6) and continue down past 150 meters. The resistivity values for the sands (229–1174 Ωm) suggest the groundwater is likely fresh. Extremely low resistivity (<10 Ωm) would have suggested salt-water intrusion or heavy mineralization, which is not present in the deep layers here. The thickness of the sand and silty sand layers (totaling over 120m) indicates a high storage capacity, suggesting this location has good potential for a productive borehole.the presence of "silt" might mean lower permeability compared to the upper sand. The higher silt content suggested by the SP curve fluctuations indicates lower hydraulic conductivity compared to the upper sand. The primary aquifer should be the target. Also delineating between porous sands and impermeable clays, helps in designing the borehole screen placement.

C) Saltwater Intrusion: Because Ibeno is a coastal region, the most significant threat to water is the ocean. Hence "Saline Intrusion." This helps us to know if the salt from the Atlantic Ocean has reached the groundwater at Upenekang community and to establish "fresh-saltwater interface." This is achieved from Resistivity Interpretation in the wellog. Saltwater is highly conductive, meaning it has very low resistivity. If the resistivity drops significantly as you go deeper into the sand layers, it strongly suggests saltwater or brackish water contamination and vice versa. looking at the resistivity curves (the green and red lines) there is significant increase with depth. This means fresh water without saline intrusion. In coastal regions like

Ibeno, resistivity values are the primary indicators of salinity. If found, these extremely low resistivity values at depth are indicative of brackish or saline water saturation (Uwidia et al., 2018).

D) Coastal Aquifer Vulnerability: Aquifers of Upenekang ibeno is vulnerable due to the following factors.

*Agricultural Runoff: This is rural area farming is the major occupation.The increased use of chemical fertilizers, herbicides, and pesticides in agricultural areas is a significant contributor to groundwater contamination.
*Oil Spills and Industrialization: As a major oil-producing state, numerous oil spills from production and pipelines lead to contamination of the aquifers.
*Shallow Water Table: Shallow aquifers are prevalent, especially in the coastal regions, making them highly sensitive to contaminants from surface-level activities.
*Low-Slope Terrain: Generally low-slope terrain promotes waterlogging and infiltration, which increases the speed at which contaminants move into the groundwater.
*Coastal Saltwater Intrusion: The coastal region faces high risks of salinization of shallow freshwater aquifers due to tides and sea-level rise, particularly where groundwater has been over-abstracted.
*Weak Overburden Protective Capacity: Many aquifers in the region are covered by highly permeable materials (sand, gravel) with little to no clay or lateritic layers to protect them. This allows rapid infiltration of contaminants from the surface into the groundwater.

E) Geotechnical Assessment for Coastal Engineering

*Foundation Stability/Depth

The ground's stability for carrying civil structures can be establish with Objective to evaluate the load-bearing capacity and corrosivity of the soil.The first 5m is marked by the presence of a thick clay sequence (Layers 2, 3, and 4) is critical for construction. Clay is prone to swelling and shrinking; any heavy structure would likely require deep piling or specialized foundation design to bypass these incompetent layers and reach the more competent sands below. Because these layers exhibit low bearing capacity and high compressibility.They are also "plastic" materials that can shrink or swell and show contraction and expansion of clay(known as rheological property of clay) that causes cracks in the walls of buildings. The geo-technical implication of the presence of clay especially at VES results is unstable foundation of structures. Hence silt and sands are better. In the study area civil structures should be erected on more stable Silty Sand layers. For heavy coastal infrastructure, the geoelectric section suggests that pile foundations should bypass these clayey units and be seated in the denser Silty Sand layer starting at 22m.

*Soil Corrosivity: Using the Resistivity 10" (red curve), how "corrosive" the soil can be established. Soils with low resistivity are generally considered highly corrosive to buried steel pipes. This is vital for the oil and gas infrastructure which is common in Akwa Ibom.The very low resistivity in Layer 4 (2.87 Ωm) indicates a highly corrosive environment for buried metallic pipes or reinforced concrete.

F) Comparative Analysis

From Surface Geophysics (VES) and "Downhole Geophysics" (Borehole Logging). Fig 3 is an "interpretation" (what we think is there), while fig 5is "observed data" (what the tools actually felt). A comparison between the Geoelectric Section and the SP Log shows high correlation in lithological boundaries. However, the Borehole Log reveals thin clay intercalations within the 120m–180m Silty Sand unit that were "suppressed" in the VES interpretation. This highlights the Principle of Suppression one of the problems in surface geophysics (Okiongbo & Odubo, 2012). Sometimes thin layers (like the Clay at 100m) are missed by surface equipment but caught by borehole logs.

VI. Conclusion

The study confirms that while prolific sand aquifers exist at 40m–90m, the deep subsurface (below 200m) shows significant signs of saline contamination. It is recommended that water abstraction be limited to the upper sand unit, and that corrosion-resistant materials be used for all subsurface installations due to low soil resistivity.

References

[1] Díaz-Curiel, J., Miguel, M. J., Biosca, B., & Arévalo-Lomas, L. (2022). Using SP logs to estimate the water quality of borehole layers in the Duero basin (Iberian Peninsula). Hydrological Sciences Journal, 67(9), 925–938. https://doi.org/10.1080/02626667.2022.2050731 Cited by: 1

[2] Keys, W. S. (1988). Borehole geophysics applied to ground-water investigations. Open-File Report. https://doi.org/10.3133/ofr87539 Cited by: 333

[3] Etie, P., et al. (2021). *Hydrogeochemical evaluation of coastal aquifers in the Niger Delta.* Journal of African Earth Sciences.

[4] George, N. J., et al. (2015). *Estimation of hydraulic resistance and conductivity of alluvial aquifers.* Geophysics and Engineering.

[5] Okiongbo, K. S., & Odubo, J. (2012). *Optimization of geoelectric sounding for groundwater exploration in the Niger Delta.* Journal of Geology and Mining Research.

[6] Uwidia, I. E., et al. (2018). *Assessment of saltwater intrusion in coastal Akwa Ibom.* International Journal of Environmental Science.

[7] Ugada, U., Opara, A.I., Emberga, T.T., Ibim, D.F., Omenikoro, A.I., and Womuru, E.N., (2013): , Delineation of Shallow Aquifers of Umuahia and Environs, Imo River Basin, Nigeria, Using Geo-Sounding Data; Journal of Water Resource and Protection, 2013, 5, 1097-1109, http://dx.doi.org/10.4236/jwarp.2013.511115.

[8] Uma, K.O. and Egboka B.C.E. (1985). Water Resources of Owerri and its Environs, Imo state. Nigerian Journal of Mining and Geology 22: 57-64

[9] Uma, K.O., and Egboka, B.C.E., (1985): Groundwater Potentials of Owerri and its Environs: Nigerian Journal of Mining and Geology Vol. 22 pp57-64.

[10] Teikeu, W.A.,Njandjock , P.N.,Bisso, D.,Atangana, Q.Y.,andNlomgan, J. S.(2012), ,Hydrogeophysical Parameters Estimation for Aquifer Characterisation in Hard Rock Environment: A Case Study from Yaounde, Cameroon. *Journal of Water Resource and Protection*, 2012, 4, 944-953 http://dx.doi.org/10.4236/jwarp.2012.411110 Published Online November 2012 (http://www.SciRP.org/journal/jwarp)

[11] Obiajulu, O.O., Okpoko, E.I. and Mgbemena, C.O. (2016) Application of Vertical Electrical Sounding to estimate Aquifer Characteristics of Ihiala and its environs, Anambra State, Nigeria. ARPN Journal of Earth Science. ISSN 2305-493x vol5 No 1 June 2016.

[12] Onyeagocha, A.C, (1980): Petrography and Depositional Environment of the Benin Formation, Journal of Mining and Geology 17(2), 147-151

[13] Nwosu, L.I. and Nwosu, B.O. (2017). Groundwater Exploration for Sustainable Water Supply Development in the Rural Communities of Imo State in the Imo River Basin, Nigeria. Volume - 7 , Issue - 1 January – 2017. ISSN - 2249-555X .

[14] Nwosu , L. I., Ekine, A. S., and Nwankwo , C. N. (2013). Evaluation of Groundwater Potential from Pumping Test Analysis and Vertical Electrical Sounding Results: Case Study of Okigwe District of Imo State Nigeria. The Pacific Journal of Science and Technology. Volume 14. Number 1. May 2013 (Spring)

[15] Ezebunanwa A.C. Nwugha V.N., K.C. Emeghara and G.C Ibe.(2020): Geological and Geoelectrical Investigation of a proposed dam site using vertical electrical sounding of Osuworowo stream, Utughugwu Arochukwu, Southeastern Nigeria. JGEESI

[16] Ezebunanwa A.C., Ikoro D.O, Nwugha V.N, Eke B.O Onuoha E.C (2021): Geophysical investigation of intrusive Achara Nzerem Uturu southeastern Nigeria.
[17] Nwugha V.N. Ezebunanwa A.C. Onwuegbuchulam C.O, Mbagwu E.C, Chinaka A.I, Emeghara K.C(2025):Geophysical investigation for marl exploration using VES in Akpokponke ibii southeast Nigeria.
[18] Eluwole, B.A. and Oladimeji, L.A. (2013) .Hydrogeophysical Evaluation of the Groundwater Potential of AfeBabalola University Ado-Ekiti, Southwestern Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 4(1): 77-83. Scholarlink Research Institute Journals, 2013 (ISSN: 2141-7016) jeteas.scholarlinkresearch.org
[19] Hubbard, S.S. and Rubin, Y. (2005). Introduction to Hydrogeophysics, In Hydrogeophysics. Ed. (Rubin, Y and Hubbard, S.S.). Springer, The Netherlands. Pp. 3 - 21
[20] A. M. J. Whiteman (1982)