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Aquifer Assessment Using Resistivity Survey

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Abstract — Hydrological estimates were derived from Geophysical Parameters in order to ascertain the proficiency of the Aquifers within the Study Area. Schlumberger surveys were carried out with Electrode Spread (AB=400m) with resultant AK Model Curve . Dar Zarrouk parameters were extracted from the geoelectric data, and converted to relevant hydrological properties. The study reveals high prolific aquiferrous zones with Resisitivity values > 1000ohm-m and Modelled Transmissivity values of 2125m²/day, which can be describes as Class I Magnitude. Also, Calculated Longitudinal Conductance shows value of less than 0.1, depicting that the aquifer will be vulnerable to contamination.

Keywords — Transmissivity, hydraulic Conductivity Aquifer, Dar Zarrouk, Niger Delta, Resistivity, Hydrology.

I. Introduction

The effect of saline water intrusion in coastal plain areas has drastically degrade the quality of underground water in terms its Consumption Usage . Hence, Geophysical Survey of the subsurface rock materials are usually carried out to determine the Water bearing potentials of the proposed site, to assess the viability of the project in the given site by acquiring Hydrogeological information necessary for a productive borehole construction/installation. Some of the vital information to be obtained from the survey also includes, viability of the project at the chosen site, estimated drill depth, type of Geological formations (subsurface materials) to be encountered and Saline Water - Fresh Water interface.

Estimates of relevant hydrological properties, Transmissivity and hydraulic Conductivity are derived from the Geophysical parameters. Thus, enhancing the chances for locating zones of high quality water saturated layers (aquifer). Adequate knowledge of these Hydrological properties is essential for proper design and construction of the water borehole. Resistivity measurements were performed at the following predetermined locations at Etche, Rivers State.

II. Site Description and Hydrogeology.

The Site is Situated in Port Harcourt., which is geographically located between latitude 4°45'22.5108" and longitude E7°02'9.5208" Port Harcourt in the Niger Delta region of Nigeria (Figure1). Port Harcourt is located by the Bonny River about 64km from the sea. The climate of the area is tropicalmarked by two distinct seasons, which are rainy and dry seasons. The rainy season starts from March to October while the dry season begins from November to February. (G. I. Alaminiokuma and T. Warmate, 2020)

Geologically, the site is underlain by the Coastal Plain sands, which in this area is overlain by soft-firm silty clay sediments belonging to the Pleistocenic Formation. The general geology of the area essentially reflects the influence of movements of rivers, in the Niger delta. In broad terms, the area may be considered Dry flat Country. (short and Stauble, 1967). The Niger Delta consists of three distinct Lithological Formation , the Akata formation , Agbada formation and the Benin formation. The Akata Formation consist of Marine shale . The Agbada formation consists of alternate Layers of Sand Stone and Shale. The Benin formation consists of sands, clay , Peat and some Granular materials. The Coastal Plain slopes gradually from an elevation of 240m to 15m above mean sea level and is largely caused by rain forest. The aquifer has a south west gradient towards the Delta and is thickened seawards in the same direction of ground water movement. The Study area is situated in the Coastal Plain region, quaternary in Age. The Zone is made of Coarse to Medium sand, with Silty and Clay Lenses. Within the Project area , groundwater is abstracted from the Benin formation , mainly in its upper section. (<300m).The aquifer at shallow depth(>10m) are unconfined while the deeper aquifers are confined and isolated from the ground surface and the natural recharge comes Northern high Coastal Plain..

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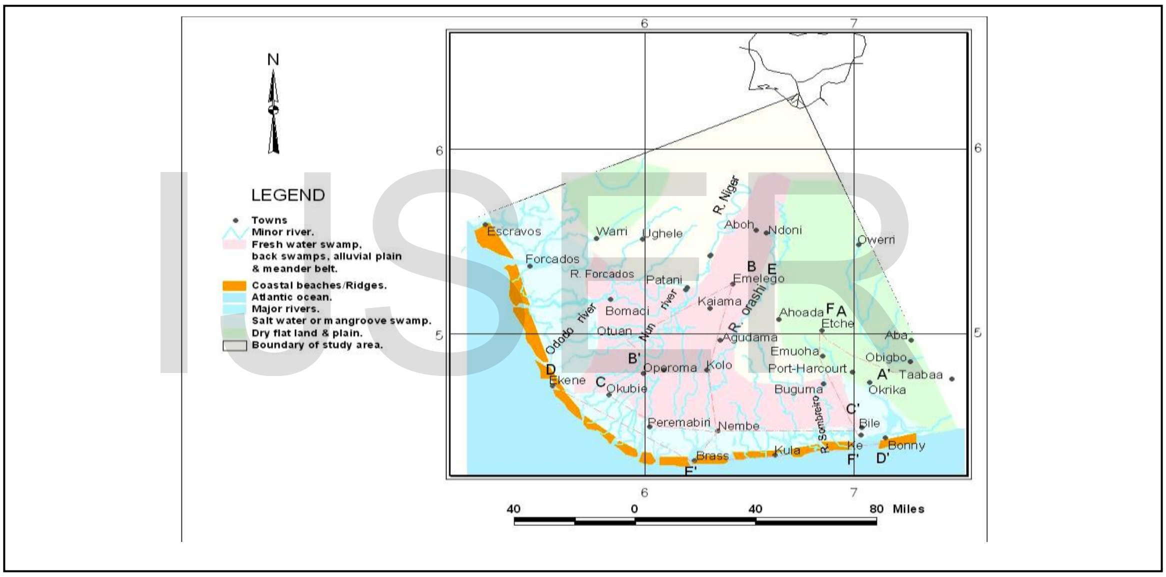
The Upper unconfined aquifer varies from 15m to nearly 100m . the middle semi confined aquifer consists of medium to coarse grained sands with clay lenses and fine clayey sands(100m-200m). The Lower Aquifer extends from 200m - 300m

The study area, depicts an annual rainfall of 2500mm, while the average specific yield of the aquifer in these areas is 10,500liter/hr/m and the Transmissivity is >100m²/day (offodile, 2013). Okiongbo, et al (2012), stated Transmissivity values range, from 1634.0 m²/day to 5292.0 m²/day within yenagoa, part of Niger Delta. These values are typical of an unconsolidated fine-medium-coarse sand.



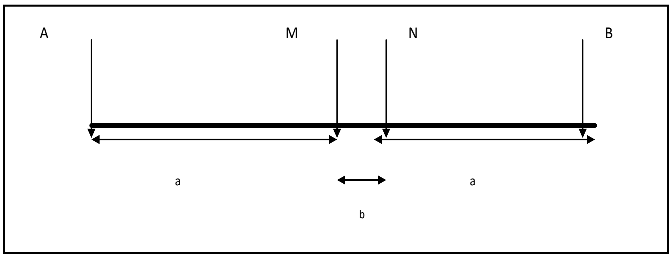


Fig 2. Schlumberger Array Configuration

3.0 LITERATURE /METHODS

The geophysical method applied in this survey, is the resistivity method, which measures the apparent resistivity of the subsurface, including effects of any or all of the following: soil type, bedrock fractures, contaminants and ground water. Variations in electrical resistivity may indicate changes in composition, layer thickness or contaminant levels.

Soil electrical resistivity indicates the relative capacity of the soil to carry electrical current and is a main indicator in determining the permeability of the soil thereby predicting its water bearing capacity. It is therefore the most important parameters taken into account in groundwater Survey.

3.1 BASIC PRINCIPLES OF RESISTIVITY (DC) METHOD:

Resistivity is measured by passing a current of known value in the ground by means of two electrodes (A, B) and measuring potential difference between two intermediate points in the ground using another two electrodes (M, N). As the electrode spread (A, B) increases, depth of probe increases, thereby, giving a vertical electrical sounding, VES.

The equivalent soil resistivity, ρa, is calculated using the relevant formula (derive from ohms law):

$$\rho a = \frac{\pi \Delta V}{4.I.MN}(AB - MN)(AB + MN)$$

Where, ΔV = voltage
I = current
ρa=apparent resistivity

An aquifer can be characterized by its Transmissivity, its quantitative expression of the productivity of an aquifer and Coefficient of Storage, which determines its storage capacity (Offodile, 2013). The combination of thickness and resistivity into single, variables otherwise known as Dar Zarrouk parameters can be used as a basis for the evaluation of aquifer properties (Niwas and Singhal, 1981).The Dar Zarrouk parameters consists of the Transverse Resistance (R_T) and Longitudinal Conductance (Lc). For a horizontal, homogeneous, and isotropic layer, the Transverse Resistance R_T (Ωm^2) is defined as:

$$R_T = \rho h \quad (1)$$

and the Longitudinal Conductance Lc (mho) is defined as:

$$L_C = h/\rho \quad (2)$$

where h is the thickness of the layer (in metres) and ρ is the electrical resistivity of the layer in ohm-metres. But aquifer Transmissivity (T) is expressed as:

$$T = kh \quad (3)$$

where k is the Hydraulic Conductivity (m/day). These relationship helps us infer the Transmissivity and Coefficient of Storage. Ioannis et al, proposed the following equation for k

$$k(10^{-4}m/s) = 2.12f - 1.59 \quad (4)$$

Values of f, formation factor, which is dependent on the aquifer, (Raghunath, 2007) can be deduced from wyllie's relations , based on porosity value of 19.3 and cementation factor of 3 within the study area (Alaminokuoma, *et al*, 2015). Amos-Uhegbu, *et al*. (20014), stated formation factor, f, of 2.61 within the Benin formation around Amizi area, Southern Nigeria, within depth less than 200m.

Niwas and Singhal (1981), proposed a relationship between Transverse Resistance, R or longitudinal conductance and T

$$T = kR\sigma \quad (5)$$

Where $\sigma = conductivity, R = Transverse\ Resistivity\ and\ K = Hydrualic\ Conductivity$

4.0 RESULTS OF GEOTECHNICAL STUDIES

Raw field data was transferred to computer on completion of Field Work, A forward modelling subroutine was used to calculate the apparent resistivity (ρa) values, and a non-linear least-squares optimisation technique was used for the inversion routine.

TABLE 1. Field Data for Point 1

Table Showing Geolectric Parameters and the Vulnerabilty Class(Henriet, 1975)

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Vulnerability Classes	*Geoelectrical Model Parameters*		*Dar Zarrouk Parameter*
	Resistivity (ohm.m)	*Thickness (meters)*	*Longitudinal Conductance (S) (siemens)*
Very Low	< 10	> 25	> 2.5
Low	10 a 20	25 a 13	0.7 a 2.5
Moderate	20 a 40	13 a 10	0.3 a 0.7
High	40 a 100	10 a 5	0.1 a 0.3
Extreme	100 a 300	< 5	< 0.1

TABLE 2. Field Data for Point 2

AB/2(m)	MN	Resistivity
1	0.6	70.38729
1.5	0.6	47.81592
2	0.6	62.41012
3	0.6	65.46712
5	0.6	69.87421
7	0.6	251.611
7	2	72.7224
10	2	71.03151
15	2	119.5712
15	6	78.78888
20	6	83.89557
25	6	93.48827
30	6	932.58
40	6	233.1345
45	6	158.256
50	6	922.9653
55	6	157.8373
60	6	201.084
70	6	181.7333
80	6	247.5021
90	6	249.8231
90	10	25.3555
100	10	34.45365
120	10	13.54125
120	14	321.8724
150	14	397.7996
200	14	182.7929
200	30	54.12052

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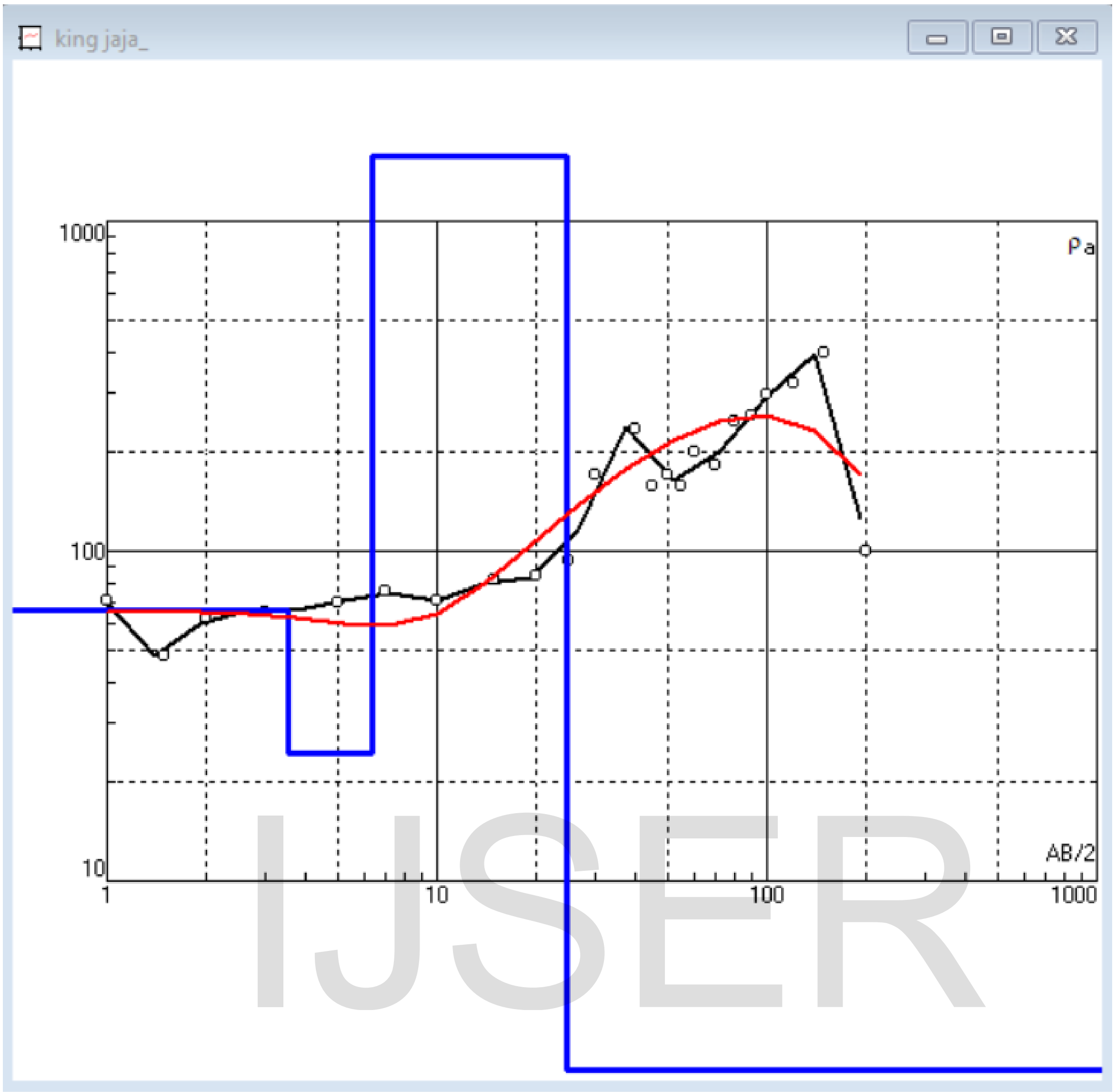

Error = 22.9%

N	1	2	3	4
ρ	65.8	24.3	1564	1.11
h	3.54	2.79	18.5	
d	3.54	6.33	24.8	
Alt	-3.539	-6.326	-24.81	

Fig. 3. Showing Data and Model Curve

TABLE 3. Geolectric Results for Point 1

Layers	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Longitudinal Conductance (Siemens)	Transverse Resistance (ohm-m²)	Lithology
1	65.8	3.54	3.54	0.537	232.9	Clayey
2	24.3	2.79	6.33	0.1148	67.7	Clayey
3	1564	18.5	24.8	0.011	28934	Sandy
4	1.11					Sandy

TABLE 5. Aquifer Properties, Point 1

Aquifer/layer	Resistivity (ohm-m)	Transverse Resistance (ohm-m²)	Hydraulic Conductivity (10^{-4})m/s	Transmissivity (m²/day)
3	1564	28934	**13.3**	**2126**

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5.0 DISCUSSION

The surveys has an AB (C1, C2) =400m with Sounding Depth of > 80m, . The geoelectrical Curves shown in figure 3 is a four layers AK model and are mainly sandy formations . The Curves obtained within this area of study shows little variation, with layer 3 depicting Porous and Permeable characteristics , while Layer 4 can be regarded as a saline aquifer, due to its very low resistivity (1.1ohm-m) . Dar Zarrouk Parameter , Transverse Resistance shows high values, indicative of a thick, prolific aquiferous zone and the absence of clay content. Modelled Transmissivity values of 2125m^2/day for layer 3 characterizes the aquifer within these layers as class I (Jirri, 1993). This indicates that groundwater withdrawal potential will be high and is of regional importance. The fourth Layers with resistivity value of 1.1ohm-m indicates a Saline, Permeable and Porous Aquifer due to salt water intrusion .

Longitudinal Conductance indicates that the Overburden Protective capacity is Poor within the area of study as shown in the table, with values less than 0.1. This implies that the aquifer is vulnerable to contamination. This is as a result of the absence of clay mineral in the formation , which is responsible for high Permeability

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6.0 CONCLUSION

The area is characterized by a thick and prolific aquiferous zone as indicated by Transmissivity values, which shows a Class I type . This is due to the composition of the aquifer zone, which consists of unconsolidated medium to coarse grained sands and gravel. Also the Transmissivity values are consistent with values proposed by other authors within the study area and also reflects the high productivity of groundwater in the study Area.

It is recommended that drill depth should be done within the third layer within depths of 18-24m, due to the saline water intrusion layer below.

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