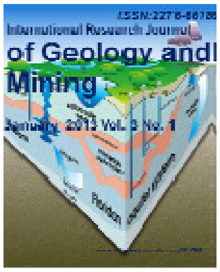

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Full Length Research Paper

Aquifer hydraulics and delineation of groundwater quality zones using electrical resistivity method at Oduma and environs in Enugu State, Southeastern Nigeria

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The electrical resistivity method has been used to characterize the groundwater hydraulics and delineate groundwater quality zones at Oduma and environs in Enugu state, Southeastern Nigeria. Oduma lies within latitudes 6^{o} 02^{l} N to 6^{o} 07^{l} N and longitudes 7^{o} 35^{l} E to 7^{o} 41^{l} E with an area extent of about 102.6sqkm. The area is underlain by Awgu Shale group with its lateral arenaceous facie – Owelli Sandstone outcropping south of Oduma. Thirteen (13) vertical electrical soundings (VES) were carried out within the study area. Interpretated VES data shows predominance of Q and H curve type, indicating a fracture-shale subsurface. Contour maps of iso-resistivity, depth, transverse resistance, longitudinal conductance, aquifer transmissivity and hydraulic conductivity were constructed. Computed Transmissivity values indicate a low yield aquifer.The established empirical relationship between earth resistivity and total dissolved solids (TDS) was used to delineate the fresh, brackish and saline groundwater zones. The various contour maps will serve as a useful guide for groundwater exploration in the study area.

Keywords: Resistivity, transmissivity, hydraulic conductivity, groundwater quality zones.

INTRODUCTION

Oduma lies within latitude 6^{o} 02^{l} N to 6^{o} 07^{l} N and longitudes 7^{o} 35^{l} E to 7^{o} 41^{l} E with an area extent of about 102.6sqkm. It is located in Aninri local government area, Enugu state, southeastern Nigeria. (Figure1). The increasing population within Oduma and neigbouring towns has necessitated the high demand of groundwater development in the area. Unfortunately, groundwater in these areas had proved unsuitable for drinking purposes. Some of the water wells visited during this study tested salty as corrosion and rusting were evident in the risers and at the base of the well heads. In addition to this, abortive wells abound in the study area as some water wells were not functioning. Groundwater quality data largely do not exist in the area. Hence delineating the groundwater quality zones, in addition to aquifer hydraulics characterization, will provide a better picture for groundwater exploration and development at Oduma.

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Physiography

The study area is fairly a lowland topography (Figure 2). Amokwe community is about the highest in the area, with an elevation of 120meters above sea level (ASL). The lowland is indicative of the cultural land use system in the area. As the area is predominately rice farm terrain as a result of stagnant water. The flat topography is also controlled by the subsurface geology of the area.

Geology

The study area falls within the geologic complex called, the Lower Benue Trough. It is underlain by Awgu Shale unit which is coniacian in age, with an arenaceous facies (Owelli Sandstone) development to the south of Oduma (Figure 3). The unit consists of bluish grey, well bedded

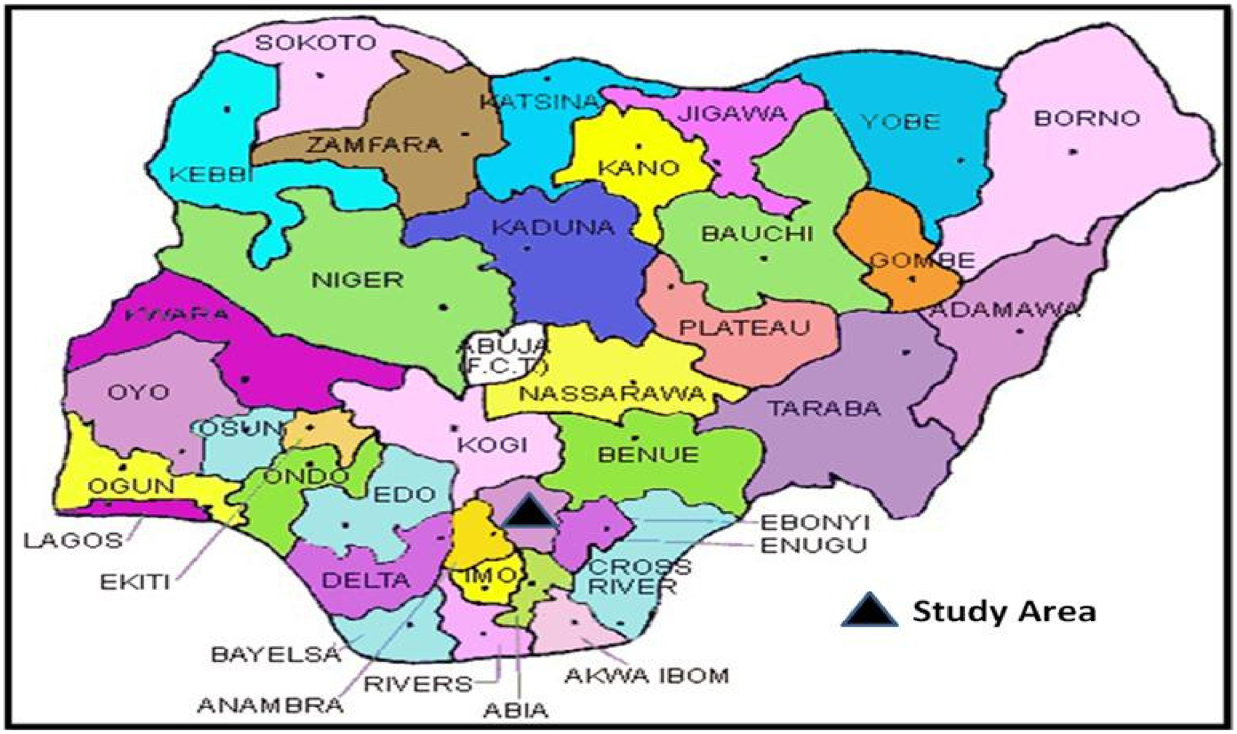

Figure 1. Map of Nigeria showing the study area (World Gazette, 2011).

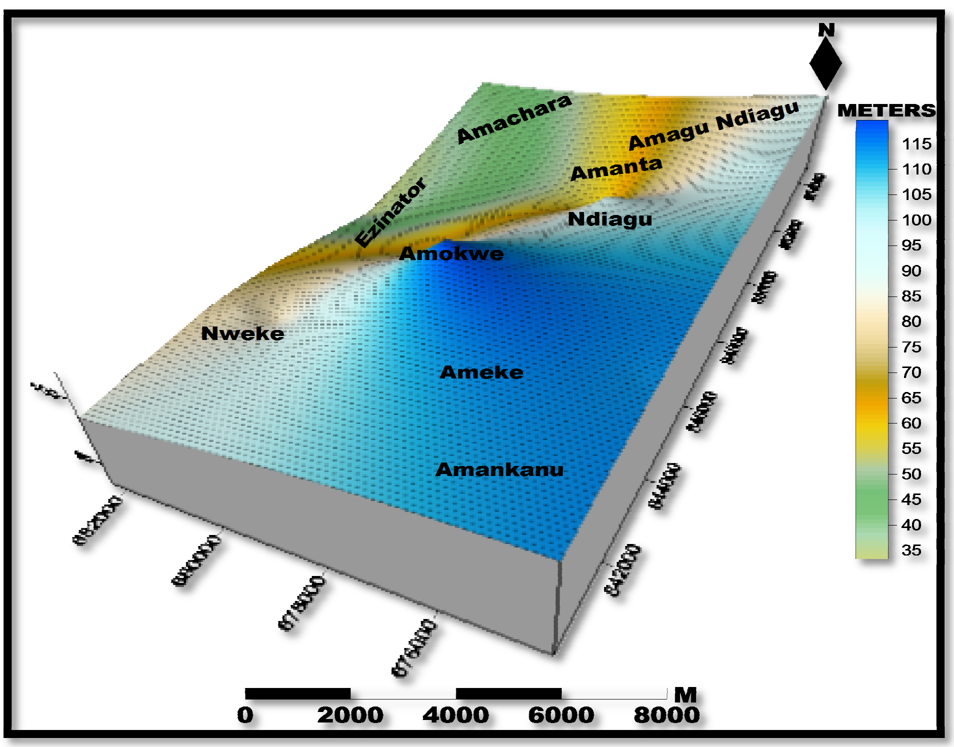

Figure 2. Surface map of the study area.

shales with occasional intercalations of fine-grained, pale yellow, calcareous sandstones and shaly limestones (Reyment, 1965). It is about 900m thick and gently folded.

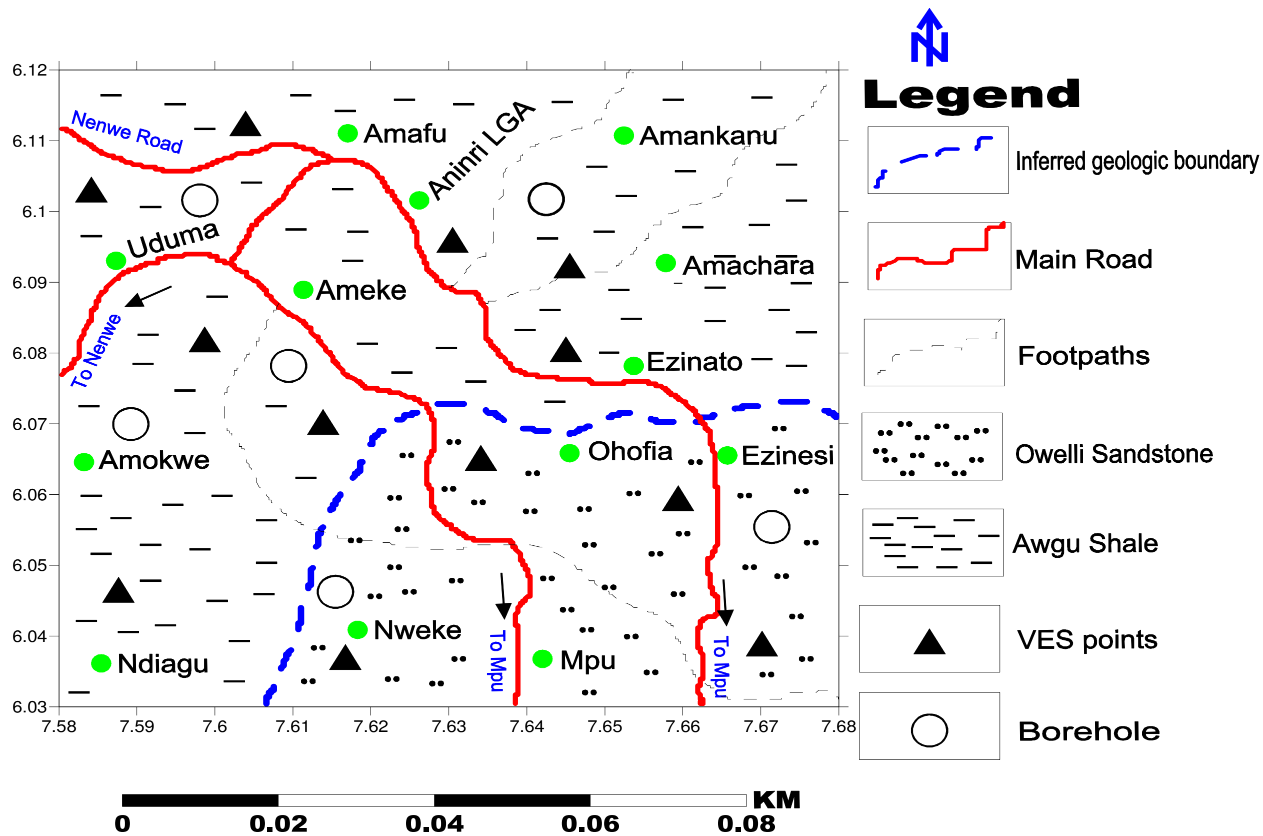

Figure 3. Geologic map of the study area showing VES stations and borehole points

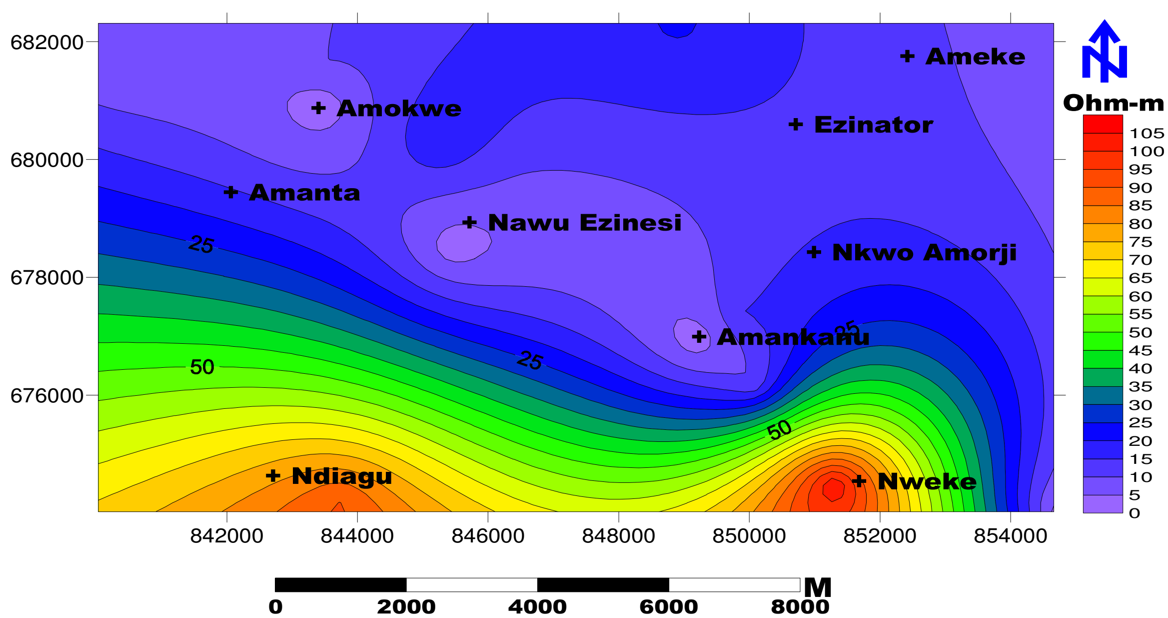

Figure 4. Iso-apparent resistivity map of aquiferous horizon in the study area.

Hydrogeology

The study area falls within the Cross River Basin, which is hydrogeologically a problematic groundwater basin (Offordile, 2002). This is as a result of poor yield and saliferous groundwater. More than 90% of the basin is

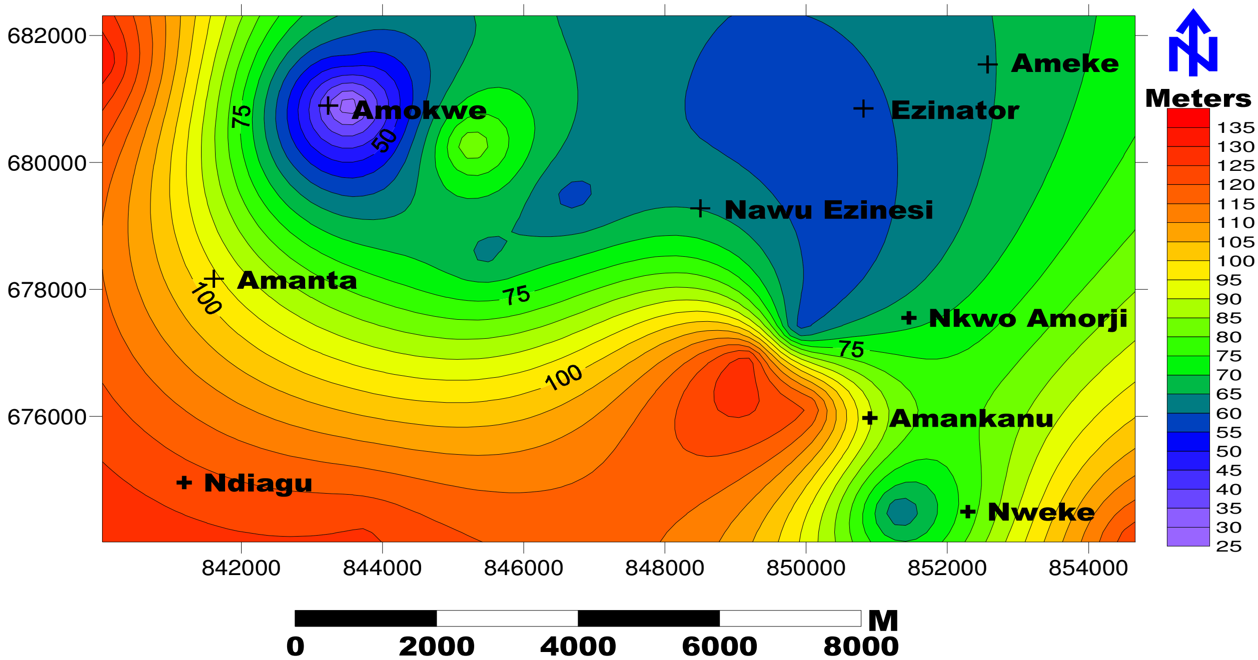

Figure 5. Aquifer depth map of the study area.

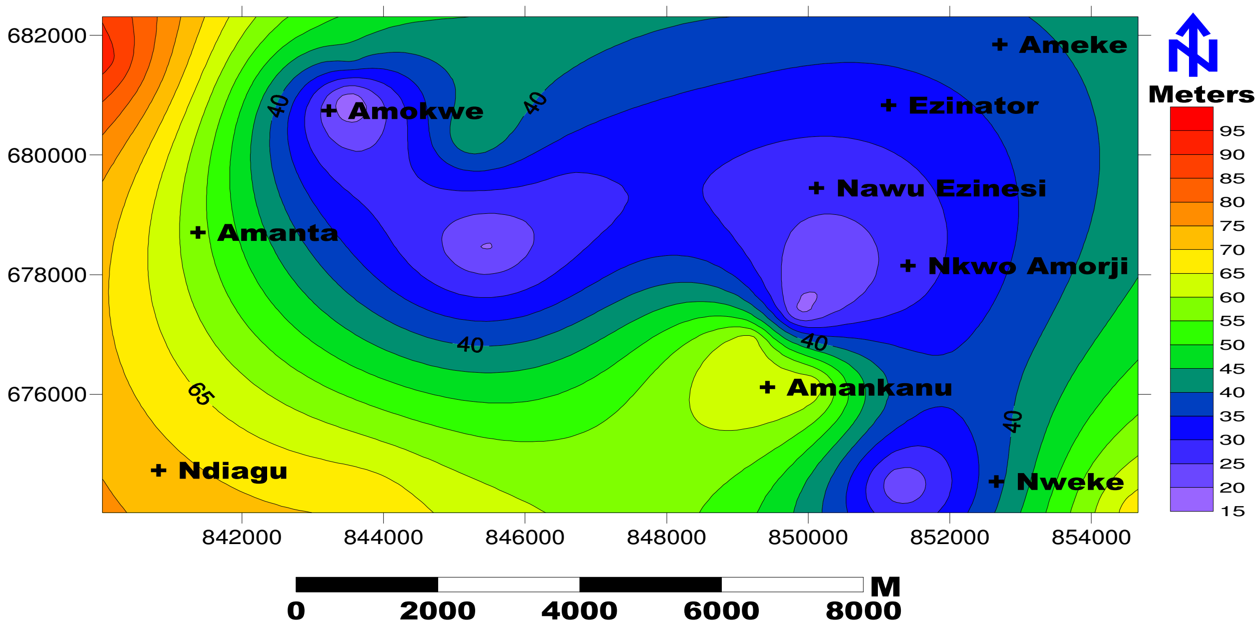

Figure 6. Isopach map of the aquiferous horizon in the study area.

underlain by cretaceous rocks of the Asu River, Ezeaku, Awgu, Nkporo and Mamu Formations, with the oldest, the Asu River Formation, underlain by the basement complex rocks. With the exception of Awgu and Ezeaku formation, all these rock units are very poor aquifers. The sandstones within the Awgu formation are thin and generally limited in extent and as a result, give poor yields. Aneke (2007) proposed an expoloration strategy for exploiting the groundwater from the fractured shaley units which are the main water bearing units in the study area.

Theory and method

The electrical resistivity method is utilized in diverse ways

Table 1: Interpreted model geoelectrical parameters and curve types from the study area.

S/N	Location	VES No	NL	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Curve type
1	Nkwo Amorji	1	7	5	2	2	6	10	10	38	-	0.6	1.2	1.2	2.0	7.0	42.0	-	HA
2	Nawu Ezinesi	2	7	50	35	15	6	5	8	125	-	0.8	0.4	1.8	12.0	15.0	28.0	-	QQA
3	Ezinator	3	7	15	5	3	5	8	15	80	-	0.8	1.4	2.8	18.0	17.0	18.0	-	QAA
4	Nweke	4	7	380	220	100	20	5	105	1152	-	0.8	1.2	2.5	10.5	25.0	20.0	-	QQA
5	Ameke	5	7	1205	2785	12	14	23	4	35	-	0.8	1.1	2.6	20.5	31.0	69.0	-	KAH
6	Amaorji	6	7	280	225	18	9	7	6	18	-	0.8	1.7	2.0	5.5	32.0	93	-	QQH
7	Amankanu	7	7	750	520	40	18	4	2	85	-	1.0	1.5	5.0	14.5	43.0	63.0	-	QQH
8	Enugu Agu	8	7	780	120	18	25	24	11	55	-	0.8	1.7	4.3	18.2	31.0	64.0	-	QKH
9	Ndiagu	9	7	1002	3452	275	13	23	90	20	-	0.8	1.2	5.5	18.5	30.0	69.0	-	KHK
10	Amokwe	10	6	165	12	6	10	2	11	-	-	0.8	1.7	2.5	40.0	19.0	-	-	QK
11	Amanta	11	6	46	13	8	14	21	8	-	-	0.8	1.2	4.0	14.0	40.0	-	-	QA
12	Amachara	12	7	14	9	13	10	14	20	8	-	0.8	1.7	1.5	11.0	25.0	45.0	-	HHK
13	Amagu Ndiagu	13	5	105	75	22	2	250	-	-	-	0.8	1.4	7.8	15.0	-	-	-	QH

for groundwater exploration (Zohdy, 1976; Choudhury, et al, 2001; Frohlich and Urish, 2002). Electrical surveys are usually designed to measure the electrical resistivity of subsurface materials by making measurements at the earth surface. Current is introduced into the ground by a pair of electrodes, while measuring the subsurface expression of the resulting potential field with an additional pair of electrodes at appropriate spacings.

Data acquisition and Interpretation

A total of thirteen vertical electrical sounding (VES) was acquired within and outside the study area (Figure 2). Some were stationed very close to existing boreholes, for correlation purposes. The schlumberger electrode configuration was used with maximum current electrode separation ranging from 400m to 600m.

After acquiring the data, the measured field resistance (R) in ohms was converted to apparent resistivity (ρ_a) in ohm-meter by multiplying resistance (R) by the geometric factor (K). A log-log graph plot of apparent resistivity (ρ_a) against current electrode distance (AB/2) was plotted for each VES station to generate a sounding curve. Using the conventional parital curve matching technique, in conjunction with auxillary point diagrams (Orellana and Mooney, 1966; Koefoed, 1979; Kellar and Frischknecht, 1966) layer resistivities and thickness were obtained, which served as a starting point for computer-assisted interpretation. The computer program RESOUND was used to interpret all the data sets obtained. From the interpretation of the resistivity data, it has been possible to compute for every VES station, the longitudinal conductance(S)

$S = h_i/\rho_i$ ……………………………………. (1)

And transverse resistance(R)

$R = h_i.\rho_i$ ……………………………………. (2)

Where h_i and ρ_i are thickness and resistivity of the aquiferous layer. These parameters R and S and known as the Dar-zarrouk variable and Dar-zarrouk function respectively (Maillet, 1947). Further quantitative analysis for aquifer hydraulics in the study area was based on equations 1 and 2 above using analytical relationship of Niwas and Singhal (1981). They showed that: in areas of similar geologic setting and water quality, the product kσ (hydraulic conductivity) remain fairly constant.

Interpretation

The form of curves obtained by sounding over a horizontally stratified medium is a function of the resistivites and thicknesses of the layers as well as the electrode configuration (Zohdy, 1976). The resistivity curve type associated with the study area from VES 1-13 include: HA, QQA, QAA, QQA, KAH, QQH, QKH, KHK, QK, QA, HHK, and QH curve types respectively (Table 1). The first dominant curve type is Q. This is indicating a shaly terrain. The H curve type is the second dominant. This also indicates fractured shale horizons which are targets for groundwater exploration.

RESULT AND DISCUSSION

Contour maps of the apparent resistivity, the isopach, the depth, the longitudinal conductance, the transverse resistance, the transmissivity and the hydraulic conductivity of the aquiferous horizon have been constructed using the results of the resistivity sounding interpretation. Apparent resistivity variation (Figure 4) indicates a high resistivity to the southeast and southwest with low resistivity to the north, around Amokwe and Nawu Ezinesi. Aquifer depth variation is a function of topography. A NW-SE trend variation predominates (Figure 5). The isopach map also show similar trend (Figure 6). The distribution of the aquifer transverse resistance and longitudinal conductance computed from

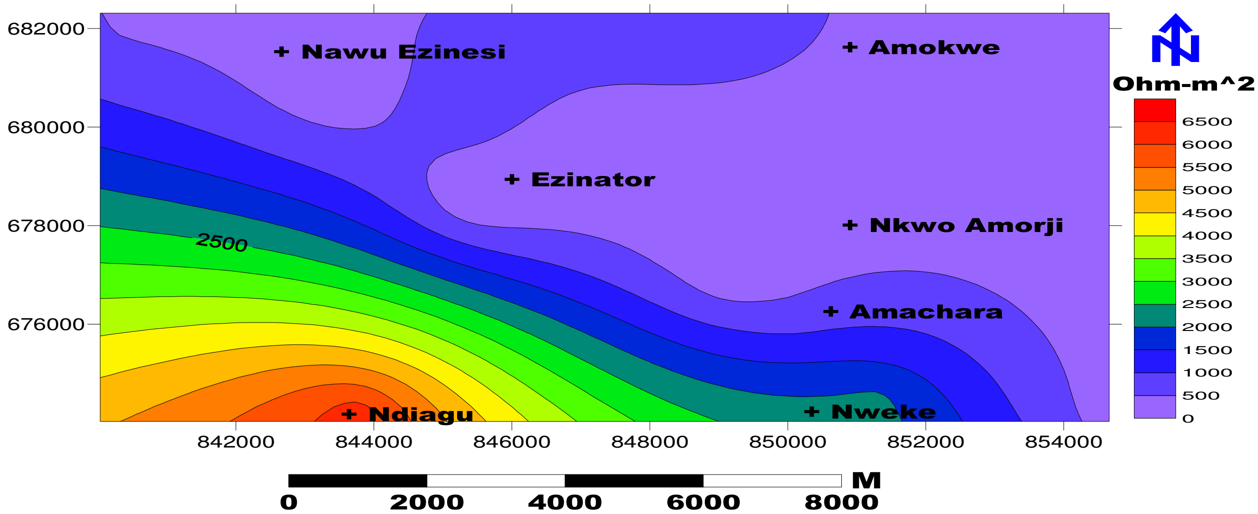

Figure 7. Transverse Resistance map of the study area.

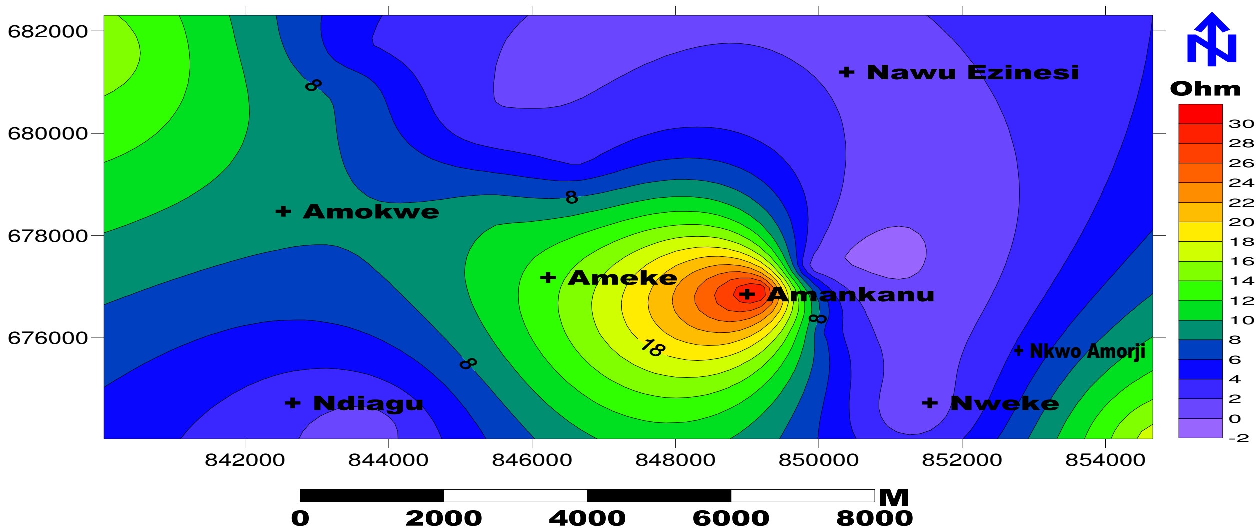

Figure 8. Longitudinal Conductance map of the study area.

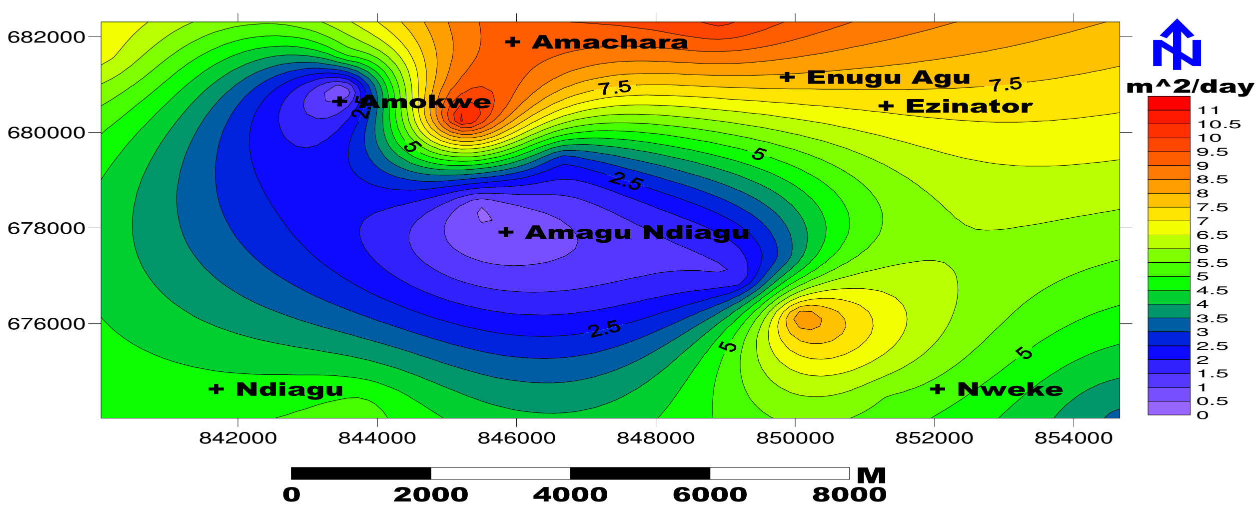

Figure 9. Aquifer Transmissivity map of the study area.

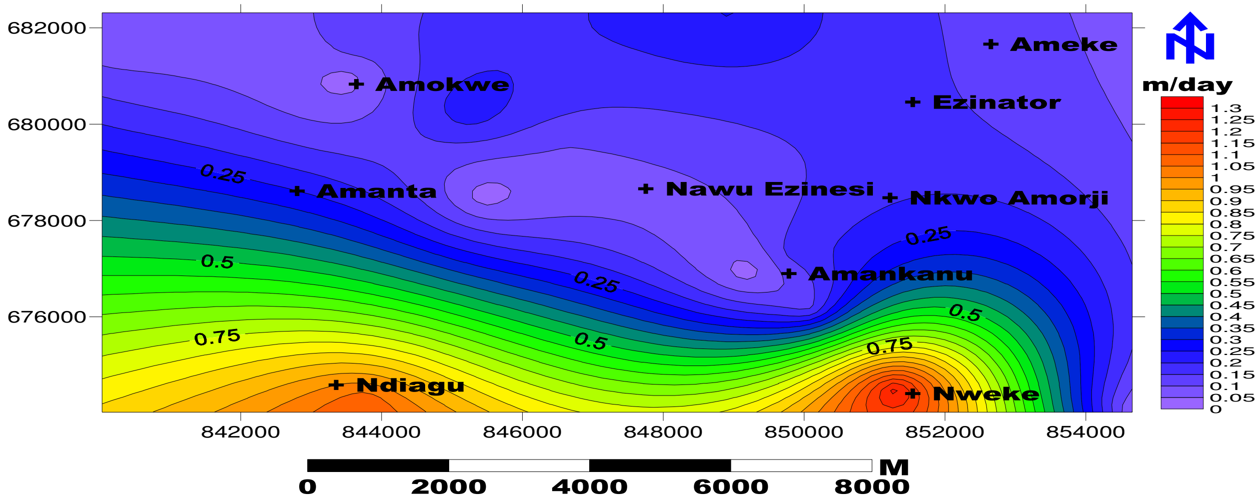

Figure 10. Aquifer Hydraulic conductivity map of the study area.

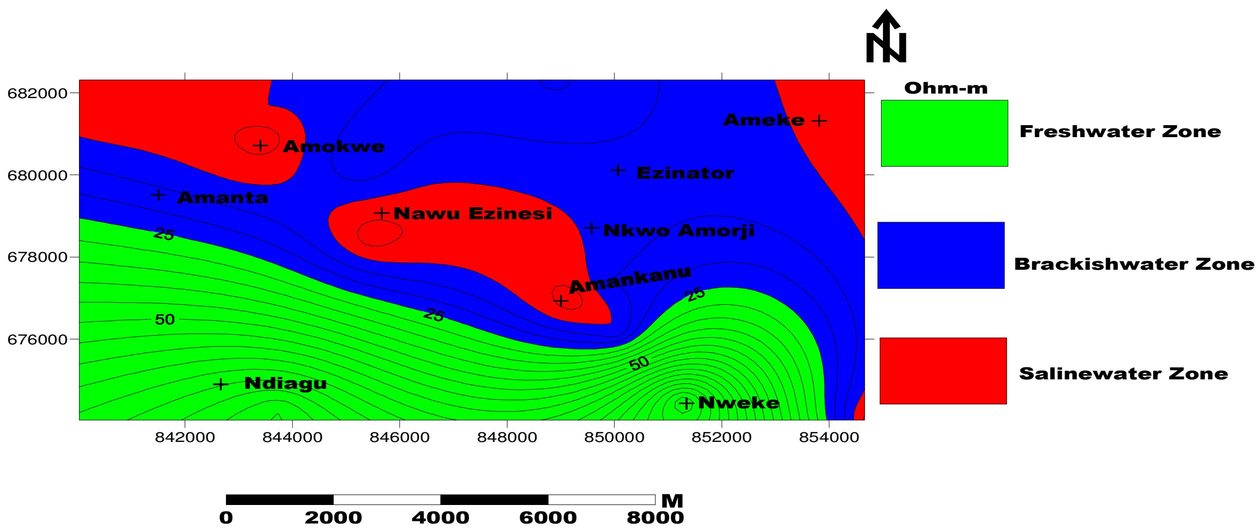

Figure 11. Groundwater quality zones of the study area.

the VES interpretation is shown in figure 7 and figure 8 respectively. Maximum values of transverse resistance are observed around Ndiagu-Nweke-Amachara axis. Aquifer transmissivity (Figure 9) does not show similar trend, with highest value of 11m^2/day at Amachara, indicating a low permeability aquifer (Ekwe,*et al*, 2010) and very low potential (Ezeh, 2012). The longitudinal conductance shows a thick resistive horizon at Amankanu and also in a NW-SE trend. Hydraulic conductivity computed from VES interpretation (Figure 10) show an aquifer with a poor yield, practically depicting a shaly terrain (Figure 12).

Groundwater quality zones

The groundwater quality zones was delineated (Figure 11) based on the integration of the resistivity and total dissolved solute (TDS) data. Specific electrical conductivity (EC) measurements of well-water samples were converted into water resistivities ($\rho_w = 1/\sigma_w$) and TDS

TDS (mg/l) = 0.7 * electrical conductivity (µs/cm) ………………… (3) (Freeze and Cherry, 1979)

Total dissolved solute is a function of salinity. These zones are fresh (ρ_a>25Ωm), brackish (ρ_a = 10 - 25Ωm) and saline groundwater (ρa < 10Ωm).

The freshwater zone predominates southwards within the country around Nweke, Ndiagu down to Mpu and Okpanku while the saline water zone is thin, occupy the central portion of the study area in a NW – SE trend. At Nawu Ezinesi, the salt water was evident as the borehole had been abandoned. The brackish water is a narrow strip and shallow in a NW – SE trend but becomes thicker

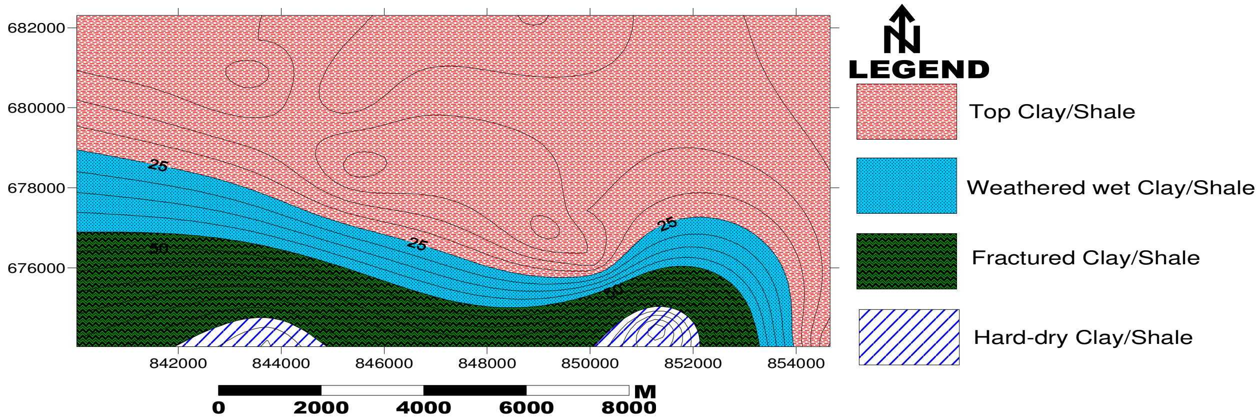

Figure 12. Possible geoelectric Layer distribution.

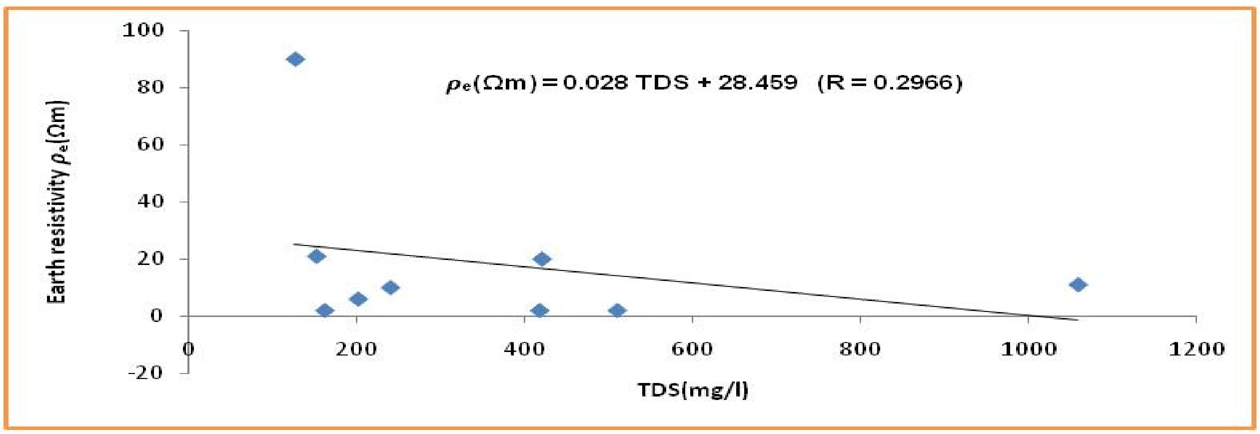

Figure 13. A plot of Earth resistivity against Total dissolved solids (TDS)

north of Nawu Ezinesi within Ezinator, Nkwo Amorji and may also extend to Nnewe and neighboring towns. The earth resistivities and TDS were plotted (Figure 13), and the fitted line indicates the following empirical relationship between earth resistivity and TDS concentrations with correlation coefficient of 0.2966

ρ_e (Ωm) = 0.028 TDS + 28.459 …………………… (4)

Where TDS is the total dissolved solids in mg/l, and ρ_e is the earth or apparent resistivity in ohm-m. This relationship between earth resistivity is strongly affected by groundwater salinity, and hence provides a reaffirmation of the basis for applying resistivity methods to study groundwater quality within shaly terrains or low permeability formations.

CONCLUSION

The computed aquifer hydraulic parameters from VES data indicate a low yield area. The concept of Dar-zarrouk parameters was well applied in computing these parameters. Based on the relationship between earth resistivity and total dissolved solids (TDS), three groundwater quality zones were delineated. A depth greater than 60meters but less than 100meters may be needed in order to intercept the freshwater horizon.

The study has therefore provided a better understanding of the groundwater system at Oduma and environs and this will no doubt guide future groundwater exploration strategies in the area and beyond and also eradicate the problem of saltwater and abortive wells in the area.

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