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Geoelectrical studies for the delineation of potential groundwater zones at Oduma in Enugu State, Southeastern Nigeria

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This work evaluates the use of geoelectrical method in the delineation of potential groundwater zones at Oduma in Enugu state, Southeastern Nigeria. Oduma lies within latitudes 6°02/ N to 6°07/ N and longitudes 7°35/ E to 7°41/ E with an area extent of about 102.6 km^2. 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 aquifer transmissivity from VES data values indicates a low yield aquifer. The latter was used to delineate the potential groundwater zones based on Gheorge aquifer transmissivity classifications. Comparisons of aquifer hydraulics estimated from geoelectrical sounding and the pump test analysis indicates a fairly good match. Three potential groundwater zones were delineated; the low, very low and negligible potential zones. The various contour maps and potential groundwater zone map will serve as a useful guide for groundwater exploration in the study area.

Key words: Resistivity, transmissivity, hydraulic conductivity, groundwater zones, aquifer yield.

INTRODUCTION

Oduma lies within latitude 6°02/ N to 6°07/ N and longitudes 7°35/ E to 7°41/ E with an area extent of about 102.6 km^2. It is located in Aninri local government area, Enugu state, southeastern Nigeria (Figure 1). The increasing population within Oduma and neigbouring towns has necessitated the high demand of groundwater development in the area. Cases of abortive water wells have been reported within Oduma and environs. Knowledge of groundwater zone is essential for a robust groundwater development program in the area. The natural flow of water through an aquifer is determined from the hydraulic properties of the aquifer. Hydraulic conductivity (k), transmissivity (T) and storativity (S) are the aquifer properties. Transmissivity is the hydraulic conductivity multiplied by the saturated thickness of the aquifer. Predictions of these hydraulic properties are mainly from pumping test analysis. Now geophysical methods provide an effective technique for aquifer evaluation. Estimates of hydraulic properties from geoelectrical soundings have been made by several authors (Ezeh and Ugwu, 2010; Kelly, 1979; Urish, 1987). These parameters were estimated using empirical and semi-empirical relationships (Huntly, 1987; Koinski, 1981). Their study was aimed at characterizing the aquifers for optimum yield.

In the present study, an attempt has been made by

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

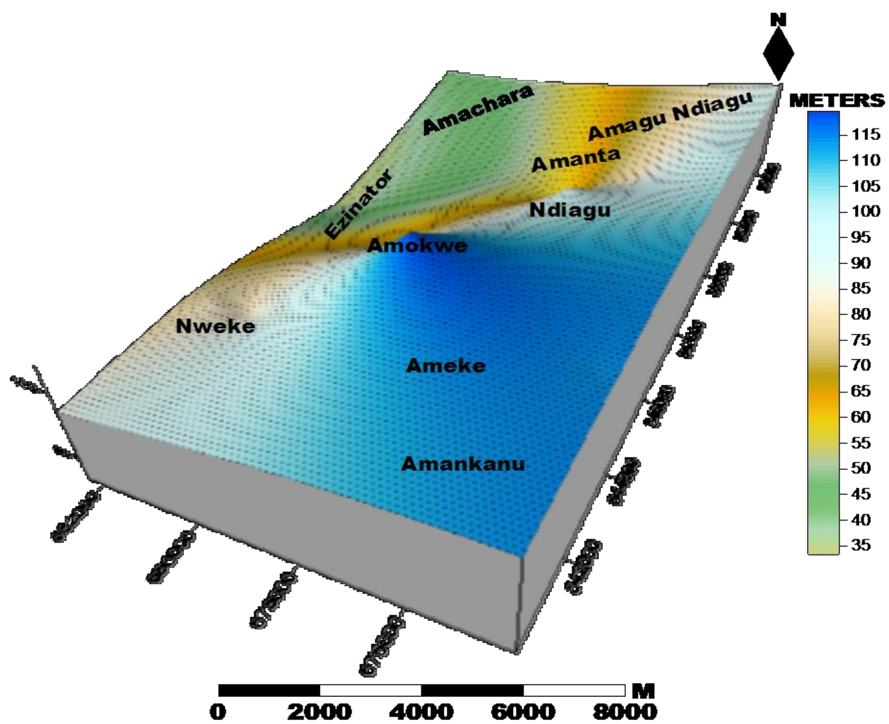

Figure 2. Surface map of the study area.

using the distribution of these hydraulic parameters to delineate the groundwater potential zone at Oduma and environs. Modeled estimates of the hydraulic parameters from geoelectrics were compared with data from pumping test to have a better picture of groundwater potential zone.

Study area

Physiography

The study area is fairly a lowland topography (Figure 2). Amokwe community is about the highest in the area, with

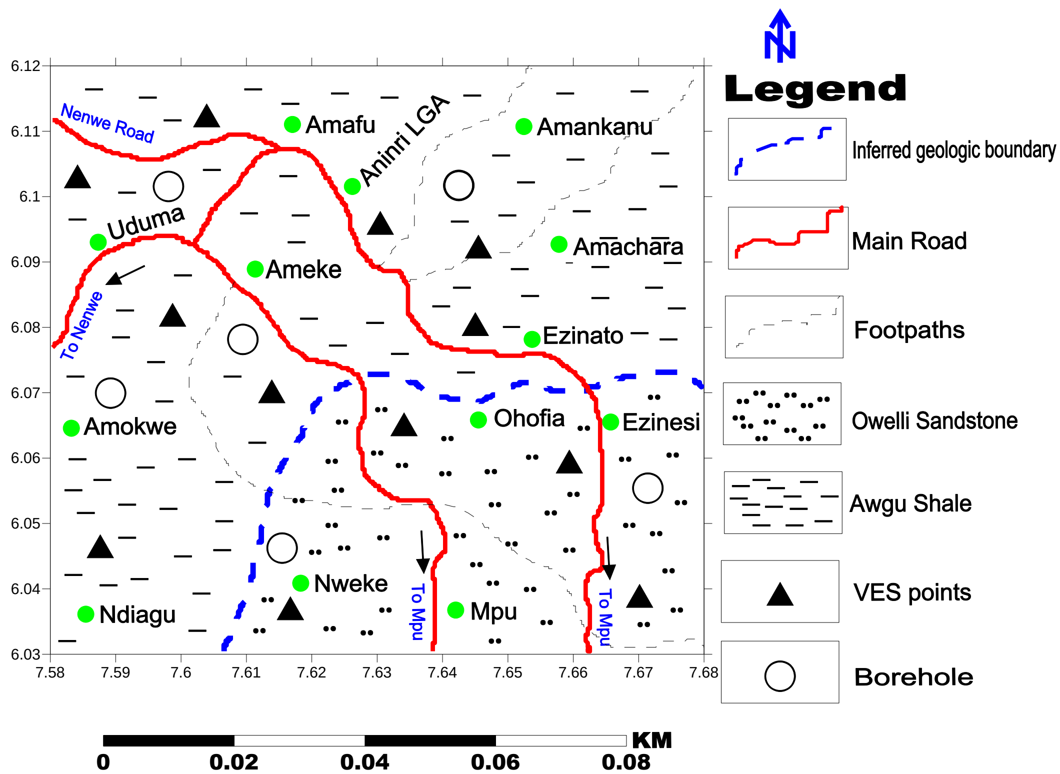

Figure 3. Geologic map of the study area showing VES stations and borehole points.

an elevation of 120 m 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 shales with occasional intercalations of fine-grained, pale yellow, calcareous sandstones and shaly limestones (Reyment, 1965). It is about 900 m thick and gently folded.

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 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 exploration strategy for exploiting the groundwater from the fractured shaley units which are the main water bearing units in the study area.

THEORY AND METHODS

The electrical resistivity method is utilized in diverse ways 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 spacing.

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 400 to 600 m. The equipment used for the fieldwork was the versatile Ohmega resistivity meter.

Table 1. Interpreted model geoelectric 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

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 partial curve matching technique, in conjunction with auxiliary 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).

$$S = h_i/\rho_i \quad (1)$$

And transverse resistance(R)

$$R = h_i.\rho_i \quad (2)$$

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

Interpretation

The form of curves obtained by sounding over a horizontally stratified medium is a function of the resistivities 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.

RESULTS AND DISCUSSION

Geoelectrical sounding

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 the VES interpretation is shown in Figures 7 and 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).

Borehole data

Aquifer parameters from pumping test analysis were also acquired. They are transmissivity (Figure 13), hydraulic conductivity (Figure 14) and aquifer yield (Figure 15). Contour maps for the former were also produced.

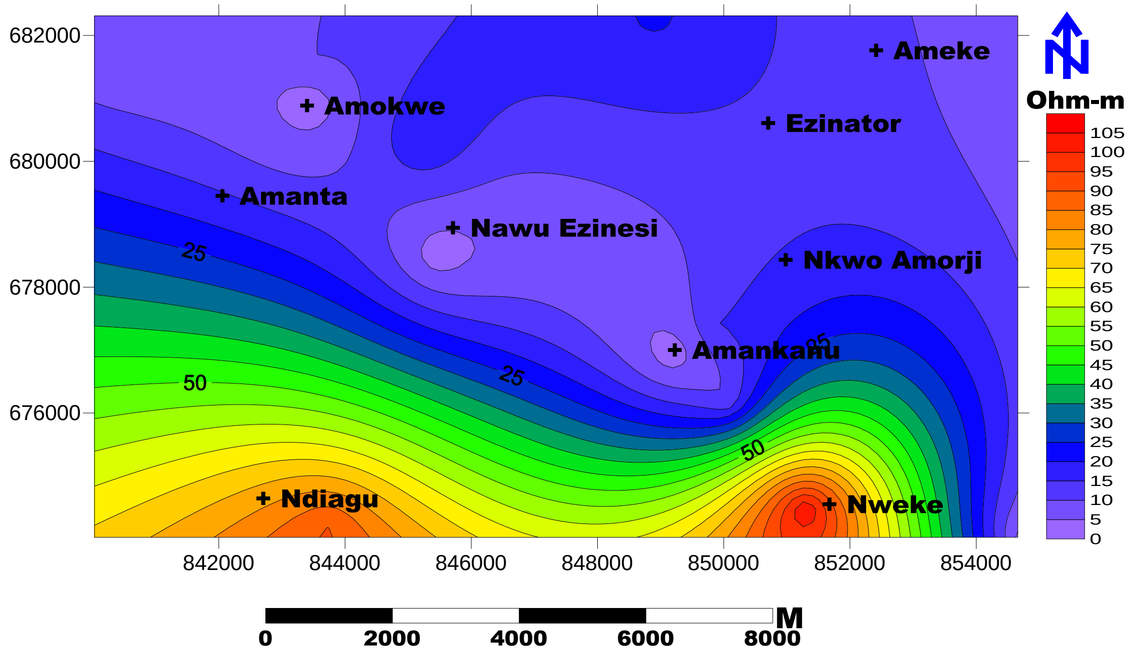

Figure 4. Iso-apparent resistivity map of aquiferous horizon in the study area.

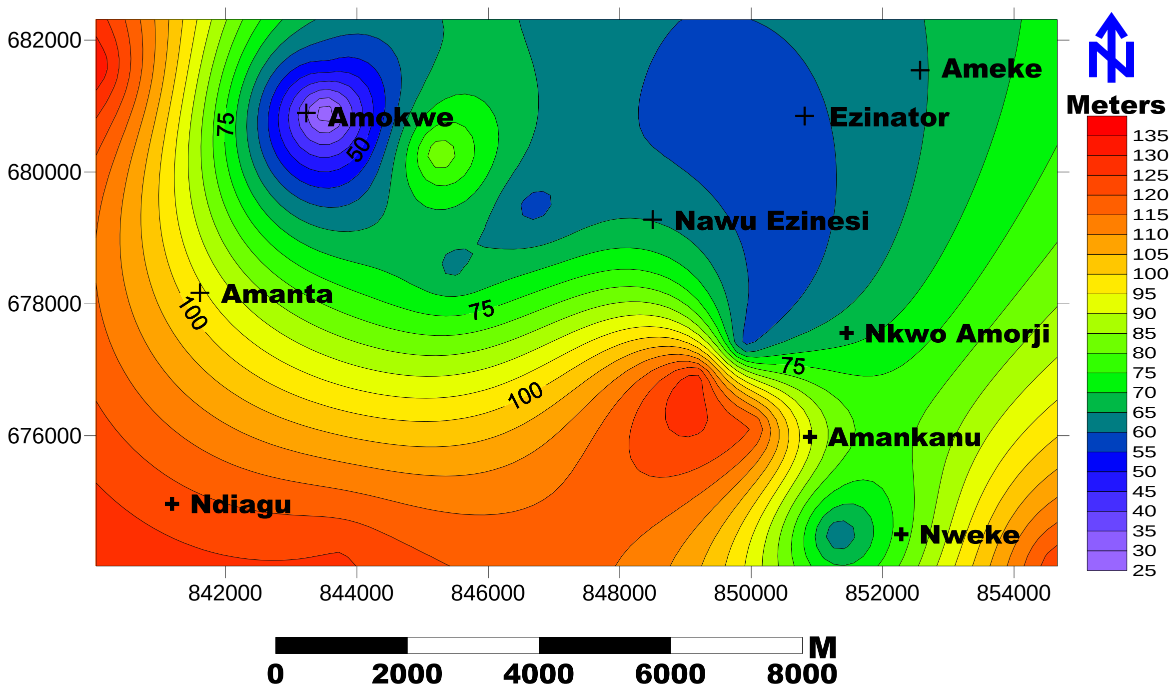

Figure 5. Aquifer depth map of the study area.

Comparisons of aquifer hydraulics estimated from geoelectrical sounding and the pump test analysis indicates a fairly good match. Estimated aquifer transmissivity (Figure 9) around Nweke, Amokwe, Amachara and Ndiagu fairly matches aquifer transmissivity from pump test data. Similarly the estimated hydraulic conductivity from geoelectrical sounding also fairly matches hydraulic conductivity from pumping test data in the study area. The aquifer yield (Figure 15) depicts the true picture of the study area as a

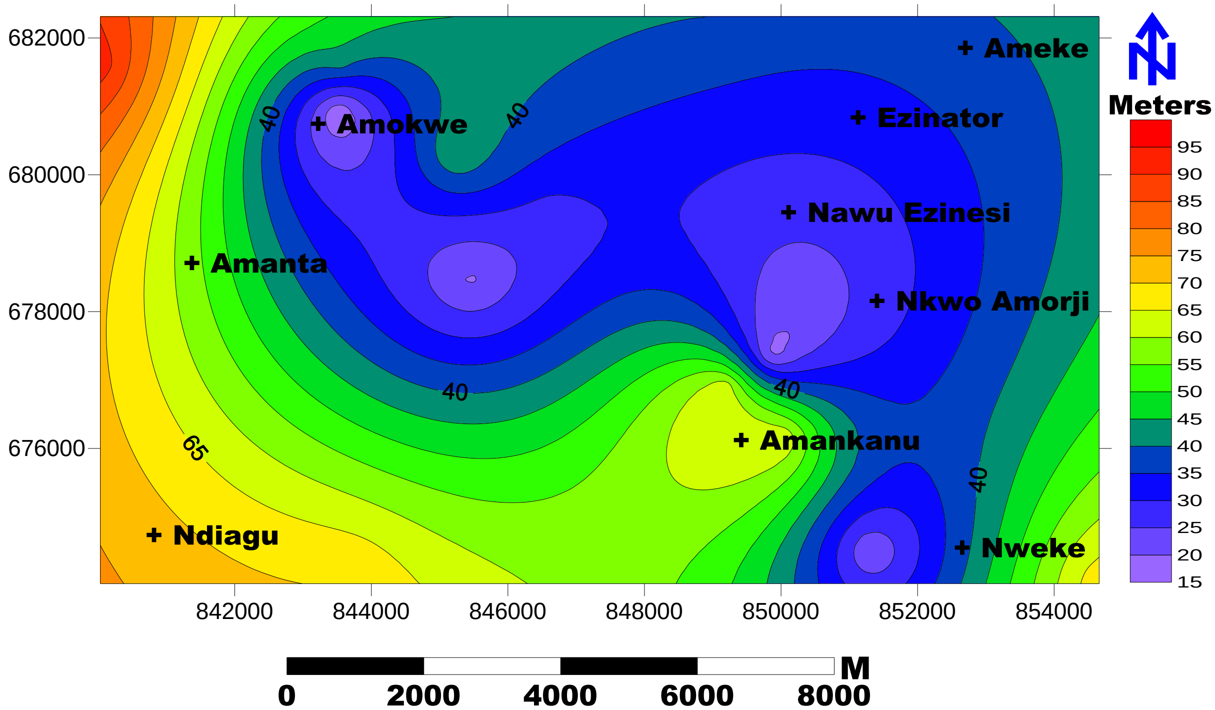

Figure 6. Isopach map of the aquiferous horizon in the study area.

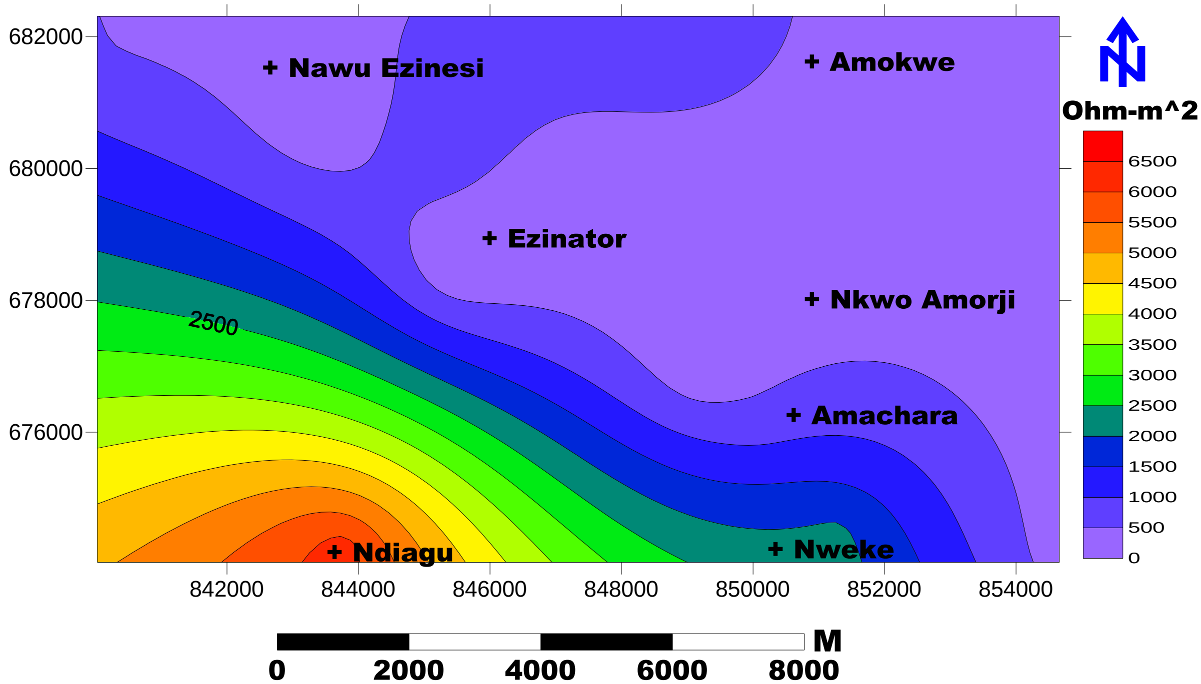

Figure 7. Transverse resistance map of the study area.

low permeability area. The highest aquifer yield in the area is about 6.20 m^3/h at southeast corner near Nweke village.

Groundwater potential evaluation

The groundwater potential zones was delineated (Figure

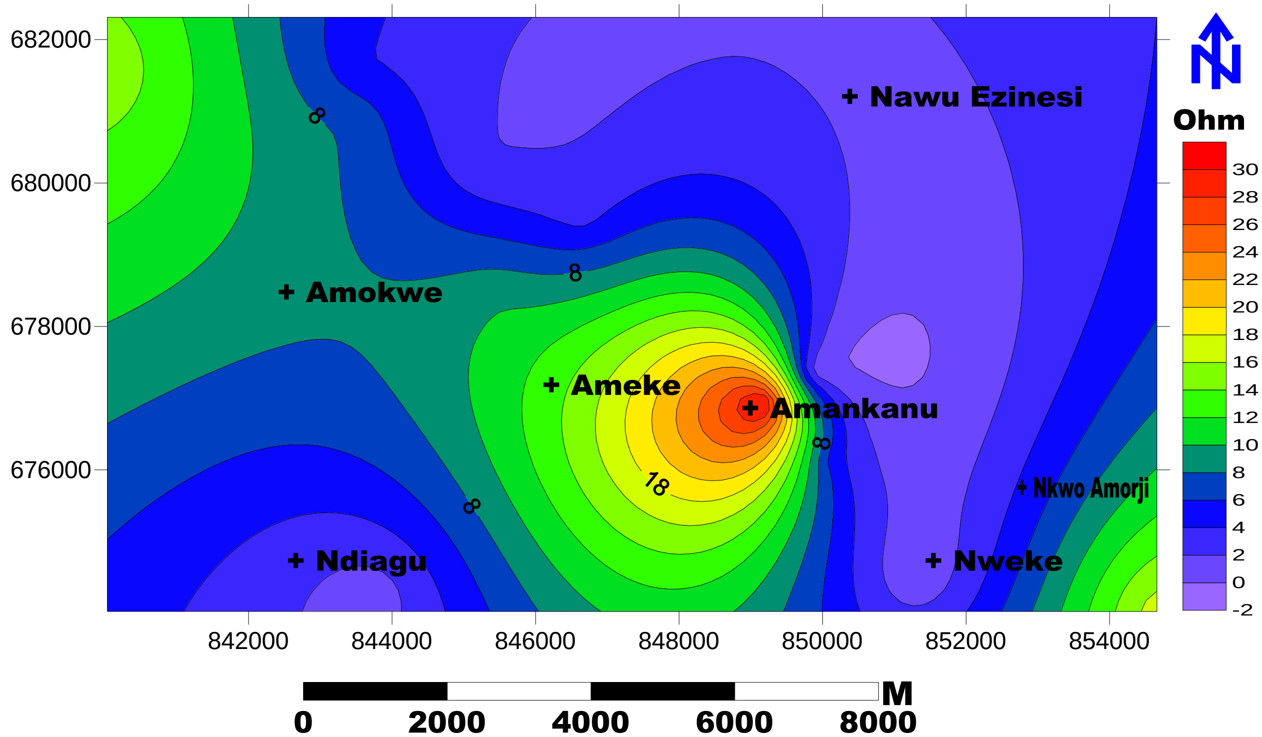

Figure 8. Longitudinal conductance map of the study area.

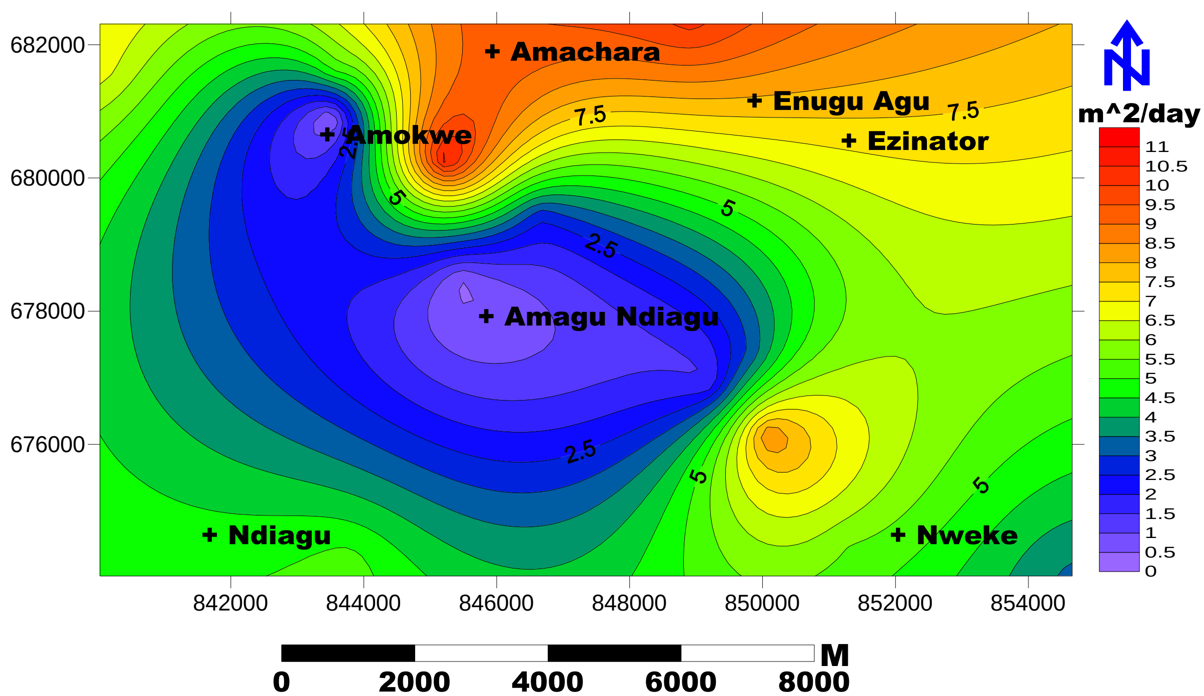

Figure 9. Aquifer transmissivity map of the study area.

11) based on Gheorghe (1978) aquifer transmissivity classifications. Groundwater potential is a function of complex inter-relationship between geology, physiography, groundwater flow pattern, recharge and

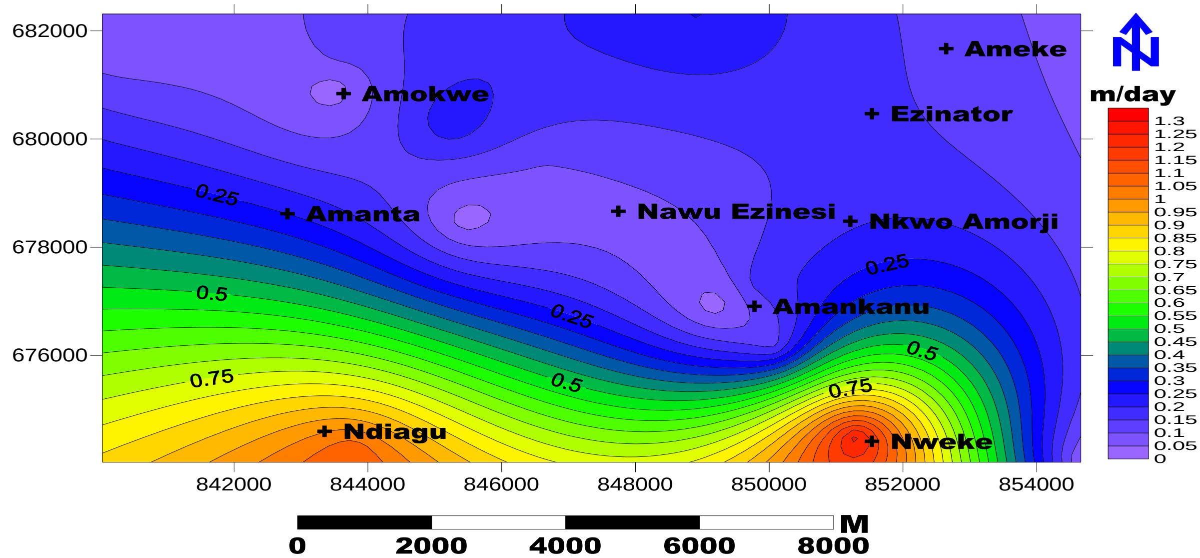

Figure 10. Aquifer hydraulic conductivity map of the study area.

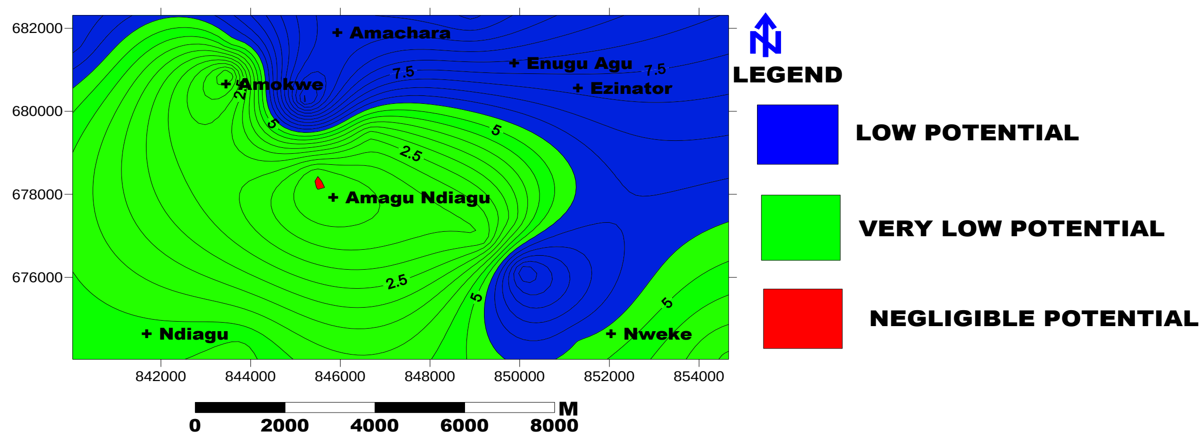

Figure 11. Groundwater potential zones of the study area.

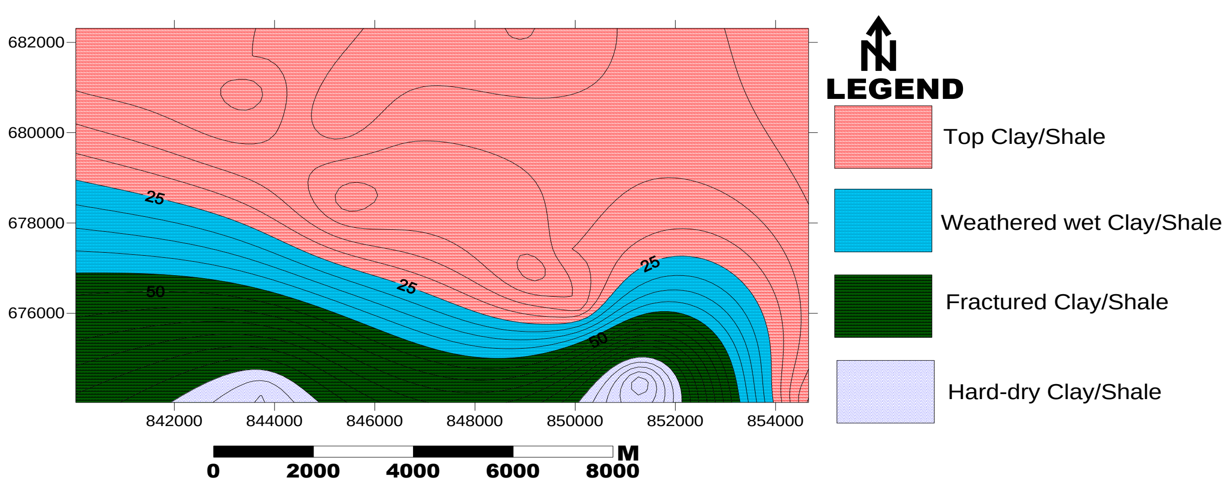

Figure 12. Possible geoelectric layer distribution.

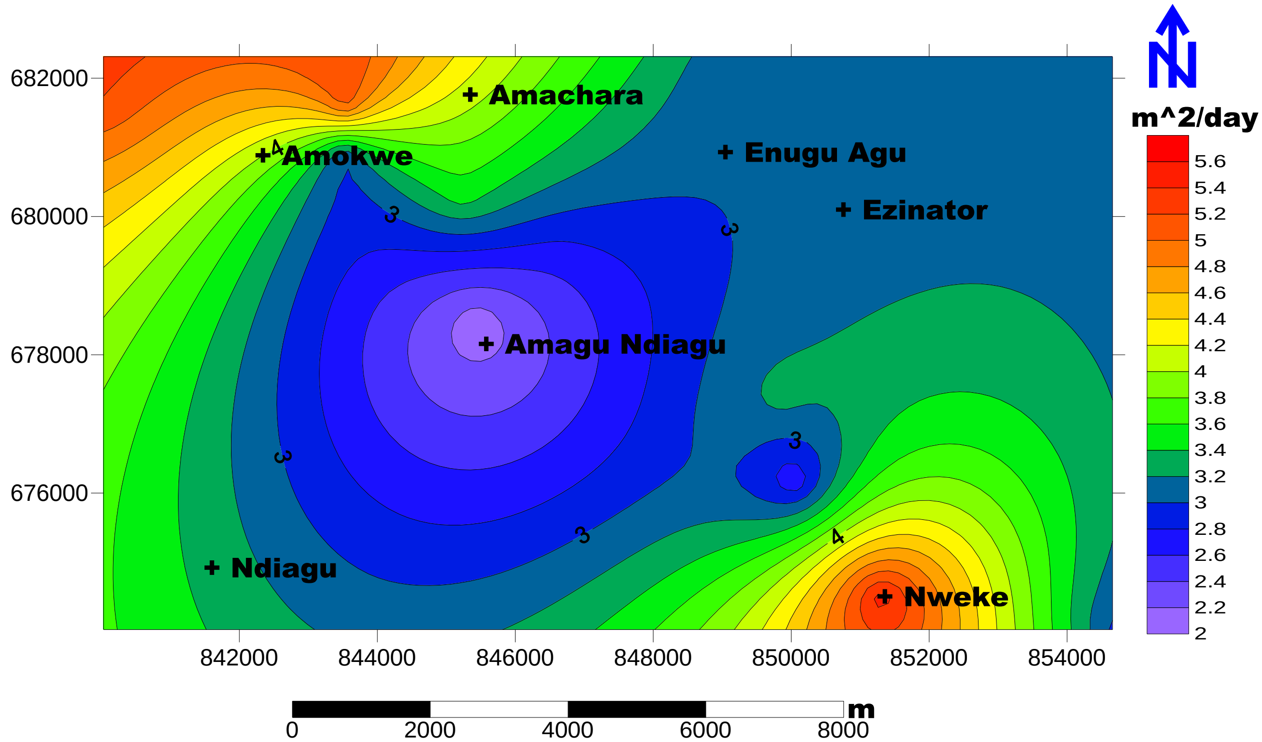

Figure 13. Aquifer transmissivity map (from pumping test analysis) of the study area.

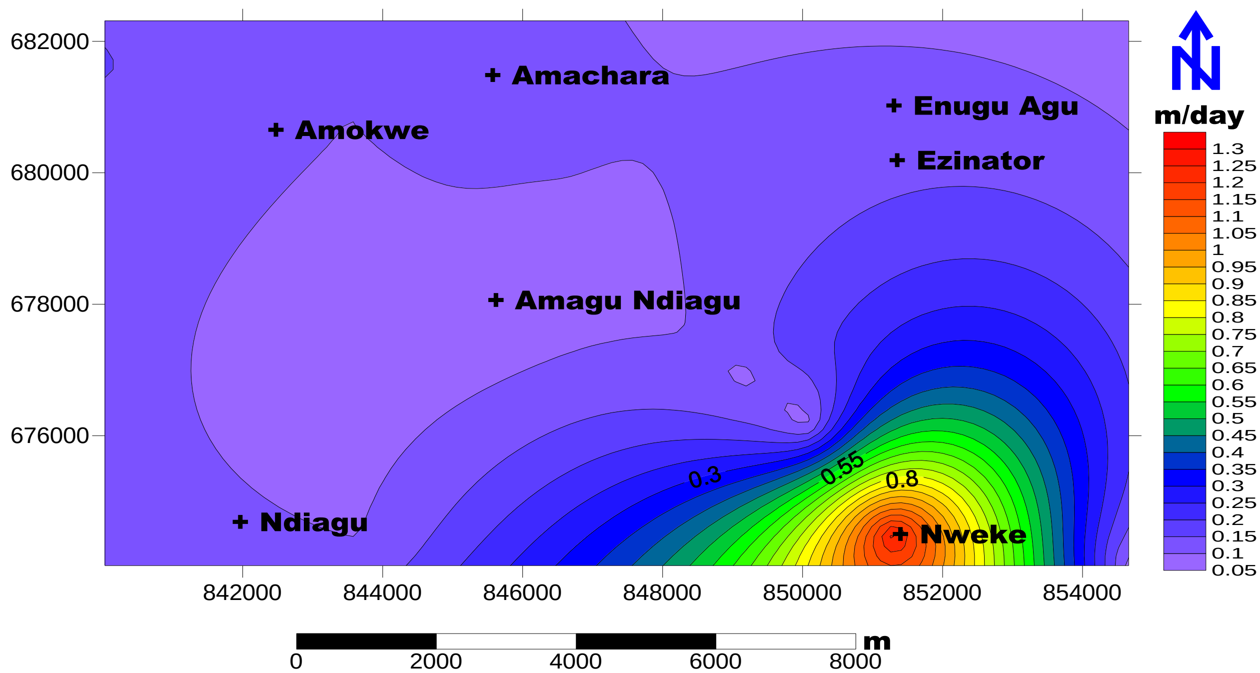

Figure 14. Aquifer hydraulic conductivity map (from pumping test analysis) of the study area.

discharge processes (Ezeh, 2012). The present evaluation of the groundwater potential of the study area has been based on aquifer geoelectrical parameters obtained from VES interpretation results. Three potential

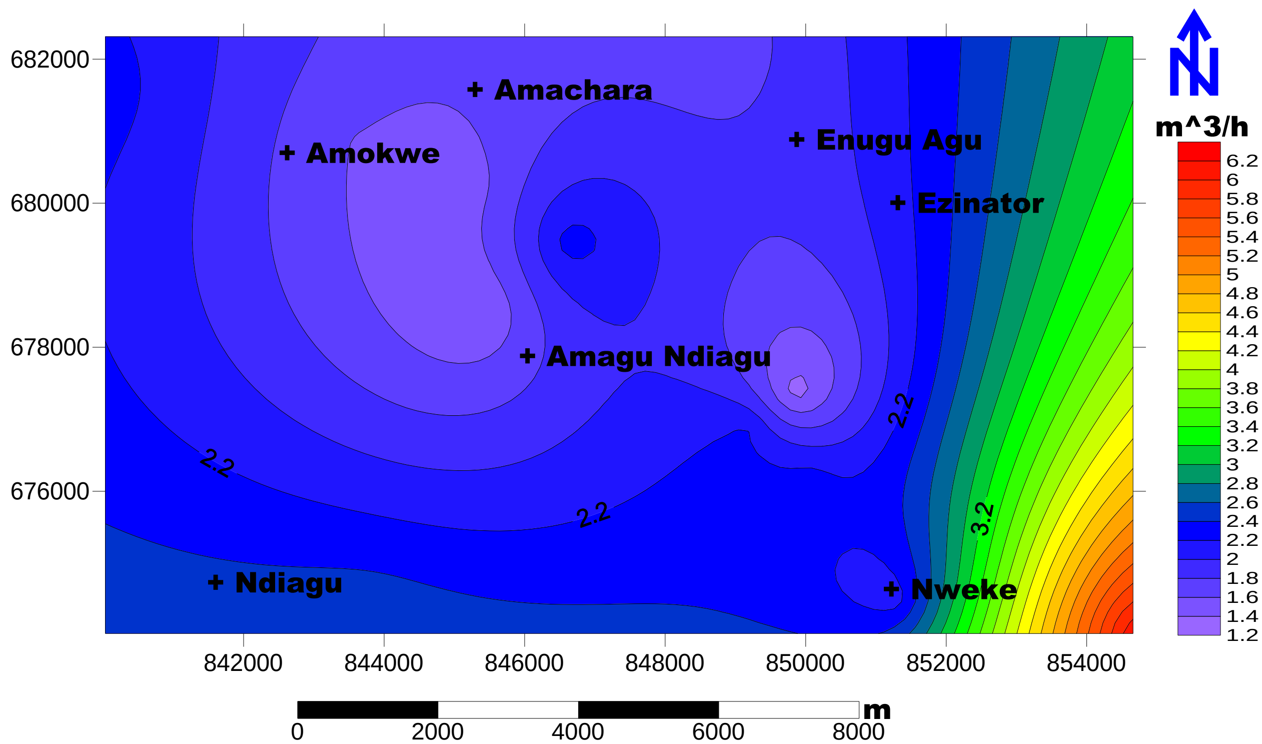

Figure 15. Aquifer yield map (from pumping test analysis) contour map from the study area.

groundwater zones were delineated. The zones are low, very low and negligible potentials. The country around Amagu Ndiagu, Ndiagu, Nweke and Amokwe are of very low potential while areas to the northeast around Enugu Agu, Ezinator and Amachara are of low potential. Negligible potential was quite insignificant.

Conclusion

Based on the geoelectrical studies, the potential groundwater zones were delineated; the low, very low and negligible potential zones. Computed aquifer hydraulics parameters indicate a low aquifer yield. However, this should not stall further groundwater exploration in the area but more detailed hydrogeological and geophysical investigations must be carried out to determine good point(s) for groundwater development. A depth greater than 60 m but less than 100 m may be recommended.

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