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Estimation of Aquifer Hydraulic Properties and Protective Capacity of Overburden units From Geoelectrical Sounding: Case of Groundwater Aquifers, Nkanu-West LGA, Enugu, Nigeria.

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ABSTRACT

Estimation of Aquifer Hydraulic properties and protective capacity of overburden units in groundwater aquifers of Nkanu-West local government area, Enugu state has been carried out. The project area lies within latitude 06^0 25^I 00^{II}N to 06^0 38^I 00^{II}N and longitudes 007^0 13^I 00^{II}E to 007^0 24^I 00^{II}E with an area extent of about 489.4sqkm, over two main geological formations. A total of seventy-eight Vertical Electrical Sounding (VES) were acquired within the study area, employing the Schlumberger configuration. Resistivity and thickness of aquiferous layers were obtained from the interpreted VES data, using the INTERPEX resistivity software. The resistivity and depth to aquiferous layer varied from 50 to 1250Ωm and 40 to 180m respectively across the study area. Knowing resistivity and thickness, it was possible to compute transverse resistance and the longitudinal conductance. Using the relationship between transverse resistance and transmissivity, it was possible to estimate the aquifer hydraulics (transmissivity and the hydraulic conductivity) and the protective capacity of overburden units from VES data. Transmissivity ranges from $15m^2$/day to $140m^2$/day while hydraulic conductivity ranges from 0.5m/day to 8.0m/day. Based on transmissivity classifications, the study area is rated low to moderate groundwater potentials. The longitudinal conductance (ranging from $0.01\Omega^{-1}$ to $20\Omega^{-1}$) of the area enabled the protective capacity of the aquifer to be classified as moderate to good. Contour variation maps of apparent resistivity, overburden depth, transverse resistance, longitudinal conductance, aquifer transmissivity and hydraulic conductivity were constructed. The various constructed contour maps, the estimated aquifer hydraulics and overburden protective capacity, will serve as a useful guide for groundwater exploration and development in the study area.

1. Introduction

Nkanu-West local government area, lies within within latitude 060 25^I 00^{II}N to 060 38^I 00^{II}N and longitudes 0070 13^I 00^{II}E to 0070 24^I 00^{II}E with an area extent of about 489.4sqkm. The high population growth within and around neighboring towns, brought a high demand of sustainable groundwater development in the area. The natural flow of water through aquifer is determined from the hydraulic properties of aquifer (Igwebuike, et al, 2014). Hydraulic conductivity (k) and Transmissivity (T) are the aquifer hydraulic properties. Estimation of these parameters using geoelectrical method, now proof effective technique for aquifer evaluation (Ezeh, 2012, Okonkwo and Ujam, 2013, Abiola, et al, 2009). In the present study, an attempt has been made to use the interplay between computed aquifer resistivity, transverse resistance and longitudinal conductance to model the aquifer hydraulic properties and overburden protective capacity.

2. Location and Physiography

The study area is located in Nkanu-west local government area, southeast of Enugu state, Nigeria (Figure. 1). The area lies within latitudes 060 25^I 00^{II}N to 060 38^I 00^{II}N and longitudes 0070 13^I 00^{II}E to 0070 24^I 00^{II}E with an area extent of about 489.4sqkm. The project domain is bordered to the north by Enugu-south LGA, while to the northwest and west by Udi LGA. To the southwest, it is bordered by Awgu LGA and to the North-East, East and South, by Nkanu-East LGA (Figure.1). The topography in the study area is undulating (Figure.2). Akagbe-Ugwu and Akpugo is about 240meters (800ft) above sea level (ASL) while Obeagu and Agbani are about 150meters (500ft) ASL.

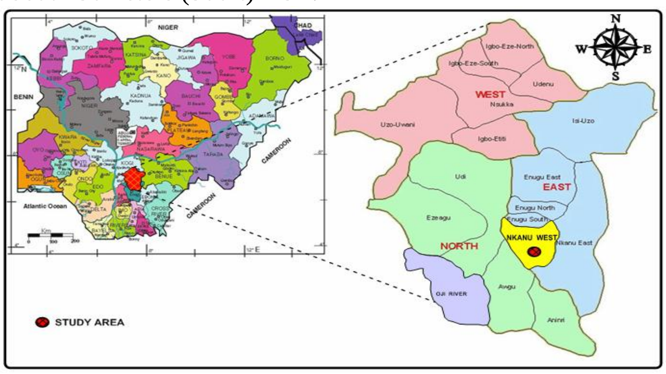

Figure 1. **Map of Enugu State showing the location of the study area. Inset, map of Nigeria (Modified from Obaje, 2009).**

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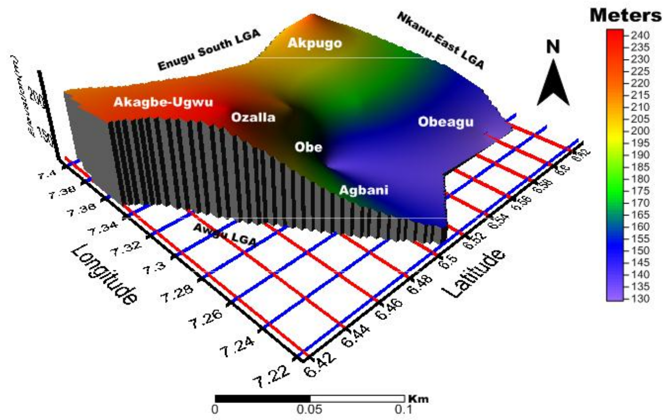

Figure 2.Surface map of the study area.

3. Local Geology

The study area falls within the geologic complex (Figure.3a) known as the Lower Benue Trough (Obaje, 2009). Locally, it is underlain by the Awgu Shale units, which is coniacian in age and the Agbani Sandstone unit (Figure.3b). The Agbani Sandstone unit is a lateral equivalent of Awgu Shale units. The sandstone is laterally not extensive, as it outcrops only within the country around Agbani. It consist of medium to coarse grained, white to reddish brown, moderately consolidated at depth and highly consolidated at outcrop areas. Thickness variation and lateral gradation is predominant in areas (towns) far from Agbani town center. The Awgu Shale 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 900meters thick and gently folded.

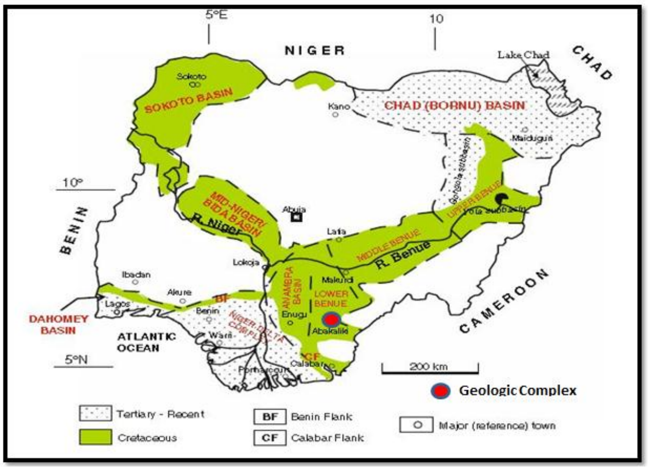

Figure 3a. Sedimentary basins of Nigeria (Obaje, 2009).

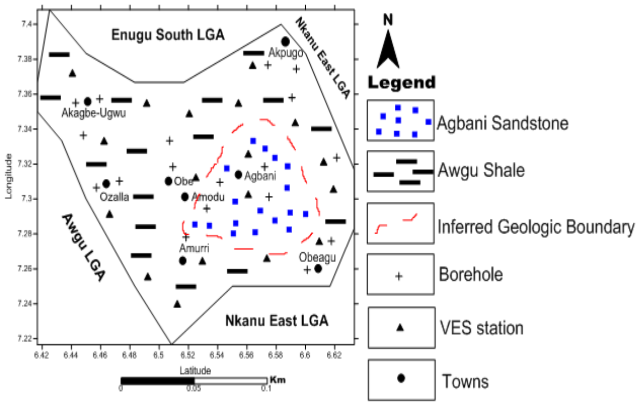

Figure 3b.Geologic map of the study area.

4. Hydrogeology

The study area falls within the Cross River Basin, which had been described as 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 Formations, 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 moderate to low yields. Aneke (2007) proposed an exploration strategy for the groundwater from the fractured shaley units which are the main water bearing units in the study area.

5. Theory and Methods

Evaluation of groundwater potential was done using information from Electrical Resistivity (ER) method. The ER method is utilized in diverse ways for groundwater water exploration (Zohdy, 1976; Choudhury, et al, 2001; Frohlich and Urish, 2002). Electrical surveys are usually designed to measure the ER of subsurface materials by making measurements at the earth surface. Currents are introduced into the ground by a pair of electrodes, while measuring the subsurface expression of the resulting potential fields with an additional pair of electrodes at appropriate spacing.

6. Data Acquisition and Interpretation

A total of Seventy-Eight Vertical Electrical Sounding (VES) was acquired in more than thirty locations within the study area (Figure.3). Some VES stations were very close to existing boreholes for correlation purposes. The Schlumberger electrode configuration (Figure. 4) was used, with a maximum current and potential electrodes separation of AB=800meters and MN=40meters respectively. The equipment used for the fieldwork was the versatile ABEM terrameter SAS 1000 resistivity meter. After acquiring the data, measured field resistance (R) in Ohms was converted to apparent resistivity (ρa) in Ohm-meter by multiplying resistance (R) by the geometric factor (k). A log-log graph plot of apparent resistivity (ρa) 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 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 INTERPEX was used to interprete all the datasets obtained. From the interpretation of the resistivity data, it has been possible to compute for every VES station, the Transverse resistance (T)

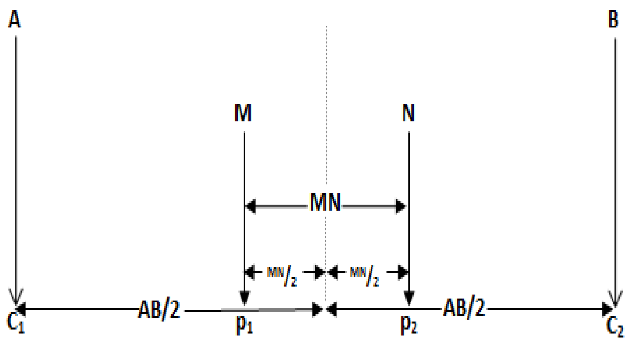

Figure 4.Schlumberger electrode configuration.

$T = h \times \rho a$ ………..………………………… (1)

And longitudinal conductance (S)

$S = h/\rho a$ ..…………………………………… (2)

Where h and ρ a are thickness and apparent resistivity of the aquiferous layer. These parameters T and S are known as the Dar-Zarrouk variable and Dar-Zarrouk function respectively (Maillet, 1947).

7. Estimating Aquifer Hydraulic properties.

Both parameters T and S and the derived concept of Dar-Zarrouk curves (Maillet, 1947) are of prime significance in the development of interpretation theory for VES data. Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity and transverse resistance on the one hand and between aquifer transmissivity and aquifer longitudinal conductance on the other. Taking into account a prism of aquifer material having unit cross-sectional area and thickness (h), they combined equations 1 and 2 to obtain the following relationship between Transmissivity (Tr) and the so called Dar-zarrouk parameters.

$Tr = K\sigma R = K/\sigma \times S$ ……………………………………....(3)

Where σ is the aquifer conductivity or electrical conductivity and K, the hydraulic conductivity of aquifer. In equation 3, the quantities Kσ and K/σ are assumed to remain fairly constant in areas of similar geologic setting and water quality (Niwas and Singhal, 1981). Therefore, with known values of K for the existing boreholes and with σ values extracted from the sounding interpretation at the borehole locations, it is possible to determine transmissivity and its variation within a geologic formation including places where no boreholes are available.

8. Results and Discussion

8.1. Geoelectrical Sounding

Contour maps of the apparent resistivity, the isopach, the overburden depth, the transverse resistance, the longitudinal conductance, the transmissivity and the hydraulic conductivity of the aquiferous horizons has been constructed using the results of the resistivity sounding interpretation. Apparent resistivity variation (Figure.5) indicates a high resistivity within Agbani town and a low resistivity trend in a NW-SW direction, occupying towns around Akagbe-Ugwu, Ozalla, Obe and Amurri. Aquifer thickness (Figure.6) is variable, increasing from the northwest and Northeast to the central part of the study area. However, areas with thicker aquifer did not correlate with areas of high resistivity values. This is because resistivity depends more on the saturation of the layers and not necessarily on the thickness of the aquifer. The overburden depth (Figure.7) includes all rock materials above the aquiferous horizon or bedrock. The depth to the aquiferous horizon varies from 40meters to 180meters. The distribution of the transverse resistance, longitudinal conductance and the electrical conductivity computed from the VES interpretation are shown in Figures.8, 9 and 10 respectively. Maximum values of transverse resistance are observed around Amurri – Agbani – Akpugo axis. Electrical conductivity is the inverse of resistivity. High electrical conductivity (Figure.10) values occur around Amodu and Obe axis. This indicates that the country around Amodu and Obe is a shaley terrain. Computed aquifer transmissivity (Figure.11) and hydraulic conductivity (Figure.12) from VES interpretation, show similar trend, with good signals stretching the axis of Amurri –Agbani – Akpugo, with a recorded aquifer transmissivity value of 140m2/day. Hence, indicating a moderate permeability aquifer.

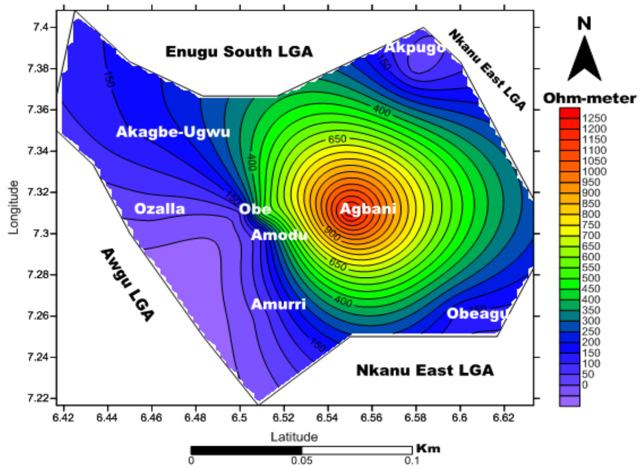

Figure 5. **Apparent resistivity Map of the study area.**

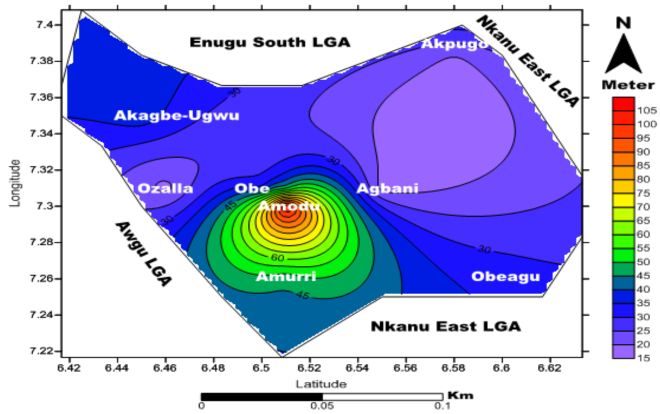

Figure 6. **Aquifer isopach map of the study area.**

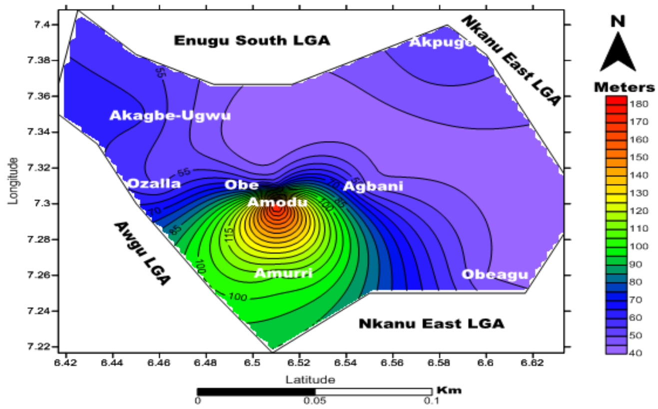

Figure 7. Overburden depth map of the study area.

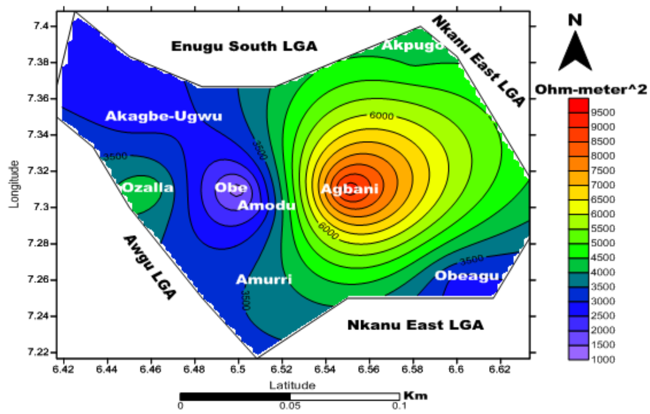

Figure 8. Transverse resistance map of the study area.

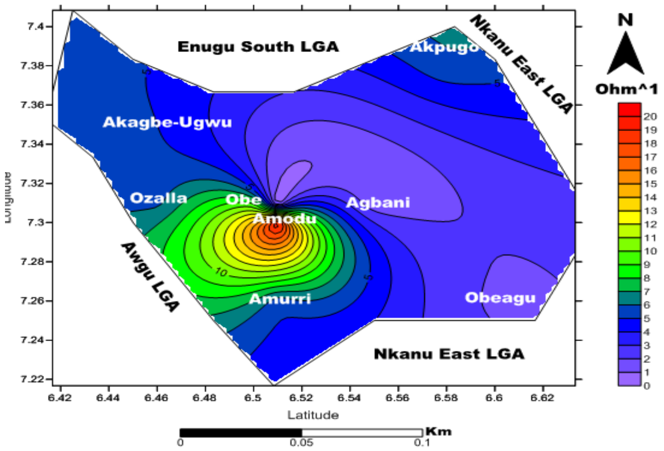

Figure 9. Longitudinal conductance map of the study area.

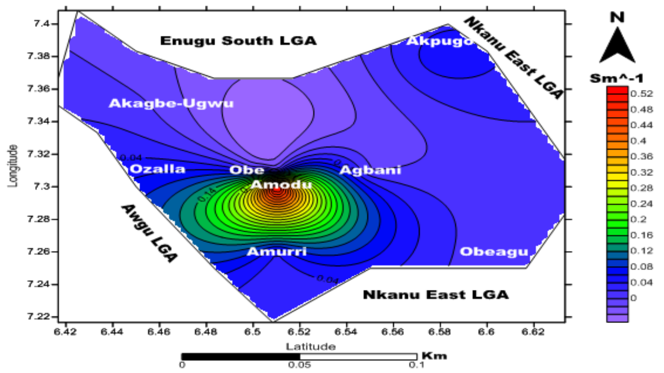

Figure 10. Electrical conductivity map of the study area.

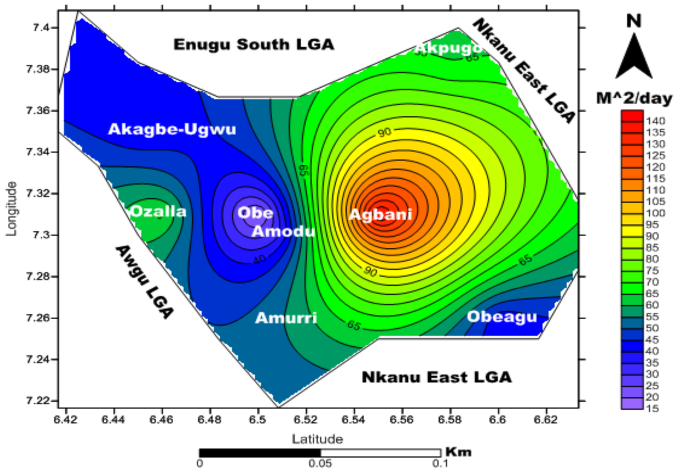

Figure 11. Aquifer transmissivity map of the study area.

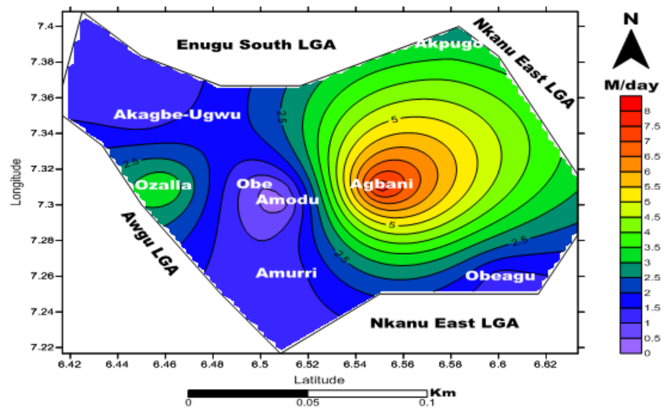

Figure 12. Hydraulic conductivity map of the study area.

8.2. Aquifer Protective Capacity Evaluation

The Dar-zarrouk parameters, Transverse resistance (T) and Longitudinal conductance(S), obtained from the geoelectric layer parameters (equation 1&2) respectively. These were used to determine the overburden protective capacity of the aquifer units in the study area. The longitudinal conductance map (Figure 9) computed from equation 2 for all the VES locations.This was utilized in the evaluating the overburden protective capacity in the study area. The earth subsurface acts as a natural filter to percolating fluid. Hence, its ability to retard and filter percolating ground surface polluting fluid is a measure of its protective capacity (Olorunfemi et al., 1999).

The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underling aquifer (Abiola,et al., 2009). The values of longitudinal conductance(S) obtained from the study area, were used to generate the longitudinal conductance map (Figure 9) using SURFER 10 Contouring Toolkits. Aquifer overburden protective capacity could be zoned (Table 1) into excellent and good protective capacity (Oladapo and Akintorinwa, 2007). Zones where the conductance is greater than 10Ω-1 are considered zones of excellent protective capacity. The portion having conductance values ranging from 0.7 to 9.9Ω-1 are considered zones of good protective capacity. Also, the portion ranging from 0.2 to 0.69Ω-1 was classified as zone of moderate protective capacity; that ranging from 0.1 to 0.19Ω-1 was classified as weak protective capacity and the zone where the conductance value is less than 0.1Ω-1 was considered poor protective capacity. However, in the study area, the protective capacity is zoned into excellent and good protective capacity rating (Figure 13). Areas around the Agbani-Obeagu and part of Akagbe-Ugwu and Amurri, fall within the zone of good protective capacity with a relative overburden depth of 40-95meters, while areas around around Amodu-Ozalla-Obe axis fall within excellent propective capacity at overburden depth of 90-180meters.

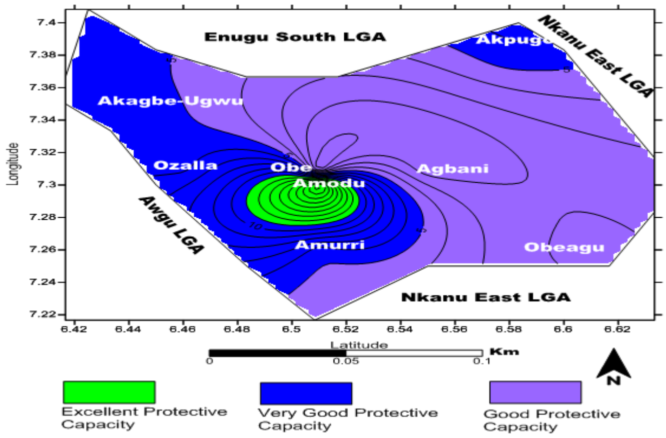

Figure 13. Overburden (Aquifer) protective capacity map of the study area.

Table 1. Longitudinal Conductance/Protective Capacity Rating (Oladapo and Akintorinwa, 2007).

Longitudinal Conductance(Ω^{-1})	Protective Capacity Rating
>10	Excellent
5 - 10	Very good
0.7 – 4.9	Good
0.2 – 0.69	Moderate
0.1 – 0.19	Weak
<0.1	Poor

9. Conclusion

The use of geoelectric sounding has proved useful for estimating aquifer hydraulic properties and protective capacity of overburden unit. The computed aquifer transmissivity and hydraulic conductivity correlates favourably with available borehole data. Values of longitudinal conductance from resistivity information gave a protective capacity rating of good to excellent.

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