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Georesistivity, Aquifer Hydraulic Characteristics and Groundwater Potential Zones of Mpu Town and Environs, Enugu State, Nigeria.

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ABSTRACT

This work employs geoelectrical method to evaluate the resistivity of subsurface materials, characterize the aquifer hydraulic properties and delineate potential groundwater zones at Mpu town and environs, Enugu state, Nigeria. Mpu lies within latitudes 05° 57' 0'' and 06° 02' 0'' N and longitude 007° 40' 0'' and 007° 45' 0''E with area extent of 55.37square km. The study area is underlain by Awgu Shale, with its lateral arenaceous facie; Owelli Sandstone outcropping north of Oduma. Fifteen (15) vertical electrical soundings (VES) were carried out within the study area, using the Schlumberger electrode configuration. Interpreted VES data shows predominance of Q and H curve type, indicating a fractured – clay/shale subsurface. Georesistivity layers show a clay/shale - sandy shale - dry shale - fractured shale sequence. Contour maps of resistivity, thickness, overburden depth, transverse resistance, longitudinal conductance, aquifer transmissivity and hydraulic conductivity were constructed. Computed aquifer transmissivity show trends with good signals and recorded transmissivity value of 135m^2/day. Thus, indicating moderate yield. Low yield areas correspond to high hydraulic conductivity zone. Low and moderate groundwater potential zones were delineated. Comparisons of georesistivity sections and various contour maps show fairly good match in analysis. The study will serve as a useful guide for groundwater development in the study area.

Introduction

Mpu town is located in Aninri local Government Area, Enugu state, Nigeria (Figure 1). Globally it lies within latitude 05° 57' 0'' and 06° 02' 0'' N and longitude 007° 40' 0'' and 007° 45' 0''E with area extent of 55.37square km. One of the indices for observing population growth is the demand for portable and sustainable water supply. Surface waters like rivers, streams, springs, etc may not be sustainable in dry seasons. Due to the recent emphasis on Agriculture by the federal republic of Nigeria, the population in Mpu and environs has risen sporadically.

Figure 1. Map of Nigeria showing the study area.

This is because arable lands exist in the study area. Based on the above factors, there is now high demand for sustainable water supply. Groundwater remains a sustainable source of water supply, to proffer solution to the inhabitant of Mpu and its environs.

In the present study, an attempt has been made to evaluate the resistivities of the underlying rocks in the study area, with the view to understanding their hydraulic properties, in terms of groundwater development.

Physiography and Drainage

Topographically, the study area is undulating (Figure 2) with a maximum height of 120m above sea level.

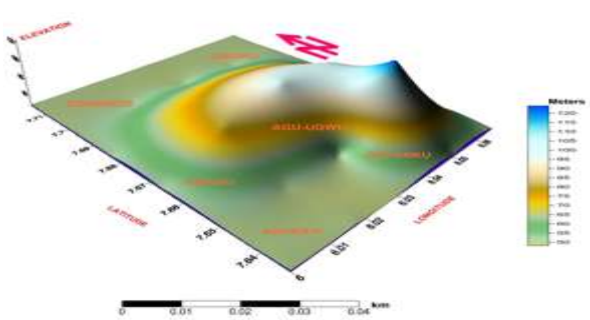

Figure 2. Surface map of the study area.

The sandstone ridges in Mpu area form the topographic highs while the adjacent low lands are occupied by shaley terrain.

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The highest contour in this area amounts to about 450ft and is of Mpu Sandstone member of the Owelli Formation.

The Awgu Shale Formation stands relatively in a lower elevation and slopes south-east. The ridges are linearly aligned in a general form that is from east to west in direction. The low lands, which is Awgu Formation provides good soil that promotes agricultural activities.

Drainage is controlled by the Asu River and its tributaries, especially the Ehu and Ivo drainage system (Figure 3).

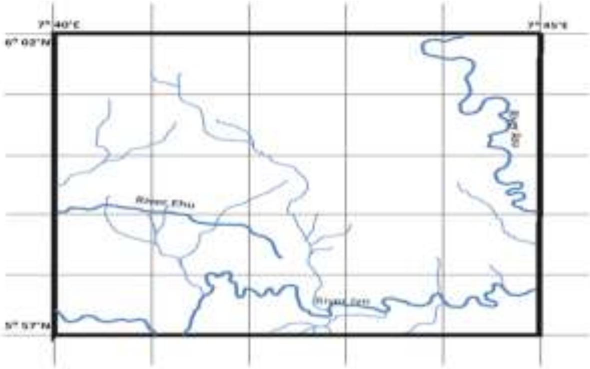

Figure 3. Drainage map of the Study area.

Areas of moderate relief are often characterized by intermediate condition of erosion between the extremes in areas with high relief on one hand and low relief on the other where the underlying Abakaliki shale is easily eroded.

Vegetation and Climate

The study area falls within the rain forest and the savannah belts of the South eastern Nigeria (Figure 4).

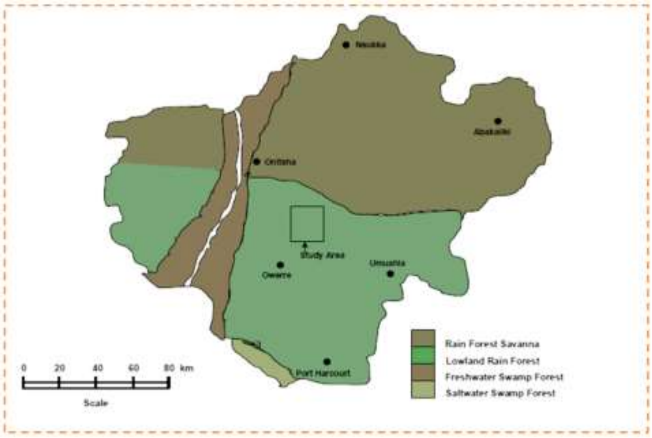

Figure. 4. Vegetation map of Southern Nigeria (Igbozuruike, 1975).

The dominant vegetation is characterized by scrubs, with abundance of palm trees, particularly in the Southern and Central zones. Two main seasons dominate in the climate of Mpu area, just like other parts of Eastern Nigeria. These are the rainy season, which begins in late April and terminates in early October; and the dry season which lasts from late November to early April.

Mpu area is conducive and ideal for field studies as it has a tropical climate with a mean temperature of about 26°C (Figure 5). The months of November to March are usually harsh on the human skin as they provide the hottest and driest days. Rainfall duration is usually between April to October, though most intense in July. The Rainfall at this time is usually very heavy and could average between 80-100 inches. Field study in this area is most appropriate towards the months of October and December because during this period there is little or no rainfall.

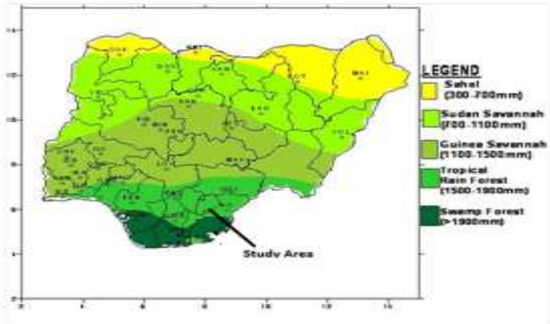

Figure 5. Climate map of Nigeria (Igbozuruike, 1975).

Field study should be discouraged during rainy season because the swampy terrains make work extremely tedious.

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 6).

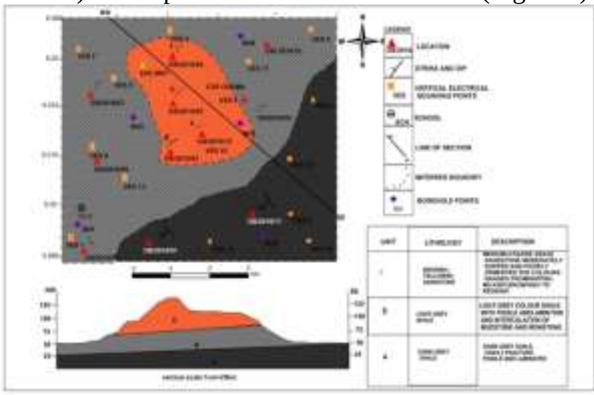

Figure 6. Geologic map of the study area showing VES and BH locations.

The unit consists of bluish grey, well bedded shales with occasional intercalations of fine-grained, pale yellow, calcareous sandstones and shaley limestones (Reyment, 1965). It is about 900m thick and gently folded.

Hydrogeology

The study area falls within the Cross River Basin, which is hydrogeologically a problematic groundwater basin (Affordable, 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 Asu River Formation being the oldest, underlain by the basement complex rocks. With the exception of Awgu and Ezeaku Formations, all these rock units are very poor aquifers. The sandstone units 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 bearing units in the study area.

Methodology

Theoretical Basis

Georesistivity data are acquired using electrical resistivity techniques. These techniques are based on the resultant effect of the flow of electric current through subsurface earth materials. The measurement of resistivities of the subsurface material involves the supply of direct current into the ground through a pair of current electrodes and the resulting potential through another pair of electrode called potential electrodes. (Figure 7). With an electrical current passed into the ground and two potential electrodes to record the resultant potential difference between them, we can obtain a direct measure of electrical impedance of the subsurface material (Burger, 1992).

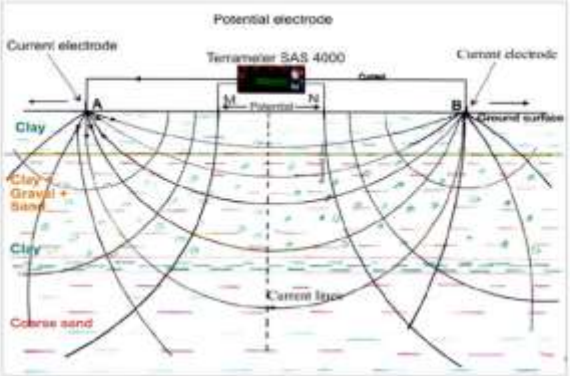

Figure 7. Principles of Resistivity measurements (Robinson and Coruh, 1988).

The resistivity of the subsurface material observed is a function of the magnitude of the current, the recorded potential difference and the geometry of the electrode array used (Amadi, et al, 2011). Measurement of resistivity is, in general, a measure of water saturation and pore space connectivity. Resistivity measurements are associated with varying depths relative to the distance between the current and potential electrodes in the survey and can be interpreted qualitatively and quantitatively in terms of a lithologic and/or geohydrologic model of the subsurface (Amadi, 2010).

Data Acquisition

A total of fifteen (15) vertical electrical sounding (VES) was acquired within and outside the study area (Figure 6). Some were stationed very close to existing boreholes, for correlation purposes. The Schlumberger electrode configuration was employed (Figure 8), with maximum current electrode separation ranging from 400 to 600 m. The equipment used for the fieldwork was the versatile ABEM SAS 4000 resistivity meter.

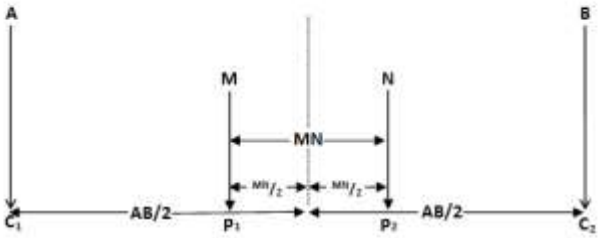

Figure 8. Schlumberger electrode configuration.

Data Processing and Interpretation

After acquiring the data, the measured field resistance (R) in ohms was converted to apparent resistivity in ohm-meter by multiplying resistance (R) by the geometric factor (K). The computer program RESOUND was used to interpret all the data sets obtained. From the interpretation of the resistivity data, it was possible to compute for every VES station (Table 2), the longitudinal conductance (S).

$S = h/\rho$ (1)

And transverse resistance (R)

$R = h*\rho$ (2)

Where h and ρ 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 analyses of aquifer hydraulic 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 kσ (hydraulic conductivity) remain fairly constant.

Resistivity Curve Types

The form of resistivity curve type 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 (Table 1) from VES 1-15 include: HQK, QQHA, HHA, QQ, HHK, QAAA, QH, QQHA, HAKH, KH, HKH, HHKH, HKQH and QAKH curve types respectively. Frequency distribution of the curve types were computed (Figure 9). The first dominant curve type is H curve type. This indicates fractured shale horizons which are targets for groundwater exploration. The second dominant curve is Q. This is indicating a shaley terrain.

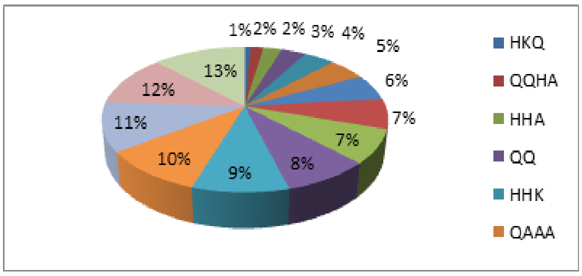

Figure 9. Frequency distribution of VES curve types in the study area.

Estimating Aquifer hydraulic characteristics

Both parameters R 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 characterize the aquifer hydraulic properties (transmissivity and hydraulic conductivity) and its variation within a geologic formation including places where no boreholes/records are available (Table 2).

Results and Discussion

Georesistivity sounding.

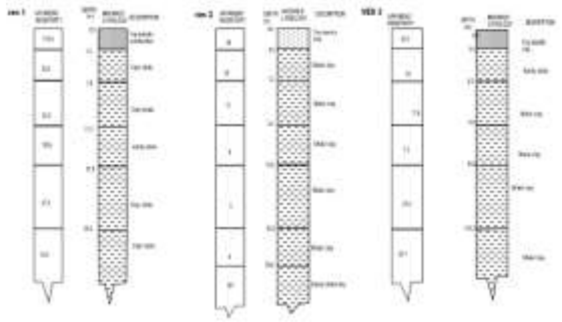

Figure 10a. Geoelectric layer section for VES 1, 2, 3 in the study area.

Table 1. Summary of VES Data in the study area.

S/N	L0CATIONS	NUMBER OF LAYERS	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	T_1	T_2	T_3	T_4	T_5	T_6	D_1	D_2	D_3	D_4	D_5	D_6	Curve type
1	MPU1	6	701.6	32.5	52.2	138.6	27.9	16.2		1.0	0.9	9.6	16.1	67.5		1.0	1.9	11.5	27.6	95.2	-	HKQ
2	ODUMA1	7	50.0	35.0	15.0	6.0	5.0	8.0	125.0	0.8	0.4	1.8	12.0	15.0	28.0	0.8	1.2	3.0	15.0	30.0	58.0	QQHA
3	MPU2	6	20.3	7.9	13.9	7.3	27.9	29.1	-	3.4	4.8	5.9	54.1	75.4	-	3.4	8.2	14.1	68.2	143.6	-	HHA
4	NENWE1	4	554.7	17.5	7.3	1.7	-	-	-	1.0	5.5	54.2	-	-	-	1.0	6.5	60.7	-	-	-	QQ
5	NENWE2	6	258.9	42.4	114.8	9.3	341.2	14.0	-	1.5	5.6	14.6	37.3	54.9	-	1.5	7.1	21.6	58.9	113.8	-	HHK
6	AGUENYI1	7	15.0	5.0	3.0	5.0	8.0	15.0	80.0	0.8	1.4	2.8	18.0	17.0	18.0	0.8	2.2	5.0	23.0	40.0	-	QAAA
7	NENWE3	5	468.5	88.6	6.9	3.8	10.4	-	-	3.5	13.6	12.2	51.5	-	-	3.5	17.1	38.3	39.8	-	-	QH
8	ODUMA3	7	380.0	220.0	100.0	20.0	5.0	105.0	1152.0	0.8	1.2	2.5	10.5	25.0	20.0	0.8	2.0	4.5	15.0	40.0	60.0	QQHA
9	ODUMA4	7	5.0	2.0	2.0	6.0	10.0	10.0	38.0	0.6	1.2	1.2	2.0	7.0	42.0	0.8	1.8	3.0	5.0	12.0	54.0	HAKH
10	UBURU1	7	45.0	10.0	14.0	23.0	28.0	4.0	16.0	0.8	1.2	3.0	10.0	28.0	52.0	0.8	2.0	5.0	15.0	43.0	95.0	HAKH
11	NENWE4	5	171.1	409.4	35.0	14.8	87.1	-	-	2.1	5.1	5.0	41.5	-	-	2.1	7.2	12.2	53.7	-	-	KH
12	UBURU2	7	36.0	40.0	38.0	8.0	9.0	4.0	7.0	0.5	1.5	2.0	20.0	28.0	46.0	0.5	2.0	4.0	24.0	52.0	98.0	HKH
13	AGUENYI2	7	16.0	5.0	6.0	6.0	13.0	10.0	13.0	0.8	1.2	2.0	13.0	35.0	43.0	0.8	2.0	4.0	17.0	52.0	95.0	HHKH
14	MPU3	7	32.0	8.0	12.0	22.0	20.0	9.0	16.0	0.8	1.2	3.0	7.0	26.0	54.0	0.8	2.0	5.0	12.0	38.0	92.0	HKQH
15	MPU4	7	165	10.0	5.0	6.0	15.0	1.0	12.0	0.8	1.7	1.5	36.6	25.0	28.0	0.8	2.5	4.0	40.0	65.0	93.0	QAKH

Table 2. Summary of the Geoelectric parameters and the computed aquifer hydraulic properties of the study area.

S/N	LOCATION	VES NO	AQUIFER RESISTIVITY (ΩM)	OVER BURDEN DEPTH(M)	THICKNESS (M)	TRANSVERSE RESISTNCE (T)(ΩM2)	LONGITUDINAL CONDUCTANCE (S) (Ω-1)	EARTH CONDUCTIVITY	ESTIMATED TRANSMISSIVITY (M3/DAY)	ESTIMATED HYDRAULIC CONDUCTIVITY (M/DAY)
1	MPU1	VES1	16.2	95.2	67.5	5346.68	2.7485	0.0617	133.667	1.98
2	ODUMA1	VES2	125	58	28	452	8.64742	0.008	11.3	0.4
3	MPU2	VES3	29.1	143.6	75.4	2687.55	11.313	0.0344	67.188	0.89
4	NENWE1	VES4	1.7	60.7	54.2	1046.21	7.7408	0.5882	26.1552	0.48
5	NENWE2	VES5	14	113.8	54.9	4265.24	18.0878	0.0714	106.631	1.94
6	AGUENYI1	VES6	80	58	18	523.4	8.1916	0.0125	13.085	0.72
7	NENWE3	VES7	10.4	39.8	51.5	5040.69	16.7861	0.09615	126.017	2.44
8	ODUMA3	VES8	1152	60	20	3253	5.7481	8.6806	81.325	4.06
9	ODUMA4	VES9	38	54	42	509.8	6.5533	0.0263	12.745	0.3
10	UBURU1	VES10	16	95	52	1312	14.7869	0.0625	32.8	0.63
11	NENWE4	VES11	87.1	53.7	41.5	3236.43	2.9717	0.0115	80.9101	1.94
12	UBURU2	VES12	7	98	46	750	17.2155	0.1429	18.75	0.4
13	AGUENYI2	VES13	13	95	43	993.8	9.7823	0.0769	24.845	0.57
14	MPU2	VES14	16	92	54	1231.2	8.0442	0.0625	30.78	0.57
15	MPU3	VES15	12	93	28	775.5	36.1416	0.0833	19.3875	0.69

Geoelectrical layers were constructed for all VES locations (Figure 10a-e), in order to infer lithologies from the interpreted layer resistivity models. This is relating the layer resistivity values to geology, by qualitatively interpreting the resistivity values (Telford, et al, 2001).

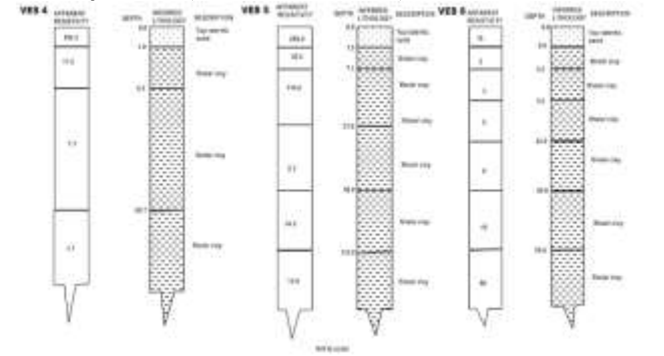

Figure 10b. Geoelectric layer section for VES 4, 5, 6 in the study area.

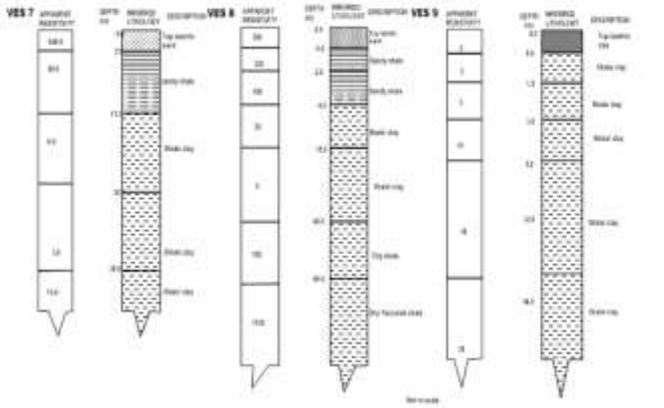

Figure 10c. Geoelectric layer section for VES 7, 8, 9 in the study area.

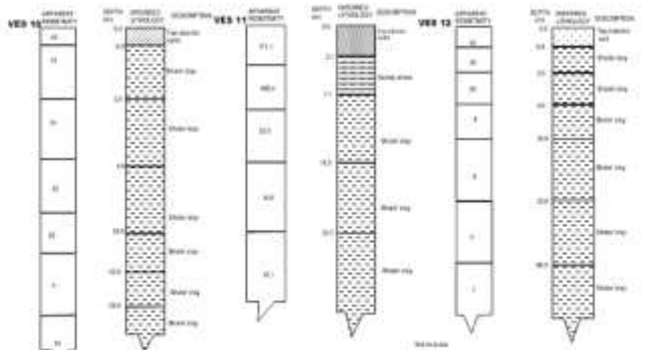

Figure 10d. Geoelectric layer section for VES 10, 11, 12 in the study area.

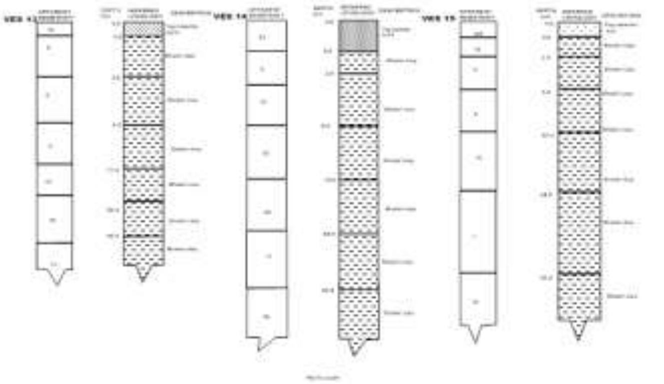

Figure 10e. Geoelectric layer section for VES 13, 14, 15 in the study area.

The inferred lithologies show a clay/shale - sandy shale - dry shale - fractured shale sequence. This is comparable to the local geology (Figure 6). The study is predominantly underlain by clay/shale unit. Therefore, groundwater development may be dicey, expect accurate location of the fracture zones are done. Contour maps of the apparent resistivity, the thickness, 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. These contour plots were done using surfer 10 contouring software Toolkits.

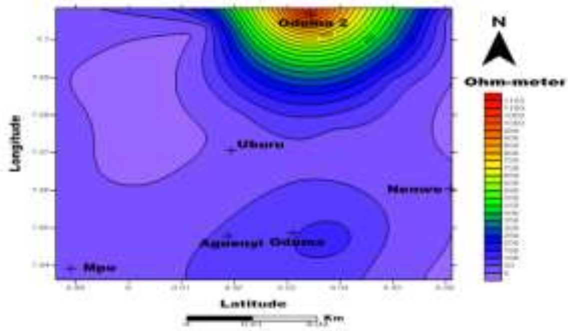

Figure 11. Apparent resistivity map of the study area.

Apparent resistivity variation (Figure 11) show high resistivity at the northern fringe of Oduma 2. Low resistivity trend NW-SE direction, occupying towns around Uburu, Nenwe and Mpu. The high resistivity is marked by the conical hills observed at the northern fringe of Oduma, during the fieldwork. The conical hills are consists of moderately consolidated sandstones and capped by ironstones.

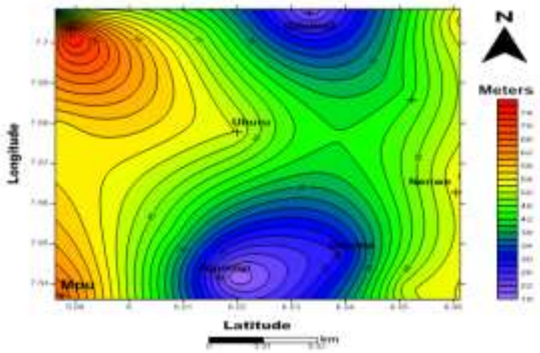

Figure 12. Aquifer thickness map of the study area.

Aquifer thickness (Figure 12) is variable across the study area. It ranges from 18meters to 74meters. Aquifer is thicker at north and southern fringes and lesser in thickness at the central part of the study area. However, areas with thicker aquifer correlate favourably with areas of high resistivity values, hence, may be possible areas for groundwater development.

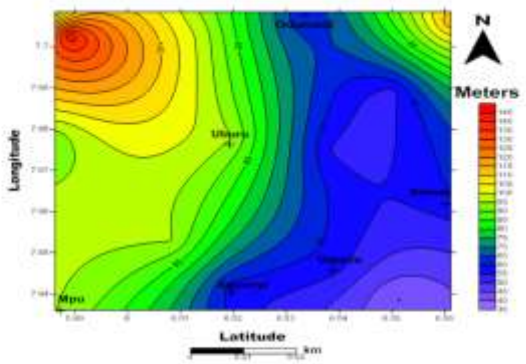

Figure 13. Overburden depth map of the study area.

The overburden depth (Figure 13) includes all rocks materials above the aquiferous horizon or bedrock. The depth to the aquiferous horizon varies from 35meters to 145meters. The overburden depth decreases from NW to SE. The variation of the transverse resistance and longitudinal conductance computed from the VES interpretation are shown in Figures 14 and 15 respectively. Maximum values of transverse resistance are observed around Oduma – Mpu – Aguenyi axis. While minimum values transverse resistance trend Uburu – Nenwe axis.

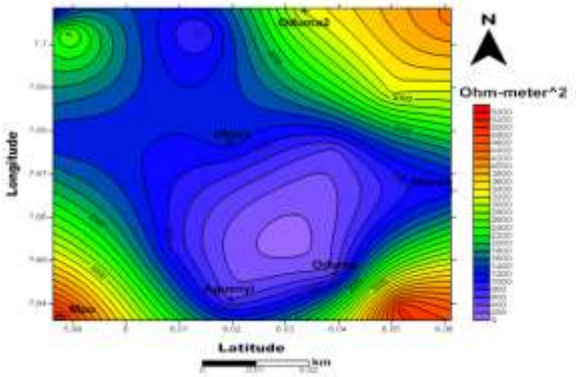

Figure 14. Transverse resistance map of the study area.

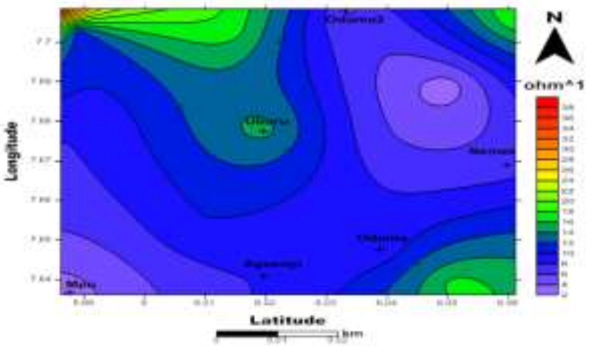

Figure 15. Longitudinal conductance map of the study area.

Aquifer Hydraulic Characterization

The Dar-Zarrouk parameters, Transverse resistance (R) and Longitudinal conductance (S), obtained from the geoelectric layer parameters (equation 1 and 2) respectively were used to characterize the aquifer hydraulic properties in the study area. Using equation 3, it was possible to compute aquifer transmissivity and aquifer hydraulic conductivity. Computed aquifer transmissivity (Figure 16) show trends with good signals, stretching the axis of Mpu – Aguenyi – Oduma axis, with a recorded aquifer transmissivity value of 135m^2/day. Hence, indicating a moderate potential aquifer. Uburu – Nenwe axis show possible low yield zone. This zone corresponds to the high hydraulic conductivity (Figure 17).

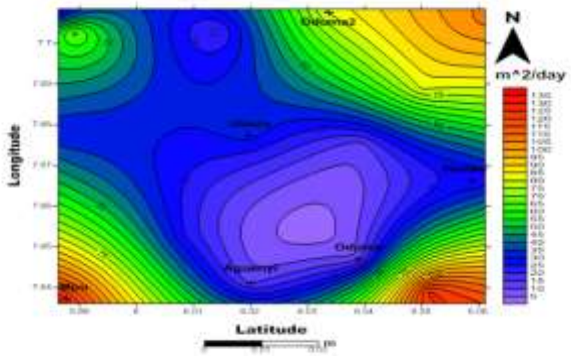

Figure 16. Computed Aquifer Transmissivity map of the study area.

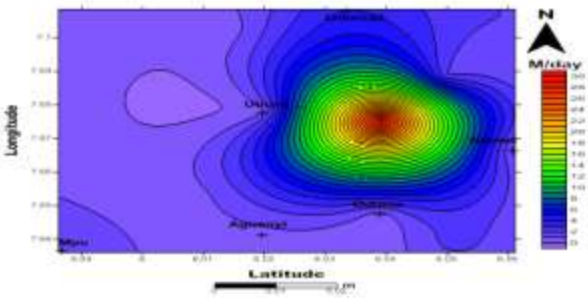

Figure 17. Computed aquifer hydraulic conductivity map of the study area.

Groundwater Potential Evaluation

The groundwater potential zones was delineated (Figure 18), based on Gheorghe (1978) aquifer transmissivity classification. Groundwater potential is a function of complex inter-relationship between geology, physiography, groundwater flow pattern, recharge and 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. Two potential groundwater zones were delineated. The zones are low and moderate potentials. The country around Oduma and Mpu are of moderate potential, while Nenwe, Uburu and Aguenyi are within the low potential zones. Development of groundwater in the study area may be dicey. However an integrated geophysical exploration approach is suggested.

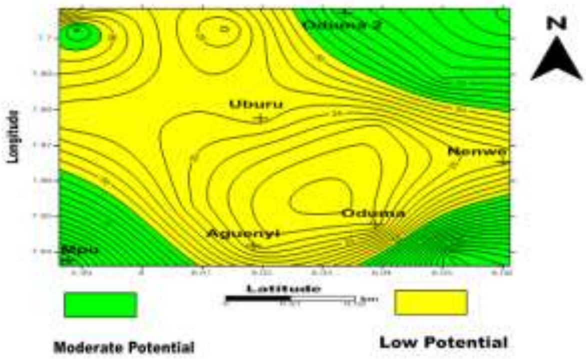

Figure 18. Groundwater potential zones map of the study area.

Conclusion

The use of geoelectrical method has proved useful for evaluating the resistivity of the subsurface materials and characterizing the aquifer hydraulic properties in the study area. A true picture of the subsurface rock types has been presented. Groundwater dispositions show moderate to low yield aquifer. However, for a better yield, integrated geophysical exploration techniques are required to locate fracture zones. The various contour maps and georesistivity sections will serve as a useful guide for groundwater development in the study area.

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