AN INVESTIGATION OF GROUNDWATER POTENTIAL OF SOUTHERN ANAMBRA STATE, NIGERIA USING ELECTRICAL RESISTIVITY SOUNDINGS

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ABSTRACT

An electrical resistivity sounding has been employed on investigation of groundwater potentials within the southern Anambra State, Nigeria.Fifty-two vertical electrical sounding data were obtained within the area using Schlumberger array. The resistivity data which were interpreted with the aid of IX1D Interpex software formed the basic data for calculating and modeling aquifer characteristics. The Atomic Absorption Spectrometer (AAS) machine was used to analyze the physico-chemical components of the fourteen groundwater samples collected around the area. The VES interpretations revealed that the forth to sixth layers are delineated as prospective aquifer units with depth range from 44.36 meters to 215.08 meters across the study area. The computed aquifer parameters from the interpreted VES data show 0.053 to 6.189 m/day hydraulic conductivity and 1.824 to 430.628m^2/day transmissivity. The water analyses reveal that mostly all the parameters analyzed fall within the acceptable limit for drinking water. Three zones of groundwater productivity potential have been obtained in the area: high, intermediate and low, but the study area is predominately of intermediate transmissibility, meaning that the groundwater potentials can serve for local water supply. The groundwater flows within the area trend majorly in NE-SW direction. The groundwater vulnerability model reveals that the gap between the peaks of the watertable and the topography in the area is 140m, which implies that the vertical movement of any contaminant will be strongly retarded by the earth materials before reaching the aquifer. The study concludes that the aquifers within the study area are capable of yielding enough water that would serve for local water supply/scheme which is satisfactory for human consumption.

Keywords: VES curve, Aquifer, Hydraulic conductivity, Transmissivity and Groundwater vulnerability.

INTRODUCTION

Water is the most essential resource in the sustenance of life. Indeed, water is life and the health of any community depends largely on the quality of water available to the community. It constitutes an inevitable parameter for extensive socio-economic development of any nation (Gyan-Boakys, 1999). The availability and access to fresh potable water is an important issue all over the world and the southern Anambra State is no exception. Water exists on the surface of the earth as streams, rivers, lakes, ponds etc. as well as underground, where it is referred to as groundwater. All society such as the southern Anambra State depends on water resources in numerous ways, such as domestic, industrial, agricultural, and construction purposes. Historically, water has played a significant role in the transmission of human disease. Typhoid fever, cholera, infectious hepatitis, bacillary and amoebic dysenteries and many varieties of gastrointestinal disease can all be transmitted by water. The seasonal occurrence of water borne disease outbreaks however points out to the continuing importance of assessment of quality of private and public water supplies in any environment.

Actually, groundwater constitutes the only reliable water supply for drinking and irrigation purposes and it remains the largest available source of fresh water (Anakwuba*et al.*, 2014). It is exceptionally important as a source of relatively low-cost and high-quality municipal and domestic water supply in urban centres of the developing world (Okoro*et al.*, 2010). However, recent studies have shown that special care and skills are needed for its exploration and exploitation. Even though it is generally a renewable resource, extra effort is necessary to determine the location(s) for its development and the extent of the development in order to avoid over-exploitation which may lead to serious repercussions. For example, in the study area where Imo

Shale and Nanka Sand are thick, there is need to make maximum utilization of the available water resources. It is therefore necessary to employ quick and efficient methods for groundwater exploration especially in these days of scarce resources. It has the advantage of non-destructive effect on the environment, cost effective and less ambiguous interpretations of results when compared to other geophysical survey methods (Todd, 1980). This method is the electrical resistivity which is an aspect of geophysical methods of exploration.

Furthermore, the study area is underlain by various geological formations that have hydrogeological implications. The depths of aquifers in these geological formations vary widely. Despite the fact that Anambra State government has spent heavily in providing potable and sustainable water supply for her populace by drilling many water boreholes around the state, there are no functional boreholes within some of the communities like Urum and Mgbakwu of the Northern part of the study area.

As a result of the aforementioned, and especially the satisfaction of the demands of the growing population of the study area, the search for potable source of water (both quantity and quality) becomes apparent. In this study therefore, an Investigation of groundwater potential of southern Anambra State, Nigeria using electrical resistivity soundings is being carried out. The findings of the study will be beneficial to the immediate communities who depend on the waters for their livelihood, all stakeholders in the water sector and the government. In addition to addressing the water quality of the area, the numerous resources being wasted in government projects with respect to borehole development will be highly checked. The study will also provide accurate depths of water boreholes and become a pilot survey for all water related projects in all the communities within Southern Anambra State.

Location and Geology of the Study Area

The Southern Anambra State is located in the South-Eastern part of Nigeria. It is bounded between Longitudes 6^o40^l and 7^o20^l E and Latitudes 5^o45^l and 6^020^l N (Fig. 1) and contains more than fifty different communities including the State Capital Territory, Awka. It covers an area of about 4950 square kilometres (75km x 66km). The study area is bounded with four (4) different states namely, Enugu and Delta States at the eastern and western parts respectively; Abia and Imo States at the southern part. The study area has numerous good networks of roads (both federal and state) that made accessibility possible. Some of the roads include Enugu-Onitsha Expressway, Onitsha-Owerri Express-way, Awka-Onitsha Old Road, Awka – Umunze, Awka – Ekwulobia –Uga Road, Nnewi – Okigwe Road, Onitsha-Aguleri-Omasi Road, UmunzeNibo-Ndiowu main road, Oko-Ufuma Road, etc.

Geologically, the study area is located within the Anambra Basin and the Niger Delta Basin (Fig. 1). The Anambra Basin was deposited and filled in two sedimentary phases: transgression and sea regression. The transgression, which occurred during the Campanian-Maastrichtian period, gave rise to deposition of Nkporo Shale, Mamu Formation, Ajalli Sandstone, Nsukka Formation and Imo Shale. Sea regression as a result of the sea becoming shallower lead to the deposition of Mamu (Lower Coal Measures) followed by the deposition of whitish, friable Ajalli Sandstone. Later, the Nsukka Formation (Upper Coal Measure) was deposited between upper Maastrichtian and early Paleocene. During the Paleocene, another sea transgression across the whole Southern Nigeria was recorded and this terminated the advance of the upper Cretaceous Niger Delta. The main rock unit of this age in the Anambra Basin is the Imo Shale, though it is found to outcrop in an actuate belt from Western to Eastern Nigeria. The end of Paleocene witnessed another sea regression and the deposition of sediments of Tertiary Niger Delta. The Eocene however showed continued regression and the deposition of Ameki Formation and its lateral equivalent, Nanka Sands (Nwajide, 2013). The regression of this period was as a result of the third tectonic episode in Nigeria. By the end of Eocene, the Anambra Basin was filled with mainly continental sediments and the Niger Delta prograded southwards towards the Gulf of Guinea marking the beginning of the modern Niger Delta.

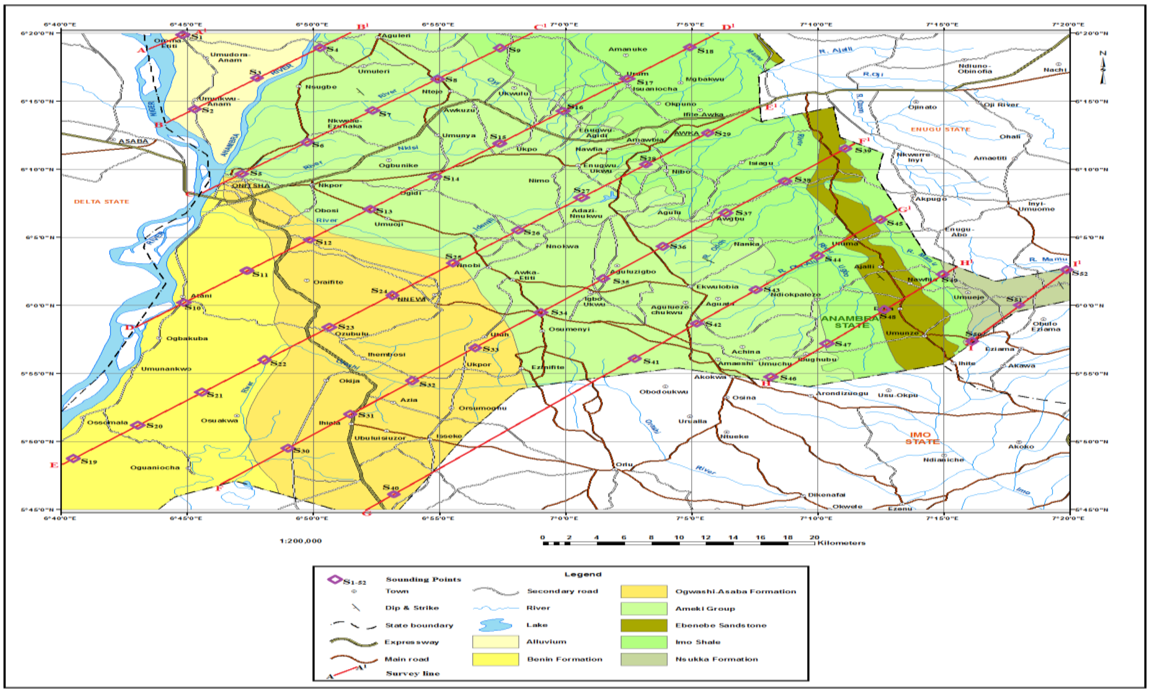

Figure 1: Location and Geologic Map inscribed with Survey lines and Sounding Points of the study area

METHODOLOGY

Combined field and workstation based approaches were used in this study to achieve the set objectives. These include detail field data gathering at different sounding areas; identification of geological and topographical features as well as delineation of depth to the prospective aquifer layers of the area and analysis proper. Geological and geophysical mapping were done using any existing geological map, obtained VES data and borehole data within the study area. For geological and topographic features, different geologic units and formations were determined using the rock types and vegetation distribution respectively.

Meanwhile, the Schlumberger array was used to collect Vertical Electrical Sounding (VES) data (Table 1) along eight (8) different survey lines with total of fifty-two (52) survey stations placed at equal intervals of 6 km apart and maximum current electrode spread of 300m (Fig. 1) using resistivity meter named the Petro-Zenith. The apparent resistivity values obtained from the measurements will be plotted against half the current electrode spacing on a bi-logarithmic graph in order to determine the apparent resistivities and thicknesses of various layers penetrated using resistivity inversion software IX1D that was developed by Interpex Limited. The software has been used in many similar research works and has proven very effective for groundwater investigations (Anakwuba*et al.*, 2014, Obiabunmo*et al.*, 2014; Anizoba*et al.*, 2015; Chinwuko*et al.*, 2015; Chinwuko*et al.*, 2016; Osele*et al.*, 2016; Amadi*et al.*, 2017; Udoh*et al.*, 2021; Anakwuba*et al.*, 2021).

Usually, the VES results formed the input data for estimating and modeling aquifer parameters. As a result, the hydraulic conductivity (K) of the aquifer layers across the area was estimated using equation generated by Heigold*et al.* (1979):

$$K = 386.40 R_{rw}^{-0.93283} \quad (1)$$

Where, K= Hydraulic conductivity; R_{rw} = *Apparent r*esistivity of the layer.

Also, the aquifer transmissivity (T) across the area was estimated using the equation generated by Niwas and Singhal (1981):

$$T = Kh \quad (2)$$

Where, T = Aquifer transmissivity; K= hydraulic conductivity; h =Leachate thickness.

More so, the distribution maps of the aquifer parameters were generated such that, the migration conduits of the groundwater could be delineated. Cross sections along the watertable map and elevation map were superimposed in order to model the groundwater vulnerability path linked with them.

Nevertheless, the water analysis involved laboratory analyses of the collected water samples according to world health organization (WHO) standard practice for physico-chemical and microbial properties. Fourteen water samples were collected and the plastic containers used were rinsed three times with the sample to be collected. The samples were preserved using a plastic cooler with ice to maintain the temperature such that there would be no change in the constituent of the sample. The water was then taken to the Springboard Laboratory Awka, Anambra State, within 24 hours for analyses. Cation analysis was done using Atomic Absorption Spectrometer (AAS), while the anions were analysed using the Ultraviolet (UV) Spectrophotometer. Some parameters such as temperature, pH and turbidity were measured at in-situ using the portable thermometer, pH meter and turbid meter respectively.

Table 1: Representation of VES Data Acquisition

AB/2 (m)	MN/2 (m)	S1 (Ωm) Oroma-Etiti	S2 (Ωm) Anam	S15(Ωm) Ukpo	S44(Ωm) Ufuma	S52(Ωm) Owerre-Ezukala
1.5	0.5	160.39	154.45	1066.72	1350.10	1850.01
2	0.5	190.27	167.9	1063.23	1300.21	1399.56
3	0.5	240.2	252.38	729.53	1250	1189.76
4	0.5	290.7	384.16	732.74	1151	1030
6	0.5	412.84	421.17	914.67	1185.13	980.10
8	0.5	443.18	445.16	1006.72	1280.11	1109.01
10	0.5	649.34	720.42	1291.94	1550.10	1280.10
15	0.5	841.79	709.21	1594.96	1545.00	1510.06
15	3.5	607.12	1130.11	1340.40	1775.00	1680.01
20	3.5	584.31	643.77	1473.21	1800.16	2201.07
25	3.5	442.77	439.28	1636.37	2101.00	3000.08
30	3.5	226.40	263.11	2013.67	2300.13	3410.23
40	3.5	214.92	256.54	2701.28	2410.33	5011.21
50	3.5	149.51	58.36	4221.05	2310.11	5502.11
50	14	110.42	52.09	5012.80	2000.41	5486.17
75	14	80.94	61.83	5311.02	2045.33	5972.96
100	14	67.97	45.88	5740.78	1900.1	6001.13
125	14	47.97	44.28	6234.4	1742.22	6114.07
150	14	103.89	71.7	4853.44	1607.48	6345.12
175	14	192.27	119.25	4336.14	1501	5502.18
200	14	280.72	188.22	3963.73	1310.5	5317.09
225	14	386.56	201.46	3416.5	1266.52	5098.75
250	14	347.32	192.11	2671.36	1153.01	4181.32
275	14	123.16	100.36	2011.32	1100.12	4011.41
300	14			1991.36	532.211	3721.55

RESULT AND DISCUSSION

VES Curve Interpretation

Fifty two vertical electrical sounding (VES) curves obtained from the study area (Fig. 2) were interpreted qualitatively and they varied considerably across the study area. The results revealed that the study area has seven (7) typical curve types (Table 2) according to Telford *et al*., 1998, Anakwuba*et al*., 2014, Chinwuko*et al*., 2015, and Anizoba*et al*., 2015. The most predominant among these curve types in the studyarea are HK and KHK-curve types with 28.8% and 23.1% respectively, whereas the remaining 48.1% belongs to the other five curve types within the study area (Fig. 2 and Table 2).Generally,the generated resistivity curve types show typical H-curves (namely; H, HK, KH, and HKH) which are quite common in a sedimentary environment for multilayer structures as established by previous authors such as Anakwuba*et al*. (2014), Chinwuko*et al*. (2015) and Anizoba*et al.* (2015).

Table 2: Identified curve types within the study area

Curve Types	No of Curve Types	Percentage
HKH	3	5.8
H	8	15.4
AK	3	5.8
KH	10	19.2
Q	1	1.9
KHK	12	23.1
HK	15	28.8
Total	52	100

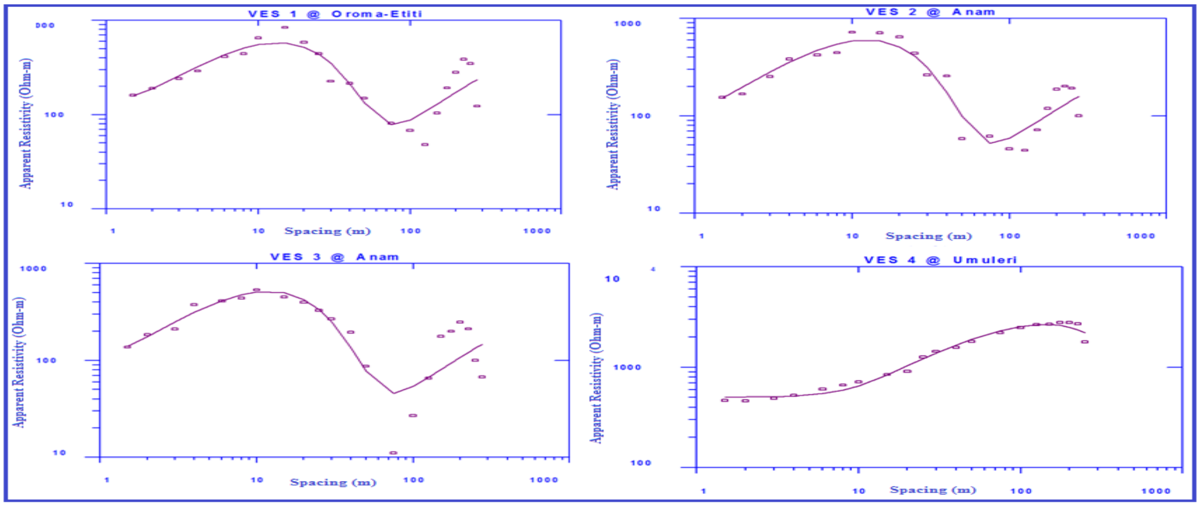

Figure 2: Geo-electric curves within the study area

Correlation of Geo-electric and Borehole sections

The correlation of interpreted geo-electric section and lithologic section from the borehole located close to some of the sounding stations across the study area (Fig. 3), show that the overburden thicknesses in the lithologic sections are higher than those in geo-electric sections. In the underlying layers, the geo-electric units show suppression and merging of some lithologic units from the borehole (Fig.4.3). This is because geo-electric units are not the same as lithologic units. A given lithologic unit with variations in resistivity will give rise to so many geo-electric units. Hence, different lithologic units with similar resistivities would be merged as one geo-electric unit. Consequently, the water table between the geo-electric and borehole sections varied considerable across the study area.

Considering Fig. 3, at Anam, the depth of overlying layer which is delineated as dry sandstone with resistivity of 741.36Ωm, is met at 167m in the borehole near VES 2 and 137.58m in the geoelectric unit; whereas the depth of water saturated unit with resistivity of 517.92 Ωm is met at 207m in the borehole and 205.24m in the geoelectric unit. Also, at Umuleri (Fig. 3), the depth of overlying layer which is delineated as dry sandstone with resistivity of 3241.62Ωm, is met at 22m in the borehole near VES 4 and 12.39m in the geoelectric unit; whereas the depth of water saturated unit with resistivity of 1689.51Ωm is met at 102m in the borehole and 104.42m in the geoelectric unit. More so, also, at Onitsha (Fig. 3), the depth of overlying layer which is delineated as dry sandstone with resistivity of 2637.10Ωm, is met at 31m in the borehole near VES 5 and 47.93m in the geoelectric unit; whereas the depth of water saturated unit with resistivity of 1519.45Ωm is met at 99m in the borehole and 101.59m in the geoelectric unit. Following these layers are impermeable layers whose base were not reached and as such, the thicknesses were not deduced. These findings within the study area are in accordance with Anakwuba*et al.* (2014); Chinwuko*et al*. (2015); Chinwuko*et al.* (2016); Osele*et al.* (2016).

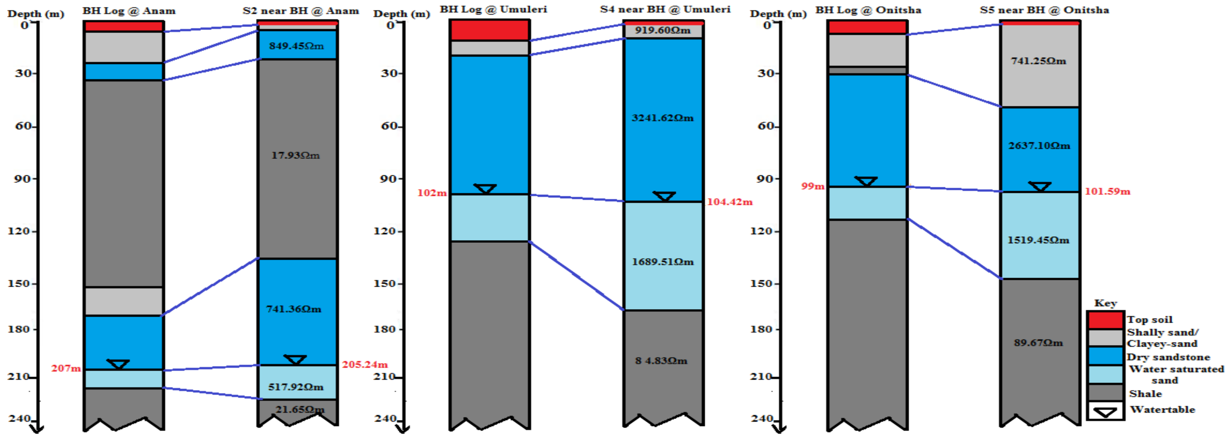

Figure 3: Comparison of geo-electric and borehole sections in the area

Estimation of Aquifer Parameters

The results of the hydraulic conductivity of the aquifer obtained within the study area show that the value of hydraulic conductivity within the area is relatively shallow to far which ranges from 0.0527723 m/day to 6.1889683 m/day with an average of 0.458754 m/day and the interpreted layer is water saturated sandstone. The map showing hydraulic conductivity distributions across the area with contour interval of 0.2 m/day were produced (Fig. 4). This map signifies that the study area has various hydraulic conductivity of the water saturated layer with its trend direction in northeast-southwest (NE-SW) path. Fig. 4 depicts that some parts of southwestern and northeastern area possess higher hydraulic conductivity (1.20 – 6.1889683m/day) while at the other parts of the area, there are lower values of hydraulic conductivity (0.05 – 1.00 m/day).

In addition, the results of the transmissivity of the aquifer obtained within the study area show that the value of transmissivity within the area is relatively shallow to far which ranges from 1.8243 to 430.6284m^2/day with an average of 23.1149m^2/day and the interpreted layer is water saturated sandstone. The map showing transmissivity distributions across the area with contour interval of 10.00m^2/day was produced (Fig. 5). This map signifies that the study area has various transmissivity of the water saturated layer with its trend direction in northeast-southwest (NE-SW) path. Fig. 5 depicts that some parts of southwestern and northeastern area possess higher transmissivity (120.00-430.63m^2/day) while at the other parts of the area, there are lower values of transmissivity (1.82-110.00 m^2/day).

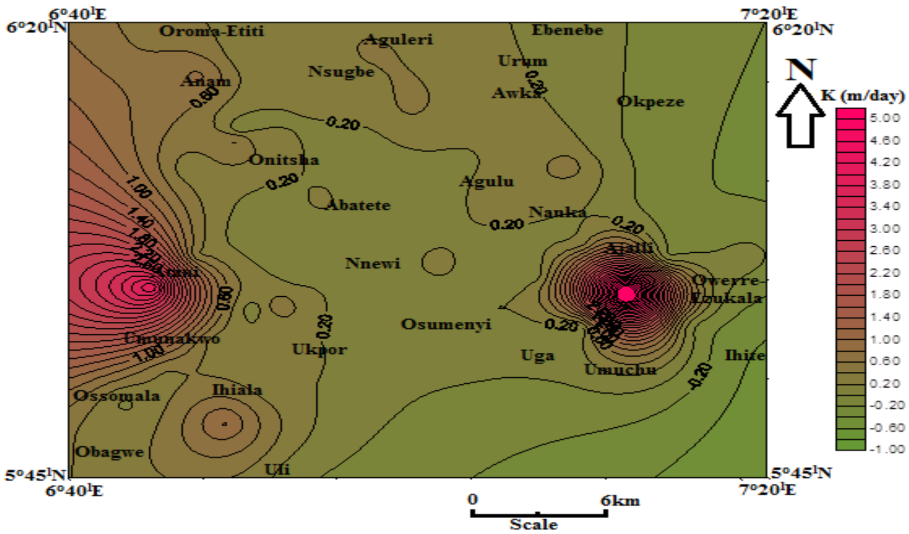

Figure 4: Aquifer Hydraulic Conductivity within the study area (Contour Interval ~ 0.2m/day)

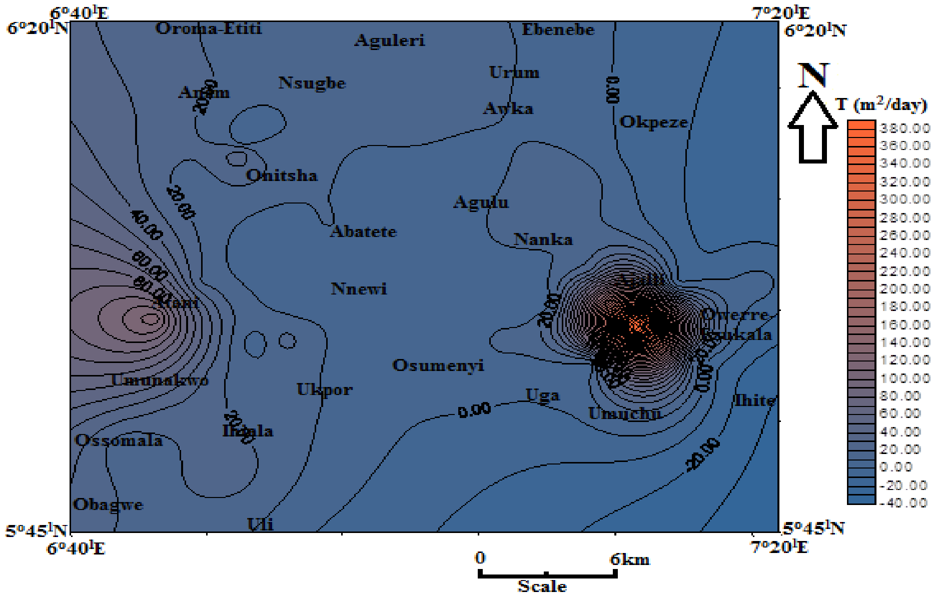

Figure 5: Aquifer Transmissibility within the study area (Contour Interval ~2.0m^2/day)

Elevation Map of the Study Area

The obtained results for elevation from the geophysical survey carried out within the study area are presented as a distribution map in Fig. 6. The obtained results show that the value of elevation within the area is relatively low to high (18 – 261m) with an average of 119.8m, meaning that the study area possess different topographical (elevation) values.The map showing elevation distribution across the area with contour interval of 10m was produced (Fig. 6). This map signifies that the study area has various elevation with its trend direction in northeast-southwest (NE-SW) path. Fig. 6 depicts higher elevation (120 – 260m) around southeastern and central part of the area with the greenish colour while at the other parts of the area; there are lower values of elevation (18-110m) associated with purple colour.

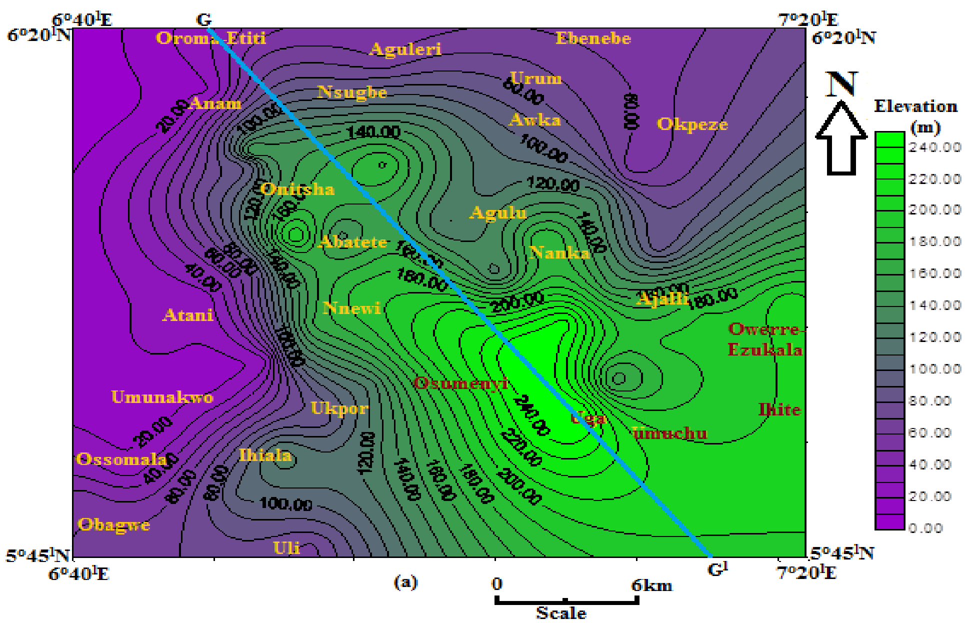

Figure 6: Elevation map with cross sections across the area (Contour Interval ~10m)

Estimation of Watertable With Respect to Mean Sea Level

The watertable is the plane which forms the upper surface of the zone of groundwater saturation in an unconfined aquifer. The level of the watertable is controlled partly by topography, the nature of the near surface rock and climatic condition. Thus, the depth to the top of the aquifer (watertable) deduced from the geoelectric sections were substracted from the topographic elevation measured from the mean sea level. The differences showed areas with negative and positive values relative to the mean sea level. The obtained results show that the value of fractured contrast within the area is relatively low to high (-188.20 to 118.69m). The map showing watertable distribution across the area with contour interval of 15m was produced (Fig. 7). From the map, the groundwater flow direction is NE-SW within the study area. Also, the watertable map depicts that around northern and western parts of the area, there are associated with lower values of watertable that ranged from -188.20 to -5.00m), whereas at the other parts of the area, there are higher values of watertable level which ranged from 10.00 to 118.69m.

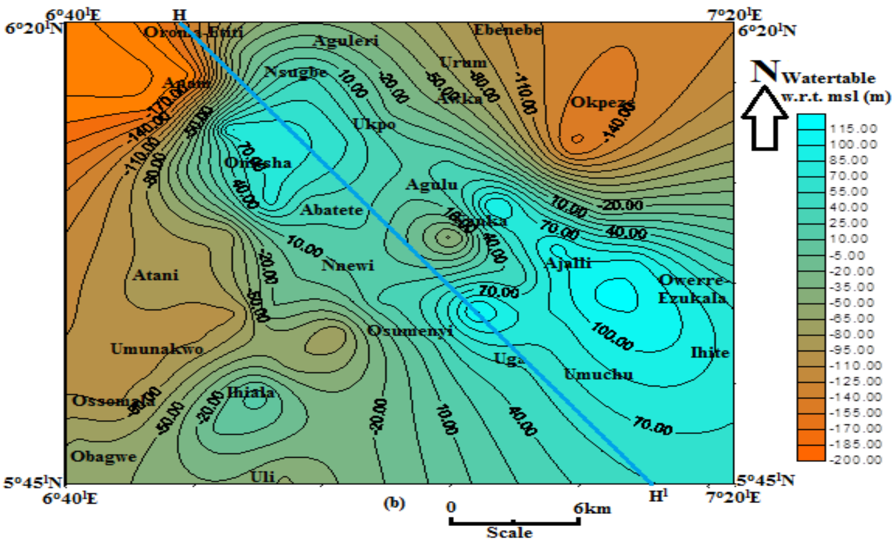

Figure 7: Watertable map with cross sections across the area (Contour Interval ~15m)

Water Analysis Results

The results of the water analysis of some selected boreholes from the study area are presented in Table 3. Five physical parameters namely; appearance which signifies clear quality; temperature shows ambient quality; colour, turbidity and odour results reveal nil (none) across the selected area. According to Nigerian Standard for Drinking Water Quality in 2015 (NSDWQ), all the physical parameters are within the acceptable limit and therefore, they are satisfactory for human consumption. More so, a total of eighteen (18) chemical parameters (namely; pH, conductivity, total dissolved solid, salinity, chloride, carbonate, bicarbonate, total hardness, calcium, magnesium, potassium, sulphate, nitrite, nitrate, iron, manganese, copper, and residual chlorine) were tested and their results are presented in Table 2. The pH values deduced range from 4.82 to 7.36 levels across the area. Some areas like Abo-Nnokwa, Umuele Umudim Nnewi, Umunono Community-Igbokwu, Central School Echemnankwo-Nnobi, Ofolagbom Nnobi, Ugwuakwu-Umuchu, Ogunzele-Awka Etiti, Eziogwugwu Otolo-Nnewi, and others possess pH levels which are not within the acceptable limit but within the pH of underground water around the environment (NSDWQ 2015). Other areas met the acceptable limit of the NSDWQ (2015). Other parameters results fall within the acceptable limit for drinking water according to Nigerian Standard for Drinking Water Quality in 2015 (NSDWQ, 2015) and therefore, they are satisfactory for human consumption.

Finally, the result of the microbial analyses (Table 3) shows that all samples except that of Nnobi and Nnewi which have zero level of bacteriological pollution with Total Coliform and Faecal Coliform counts within acceptable limit of the NSDWQ (2015). However, there are high levels of bacteriological pollution with Faecal Coliform (5 – 8 /100ml H_2O) and Total Coliform (13 – 16 /100ml H_2O) counts above acceptable limit of the NSDWQ (2015). This is very harmful for health and therefore proper borehole treatment should be carried out to safeguard human health.

Table 3: Results of Water Analysis around the Study area

	Physical Parameters	**NIG STD**	Oraukwu Test	Nnobi Test	Amichi	Nnewi	Umuchu	Awka-Etiti
1	Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear
2	Temperature ^{0}C	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient
3	Colour (TCIJ)	15	Nil	Nil	Nil	Nil	Nil	Nil
4	Turbidity (NTU)	5	Nil	Nil	Nil	Nil	Nil	Nil
5	Odour	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	Chemical Prameters		.		.		.	
1	pH	6.5-8.5	5.1	5.1	5.1	5.11	4.9	4.88
2	Conductivity uS/cm	1000	26.8	22.6	30.6	26.4	21.2	22
3	Total Dissolved solids mg/1	500	13.4	11.4	15.3	13.2	10.6	11
4	Salinity mg/1	500	Nil	Nil	Nil	Nil	Nil	Nil
5	Chloride ($C1^-$) mg/1	250	Nil	Nil	Nil	Nil	Nil	Nil
6	Carbonate ($CO^{2-}{}_3$) mg/l	500	Nil	Nil	Nil	Nil	Nil	Nil
7	Bicarbonate (HCO_3^-) mg/1	500	14	13	11	11	8	10
8	Total hardness mg/1	500	39	23	19	17	18	41
9	Calcium (Ca^{2+}) mg/1	200	15	6	13	9	12	15
10	Magnesium (Mg^{2+}) mg/1	250	24	17	6	8	6	26
11	Potassium (K^+) mg/1	250	-	-	-	-	-	-
12	Sulphate ($SO4^{2-}$) mg/1	100	2	3	Nil	Nil	Nil	Nil
13	Nitrite (NO_2^-) mg/1	0.2	0.02	0.04	0.03	0.03	Nil	Nil
14	Nitrate (NO_3^{2-}) mg/1	50	3.1	3.42	2.2	2.2	1.8	1.8
15	Iron (Fe^{2+}) mg/1	0.3	0.25	0.2	0.2	0.1	0.01	0.12
16	Manganese (Mn^{2+}) mg/1	0.2	0.04	0.02	0.01	0.02	Nil	0.01
17	Copper (Cu^{2+}) mg/1	1	-		-	-	-	-
18	Residual Chlorine (CI_2) mg/1	0.25	-		-	-	-	-
	Bacteriological Parameter	.						
1	Total Coli form / 100 ml H_20	10	0	*15*	0	13		0
2	Feacal Coli form /100ml H_20	0	0	*6*	0	8		0

GROUNDWATER PRODUCTIVITY POTENTIAL IMPLICATIONS

Figure 4 shows the spatial distribution of Hydraulic conductivity across the study area. Low hydraulic conductivity (0.05 – 1.00 m/day) is observed in some parts while high hydraulic conductivity (1.20 – 6.1889683m/day) is observed in some parts of southwestern and northeastern of the study area. According to Adeniji*et al.* (2017), areas with high hydraulic conductivity are most likely to have good aquifer recharge quality/capability which is applicable in the study area.

Figure 5 shows that high trasmissivity is observed at most parts of the study area. For characterization of rocks as a water conductivity media, transmissivity is a major property (Fatoba*et al.*, 2014). From the computed aquifer results, it can be deduced that groundwater flow potential increases as transmissivity and hydraulic conductivity increases. Kransy (1993) standards for transmissivity were adopted for classification of the groundwater potentials of the study area as shown in Table 4 and Fig. 8. The results revealed that the study area is predominately of intermediate transmissibility with 52% of the entire VES points and this implies that the groundwater potentials available here can sever for local water supply like small communities. Also, about 44% of the entire VES points are associated with low transmissibility classification which implies that the groundwater potentials available here can serve for small withdrawal for local water supply mainly for individual uses (private consumptions). Meanwhile, 4% of the entire VES points are associated with high transmissibility classification which implies that the groundwater potentials available here can serve for withdrawal of lesser regional importance that can serve more than one communities.

Generally, the groundwater productivity potential in the area has been classified into three zones namely; high, intermediate and low. This study has revealed that no single aquifer parameters/index determines the groundwater productivity potential but a combination of two or more factors. Also, all the spatial distribution maps of the aquifer parameters generated across the study area, signified that the trend directions of all the contours occurs along northeast-southwest (NE-SW) path. This implies that all the groundwater flow within the study area will possibly follow this trend.

Table 4: Deduced classification for transmissibility in the study area

Transmissivity (m2/day)	VES Points	% of VES	Designation	Groundwater supply potentials
1000	Nil	None	Very high	withdrawal of great regional importance
100-1000	10 & 48	4	High	withdrawal of lesser regional importance
10-100	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 14, 16, 17, 18, 19, 20, 21, 22, 30, 31, 32, 37, 38, 42, 44, 47, & 51	52	Intermediate	withdrawal of local water supply (small community, plants, etc.)
1.0-10	12, 13, 15, 23, 24, 25, 26, 27, 28, 29, 33, 34, 35, 36, 39, 40, 41, 43, 45, 46, 49, 50, & 52	23	Low	Small withdrawal for local water supply (private consumption)
0.1-1	Nil	None	very low	Withdrawal for local water supply (private consumption)
<0.1	Nil	None	Impermeable	Sources for local water supply are difficult

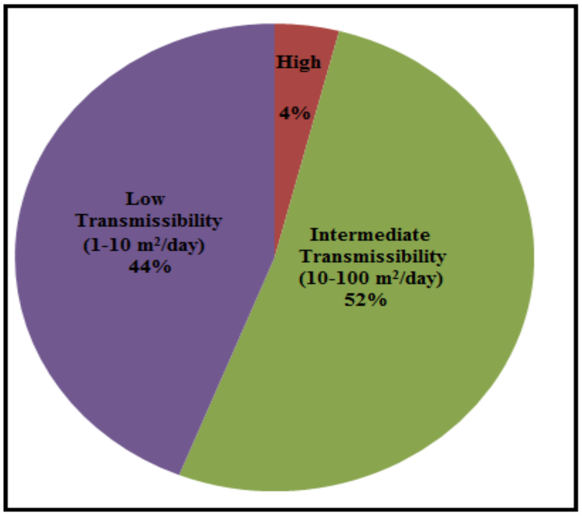

Figure 8: Groundwater potential of the study area

Hydrogeological Implication of Integration of Elevation and Watertable

Two cross sections were taken at both the elevation map (Fig. 6) and watertable level map (Fig. 7) at the study area respectively. The profiles running from G-G[l] at Fig. 6 and H-H[l] at Fig. 7 were superimposed in order to estimate the groundwater vulnerability (Fig. 9) obtainable in this area. Here, it was observed that the watertable follows the topography which implies that the topography controls the configuration of the groundwater (Fig. 9). Also, the gap between the peaks of the watertable and the topography in the area is 140m (Fig. 9). This implies that the vertical movement of any contaminant will be strongly retarded by the earth materials thereby allowing physical (filtration), chemical and biochemical processes to remove contaminants before reaching the aquifer. This is confirmed by the water analysis results, where most of the parameters fall within the acceptable limit for drinking water according to Nigerian Standard for Drinking Water Quality in 2015 (NSDWQ, 2015) and therefore, they are satisfactory for human consumption.

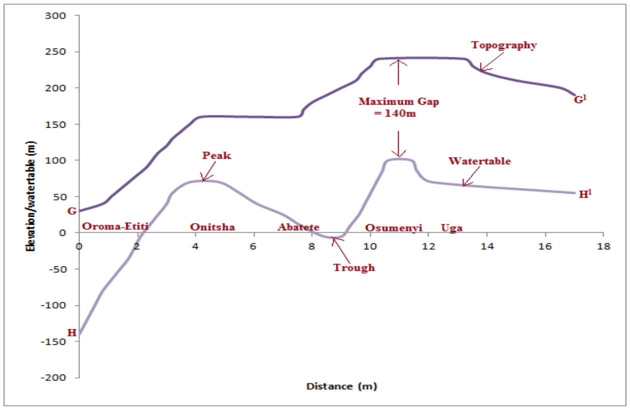

Figure 9: Groundwater Vulnerability model within the Study area

CONCLUSIONS

This study investigated the groundwater potential of southern Anambra State, Nigeria using electrical resistivity soundings.The VES interpretations revealed that the forth to sixth layers are delineated as prospective aquifer units with depth range from 44.36 meters to 215.08 meters across the study area. The computed aquifer parameters from the interpreted VES data show 0.053 to 6.189 m/day hydraulic conductivity and 1.824 to 430.628m^2/daytransmissivity. The water analyses reveal that mostly all the parameters analyzed fall within the acceptable limit for drinking water. Three zones of groundwater productivity potential have been obtained in the area: high, intermediate and low, but the study area is predominately of intermediate transmissibility, meaning that the groundwater potentials can serve for local water supply. The groundwater flows within the area trend majorly in NE-SW direction. The groundwater vulnerability model reveals that the gap between the peaks of the watertable and the topography in the area is 140m, which implies that the vertical movement of any contaminant will be strongly retarded by the earth materials before reaching the aquifer. The study concludes that the aquifers within the study area are capable of yielding enough water that would serve for local water supply/scheme which is satisfactory for human consumption.

ACKNOWLEDGEMENTS

This study was carried out under the TETFund Research Project Intervention of the Federal Government of Nigeria. The authors are grateful to the TETFUND Implementation Committee of Federal College of Education Umunze, Nigeria for facilitating the grant. We acknowledged the traditional rulers and President Generals of the different communities for their hospitality and kindness throughout the study.

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