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SUBSURFACE RESISTIVITY AND IMPLICATIONS FOR GROUNDWATER POTENTIALS IN PARTS OF ETCHE, RIVERS STATE, NIGERIA

[*1]Eke, P.O., [2]Worgu, B., [3]Ziriki, G.
[1]Department of Physics, Ignatius Ajuru University of Education, Port Harcourt, Nigeria
[2]Department of Physics, Ignatius Ajuru University of Education, Port Harcourt, Nigeria
[3]Department of Physics, Bayelsa Medical University, Yenagoa, Nigeria

***Corresponding Author (Email):** peter.eke@iaue.edu.ng

Abstract
This study determines the groundwater potentials of parts of Etche using the vertical electrical sounding (VES) method. The resistivity of subsurface formations can be interpreted to obtain aquifer characteristics and infer the groundwater potentials of a region. Etche in Rivers State, Nigeria, has urban cities that are developing every day with an increasing need for domestic water use. This study determines the groundwater potentials of parts of Etche using the vertical electrical sounding (VES) method. Twenty-three (23) vertical electrical soundings were carried out with locations in Akpoku, Chokocho, Elele, Ikwerrengwo, Obite, Odagwa, Okehi, Okomoko, Orwu, Ozuzu, Ulakwo, Umuakuru, Umualikpo, Umuanyagu, Umuasukpo, Umuazu, Umuebulu, Umuogodo, Umuokwa, Umuokwanukwu, Umuometa, Umutube, and Umuoye, all in Etche, using ABEM (SAS) 4000 Terrameter. The Schlumberger electrode configuration, with a maximum electrode spacing of 500 m was used. The apparent resistivity values obtained were plotted against half the current spread in IPI2WIN software to obtain the curve types, formation true resistivities, the geoelectric layers, formation thickness and depths. These were analyzed to obtain aquifer depths, thickness, transverse resistivity, longitudinal conductance, transmissivity and storativity of the region. From the results, the curve types are mostly A, K, B and KH curves. The resistivity values range from 405 Ω in Chokocho to 4985.6 Ω in Odagwa, with an average value of 2314.8 Ω for the surveyed areas. Aquifer thickness ranges from 8.2 m in Orwu to 97 m in Umuokawnukwu with an average of 47.5 m for the area. The average aquifer depth for the region is 59.1 m, with Orwu having 10.8 m and Umuokwanukwu having 105 m. Transverse resistivity values range from 12775.6 Ωm^2 in Orwu to 176477.1 Ωm^2 in Umuaskpo and an average value of 103220.2 Ωm^2 for the region. Longitudinal conductance range from 0.00437 Ω^{-1}in Odagwa to 0.14321 Ω^{-1} in Chokocho with the region having an average value of 0.3093 Ω^{-1}. Transmissivity values range from 235338.7 m^2/day in Umuebubu to 127756.6 m^2/day in Orwu and an average value of 103220.2 m^2/day in the study area. Storativity values range from 1.07 x 10^{-5} in Orwu to 9.82 x 10^{-5} in Okomoko with an average value of 1.9 x 10^{-5} for the region. These results reveal that aquifer characteristics in the study area show potential for groundwater reservoirs with the eastern part of the region being more prolific. Generally, the groundwater potential in the region is good based on the storativity and transmissivity values and boreholes can be drilled at depths of 20 m in most of the areas to obtain drinkable groundwater.

Keywords: Subsurface resistivity, Aquifer characteristics, Storativity, Longitudinal conductance, Etche.

Introduction
Groundwater is water that lies beneath the subsurface filling the pore spaces between grains in bodies of sedimentary rocks and cracks in sand crevices in all types of rocks called aquifers, which allow huge underground reservoirs of water to accumulate (Plummer et al., 1999). The primary source of groundwater is rain and snow that falls to the ground. A substantial portion of this precipitation percolates down into the ground to become groundwater. Among the factors that determine the extent and rate of precipitation that soaks into the ground are climate, land slope, soil and rock type and vegetation (Plummer et al., 1999). Approximately 15% of total precipitation ends up as groundwater, however, this figure varies locally and regionally. Plummer et al. (1999) explain that global groundwater distribution is about 0.61% and it is about 60 times as plentiful as fresh water in lakes and rivers on the surface. In aquifers, fresh water fills the uppermost parts while saltwater accumulates at

the greater depths. Good aquifers have high porosity and permeability which can be inferred from the following aquifer characteristics; conductivity, transmissivity and storativity. Studies have shown that these characteristics could be obtained from electrical resistivity methods (Ekine & Osobonye, 1996; Alile et al., 2011; Ehirim, & Nwankwo, 2010; Eke & Ekpelu, 2021) to obtain the groundwater potentials of a region.

The electrical resistivity method is one of the most reliable geophysical methods, especially in groundwater studies. There are various electrical methods for this, however, the most used for groundwater investigations is the vertical electrical soundings (VES) method which is designed to determine the apparent resistivity of formations with vertical depth. The method utilizes differences in electric potential between two electrodes and the electric current flow to obtain subsurface apparent resistivity as a function of depth or position (Reynolds, 2015; Lowrie, 2017; Robinson & Coruh, 2018). The method has several advantages that include; its ease of use in the field; its ability to provide information on depths ranging from a few meters to hundreds of meters beneath the surface and the availability of software for 2D and 3D interpretations. Except for its application in the study of groundwater, the method can be used for other hydrogeological studies like the monitoring of industrial waste contamination. Despite the advantages mentioned above, the VES method has a few limitations. First, the depth of the survey is limited to the electrode spacing, it is about 1/3 of the current electrode spacing. Secondly, the resistivity of layers may vary horizontally (in this case the electric profiling method would be better applied). Also, the layers must have consistent thickness because if there is a setup where the middle layer is much thinner than the layers above and below it, the resistivity results obtained will not be very accurate. However, information obtained from a VES method can reliably give the geoelectric sections of a surveyed area and can be used to obtain the aquifer characteristics which are parameters that are very useful means of confirming zones of prolific aquifers for groundwater supply (Fetter, 2007).

Traditionally, the people of Etche in Rivers State, Nigeria depend on surface water, while the groundwater is accessed by hand-dug wells. These two sources of water are prone to pollution and are not very safe for drinking. They may also dry up in the dry seasons. To reduce these challenges, boreholes have sprung up in most of the communities in the area in the recent past to exploit the huge reserve of groundwater in the region. However, these boreholes are cited without knowledge of the aquifer depths/characteristics. A knowledge of these properties include; the rate of water flow under a unit hydraulic gradient through a unit cross-sectional area of an aquifer (the hydraulic conductivity); the rate of water flow under a hydraulic gradient through a unit width of aquifer thickness (transmissivity) and volume of water released from storage per unit surface area (storativity) is vital in identifying potential and prolific groundwater zones (Robin & Hubbar, 2005; Abiola & Oladapo, 2009; George et al., 2014). This work provides this information to fill the gap in groundwater use in Etche. The aim is to determine the groundwater potential of parts of Etche, Rivers State, Nigeria, using the vertical electrical sounding (VES) method.

The Study Area

The study area (Fig. 1) has geographical coordinates of 4° 56' 58" North, 7° 5' 2" East. It covers an area of approximately 805.2 km² with a network of access roads and footpaths which made access to most areas surveyed possible. Etche LGA has a population of 382,671 people and a population density of about 480 per square kilometre and it lies south-south of the Niger delta of the Federal Republic of Nigeria (https://www.city-facts.com/etche, 2023). The Niger delta complex is predominantly made up of three formations, namely, Benin, Agbada and Akata formations. Several authors have written about these formations (Eke et al., 2016). In summary, the topmost formation, the Benin formation is about 2, 000 m thick with sands and sandstones. It is also the aquifer zone of the Niger Delta. The Agbada formation is the next formation with paralic sands and shales and this is the hydrocarbon habitat of the Niger Delta. It extends up about 6, 000 m below the surface. The base of the Niger delta is the Akata formation which extends to over 12, 000 m in some regions. It is the hydrocarbon source bed of the Niger delta and is made up of shales.

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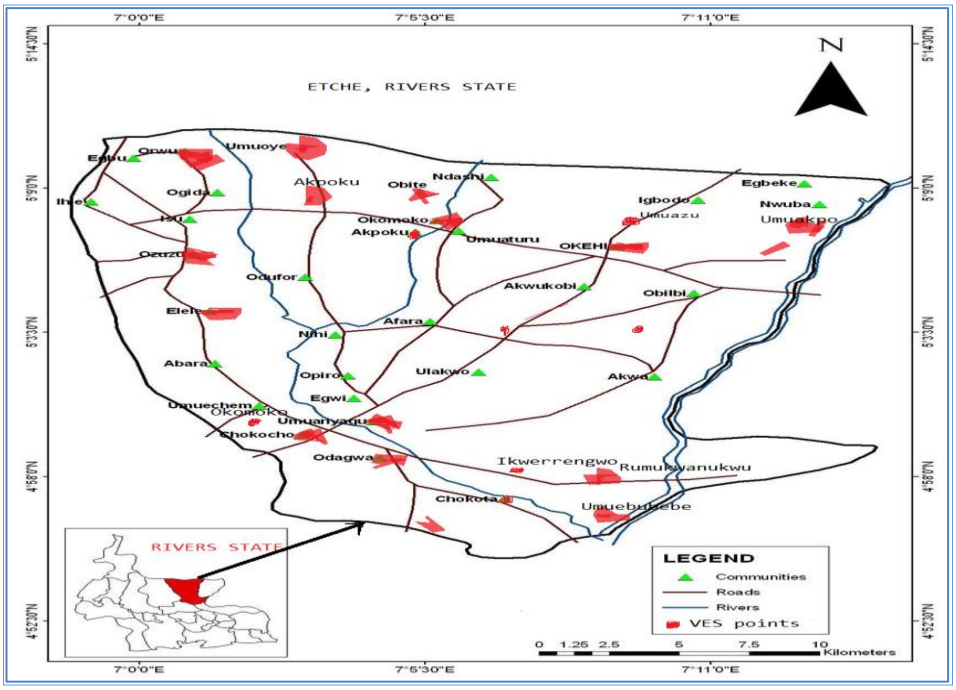

Fig. 1: Map showing locations of profile points modified from Google map of Etche, 2023 (http://www.maplandia.com/nigeria/rivers/etche/igbo-ekhe/, 2023).

Materials and Method

ABEM Terrameter SAS 4000, with all the accessories needed for a VES investigation, adopting the Schlumberger array method (Robinson and Coruh, 2018) was used for the survey. Having chosen suitable sites for the sounding survey, the necessary electrical connections were made. The maximum current electrode separation was 500 meters each way and the maximum potential separation was 50 meters for all locations. The electrode configuration was such that the separation between the potential electrodes, MN, was smaller than the current electrodes, AB. The current electrode AB was passed through the two outer electrodes at a fixed distance apart. The resulting potential difference, *V*, was measured between the potential electrodes. A record of the current, *I*, and potential difference, as well as *MN/2* and *AB/2* was made for each survey point. The measurements were repeated with a fixed *MN* and *AB* was increased symmetrically until the response from the meter became too small, then *MN* was increased and the readings were repeated with the previous *AB/2* so that the reading overlapped. The ABEM-Terrameter (SAS) 4000 resolves and records the current flow and potential values of each point on the linear array and these were used to obtain the electrical resistance of encountered formations. The apparent resistivity was obtained by multiplication of the geometric factor (*G*) and the earth resistance recorded from the ABEM-Terrameter (SAS) 4000. Practically the Schlumberger array gives the geometric factor *G* as

$$G = AB(\frac{AB^2 - MN^2}{4MN})\pi \qquad 1$$

And the apparent resistivity computed for each point as;

$$\rho_a = G\frac{\nabla V}{I} \qquad 2$$

The apparent resistivity was plotted against half the current electrode spread in a log-log graph of IPWIN 12 software to obtain the true resistivity, curve types and depth information of the various geoelectric sections encountered in the survey. Zohdy (1989) has shown that for a confined aquifer with the following parameters; thickness, *d*, resistivity, ρ, conductivity, σ, hydraulic conductivity, *K*, transverse resistance, R_T, and longitudinal conductance, L_C, (estimated as the ratio of aquifer thickness to apparent resistivity); the transmissivity, *Tr*, is obtained as

$$T_r = Kd = k\frac{R_T}{\rho} = K\sigma R_T = KL_c\rho = K\frac{L_c}{\sigma} \qquad 3$$

The volume of water released or taken into storage, the storage coefficient or storativity (dimensionless) was determined from the rule of thumb (Lohman, 1972).

Results

The curve types, geoelectric sections, true resistivity values, thickness and depths encountered in the survey for some locations are shown in Figures 3 to 9

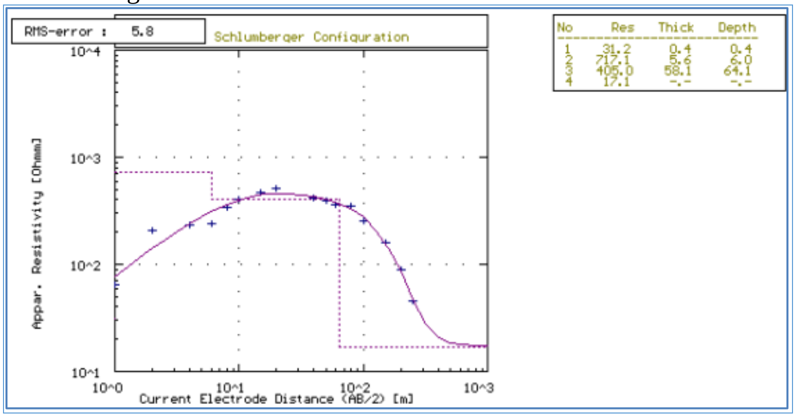

Fig. 2: VES curve and summary for Akpoku

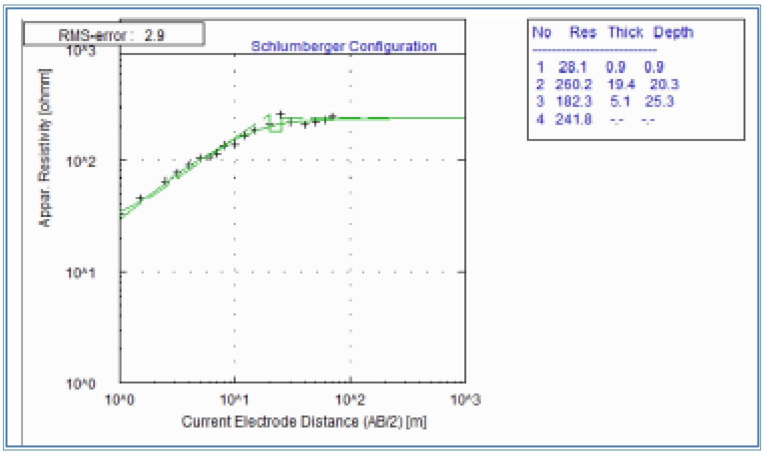

Fig. 3: VES curve for Chokocho

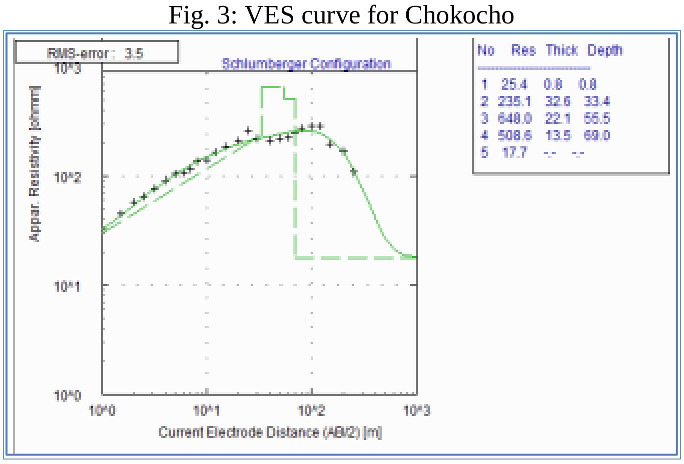

Fig 4: VES curve for Elele

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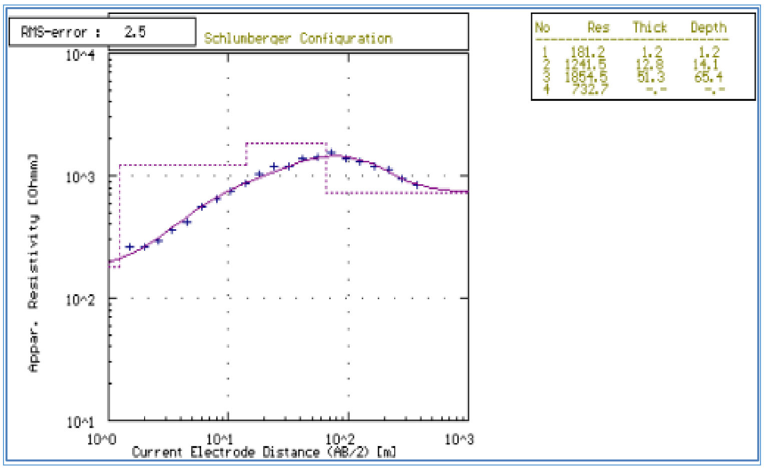

Fig 5: VES curve for Ikwerrengwo

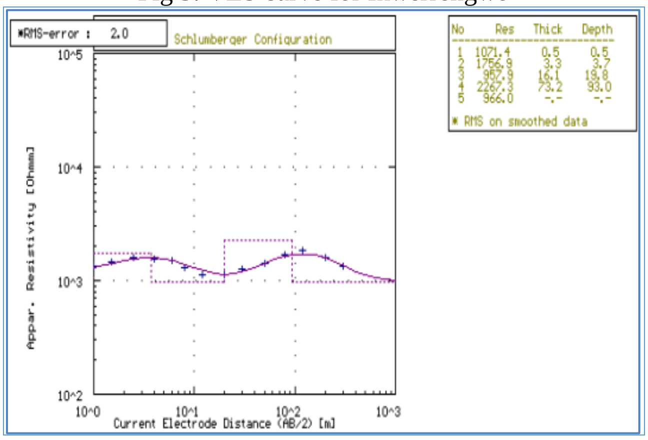

Fig 6: VES curve for Obite

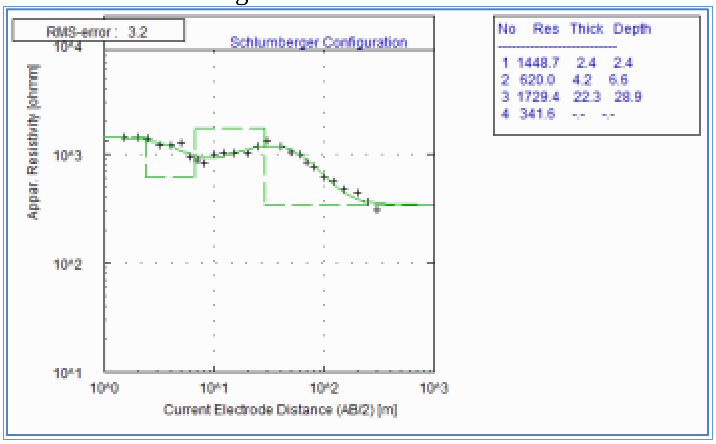

Fig. 7: VES curve for Okehi

The resistivity, aquifer thickness, depths, transverse resistance, longitudinal conductance, transmissivity and storativity of all the locations in the study area is shown in Table 1.

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Table 1: Summary of results of VES survey for all locations

S/N	Location	Resistivity ρ(Ωm)	Thickness *h(m)*	Depth *d(m)*	Transverse Resistance $R_T = \rho h$ (Ωm^2)	Longitudinal Conductance $LC = h/\rho$ (Ω^{-1})	Transmissivity $T_r = Kh = \rho h$ (m^2/day)	Storativity $S = h(1.3 \times 10^{-6})$ $\times 10^{-5}$
1	Akpoku	1175.0	41.4	61.8	48645.0	0.03523	48645.0	5.38
2	Chokocho	405.0	58.0	64.1	23490.0	0.14321	23490.0	7.54
3	Elele	2370.0	15.6	30.0	36972.0	0.00658	36972.0	2.03
4	Ikwerrengwo	1729.4	22.3	28.9	38565.5	0.01289	38565.5	2.90
5	Obite	3213.4	48.0	54.4	154243.2	0.01494	154243.5	6.24
6	Odagwa	4985.6	21.8	24.3	108686.1	0.00437	108686.1	2.83
7	Okehi	1173.0	55.0	63.7	64515.0	0.04689	64515.0	7.15
8	Okomoko	2155.5	75.5	89.5	162740.3	0.03503	162740.3	9.82
9	Orwu	1558.0	8.2	10.8	12775.6	0.00526	12775.6	1.07
10	Ozuzu	2172.5	41.4	52.0	89941.5	0.01906	89941.5	5.38
11	Ulakwo	4701.7	22.9	253	107668.9	0.00487	107668.9	2.98
12	Umuakunu	1854.5	51.3	64.4	95135.9	0.02766	95135.9	6.67
13	Umualikpo	2172.5	41.4	52.0	89941.5	0.01906	89941.5	5.38
14	Umuanyagu	1589.5	135	69.0	21458.3	0.00849	21458.3	1.76
15	Umuasukpo	2690.2	65.6	77.0	176477.1	0.02438	176477.1	8.53
16	Umuazu	1999.3	41.9	45.8	83770.7	0.02096	83770.7	5.45
17	Umuebubu	2569.2	97.9	112.7	33922.0	0.03565	235338.7	1.91
18	Umuogodo	548.9	61.8	76.0	104579.8	0.11259	33922	8.03
19	Umuokwa	1898.0	55.1	60.2	104579.8	0.02903	104579.8	7.16
20	Umuokwanukwu	2054.0	97.0	105.5	19926338.0	0.04722	199238.0	2.61
21	Umuometa	3195.3	68.1	75.3	217599.9	0.02131	217599.0	8.85
22	Umuotube	2267.3	73.2	93.0	165966.4	0.03229	165966.4	9.52
23	Umuoye	4762.5	21.5	24.0	102393.8	0.00451	102393.8	2.80
Total		53240.3	1092.5	135.9	2374065.5	0.71150	2374065.2	82.00
Average		2314.8	47.5	59.12	103220.2	0.03093	103220.2	3.57

Figures 8 to 14 show the contour maps of the depth to the water table, aquifer thickness, resistivity/hydraulic conductivity, transmissivity/transverse resistance, and longitudinal conductance. Storativity and groundwater potential of the region.

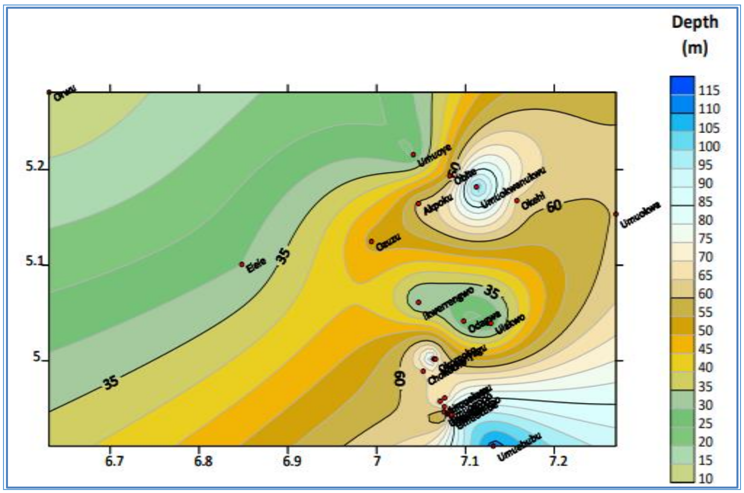

Fig. 8: Contour map of depth to the water table of the study area

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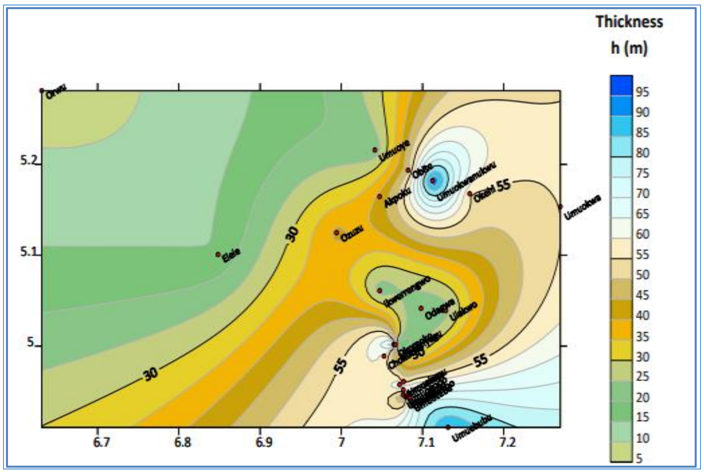

Fig. 9: Contour map of aquifer thickness of the study area

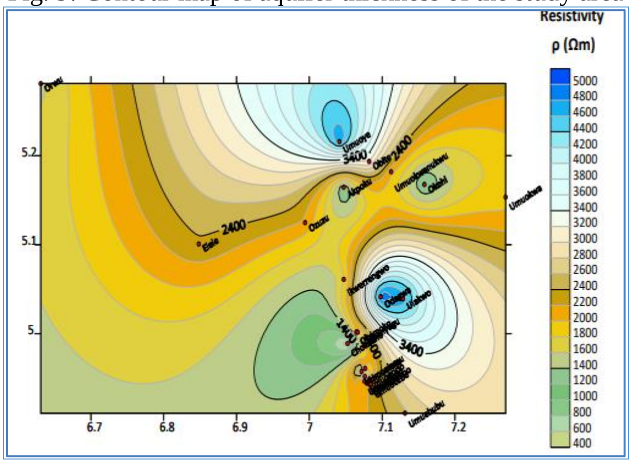

Fig. 10: Contour map of resistivity/hydraulic conductivity of the study area

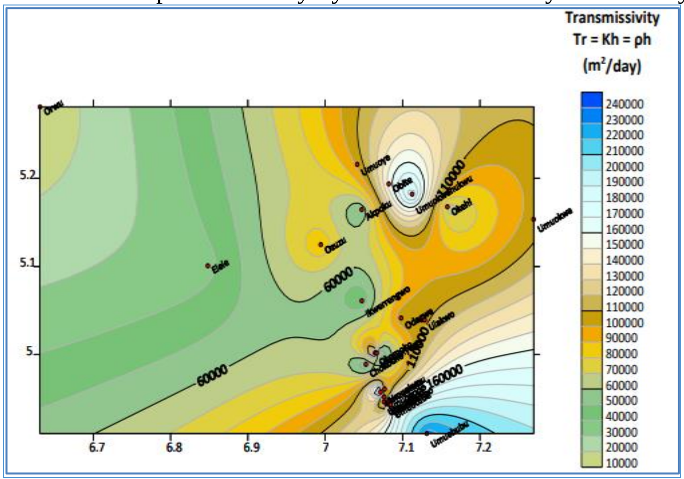

Fig. 11: Contour map of transmissivity/transverse resistance of the study area

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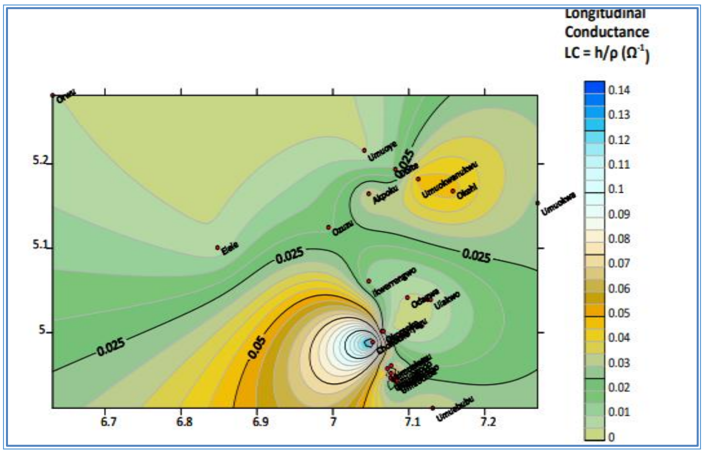
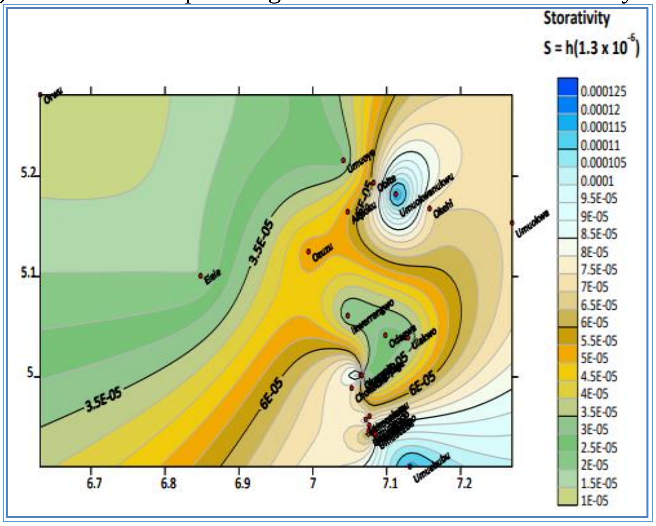


Fig. 12: Contour map of longitudinal conductance of the study area



Fig, 13: Storativity of the study area

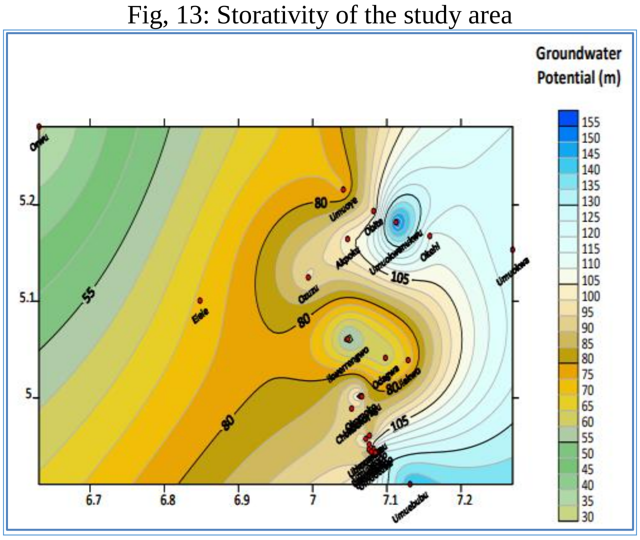


Fig.14: Groundwater potential of the study area

The results of the curve types as revealed in Figures 2 to 7 show that they are mostly A, K, B and KH curves indicating formations with three to four geoelectric sections. These have varying resistivity values from 405 m in Chokoccho to 4985 Ωm in Odagwa. From Table 1, the highest aquifer depth penetrated is 112.7 m in Umuebube with a thickness of 97.7 m, while the lowest thickness of 8.2 at a depth of 10.8 m is in Orwu. Chokocho has the highest longitudinal conductance, while Umuoye has the least. The aquifer storativity of the area ranges from 1.07 $\times 10^{-5}$ to 2.95$\times 10^{-5}$. The transmissivity/transverse resistance values range from 12775.6 m^2 /day in Orwu to the highest value of 235338 m^2 /day in Umuebule. The contour maps of aquifer parameter distributions and groundwater potential of the surveyed area are shown in Figures 8 to 14. The aquifer thickness/depths (Figures 8 and 9) indicate that the northeastern, down to the southwestern axes of the study area exhibit high aquifer thickness, while the central, northern, and southwestern flanks display low aquifers thickness (orange and yellow colours) with Orwu area having the least thickness value of 8.2 m. The areas with low thickness, have groundwater potential but may not be good for citing boreholes for domestic use because of the risk of pollution.

The eastern part of the study area has low transmissivity/transverse resistance values (Figure 11) and may not be very productive unlike the northern and southern axes of the study areas which have high transmissivity/transverse resistance values. The distribution of longitudinal conductance values across the study area (Figure 12) also shows that the southern axes of the study area have high longitudinal conductance with the Chokocho area having the highest value of 1.4 Ω^{-1}. This corresponds to the blue to light blue coloured region (0.9 to 1.4 Ω^{-1}). The northern, eastern and southwestern axes of the study area have low longitudinal conductance with Odagwa having the lowest value of 0.04 Ω^{-1}. This corresponds to the light green to the orange region (up to 0.08 Ω^{-1}). These areas may not be good for siting boreholes. Except for these areas, other parts of the study area are expected to be underlain by thick and conductive aquifer materials having relatively higher longitudinal conductance indicating that these areas have a high rate of flow under a unit hydraulic gradient through the unit cross-sectional area of the aquifers and thus making the area good for groundwater prospecting.

In Figure 13, the light green to green colour indicates areas of aquifer storativity ranging from 1.07 $\times 10^{-5}$ to 2.95 $\times 10^{-5}$, while the lemon green to purple colour indicates areas of aquifer storativity ranging from 2.95$\times 10^{-5}$ to 5.5.45 $\times 10^{-5}$. The light green to green colour revealed areas of aquifer storativity ranging from 5.45 $\times 10^{-5}$ to 9.82 $\times 10^{-5}$. These values indicate that the region has aquifers with the ability to release water from storage as the head declines. Since the fluid potential at any point in an aquifer can be found from the product of hydraulic head and acceleration due to gravity with gravity almost constant in the study area, the fluid potential is almost exactly correlated with hydraulic head h. The significance is that the hydraulic head which is a measurable physical quantity is a suitable measure of fluid potential. The hydraulic head was estimated using the depth to water table from sounding interpretations and elevation data of the study area. The hydraulic head map showing the groundwater potential distribution in the study area is shown in Figure 14. The light blue to blue colours indicates areas of groundwater potential ranging from 110 m to 157 m while the melon green to orange to purple colours indicate areas of groundwater potential ranging from 55 m to 110 m. The areas marked light green to green colours indicate areas of groundwater potentials ranging from 30 m to 55 m. These results are indicative that the eastern parts of the study area have appreciable values of groundwater potentials and are good for groundwater exploitation and the sitting of productive boreholes.

Conclusion

Vertical electrical sounding in twenty-three villages of Etche, Rivers State, Nigeria, has been carried out to obtain the groundwater potential of the region. The aquifer characteristics reveal the region has good groundwater potential, with villages and towns located in the eastern part of Etche being the most prolific as good groundwater can be obtained at depths of 20 m.

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