GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Deployment of Geophysical Technique in Groundwater Search at Guinueaworm Endermic areas in Obubra local government area of cross river state, Nigeria

Atan Obeten Egor *, Abong Augustine. Agwul and Bisong Samson Asu

Department of Physics, Faculty of physical Sciences, University of Cross River State, Calabar, Nigeria.

GSC Advanced Research and Reviews, 2023, 16(01), 268–279

Publication history: Received on 09 June 2023; revised on 17 July 2023; accepted on 20 July 2023

Article DOI: https://doi.org/10.30574/gscarr.2023.16.1.0317

Abstract

This study was conducted in the Guineaworm prone areas in Obubra Local Government Area, the study entails the deployment of vertical electrical sounding technique in the search for groundwater. In doing this, measurement was made in 14 profiles of 500m long each, using the IGIS resistivity meter model SSR-MP-ATS. Resist software was used for analysis. The Geoelectric sounding data interpretation revealed characteristic curves with two to six geoelectric layer thicknesses. The predominant curve types in the area were the KH, HKH, and HK. The electrical resistivity of the first layer ranged between 15.8to1626Ωm, which was indicative of clay, shale, or sandy silt, three to six geoelectric layers were obtained from the interpretation of the sounding data. The resistivity of the second layer ranged from 52.3 to 370.7Ωm. This was assumed to be shalestone/shale, and it was overlain by the third layer, which had resistivity values between 121 m to 1491.9Ωm, which was assumed to be sandstone (sandstone materials make good aquifers).The fourth layer, had values between 12.3Ωm. m to 1052.7Ωm, the fifth layer, had values between 11.21Ωm. to 2277.2Ωm, and the last layer, which had a value of32Ωm.The Transmissivity measurements ranged from 16 m^2/day to 171 m^2/day, Porosities were high with strong storactivity which show that the studied area contains thick and abundant aquiferous zone. Protective capacities (PC) values of (0.01-1.260 seimens) were obtained from the VES data. Borehole depths were recommended for each profile for borehole development. The study was identified to have confine aquifer terrain because of the confining clay layer which had a large vertical extend in the adjacent layers that enclosed the aquifer layer.

Keywords: Vertical electrical sounding; Aquifer; Transmissivity; Storactivity; Groundwater

1. Introduction

There has been intermittent Guinea worm infestation in some parts of Obubra. Briefly, guinea worm infestation occurs When people drink water that has been contaminated with the copepods, the copepods die and release the larvae into the human digestive tract. There, they make their way through the infected person's stomach and intestinal walls, eventually reaching subcutaneous tissues (the space just beneath the skin). This research is concerned with water which happened to be the first medium in the developing chain of the Guinea worm infection trajectory. It is the considered view of this research that when the water source is safe, the infection process will never start and the guinea worm infection will never be. Many of the local communities who suffered from this disease used surface water as their main source of water.

In order to break the chain of infection, it is necessary to use alternative sources of water like pipe born water, rain water and or groundwater. While the choice is at the discretion of the user, the seasonal nature of rainwater makes its availability an issue at certain times of the year. On the other hand, pipe born water has become a total mirage as Governments over the years have failed to provide this. In the face of the foregoing analysis, the rural communities are left with the option of exploring and exploiting of groundwater, some communities have since adopted this option but

*Corresponding author: Egor A. O

then some of the boreholes become unproductive during the dry season. It therefor become advisable to deploy geophysical techniques in the search for water aquifers before embarking in the mission to exploit the water, this forms the Carnel of this research. In specific terms, vertical electrical sounding VES method is deployed in this research to search for ground water.

Because of the ongoing population growth, increased commercial, industrial, and agricultural operations like irrigation that are needed to address the issue of food security, demand for groundwater as a portable water source is constantly rising. Uncontrolled groundwater extraction can lead to issues like aquifer contamination, aquifer exhaustion, and land subsidence. According to [1], it is claimed that Mexico's government was unable to control the exploitation of groundwater, which resulted in major issues with water depletion and contamination in some northern areas and salt water incursion into coastal aquifers in the country's northwest [1].

Surface water and subsurface or groundwater resources can be broadly divided into these two categories. Surface water bodies include places with rivers, lakes, ponds, streams, and rivers. The term "groundwater study" refers to the study of subterranean water that extends into a saturation zone, where nearly all of the interstices are filled with water and where, as a result, the rules of saturation flow regulate the retention and movement of water. According to [2] groundwater is mostly derived from precipitated air moisture that has seeped into the soil and subsurface layers. The geophysical component of groundwater studies is always focused on a proper characterization and comprehension of the characteristics pertaining to the water table, a region in an undulating surface where pore water pressure is equivalent to air pressure.

A geologic unit below the water table contains groundwater that has the capacity to store and transfer water at rates quick enough to supply wells with a respectable amount of water. Aquifer is the name given to this type of geologic formation [3]. Aquifuge is the term for an impermeable bed that has no interconnected interstices and, as a result, neither absorbs nor transmits water, while aquiclude is the term for a semi-permeable formation that, despite being porous and capable of slowly absorbing water, will not transmit it in significant quantities to a spring or well, but may be important in the regional movement of groundwater [2].

The connectivity of pores found in rock fragments and particles, as well as the size, shape, and distribution of these holes throughout the zone of saturation, all contribute to the availability of groundwater in a particular location. The significance of groundwater exploration cannot be overstated, particularly given the challenges associated with developing surface water sources in some developed nations like Great Britain and the Sudan [3], where issues like scarcity and safety of surface sources have not yet been fully resolved [4]. Cattle are alleged to perish on Marjo Island in Para Brazil due to a shortage of transportable water (Verna & Bischoff, 1989). Seasonal variation and safety in Nigeria determine the nomadic lifestyle and environmental preferences of the majority of the population in the various regions of the nation. According to [5], the demand for water, which is determined by population, social customs, and the need to develop food and industrial production, may vary in time and place only within small limits depending on the hydrological and meteorological conditions of the region. Therefore, the abundance of surface water supply in a given location shouldn't prevent the development of groundwater resources. Indeed, groundwater is a social and industrial necessity; where it recharges into a lake, it may have an impact on social and economic activities like tourism and fishing [6].

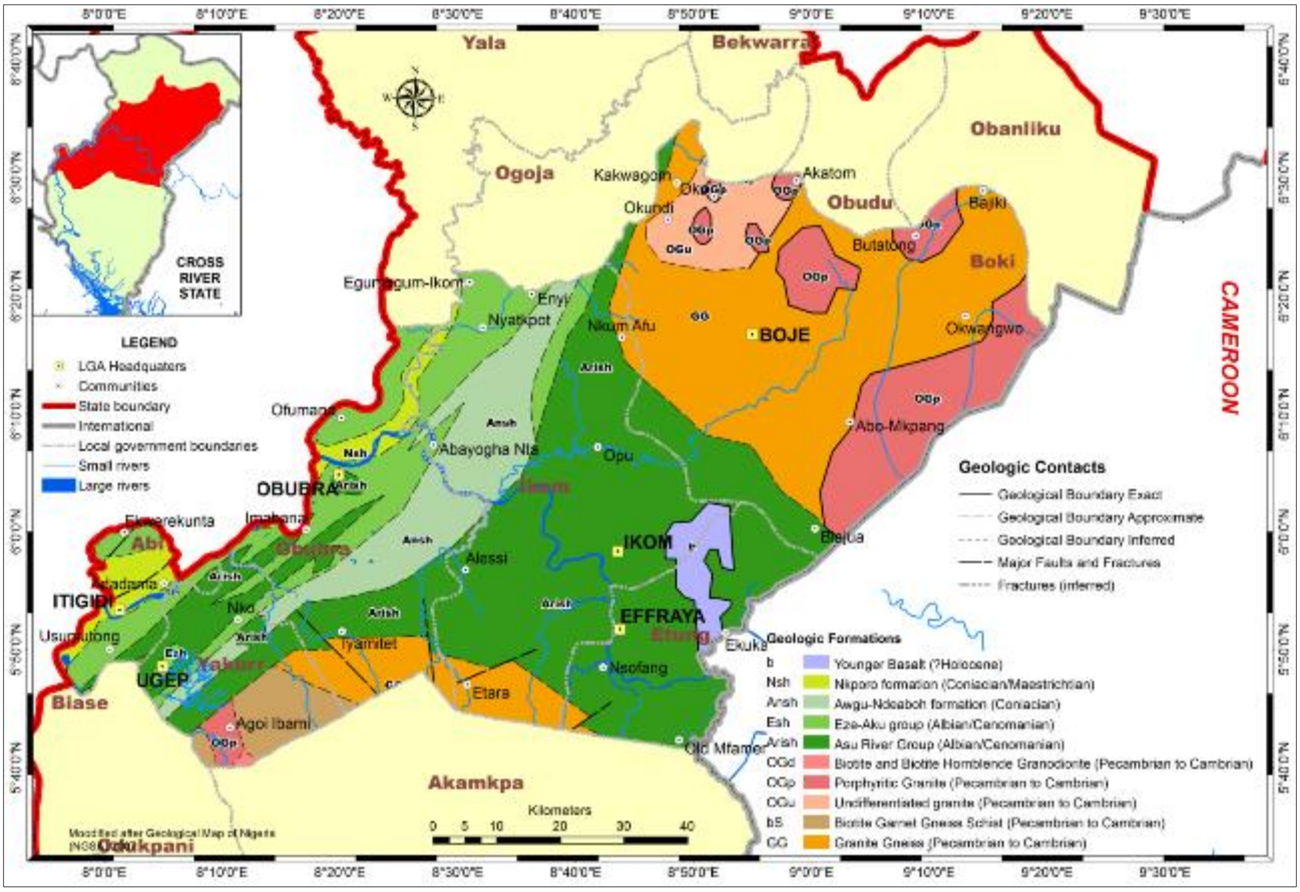
1.1. Geology and hydrogeology of the study area

This study was conducted in a few communities in Obubra, which is in Cross River State's central region and is situated between latitudes 5045°N and 6028°N and longitudes 8000°E and 9011°E. The Ikom-Mamfe Embayment and Boki Geologic Environment are part of the region.

The Northeast to Southwest trending Benue Trough's Northwest to Southeast splay portion is known as the Ikom-Mamfe embayment. It spans a 2,016km2 area in western Cameroon where it expands laterally [2]It occupies the lowlying areas between the Oban massif and the Obudu Plateau in The region includes the Boki Geologic Environment and the Ikom-Mamfe Embayment.

The Ikom-Mamfe embayment is the Northwest to Southeast splay part of the Northeast to Southwest trending Benue Trough. It extends laterally over a 2,016km2 area in western Cameroon [6] It is located in Cross River State, Nigeria, between the Oban massif and the Obudu Plateau (Fig. 1) and has a moderately undulating topography [6]. This basin includes certain communities in Abi, Yakurr, Obubra, Ikom, and Etung in Nigeria, mainly in the Cross River State (Fig. 1).Cross River State, Nigeria, is depicted in Fig. 1 and has a fairly undulating topography . This basin includes certain communities in Abi, Yakurr, Obubra, Ikom, and Etung in Nigeria, mainly in the Cross River State (Fig. 1).

The Asu River Group (ARG), Eze Aku Group (EAG), and Post-SemtonianNkporo-Afikposhales formation (NASF), three important Cretaceous lithostratigraphic units, are overlain by Precambrian basement rocks beneath the Ikom-Mamfe basin (Odigi, 2010).Along some of the Cross River flood plains, there are also a few isolated occurrences of alluvial deposits, and in some places Tertiary volcanic rocks like basalts and dolerites intrude into the overlying Cretaceous sedimentary units [7],[9], The oldest sedimentary rocks in the research region are the Albian ARG, which lie directly over the Precambrian basement. They primarily span the eastern portions of the research area and are essentially non-marine to marginally marine in nature (Fig.1). According to [10], the sediments in the ARG are made up of impervious shales, limestones with occasional sandstone intercalations, and ammonites.



Source:Modified after Geological Map of Nigeria [10]

Figure 1 Geological map of the study area

Aim of the study

In order to understand the seasonal fluctuation in well yield in some areas of Adun and Osopong in the Obubra Local Government Area, the data collected for this study will be utilised. The outcome can be used to identify regions with the potential to support water wells. The investigation will offer some geologic information that can be converted regarding the geoelectric layers of the study region. The investigation will also offer precise and logical scientific data on the vertical distribution of subsurface materials that will be used to deduce the lithological composition of the subsurface materials.This work will be helpful to epidemiologists and those who develop water resources, but it will also positively impact the growing conversation on groundwater exploration and exploitation.

This study is restricted to the areas of Obubra Local Government Area in the heart of Cross River State that have experienced guinea worm attacks. There could only be 14 soundings, and the characteristics measured were layer resistivity, depth/thickness of the geoelectric sections, and transmissivities.

In Nigeria, current research using the VES method is primarily focused on determining lithology [11] ;[12][13] ground-water potential

Similar studies by [14] , [15] have proved the resistivity techniques to be very successful in demarcating areas that have potential for sustaining water wells.

[16] identified different water bearing horizons in Calabar using the same method, they further found two aquifer terrains which were identified as follows; (i) The shallow aquifer terrain made up of coarse-grained sands and gravels and an average formation resistivity of 1,500m, and (ii) The deeper aquifer terrain made up of fine to medium grained sands and an average resistivity of 32Ωm [16] In some areas of Lagos, Nigeria, [17] employed the resistivity technique to identify the interface between fresh and salt water.s in Calabar using the same method, they further found two aquifer terrains which were identified as follows;

- The shallow aquifer terrain made up of coarse-grained sands and gravels and an average formation resistivity of 1,500Ωm, and
- The deeper aquifer terrain made up of fine to medium grained sands and an average resistivity of 32Ωm [16]

[17] used resistivity technique to determine fresh/salt water interface in some parts of Lagos, Nigeria.

In order to address the communities' requirements for water, [18] conducted research in the Indian villages of Doon and Rishikesh using the resistivity technique and seismic refraction method. These settlements are situated close to the Himalaya. Siwalik meta sediments, which are heavy gravel and sand, make up the sediments. The findings indicate that for dry loose clayey boulder-boulder gravel, the mean resistivity and velocity ranges are, respectively, 360-368 m and 483-1127 m/s. For water-saturated boulder gravel-sand gravel, they are 53302 m and 970-3517 m/s (www.uneca.org). The valuesv are 289-566 m and 970-2843 m/s for clayey boulder-boulder clay that is partially cemented. The values are 20-98mm and 569-1382m/s for highly to mildly worn friable sandstone. Additionally, compact firm sandstone has measurements of 410 m and 2740 m/s, while clayey bed mudstone has measurements of 20 to 25 m and 5000 m/s. According to the study's findings, the localities under investigation have a lot of groundwater potential.

[19] estimated the hydraulic properties of the middle Imo River Basin aquifer using electrical sounding data. Based on the study, it was discovered that the hydraulic conductivity varies from 1.24m/day in Amuzukwu to 26.41m/day in Obinze. Additionally, transmissivity values range from 41 m2/day at Osuachara to 1370 m2/day at Obinze.

2. Material and methods

The IGIS resistivity meter model SSR-MP-ATS was used in this study to measure the earth's resistivity. Other tools included the Germin made GPS map 76 model of GPS, 28 stainless steel electrodes, measuring tapes, hammers, four insulated connecting wires on portable reels, crocodile clips, etc. To transport team members to the field and survey areas, a car was waiting.

Vertical electrical sounding (VES) using Schlumberger electrode arrangement is the technique used. Seismographs and their accessories are the materials used for seismic refraction surveys in another development.

The major regions of Cross River State's geology map were carefully examined. The selection of the communities was based on the level of guinea worm infection, and maps supplied the essential direction for identifying potential villages and locations for conducting resistivity investigations and concurrent seismic refraction measurements. This was done to make sure that the data being collected was accurate and that fieldwork and logistics were scheduled in accordance with local conditions. It was decided to divide the job into two halves and schedule field activities. There are two main stages in the seismic and resistivity components. The reconnaissance phase was essential to improve the field logistics to ensure good quality data acquisition in the main phase and to create a good crew-community relation for field data acquisition.

2.1. Resistivity field work

A total of 14 locations underwent Schlumberger VES [24], with a maximum current electrode spacing (AB/2) of 500m on 14 straight profiles. the selection of the electrode spread's center at locations that allow for the deployment of electrodes along a roughly straight route. Two calibrated rolls of twine were laid out in two different directions at each station to create the traverse. Typically, this resulted in a traverse length of 500m (or 250m either way). The two potential electrodes (P1 and P2) were initially planted at 0.25m and 0.5m from the sounding center, respectively, to begin measuring the earth resistance R. The initial separation b of the two current electrodes (C1 and C2) was similarly set at 2m, with each electrode being placed 1m from the center. These electrodes were attached to the IGIS resistivity meter's corresponding terminals. The ground was watered at several measurement locations where the nearby earth was dry and hard. The earth resistance was automatically measured by pushing the measure button on the instrument panel while in the "On" mode after choosing four measurement cycles. Normally, the highest permitted current level was applied.

The current electrodes were systematically expanded for later measurements. On occasion, the potential electrodes were also enlarged. It was necessary to use cellphones to establish communication links with crew members at their various locations when there was a very large current electrode spread (i.e., for b greater than 150m) so that the extent of spread at any given measurement could be accurately determined and pertinent messages could be transmitted in the process. For comparison purposes, some soundings were conducted close to some existing boreholes.

3. Results

3.1. VES data analysis

The calculation of apparent resistivities, which was required to start the VES data analysis, was done by multiplying the resistance by the previously determined geometrical parameters as provided by equation (1) for the Schlumberger array below.

$$\rho_{as} = \frac{\pi\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\frac{\Delta V}{I} = \frac{\pi b^2 R}{4a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(1)$$

whereas is the computed and recorded Schlumberger apparent resistivity in ohm-meter units. On a piece of log-log graph paper, the estimated result of each measurement was plotted against the half current electrode spacing AB/2. After obtaining VES curves, all sounds curves with noisy parts were manually smoothed first.

The layer parameters were determined by a computer program using forward (direct) and inverse modeling techniques. When there is no match, the program automatically adjusts the layer parameters. An error tolerance limit was set so that the program could repeat the process until a match was made, at which point the made match became the layer parameters.

The forward modeling method involved assuming a model, calculating the model's response and comparing it to field data, and then modifying the model's parameters to enhance comparison. On the other hand, an iterative approach was combined with the inverse method. During this process, an initial guess was established regarding the model's resistivities and layer thicknesses. These numbers are used to construct apparent resistivity curves, which are then compared to the field curve to determine where the observed and model curves disagree and automatically adjust the procedure to minimize the disparities.

The iteration process was continued until there were no longer any significant disparities between the observed and theoretical data, often with an RMS of no more than 5%. The analysis was conducted using the SSA-V.092 tool from the RESIST [20] package, which solely employs the inverse method. As a consequence of the data analysis, several curve types were identified and categorized, including the KH, KHK, HK, K, KHKH, KQ, KQH, KHH, AKQ, KAKH, Q, QQ, QQQ, AAK, AAKH, QH, HKQ, QQH, and KKH curve types.

3.2. Computation of aquifer and Dar-Zarraouk parameter

Aquifer hydraulic parameters also known as Dar Zarrouk parameters for every VES station where calculated using equation authored by [13] using the layer parameters earlier determined, Consequently, the longitudinal conductance *S is : p*

$$S = H_i/\rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(2)$$

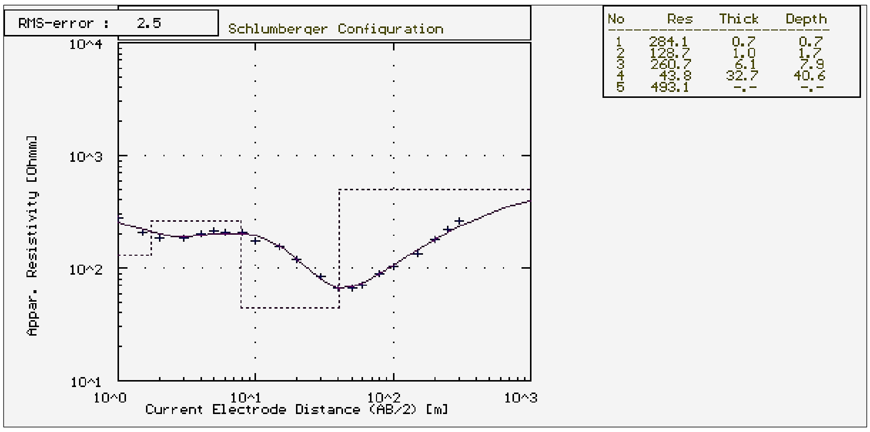
and the transverse resistance (R) is defined as

$$R = H_i\rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(3)$$

where H_i and ρ_i are the thickness and resistivity of the *i*thlayer. The parameters R and S are commonly called the Dar Zarrouk parameters.

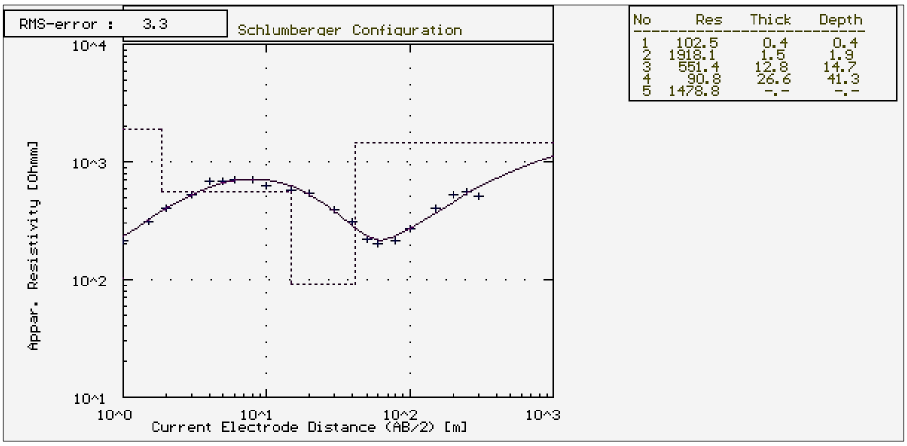
The longitudinal conductance (S) gives a measure of the non-permeable nature of the overburden clay/shale layer.Such layeris characterized with low hydraulic conductivity (K) and loThe overburden clay/shale layer's non-permeable character is quantified by the longitudinal conductance (S). Low hydraulic conductivity (K) and low resistance define this stratum. The equation states that the overburden layers' protective capacity PC is exactly proportional to its longitudinal conductance S. w resistivity. Protective capacity P_C ofthe overburden layers is directly proportional to its longitudinal conductance S andis calculated using the equation:

$$P_C \ \alpha \ S = \sum \frac{H_i}{\rho_i} \ldots \ldots \qquad (119)$$



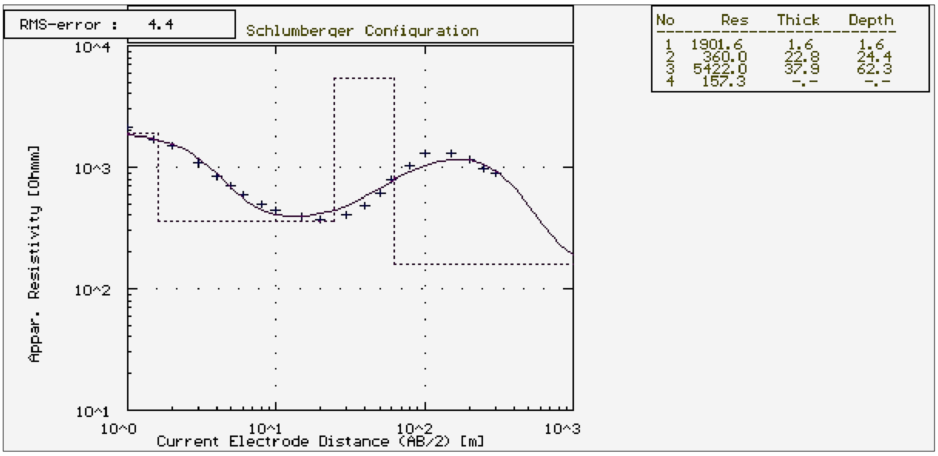
Source: Author’s field work, (2022).

Figure 2 Apparent Resistivity model curve of OCHIKPOR OFODUA (VES 1) in the study area



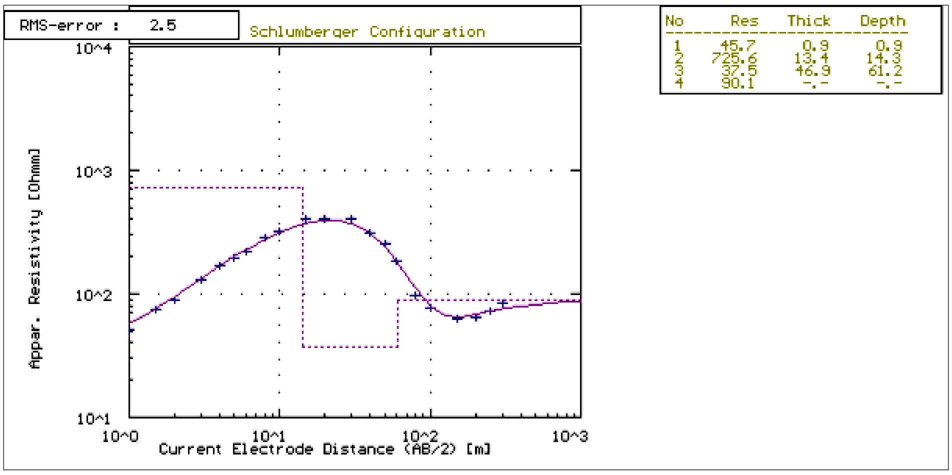
Source: Author’s field work, (2022).

Figure 3 Apparent Resistivity model curve of OKPECHI (VES 2) in the study area



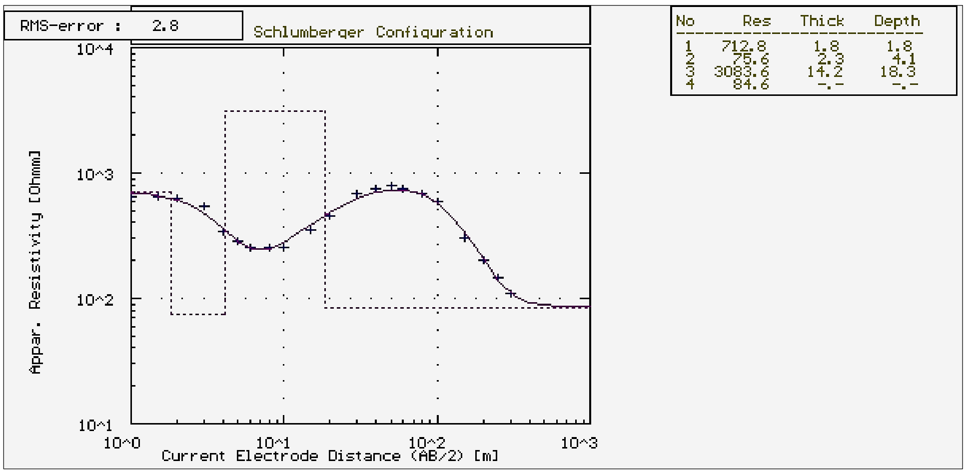
Source: Author's field work, (2022).

Figure 4 Apparent Resistivity model curve of IJODA OFODUA (VES 3) in the study area



Source:Author's field work, (2022)

Figure 5 Apparent Resistivity model curve of IJUTUM(VES 4) in the study area



Source:Author's field work, (2022).

Figure 6 Apparent Resistivity model curve of IBINE ABABENE (VES 5) in the study area

Table 1 Geoelectric Layer parameters

ves no.	**Elevation above sealevel**	**Location**	**Number of layer**	**Geo-electric layers Resistivity (Ohm-m)**						**Geo-electric layers Thickness (m)**						**Depth to bottom of Geoelectric layers (m)**				
	(m)			*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*d1*	*d2*	*d3*	*d4*	*d5*	*d6*	*h1*	*h2*	*h3*	*h4*	*h5*
1	106	Ochikpor	5	120	250	169	80	310	-	21	3.6	26.1	31.5	-	-	2.1	5.7	32	63.3	-
2	48	Mughe	4	70	186	280	49	-	-	0.9	7.2	26.9	-	-	-	0.9	8.1	34	-	-
3	40	ochikpor 2	5	50	110	206	118	51	-	1.1	2.6	5.2	10.2	-	-	1.2	3.7	8.8	19	-
4	75	Opharuk	5	1306	350	180	40	16	-	0.6	12	6.7	5.1	-	-	0.6	12.6	19	24.4	-
5	106	Ijoda	5	1628	313.2	748.8	71.4	545.9	-	0.5	1.6	2.5	12.4	-	-	0.5	2.1	4.6	17	-
6	103	Ijoda 2	5	216.8	143.5	116.78	129.02	11.21	-	1.00	1.5	5.0	18.0	-	-	1.5	2.5	7.5	25.5	-
7	96	Arobom 1	5	15.8	156.6	1496.9	1052	501	-	1.7	3.76	17.5	26.6	-	-	1.7	5.46	23	48.6	-
8	97	Arobom 2	5	406	701.2	250.1	34.2	80	-	1.0	1.50	6.00	42.01	-	-	1.0	2.5	8.5	50	-
9	51	Omon	5	144.9	25.3	141	23.3	302.5	-	0.6	3.2	11.9	38.8	-	-	0.6	3.7	16	50.1	-
10	56	Okpechi	5	172.4	30.9	167.1	12.6	2277	-	1.4	13.5	13.1	27.0	-	-	1.4	14.9	28	44.3	-
11	44	Omene	4	142.2	38.3	121	23.8		-	0.9	4.1	36.9		-	-	0.9	5.1	42.0	48	-
12	53	Ovokwa	5	340.2	370.7	160	20.12	80.11	-	10	15.2	14.6	20.0	-	-	10	25.2	50	69.8	-
13	79	Ibine	6	49.0	52.3	150	24.6	38.4	32	9.6	14	20.5	13.7	34.88	-	9.6	23.6	44	57.8	92.6
14	89	Ijutum	3	62.9	144.2	124.4	-	-	-	4.2	33.5	-	-	-	-	4.2	37.7	-	-	-

Table 2 Aquifer Dar Zarrouk and otther hydraulic parameters derived from filed results

VES Station Number	Elevation Above sealevel (m)	Location to bottom (m)	Min Depth	Min. Average thickness (m)	AquiferApparentResistivity (p) (ohm-m)	Transverseresistance *m2* (ohm-)	ProtectiveCapacityPc(Mho)	Conductivityσ (mgo-m)	Hydraulic conductivityK(m/day)	KσValue	Transitivity *m2* (/day)	Recommended borehole depth (m) groundwater development	Elevation of water table (m)
1	105	ochikpor	5.3	23.5	112.2	2397	1.268	0.2094	2.15	0.4503	50.25	5.3	41.7
2	42	Mughe	6.9	31	72.2	1251	0.197	0.2094	3.18	0.3654	98.5	6.9	8.0
3	39	ochikpor 2	17	14	62.7	3295	0.371	0.2233	4.52	0.0093	63.2	17.0	20.0
4	71	Opharuk	14	10.8	68	6630	1.478	0.1227	4.4	0.054	47.52	14.0	57.0
5	104	Ijoda	36	7	546.9	3828.3	0.0127	0.000182	3.25	0.000591	22.75	36.0	68.0
6	101	Ijoda 2	39.53	34.2	116	3967	0.294	0.0086	2.41	0.0207	82.42	39.5	61.5
7	94	Arobom 1	48.5	55.0	501	27555	0.109	0.00199	4.46	0.441	245.3	48.5	45.5
8	97	Arobom 2	50.5	3.6	250	900	0.0144	0.004	4.81	0.0192	17.32	8.5	88.5
9	59	Omon	54.4	39.8	23	915	1.7304	0.043	1.34	0.0576	53.33	54.4	4.6
10	53	Okpechi	65.1	37.0	2477	91649	0.0149	0.004	4.63	0.00185	171.31	65.1	12.1
11	49	Omene	42.0	36.9	101	3273	0.3653	0.099	2.16	0.0213	79.70	42.0	7.0
12	53	Ovokwa	27	19.5	160	3120	0.121	0.00325	5.66	0.0353	110.31	27.0	26.0
13	79	Ibine	41.5	16.5	150	2475	0.11	0.0066	0.97	0.0064	16.01	41.5	37.5
14	63	Ijutum	37.7	32	415	13280	0.0771	0.0024	3.01	0.00722	96.32	37.7	25.3

4. Discussions

A potent technique was used to distinguish the various geoelectric layers that make up the subsurface by analyzing and presenting the vertical electrical sounding data as characteristic curves as shown in Figures 2 through 6. The results are reported in Tables 1 and 2. The characteristic curves showed two to six geoelectric layers after careful inspection of the curves. Table 3

The summary of the computer-aided modeling using all the data collected from the study area is shown in Tables 2 and 3. These tables show parameters like aquifer resistivity, depth to the bottom of the aquifer, and thickness of the aquifer (transverse resistance, protective capacity, and transmissivity), which are crucial in defining the characteristics of formation in the study area.

Table 2's top layer resistivity was determined by eye examination to range between 15.8to1626Ωm. Because lateritic and medium-grained sand predominated in the research area's topsoil, the majority of the places showed moderately high resistivity, which can be explained by their composition.

The resistivity range for the second layer was 52.3Ωm. m to 370.7Ωm. Resistivity in the third layer ranged from 121 m to 1491.9Ωm. The resistivity range for the fourth layer was 12.3Ωm. m to 1052.7Ωm. Most of the sounding locations did not contact the fifth stratum, but a few that did reveal that the resistivity ranged from 11.21Ωm. to 2277.2Ωm. Up to the sixth stratum, which had a resistivity of32Ωm could be reached. High first layer resistivity values were found at Ijoda and Opharuk, whereas most other stations' first layer resistivities were very consistent (Table 1). But the difference can be explained by variations in the clayey and moisture content of the lateritic topsoil. The influence of the substantial bulk of loose, dry, and sandy topsoil upon which soundings at these locations were made is credited with contributing to the two stations' very high first layer resistivities. Such surface conditions are thought to have inhibited current penetration and decreased the likelihood of discovering deeper layers. This is clear from the recorded bottom depths of 17 meters and25 meters, which are incomparable to the depths of 19 meters to 92.6 meters inferred for the majority of soundings. It's possible that some resistive layers' masking effects extend beyond the initial layers, however they seem to have a more objectionable outcome. Lower probe depths may have been the result of highly resistant intermediate layers at certain other locations where penetration depths could not go above 50m. These middle strata most likely correspond to gravel formations.

Differences in the resistivities of layers in a survey over an area with a wide distribution of sounding points may not always indicate differences in layers or discontinuity in subsurface layering, but rather, such contrast may be attributed to conditions at the surface or some intermediate layers, as explained above.

4.1. Aquifer description

The aquiferous zone was identified using the distinctive resistivities of the several layers. That is, a transition from a higher resistivity (for the unsaturated overburden) to a lower value (for the aquifer), as is generally depicted, marks the progression from the zone of non-saturation above the water table to the aquifer. Further decrease in resistivity is thought to be caused by a deep aquifer that contains clay or by a progression towards a zone of low water quality [19], [21].

Since most of the strata above and below the aquifers in most regions are probably shales, the aquifer systems in the research areas are typically confined.

This finding is in consonance with an earlier research carried out by [23] , whose findings were that the sedimentary sequence in the Ikom-Mamfe Embayment in Southeastern Nigeria is dominated by impervious shale that are occasionally intercalated by beds of sandstones. The shales which are typically of low resistive (ρ<100Ωm) are overlain by some thin sandy (or sometimes gravelly) materials with comparatively high resistivity values (ρ>400Ωm).

In the CRPP and NASP hydrogeologic provinces, the vertical extent of the shales is truncated by some thin sandy materials with This result is consistent with prior research by [23] who discovered that impermeable shale predominates in the sedimentary sequence of the Ikom-Mamfe Embayment in southeast Nigeria, with beds of sandstones interspersed sporadically. A thin layer of sand-like (or occasionally gravelly) materials with quite high resistivity values (>400 m) lies on top of the shales, which are normally low resistive (100 m).

Some thin sand materials with relatively greater electrical resistivity values terminate the vertical extent of the shales in the hydrogeologic provinces of CRPP and NASP. These sandy materials are typically saturated, and the aquifers are either completely or partially enclosed. Sandstone or sandy strata make up the majority of the aquiferous zones.

These sandy aquifers' electrical resistivity values were found to vary with location and burial depth. Telford et al. [24] have observed and examined the relationship between electrical resistivity levels and aquifer depth. Because they are typically suppressed, it is exceedingly challenging to identify saturated sandy materials based on their electrical resistivity. The saturated sandy materials are typically overlain by another thick shale bed. The electrical resistivity values between the inter-fringing sandy materials and the shales are typically poorly contrasted, making it difficult to always attribute responses to the sandy materials.

Another significant source of groundwater, albeit predominately at shallow depth, comes from secondary structures created by tectonic activity within the shale, such as cracks, joints, lineaments, and faults. It is highly challenging to identify shale using electrical sounding data, especially when saturated because resistivity values overlap.

5. Conclusion

Geoelectric sounding data interpretation revealed characteristic curves with two to six geoelectric layer thicknesses. The predominant frequencies in the area were 19.6%, 15.4%, and 12.6% for the KH, HKH, and HK curve types, respectively. The electrical resistivity of the first layer ranged between 15.8 to1626Ωm, which was indicative of clay, shale, or sandy silt, and a maximum of six geoelectric layers were obtained from the interpretation of the sounding data at some locations while a minimum of three geoelectric layers were obtained at some other locations. The resistivity of the second layer ranged from 52.3 to 370.7Ωm. This was assumed to be shalestone/shale, and it was overlain by the third layer, which had resistivity values between 121 m to 1491.9Ωm, which was assumed to be sandstone (sandstone materials make good aquifers), the fourth layer, which had values between 12.3Ωm. m to 1052.7Ωm, the fifth layer, which had values between 11.21Ωm. to 2277.2Ωm, and the last layer, which had a value of32Ωm.The fact that the transmissivity measurements ranged from 16 m^2/day to 171m^2/day and that the porosities were high with strong storactivity showed that the studied area contains thick and abundant aquiferous zones. The protective capacities (PC) values of (0.01-1.260 seimens) obtained from the VES data evaluation suggested that the overburden impermeable rock materials (clay/shale) are significant enough to prevent surface contaminant infiltration into the aquifers within the study area. The hydraulic conductivity values from the pumping test that were acquired from CRSWBL and those derived from sounding interpretation were quite similar. It is credited to this study that, a critical evaluation of the aquifer and DarZarouk parameter led to determining the exact surface location of the groundwater as well as the depth of occurrence, this formed one of the contributions to knowledge derived from this research.

Compliance of ethical standard

Acknowledgment

Special mentioned is hereby made of The Cross River Water Board Limited who gave us access to some vital information during the course of this research. The Epidemiological Unit of the Cro ss River Ministry of Health is also acknowledged for the background information given to us on Guineaworm infestation in the state

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] El-Ashry, M. T. (1991). Policies for water resources management in Seniard regions: Water Resources Development, 7 (4): 230 – 234.

[2] Eseme, E., Agyingi, C. M. Foba-Tendo, J. (2002). Geochemistry and genesis of brine emanation from cretaceous strata of the Mamfe Basin, Cameroon, J. Afr. Earth Sc. 35:467-476 Doi: 10.1016/SO899-5362(2)00171-9.

[3] Cunningham &Saigo (1997), Environmental science: A global concern. New Canadian Edition. Ryerson Higher Education: McGraw Hill. Doi: 10:0070916647.

[4] Van-Overmeeren, R. A. (1981). A combination of electrical resistivity, seismic refraction, and gravity measurement for groundwater exploration in Sudan. Geophysics, 58: 38 – 48.

[5] Ogherejivwe, A. 0. & Osazuwa, I. B. (2002). The use of electrical resistivity method in geology mapping and engineering site investigation in Federal Polytechnic Bida Niger State. A paper presented on the 27" Annual conference of the Nigeria Institute of Physics held at Sheraton Hotel and Tower, Abuja, Nigeria18h -21% September.

[6] Ebong, E. D., Akpan, A. E. and Onwuegbuche, A. A. (2014). Estimation of geohydraulic parameters from fractured shales and sandstone aquifers of Abi (Nigeria) using electrical resistivity and hydrogeologic measurements, Journal ofAfrican Earth Sciences.

[7] Benkhelil, M. G., Ponsard, J. F. Saugy, L. (1975). The Bornu-Benue Trough, The Niger Delta and its offshore Tectono-sedimentary reconstruction during the cretaceous and Tertiary from geophysics and geology. In: Kogbe, C. A. (ed) Geology of Nigeria. Lagos: Elizabethan Press, 277 – 309.

[8] Offodile, M. E. (1975). A review of the geology and cretaceous of the Benue valley. In Kogbe CA (ed.) Geology of Nigeria; Lagos: Elizabethan Press, 375 -376.

[9] Cross River State Water Board Limited (CRSWBL) (2012). Technical Report. Cross River State Government Printing Press.

[10] Nigeria Geological Survey Agency (NGSA) (2006). Geological and mineral resources map of Cross River State, Nigeria.

[11] Okwueze E. E, Selemo, A. & Ezeanyim, V. J. (1995). Preliminary lithology deduction from a regional electrical resistivity survey of Ogoja, Nigeria. Nigeria Journal of Physics, 7: 43 – 46.

[12] Aboh, H. 0. & Osazuwa, I. B. (2004). Preliminary estimation of laterite deposits from regional geoelectrical investigation in Kaduna area, Nigeria. A paper presented in the 27" annual conference of the Nigeria institute of physics, heldat Kaduna polytechnic, Kaduna, Nigeria, 1sh 18h September. Retrieved November 6, 2012, from http://www.scholarsresearchlibrary.com

[13] Okon-Umoren, O. E. (1992). Integrated geophysical studies of the Calabar flank. Ph.D Thesis, Department of physics, University of Calabar, Calabar- Nigeria.

[14] Mbonu, P., Ebinero, J., Ofoegbu, C. & Ekine, A. (1991). Geoelectrical sounding for the determination of aquifer characteristics in parts of the Umuahia Area of Nigeria. Geophysics, 56: 284- 291.

[15] Edet, A. E., Okereke, C. S., Teme, S. C. & Esu, E. O. (1996). Application of remote-sensing data to ground water exploration: a case study of the Cross River State. Southern Nigeria. Hydroged J. 6(3):394-404, Doi: 10.1007/s10040050162

[16] Oyedele, K. F. (2001). Hydrological and hydrochemical investigation of groundwater quality in some parts of Lagos, Nigeria. African journal of environmental studies, 1, 31- 37.

[17] Toto, E. A., Benkabbour, B. & Fakir, Y, (2008). Using DC Resistivity method to characterize the geometry and the salanity of the plioquaternary consolidated coastal aquifer of the Mamora Plain, Morocco. Environ. Geol., 45:518-526.

[18] Ekwe, A. C. Onuoha, K. M. Onu, N. N. (2006). Estimation of aquifer hydraulic characteristics from electrical sounding data: The case of middle Imo River basin aquifers, South-eastern Nigeria. Journal of Spartial Hydrology, 6:121-131.

[19] ABEM, (1992). Geophysical instruments catalogue, ABEM printed matter. No. 90320. Bromma. AtlasCopco, El-Ashry, (1991).

[20] Van-Ziji J. S. (1978). On the uses and abuses of the electrical Resistivity method. Bulletin of the Association of Engineering Geophysicists. 15:85-111.

[21] Fitterman, D. V. & Stewart, M. T. (1986). Transient electromagnetic sounding for groundwater, Geophysical, 5 1:995-1005.

[22] Akpan, A. E. Ugbaja, A. N. & George, N. J. (2013). Integrated Geophysical, Geochemical and hydrogeological investigation of shallow ground water resources in parts of the Ikom-Mamfe Embayment and the adjourning area in Cross River State, Nigeria. Environ. Earth Sci. Doi:10/1007/s12665-013-2232-3

[23] Telford, W. M., Geldart, L. P. & Sheriff, R. E. (2004). Applied Geophysics (Second Edition). New York: Cambridge University Press.