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Geoelectric Investigation for the Subsurface Characterization of Groundwater in Some Parts of Onna Local Government Area of Akwa Ibom State, Nigeria

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Abstract

This study focused on the Geoelectric investigation of the subsurface characterization of groundwater in some parts of Onna Local Government Area of Akwa Ibom State. A total of Twenty (20) vertical electrical soundings were conducted using Schlumberger and Wenner configurations in some selected locations. Characterization of subsurface formations for groundwater using geoelectric methods. The probing was done using the ABEM Tarrameter SAS 300B, with maximum electrode spacing of 400m (for Schlumberger) and 140m (for Wenner array). The field data were analyzed using IP12 WIN software to obtain the subsurface resistivities and the overburden thicknesses of different VES points within the study area. In this study, the aquifer properties of transmissivity, storativity and hydraulic conductivity were calculated using the Dar Zarrouk parameters. The geoelectric section of the study area comprises the topsoil, clayed sand, gravels, coarse sand, igneous rock and other geological formations were obtained. The resistivity values of the geoelectric section of profile A varies from 2.25Ωm – 280,000Ωm and that of profile B varies from 2.25Ωm – 640,000Ωm. The thickness produced ranges from 0.512m - 45.1m and it shows that the area is endowed with productive aquifers for portable water production. The Isopach maps of two layers (2 and 3) were obtained by plotting the coordinates against the thicknesses of those layers across the 20 VES points using Surfer 28 software. The maps showed two major areas: the valley and hilly ground; some VES points shared similar characteristics and thicknesses. The iso-resistivity maps of the area were obtained at two different depths (30m and 100m). The coordinates across 15 VES points were plotted against apparent resistivity values at 30m and 100m across 15 VES points using Surfer 28 software. The iso-resistivity maps showed variation in resistivity with different colouration, indicating the apparent resistivity (500Ωm - 1000Ωm). The hydraulic conductivity and transmissivity range from 0.242 – 6,400,000m/day and 0.339 – 247,400m^2/day. Groundwater potential is high in the area as indicated by the apparent resistivity across the surveyed zones.

Keywords: *Geoelectric method, Characterization, Groundwater, Dar Zarrouk parameters*

Introduction

According to Adepelumi et al. (2008), groundwater is defined as water that is present below ground level in saturated layers of sand, gravel, and pore spaces in sedimentary and crystalline rocks. There are several varieties of groundwater, including fresh water, salt water, dark water, and so on. One of the most fundamental needs for human survival is access to clean water. For many different uses, including agriculture, industry, and household chores, groundwater is the most abundant source of potable water on Earth. The lack of contaminants and the ease of treatment make it preferable to surface water. Groundwater is becoming more important as a result of rising worldwide demand, and its storage sites must be protected from pollutants. Groundwater exploration and management need a solid understanding of aquifer hydraulic characteristics such as transmissivity, storativity, hydraulic conductivity, aquifer yield, transverse resistance, and longitudinal conductance, among others (George et al., 2015).

Recharging occurs when surface water seeps into the earth, resulting in the formation of groundwater. The steps of infiltration, percolation, and recharging combine to create it. When precipitation like rain or snowmelt seeps into the earth and becomes groundwater, this process is called infiltration. There are two zones in the recharge process: the top zone, which is the zone of aeration, and the zone of saturation, where gravity pulls the water downward into the earth. The pore spaces are filled with water and air in a zone of aeration. In contrast, water fills all pore spaces in a saturated zone (Cohen et al., 2020). The four main mechanisms by which groundwater travels are advection, diffusion, gravity, and lateral flow. As a result of gravity refilling the aquifer, groundwater flows downhill. It is propelled by hydraulic gradient and runs laterally across aquifers as well. A lot of the time, the flow will follow the water table's slope. Wherever the water table meets the surface of the earth, such as in lakes, rivers, and swamps, water is naturally released from the groundwater system. Because variables such as subterranean porosity and permeability determine the flow of groundwater, its behaviour differs from that of surface water. Discharges may be classified as follows: spring, stream, lake, well, and evapotranspiration. Aquifer characteristics (such as permeability and porosity), hydraulic gradient, water table elevation, weather, and human activities are all factors that impact groundwater outflow. Groundwater management, water supply planning, aquifer sustainability, ecosystem health, and climate change mitigation may all benefit from an in-depth understanding of groundwater recharge and outflow (Seth, 2007).

Aquifers are layers of subsurface porous and permeable rocks that act as a reservoir for groundwater. The subterranean aquifer is a great reservoir for water since it is composed of various permeable rock elements, such as gravel, sand, or silt. The water from rain eventually makes its way into an aquifer via the soil (Salako et al., 2018). Some related words to aquifers are aquitard, hydraulic head, hydraulic gradient, hydraulic conductivity, and transmissivity of aquifer. The boundary between two or more aquifers that blocks the flow of water from one to the other is called an aquitard. The solid rock layer and the clay layer are both examples of aquitards. The term "hydraulic head" describes the vertical rise of groundwater inside an aquifer. According to Amechi et al. (2022), it is also used to measure the depth below the surface of the earth. Aquifers may be restricted or unconfined; saturated or unsaturated; and perched.

To characterize groundwater, one must first determine what physical, chemical, and biological characteristics it has. For the sake of human and environmental health, aquifer management, modeling the transit of contaminants, and managing groundwater resources, it is of paramount significance. Sampling, field measurements, laboratory analysis, geophysical logging, and tracer tests are all part of the process of water characterization (Stephen et al., 2003). A rock's porosity and permeability are two factors that determine how much groundwater may seep into it. The intergrain pore spaces of a rock need to be linked for it to be permeable and allow groundwater to flow readily through it. According to Chukwu et al. (2021), permeability may be influenced by a number of factors. These include cementation, fluid viscosity, particle size and shape, cracks and defects, and porosity. Aquifer hydraulic characteristics, including transmissivity, porosity, aquifer yield, hydraulic conductivity, and so on, may now be estimated using the Dar Zarrouk parameters (Austin et al., 2011).

An subterranean aquifer containing both saltwater and freshwater may be accurately predicted using the Dar Zarrouk criteria. In order to characterize the behaviour of groundwater, hydrogeologists employ hydrological values. In the original Dar Zarrouk specifications, the thickness and resistivity of the material were included. What amount of resistance a material has to electric current flow is called its resistivity (Warmate et al, 2018). When the resistivity (ρ) and thickness (h) of the material are known, the Dar Zarrouk parameters, which consist of the transverse or perpendicular resistance (T) and longitudinal or parallel conductance (S), may be approximated (Warmate et al., 2018).

The distribution of electrical resistivity under the Earth's surface may be seen using geoelectric research, a non-invasive geophysical technique. Hydrogeology, environmental monitoring, mineral exploration, archaeological geology, and engineering geology are just a few of the many areas that make extensive use of it. It entails monitoring the voltage drop that occurs after inserting an electrical current. Resistivity sounding involves methodically increasing the distance between the potential and current electrodes, which provides information on the subsurface resistivity at various depths. Using forward and inverse modeling software, the variations in resistivity with depth are analyzed (Alabi et al, 2010). The geoelectric field makes use of a variety of arrays, including the Schlumberger, Wenner, Three Point, and Lee Partition arrays, among others. Placing four electrodes in a row around a shared midpoint forms the Schlumberger array. Current electrodes A and B are on the outside, while potential electrodes M and N are on the inside, near each other. Schlumberger configuration vertical electrical sounding offers greater resolution and requires shorter deployment time than Wenner array. Compared to Wenner and Dipole-dipole arrays, it requires less effort, making it the ideal solution for vertical electrical sounding (VES). The most basic kind of electrode array is the Wenner array, which consists of four identically spaced electrodes labeled A, M, N, and B. Current is measured by the two outside electrodes, A and B, while potential is measured by the two interior electrodes, M and N. Profiling involves lateral investigation of the earth to test soil, and sometimes vertical electrical sounding to explore groundwater and associated minerals. The Wenner is a typical tool for these types of explorations.

Geology of the Study Area

The study area is situated in the southern region of Nigeria, more precisely the Niger Delta Basin, is the Onna Local Government Area of Akwa Ibom State. Ndon Eyo, Ikot Ebiere, Ikot Udo, Ikot Ndudot, Ikot Annang, Ikot Ebidang, Ikot Ebekpo, Ikot Akpatek, Abat, and Ikot Ebiere are all included in the research. The area lies on Lat. $4^{0}51^{1}$N and $5^{0}9^{1}$N, as well as Long. $7^{0}51^{1}$E and $8^{0}9^{1}$E. A system of roads, including the Eket-Ikot Abasi road in particular and other connecting roads spread out over the region, allows access to the area. Thanks to the highways that go across the whole study area, it is easily accessible.

Being situated in the deltaic environment, the area is part of the Niger Delta Basin. The sedimentary basins that make up its geology are filled with deltaic deposit that dates back to the Tertiary period. Sand, silt, clay, and shales are among the sedimentary rocks that form the basis of Onna's lithology. Among its stratigraphic units are the Agbada, Benin, and Akata formations. Silt, clay, sandstone, shale, and limestone make up the Benin formation, which is situated in Nigeria's Niger Delta Basin. Its thickness may reach 3000m, and it contains reservoir rock that is both porous and permeable, as well as oil and gas reservoirs and aquifers that contain water. The formation's temperature varies from 800 to 1200^{o}C, making it very prospective for hydrocarbons.

The Akata formation is a shale, silt, and sand deposit located in the Niger Delta Basin. Its mild temperature varies from 60^{0}C to 100^{0}C, making it an ideal source rock for hydrocarbons. The Niger River is the sedimentary source, and its buried depth ranges from 3000 – 5000m. The Akata formation, which is made up of clay, silt, and sand, is also found in Nigeria's Niger Delta Basin. With a thickness of up to 4000m, it contains aquifers that contain water, oil and gas reservoirs, and porous and permeable reservoir rock. It has a significant hydrocarbon potential and a temperature range of 700 to 1200^{0}C. According to Ajibola (2004), the region under investigation has a relatively faultless, shallow, and stable tectonic context.

Figure 1: Map of the study Area (Google map 2024)

Materials and Methods

Materials

In the geoelectrical survey, the following instruments were used to measure the subsurface apparent resistivity and the overburden thickness of some selected locations:

- Resistivity Meter (ABEM Tarrameter SAS 300B
- 12V D.C battery
- Wires/Cables
- Five (5) steel electrodes
- Measuring tapes
- Hammers
- Radio Global Positioning System (GPS) Germin 16 CSX Model
- Data Logger/ Recording sheets and Pen

Methods

In this research work, a total of twenty (20) Vertical Electrical Soundings were carried out at different locations of the study area to determine the groundwater characteristics on those areas. Out of twenty (20) Vertical Electrical Soundings, fifteen (15) were Schlumberger arrays and the remaining five (5) soundings were Wenner configurations. The current electrode spacing varies from 200m, 300m and 400m for different locations covered for both Schlumberger and Wenner arrays.

In Wenner configuration, the study area was first mapped out with measuring tape of about 200m apart, taking the meter's position as the mid – point. Cables (currents and potentials) were well connected to the resistivity meter (ABEM Tarrameter SAS 300B)/ electrodes (steel rods), before connected to the power source (12V) battery. The meter was switched on first, to check the amount of voltage in 12V D.C supply before the commencement of recording. The connection for Wenner configuration is as shown below:

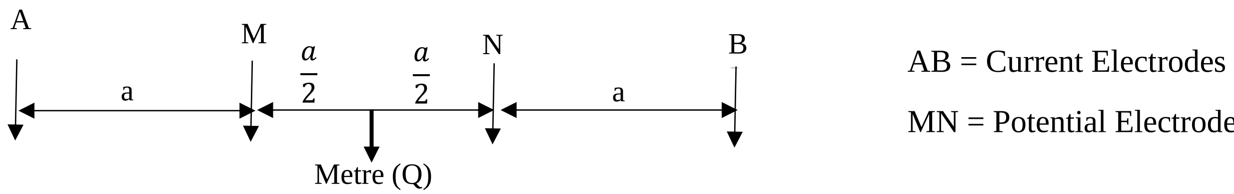


Figure 2:The Wenner configuration arrangement (Equal spacing of electrodes)

From the above diagram, the distance AM = MN = NB = a; meaning they are equally spaced. If the distance between, AM = 0.5m, then NB is 0.5m too, while the distance between either the meter and M or N is 0.25m.Then, if AM = 1.0m, NB = 1.0m, and MQ = QN = 0.5m. This process is repeated with an increasing distance between AM, MN, NB, MQ and QN until the required distance is covered. Measurement is taken in each case before electrodes are moved to new positions. Again, both machine and human errors should be minimized to obtain accurate results. The resistivity of the subsurface for each measurement is calculated using:

$$\rho = KR \qquad (1)$$

Where $\rho$the resistivity of the subsurface measured in Ωm, K is is the geometric factor and R is the resistance of the subsurface measured in Ohms. The apparent resistivity for Wenner configuration is given by:

$$\rho_a = 2\pi a \frac{V}{I} \qquad (2)$$

Where V is the potential difference in Volts, I is the electric current in Ampere, a is the electrode spacing in Wenner array and ρ_a is the apparent resistivity measured in Ωm.

In Schlumberger configuration, two of the team members first opened the measuring tape to the required dimension say 200m apart. The same procedure adopted above for ABEM Tarrameter and cables connections are employed before the D.C power source is connected to the meter (ABEM Tarrameter SAS 300B) placed at the mid – point of the measuring tape. The D.C battery power source is first checked before the metre is turn on to measure the subsurface resistance. Both cables carrying the current electrodes (A and B) and potential electrodes (M and N) were spread out for evenly distribution of current and voltage. The current electrodes were widely spread out while the potential electrodes were moved once the current electrodes were moved four to five times to ensure that Ohms' law is obeyed as shown below:

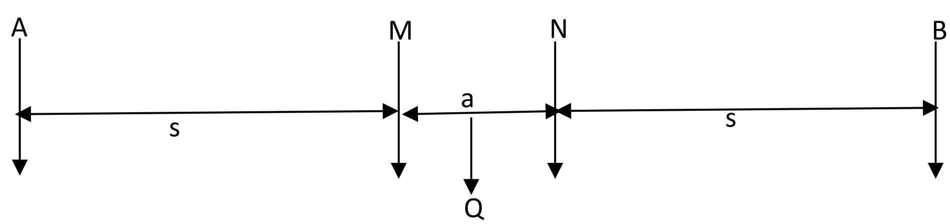


Figure 3: The Schlumberger Configuration arrangement

Where Q is the position of the meter, A and B are the current electrodes and M and N are the potential electrodes. The distance AM = NB and MQ = QN. If AM = NB = 1.0m and MQ = QN = 0.3m, the current electrodes spacing keep changing from 1.0m, 1.5m, 2.0m, 5.0m to 7.0m while the potential electrodes spacing remain constant until the above distances are covered. Again, if the current electrodes spacing changes to 10.0m, 15.0m, 20.0m, 25.0m, 30.0m, 40.0m to 45.0m, the potential electrodes at this point changes to 1.0m and is kept constant until those distances are covered. The reason for changes in electrode's position (current and potential) multiple times is to verify Ohms' law given by:

$$V = IR \qquad (3)$$

Where V is the potential difference in Volts, I is the electric current in Ampere and R is the resistance measured in Ohms.

The apparent resistivity for Schlumberger array is given by:

$$\rho_a = \frac{\pi\left(\frac{s^2 - a^2}{4}\right)}{a}\frac{\Delta V}{I} \tag{4}$$

Where V is the potential difference in Volts, I is the electric current in Ampere, a and s are electrode spacing and ρ_a is the apparent resistivity measured in Ωm. The Schlumberger array has a greater penetration than Wenner array most especially for groundwater exploration.

Results and Discussion

The data collected from twenty (20) vertical electrical sounding locations were subjected to computer iteration using IP 12 WIN software and the apparent resistivity and the depth of overburden thickness were obtained as shown below:

Table 1: Apparent Resistivity and depth of overburden Thickness of 20 VES in Onna L. G. A

		Resistivity of Layers (Ωm)						**Thickness of Layers (m)**				
VES no.	Station	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5
1		0.672	114	10294	-	-	-	0.504	0.838	-	-	-
2		1.39y	6.83	127	-	-	-	0.948	8.55	-	-	-
3		9.15	578	15.4	455	29.9	18072	0.492	0.471	2.43	15.5	18.2
4		0.242	1.24	2026	-	-	-	0.773	0.593	-	-	-
5		3.81	15.3	70.1	23.80	-	-	0.683	4.95	107	-	-
6		3.64	16.2	43406	-	-	-	0.554	1.52	-	-	-
7		1.464	4.003	43.12	692.9	-	-	0.600	2.408	30.95	-	-
8		8.14	0.849	17.1	7600	-	-	0.479	0.793	11.8	-	-
9		1.92	11553	526	-	-	-	0.194	1.18	-	-	-
10		10.4	16.4	89951	-	-	-	0.365	0.316	-	-	-
11		16.7	73.5	49881	459	-	-	0.6	2.1	2.86	-	-
12		4.25	263	42858	-	-	-	0.336	0.327	-	-	-
13		26.9	5.56	40227	108	-	-	0.521	0.849	16.2	-	-
14		57.4	105	640000	-	-	-	0.683	3.9	-	-	-
15		226	19075	1289	94.5	-	-	0.258	1	18.2	-	-
16		13.5	386	42.5	444	9896	166	0.6	0.646	1.34	21.5	25
17		93.5	2304	2.25	-	-	-	0.404	44.7	-	-	-
18		8.99	74.5	397	159	22.3	-	0.6	1.99	2.79	43.6	-
19		2.69	285	492	-	-	-	0.404	17	-	-	-
20		13.8	280000	348	2465	-	-	0.449	0.0629	5.42	-	-

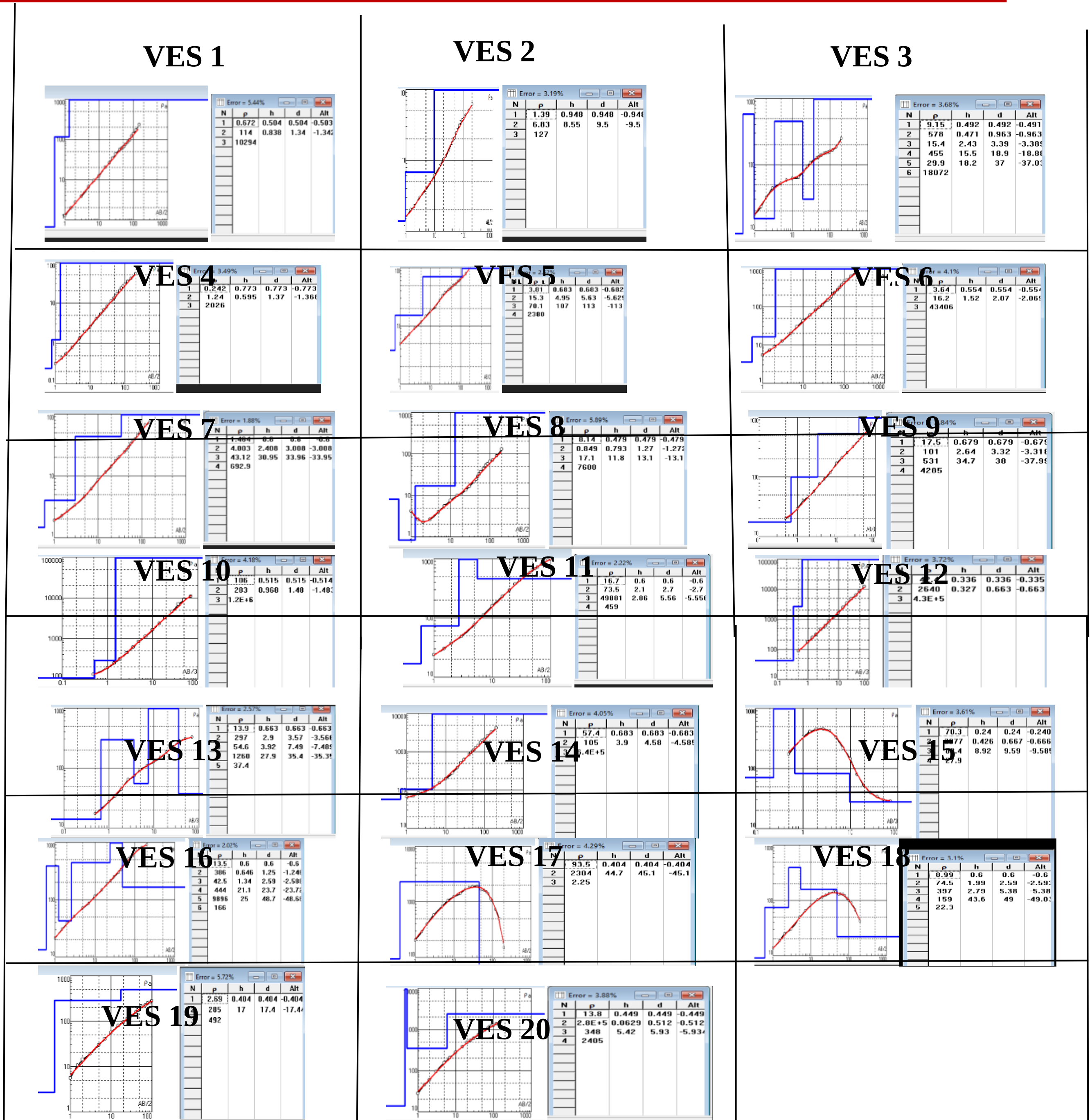


Figure 4: Resistivity Curves for 20 Vertical Electrical Soundings of the Study Area

According to table 1 and figure 4 above, the resistivity varies greatly among VES locations because of differences in subsurface formations. Twenty (20) vertical electrical soundings, together with their resistivity curves, overburden thickness, and depths, are shown in figure 4 above. Researchers can find the depth at which people of the area can get clean water for drinking by analyzing either the curve or the depth.

The resistivity readings taken at VES locations 1, 2, 3, 4, and 5 are within the typical range of groundwater, which is 10 to 100 Ωm. People residing in the aforementioned regions should aim for groundwater depths between 35 and 90 meters, with resistivity values ranging from 45 to 100 Ωm. Boreholes should be drilled between 30 and 50 meters with resistivity values between 25 and 100Ωm for VES 6, 7, and 8 locations.

It is believed that a significant amount of clay is present at VES sites 9 and 10, which have low resistivity values. The conventional resistivity values for clay, which range from 1 to 10 Ωm, are matching the resistivity values measured at those locations. At depths more than 10 meters, the resistivity readings begin to climb sharply, suggesting the presence of additional materials entrenched in the subsurface. The heavy concentration of clay, igneous rocks, and granite in these areas makes it unlikely that there will be an adequate supply of groundwater there. At VES points 11 and 12, you may find a shallow water table as well as silt particles suspended in the water. At this stage, the driller has to think about depths between 60 and 90m and resistivity values between 300 and 700 Ωm in order to access excellent water. At a depth of around 20 to 45 meters, the resistivity values for VES points 13 and 14 range from 150 to 220Ωm. Despite the fact that the measured resistivity levels are not within the typical range for groundwater. Using the specified ranges, the driller or drillers may effectively capture freshwater at those locations. The resistivity value for VES 15 is between 30 and 60 Ωm, which is within the normal range, and the depth is between 30 and 50m. At the specified depth, the inhabitants may enjoy a decent supply of freshwater. At depths ranging from 35 to 70 meters, the resistivity values for VES sites 16, 17, and 18 fall within the 120 to 170 Ωm range. With a resistivity of 159 Ωm and a depth of 43.6m, the precise depth is determined at VES 18. This depth and resistivity allow for the drilling of high-quality freshwater wells for the local population. The presence of freshwater is indicated by the resistivity value ranging from 80 Ωm to 100 Ωm at a depth of 30m to 45m at VES point 19. This point's resistivity value is within the typical range of 10 Ωm to 100 Ωm. The resistivity values of the final VES, which vary from 200 Ωm to 400 Ωm, are entirely outside the range that is needed for freshwater, and the depths measured are 20m to 35m. If the driller were to dig a hole at this depth, the well would yield as expected.

There are three main strata in the research region, located at VES points 1, 2, 4, 6, 10, 12, 14, 17, and 19. Different points with four to six levels. Top soil, with a thickness of half a meter to eight and a half meters, makes up the bulk of the upper strata. Approximately 10 meters of clay, silty clay, clayed sand, or sandy clay makes up the relatively resistant unsaturated zone that lies under the surface layer. The majority of the water from the hand-dug wells in the study area came from this zone, as can be shown in figure 4 above. A saturated zone with coarse sand or gravel makes up the third layer. Because the geology and terrain of each VES site is unique, the layers that emerge from them also vary.

Aquifer Characteristics using Dar Zarrouk Parameters: The aquifer characteristics include the aquifer hydraulic conductivity, transmissivity and storativity. These characteristics were calculated using Dar – Zarrouk parameters given as follows:

- In the absence of pumping test, the hydraulic conductivity equals the apparent resistivity of the study area.
- The longitudinal conductance, L_C is given by $L_C = \frac{h}{\rho}$, and it is also considered the aquifer storativity most especially when pumping test is not carried out on the study area. From the above equation, h is the thickness of the subsurface layers in metres and ρ is the apparent resistivity in Ωm.
- Aquifer transmissivity, T is defined as: T = kh

Where k is the hydraulic conductivity in metre per day (m/day), h is the thickness in metre (m), T is the transmissivity in m^2/day.

Hydraulic conductivity, K = apparent resistivity, ρ_a = 0.672m/day

Longitudinal conductance or storativity, $L_C = \frac{h}{\rho} = \frac{0.504}{0.672} = 0.75\Omega^{-1}$

Transmissivity, T = kh = 0.672 x 0.504 = 0.339m^2/day

The table below was computed using the same procedure above:

Table 2: Aquifer Characteristics using Dar Zarrouk Parameters (VES 1 - 20)

Number of Layers	Hydraulic Conductivity, K (m/day)	Thickness, h (m)	Depth (m)	Longitudinal conductance, $L_c(\Omega)^{-1}$	Transmissivity, T (m^2/day	Overburden Thickness (m)
				VES 1		
1	0.672	0.504	0.504	0.75	0.339	
2	114	0.838	1.342	0.00735	95.532	
3	10294	-	-	-		0.5
				VES 2		
1	1.39	0.948	0.948	0.682	1.318	
2	6.83	8.55	9.5	1.252	58.379	0.95
3	127	-	-	-	-	
				VES 3		
1	9.15	0.492	0.492	0.05377	4.502	
2	578	0.471	0.963	0.00081	272.24	
3	15.4	2.43	3.39	0.1578	37.422	
4	455	15.5	18.9	0.03483	7052.5	3.4

5	29.9	18.2	37	0.6087	544.18	
6	18072	-	-	-	-	
			VES 4			
1	0.242	0.773	0.773	3.194	0.187	
2	1.24	0.595	1.37	0.480	0.738	
3	2026	-				0.8
			VES 5			
1	3.81	0.683	0.683	0.179	2.602	
2	15.3	4.95	5.63	0.324	75.74	
3	70.1	107	113	1.526	7500.7	5.6
4	2380	-	-	-	-	
			VES 6			
1	3.64	0.554	0.554	0.152	2.017	
2	16.2	1.52	2.07	0.094	24.62	0.6
3	43406	-	-	-	-	
			VES 7			
1	1.464	0.6	0.6	0.498	0.8784	
2	4.003	2.408	3.008	0.602	9.6392	
3	43.12	30.95	33.96	0.718	1334.56	3.0
4	692.9	-	-	-	-	
			VES 8			
1	8.14	0.479	0.479	0.0588	3.900	
2	0.849	0.793	1.27	0.934	0.673	
3	17.1	11.8	13.1	0.690	201.78	1.3
4	7600	-	-	-	-	
			VES 9			
1	17.5	0.679	0.679	0.0388	11.883	
2	101	2.64	3.32	0.0261	266.64	
3	531	34.7	38	18107.1	18107.1	3.3
4	4285	-	-	-	-	
			VES 10			
1	106	0.515	0.515	0.00486	54.59	
2	283	0.968	1.48	0.00398	273.94	
3	1200000	-	-	--	-	0.5
			VES 11			
1	16.7	0.6	0.6	0.0359	10.02	
2	73.5	2.1	2.7	0.0286	154.35	
3	49881	2.86	5.56	0.000057	142,659.7	2.7
4	459	-	-	-	-	
			VES 12			

1	424	0.336	0.336	0.00079	142.46	
2	2640	0.327	0.663	0.000124	863.28	
3	4300000	-	-	-	-	0.34
					VES 13	
1	13.9	0.663	0.663	0.0477	9.2157	
2	297	2.9	3.57	0.00976	861.3	
3	54.6	3.92	7.49	0.0718	214.03	7.5
4	1260	27.9	36.4	0.0221	35154	
5	37.4	-	-	-	-	
					VES 14	
1	57.4	0.683	0.683	0.0119	39.204	
2	105	3.9	4.58	0.0371	409.5	
3	6400000	-	-	-	-	0.68
					VES 15	
1	70.3	0.24	0.24	0.0034	16.872	
2	3877	0.426	0.667	0.00011	1651.60	
3	82.4	8.92	9.59	0.1083	735.01	0.67
4	27.9	-	-	-	-	
	VES 16					
1	13.5	0.6	0.6	0.0444	8.1	
2	386	0.646	1.25	0.00167	249.356	
3	42.5	1.34	2.59	0.0235	56.95	
4	444	21.1	23.7	0.0475	9,368.4	23.7
5	9896	25	48.7	0.00253	247,400	
6	166	-	-	-		
	VES 17					
1	93.5	0.404	0.404	0.00432	37.774	
2	2304	44.7	45.1	0.0194	102,988.8	0.4
3	2.25	-	-	-	-	
					VES 18	
1	8.99	0.6	0.6	0.0667	5.394	
2	74.5	1.99	2.59	0.0267	148.255	
3	397	2.79	5.38	0.00703	1,107.63	
4	159	43.6	49	0.2742	6,932.4	5.4
6	22.3	-	-	-	-	
					VES 19	
1	2.69	0.404	0.404	0.1502	1.087	
2	285	17	17.4	0.0596	4,845	0.4
3	492	-	-	-	-	

					VES 20	
1	13.8	0.449	0.449	0.0325	6.1962	
2	280000	0.0629	0.512	0.000000225	17,612	
3	348	5.42	5.93	0.01560	1886.16	0.5
4	2405	-	-	-	-	

The Dar Zarrouk characteristics of hydraulic conductivity, transmissivity and storativity were used to derive the aquifer properties which are summarized in Tables 2 above. The water transmission capacity at VES 1, 2, 4, and 6 ranges from 0.187m2/day to 95.532m2/day, which falls within the range of T 100m2/day. In contrast, VES 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20 exhibit good to excellent water transmission across multiple layers, is exceeding 1000m^2/day. This suggests that these points are located beneath a highly permeable aquifer with excellent water transmission properties. Its daily values may be anything from 142.46m^2/day and 142,659.7m^2/day. Layers 1, 2, 3, 4, 5, 6, 7, 8, 9, 15, and 18 of VES have a storage water capacity larger than 0.1Ω^{-1}, suggesting that there is a substantial quantity of water that may be stored underground in those layers. The poor ability of the subsurface aquifers to hold water is shown by the low storage capacity of VES 10, 11, 12, 13, 14, 16, 17, 18, 19 and 20, which is less than 0.01Ω^{-1}. A very high hydraulic conductivity ranging from 0.242 m/day to 6,400,000 m/day was observed across 20 VES stations, indicating strong water transport over the research region.

The Geoelectric Section

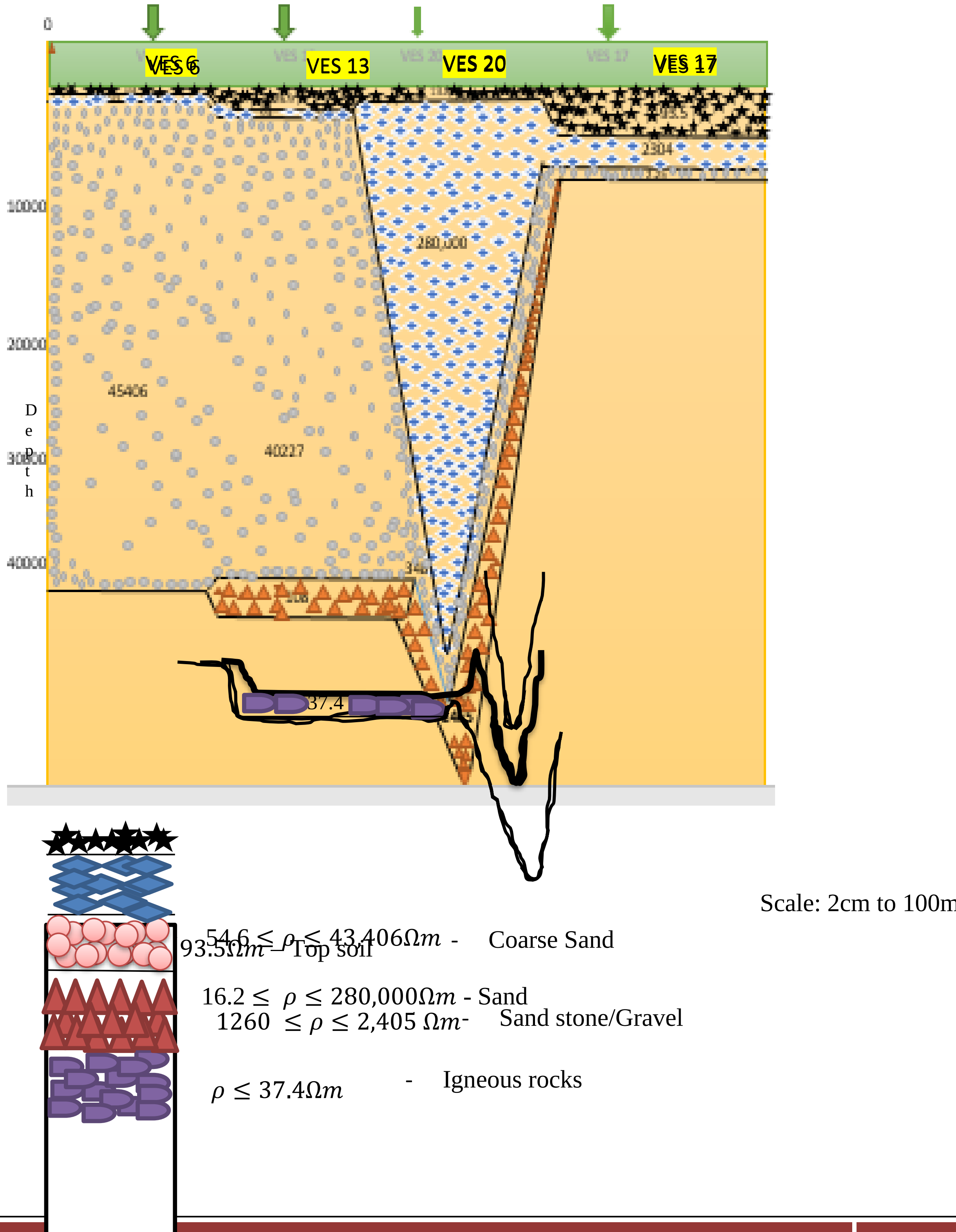
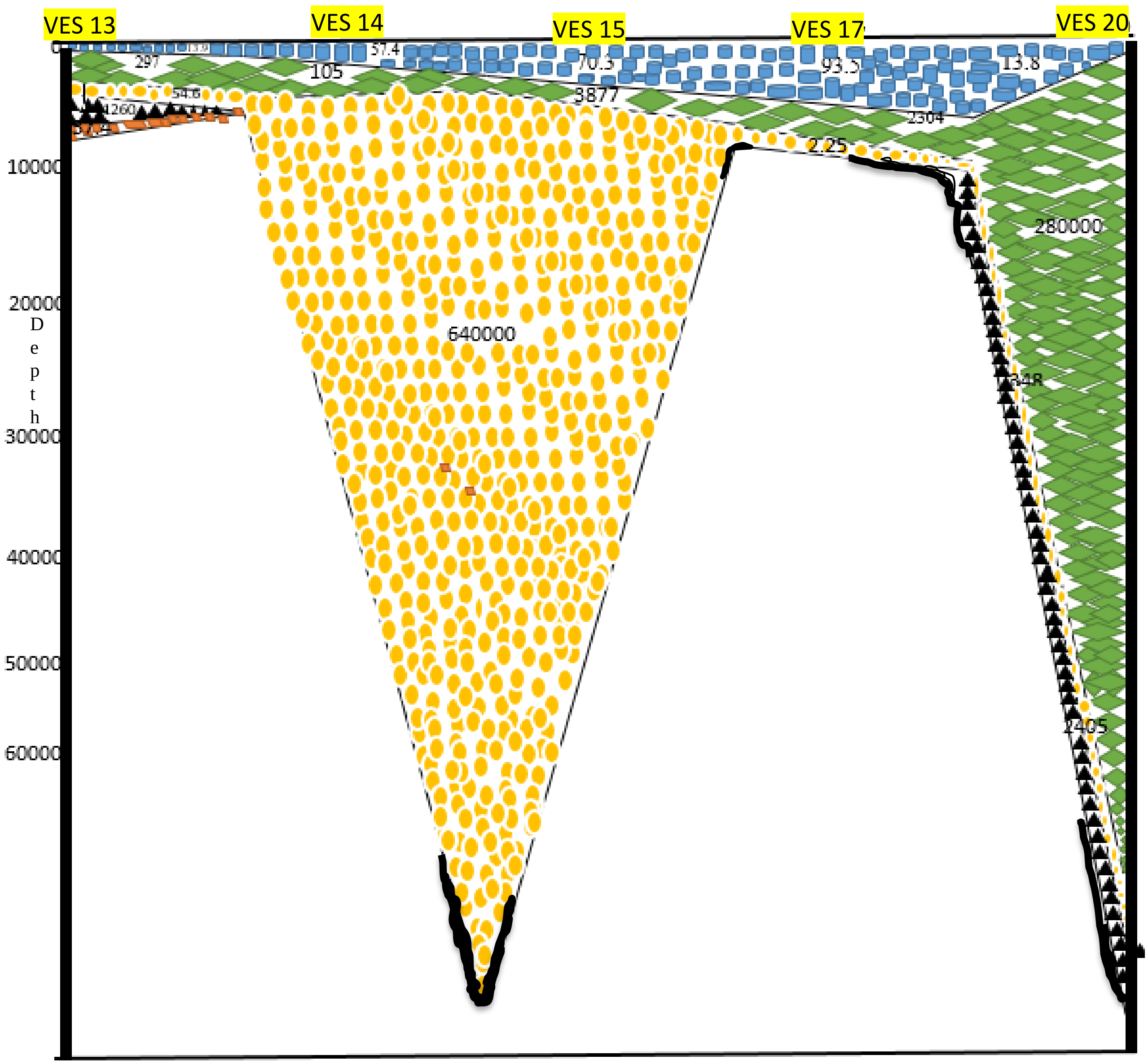
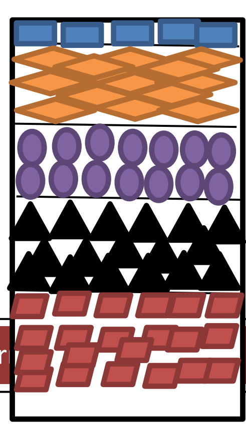


Figure 5: Interpretative Geoelectric Cross Section of Profile A





$13.8 \leq \rho \leq 93.5\Omega m$ – Top soil

$105 \leq \rho \leq 280{,}000\Omega m$ - Coarse Sand

$2.25 \leq \rho \leq 640{,}000\Omega m$ - Granite

$27.9 \leq \rho \leq 2{,}405\Omega m$ – Dolostone

$\rho \leq 37.4\Omega m$ – Igneous rocks

Scale: 2cm to 100m

Figure 6: Interpretative Geoelectric Cross Section of Profile B

The geoelectric sections for profiles A and B were prepared using the findings of the Vertical Electrical Sounding, as seen in figures 5 and 6 above. VES points of the southeastern region of the research area, VES 6, 13, 20, and 17 make up the geoelectric section of profile A. With a thickness best enough to support sufficient groundwater extraction. The resistivity values range from moderate to high (between 2.25 Ωm and 280,000 Ωm). It means that dense, unfractured igneous rocks like granite are present in those areas. It demonstrates that the area's drilling produce is anticipated to be quite fruitful.

Figure 6 shows the southern part of the research region covered by profile B, which was again created using VES 13, 14, 15, 17, and 20. Groundwater production in the region is sufficient due to the high resistivity values, which range from 2.25 Ωm to 6,400,000 Ωm, and the considerable thickness of the rock. Variable geological formations are shown by the resistivity values, which span from fine sand and topsoil to thick, unfractured, and dry granite boulders. Figures 5 and 6 are geoelectric sections, which provide a visual representation of the stratified strata of the Earth's subsurface as identified by electrical resistivity depth probing or drilling. The apparent resistivities of the strata are used to identify them. Discovering underlying geological features and aquifer units, detecting water-table levels and evaluating whether water is fresh or salty, researching groundwater pollution, and tracking hydrocarbon leaks in the subsoil are all possible using geoelectric sections.

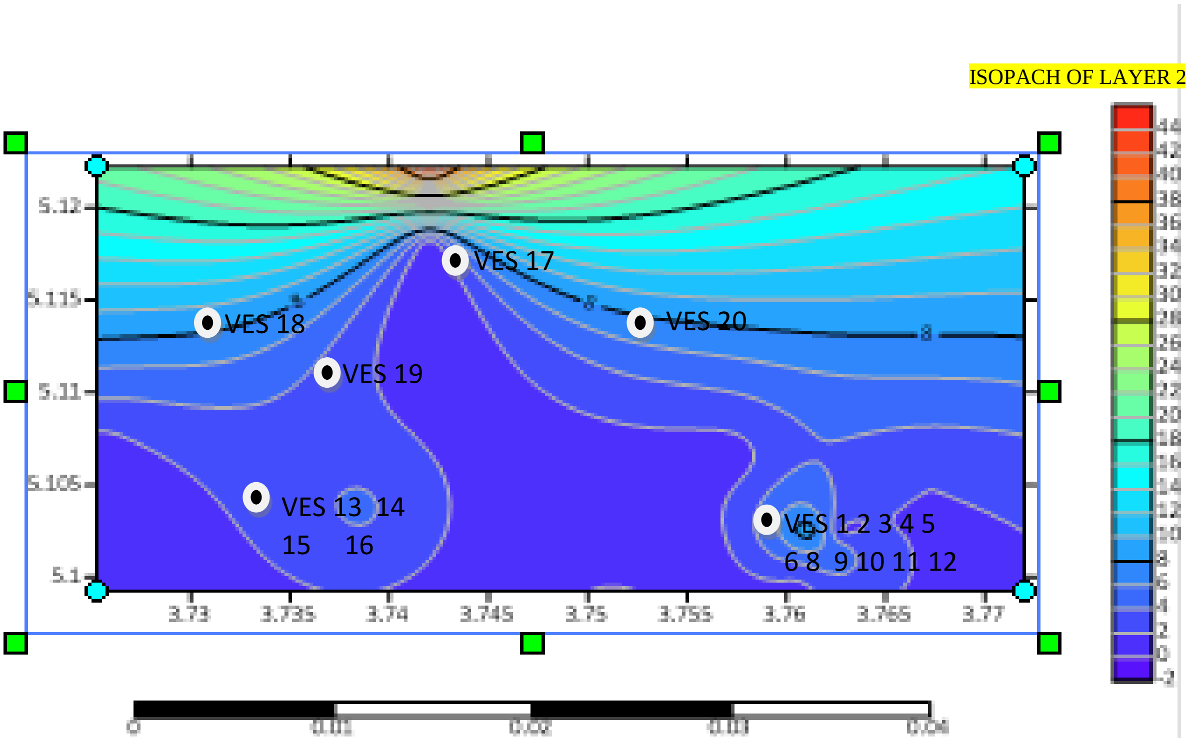


Figure 7: Isopach Map of layer 2 of the study area

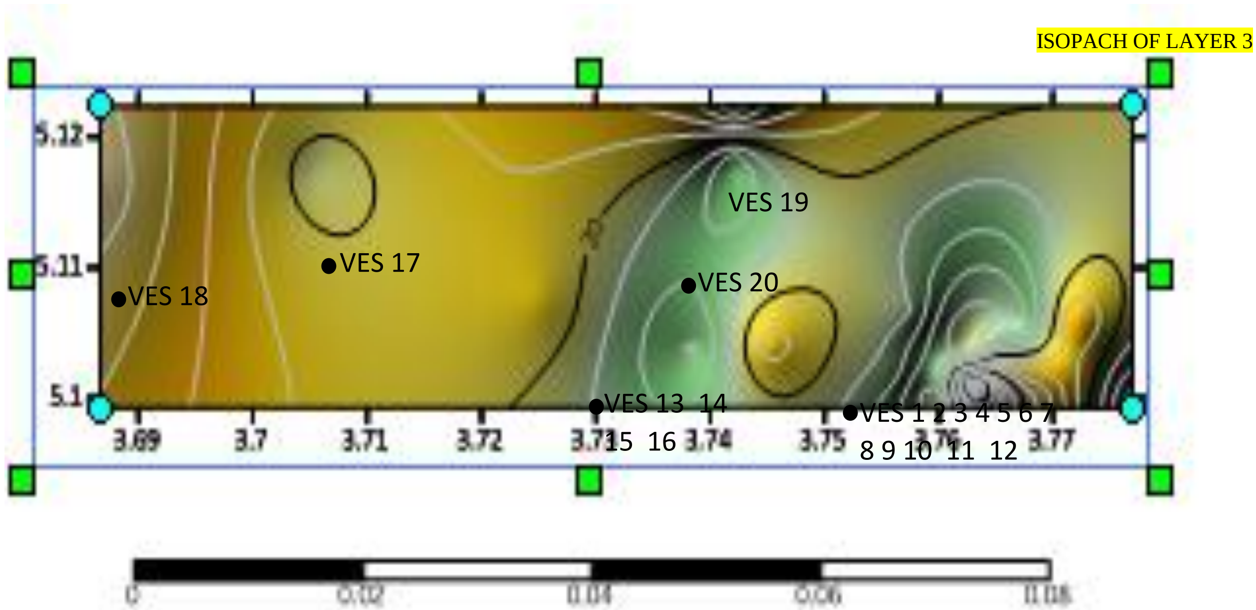


Figure 8: The Isopach Map of layer 3 of the Study Area

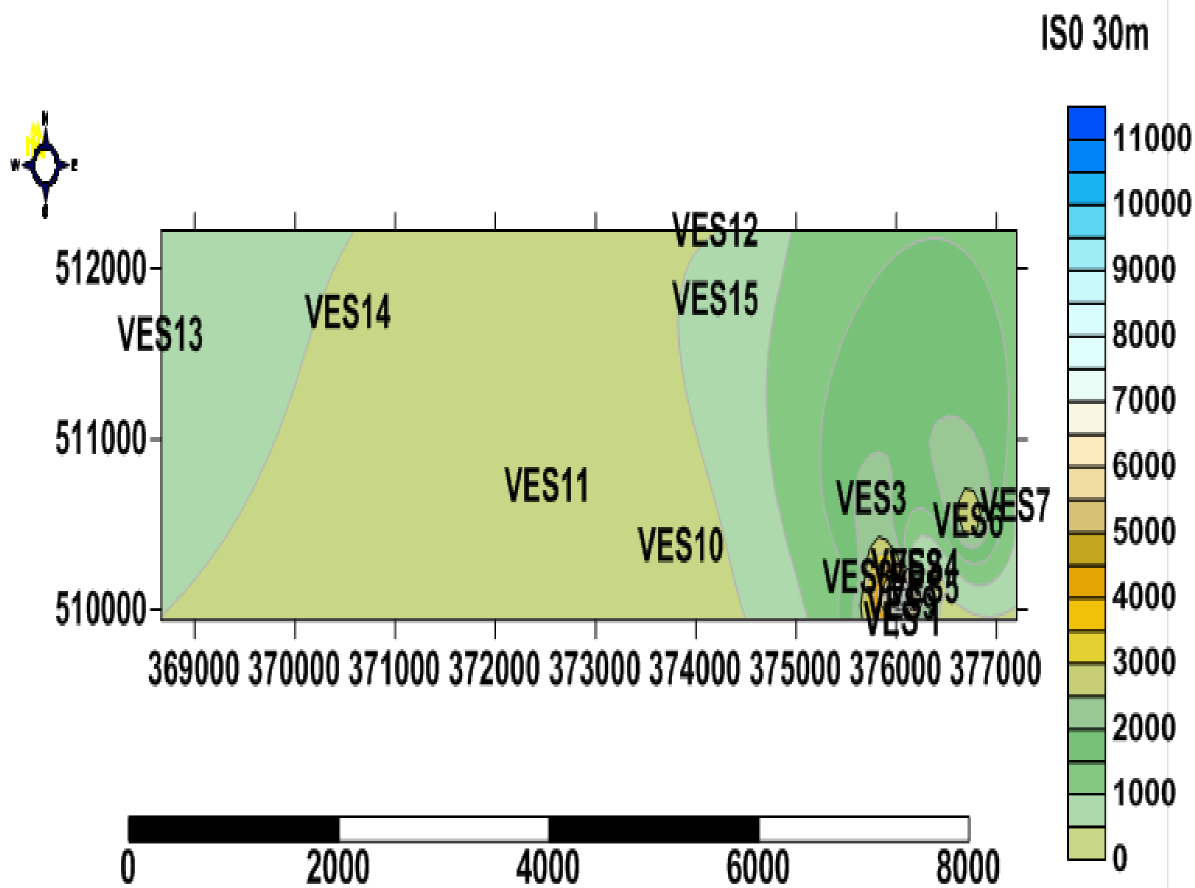


Figure 9: An Iso-resistivity Map at 30m of the Study Area

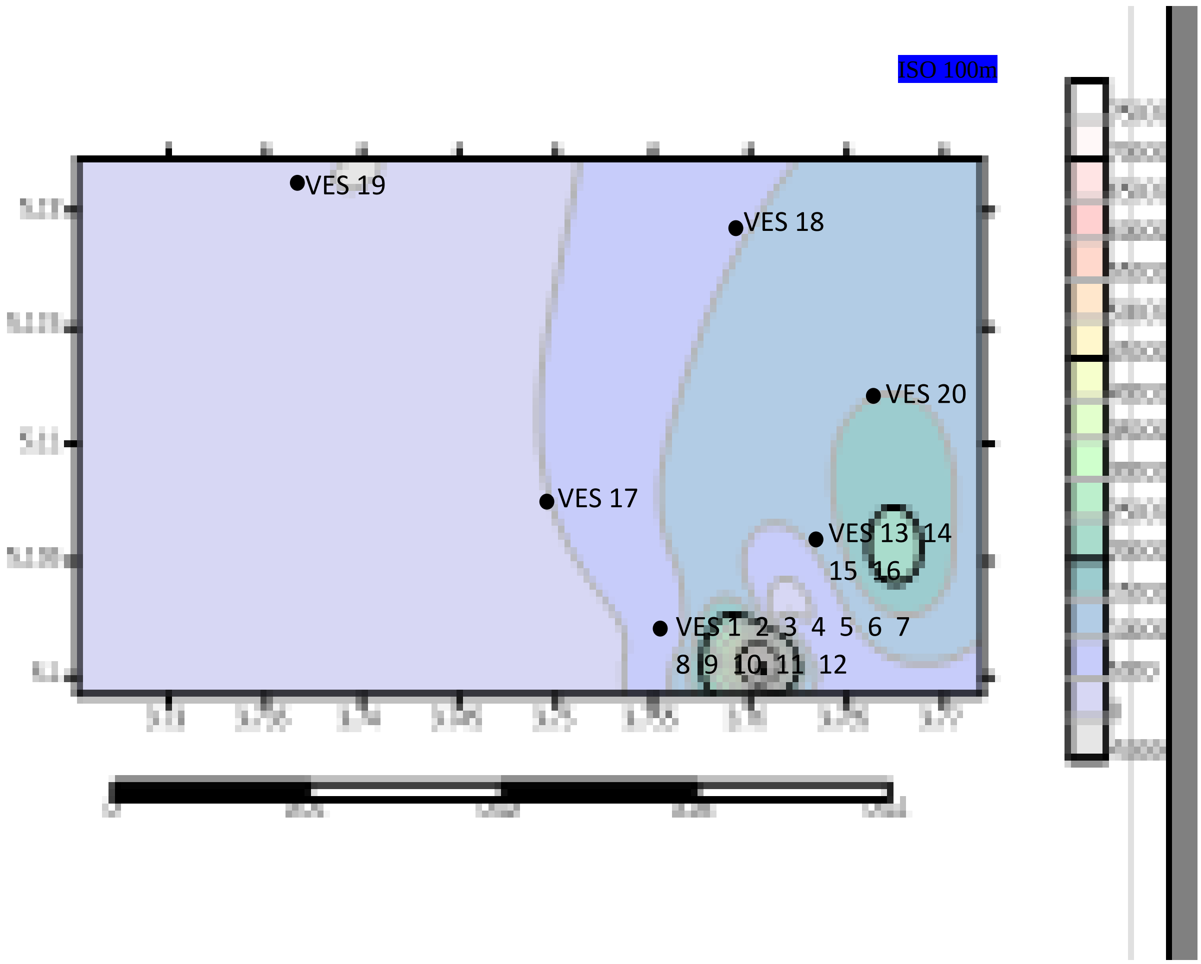


Figure 10: An Isoresistivity Map at 100m of the Study Area

The Isopach and Isoresistivity Maps of the Study Area

Figure 7 and 8 show an isopach maps demonstrating the different thicknesses of geological formations, reservoirs, and other similar objects. As can be seen from the image, VES 1–12 are located in a valley and have same forms and thickness. The map shows that VES 12, 14, 15, and 16 all have comparable features. Figure 7 shows that VES 17, 18, 19, and 20 are all located on steep terrain and have a comparable thickness. In geology, an isopach is a line that joins locations in the same thickness of a formation or series of formations on a map. Due to its measurement of the shortest distance between two surfaces, isopach maps provide more precise thickness information than other map formats. Two other names for isopach maps are TST maps, which stand for True Stratigraphic Thickness. Among their many potential uses are the following: producing subsidence maps, estimating reservoir volume, and assessing reservoir pore volume.

Visible on an iso-resistivity map is the depth-dependent vertical resistivity variation. As seen in figures 9 and 10, the resistivity gradually decreases as one descends within the formation, moving from a very resistant overburden to a less resistive layer near the core.

Conclusion

First-hand knowledge on the area in relation to borehole drilling was obtained through this research by adopting a geoelectric method where an estimate of the saturated zones and their thicknesses were ascertained. There is now no room for uncertainty when estimating the likely depth to the saturated zone in the region. Drillers and water resources staff in Onna Local Government Area and its environs may use this study as a suitable reference to develop strategies for a long-term water supply.

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