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Research Article

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Estimation of Groundwater Potential in Njikoka, Anambra State, Southeastern Nigeria Using Resistivity and Pumping Test Method

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Abstract
The research, which is focused on the prediction of aquifer parameters was carried out in order to highlight the essence of better knowledge of the groundwater sustainability of Njikoka and environs using a geophysical approach (Cooper-Jacob's method modified by David, 1959). Two (2) vertical electrical sounding (VES) in all the six (6) towns that made up Njikoka and environs, which resulted in twelve (12) VES locations. From VES obtained, geoelectric sections of the locations were modelled and aquifer information of the study area was inferred as thus; hydraulic conductivity, transmissivity, longitudinal conductance, transverse resistivity, thickness, depth to water table from mean sea level (MSL), and resistivity. Suitable software IPI2WIN was used to plot the apparent resistivity against the electrode spacing values obtained from the litho units of the subsurface. The VES curve types produced from the area show thus; A, H, K, AK, and KH, which was very useful to calculate the spatial percentages of the aquifer distribution in the study area. The geoelectric section delineated three (3) to five (5) layers of different lithology and aquifer depth from the surface level ranging from 15 m to 100 m with prevalently unconfined water saturated sands. The aquifer average resistivity value varied from 37 Ωm to 3451 Ωm throughout the study area. Two locations were chosen for pumping test exercises VES 3 and VES 9 whose data helped to calculate the proportionality constant Kσ = A, needed to estimate the transmissivity and hydraulic conductivity quantity. The two important aquifer parameters were calculated to be thus; transmissivity values ranged from 0.28 m2/day to 22.54 m2/day and the hydraulic conductivity varied from 0.003 m/day to 0.9 m/day. Only part of Enuguagidi showed evidence of little groundwater potential with 8.33% whose transmissivity and hydraulic conductivity rating were low fairly good and well-structured clay respectively, while the majority of the aquifer layers with 91.67% were classified as poorly structured clayey in transmissivity and hydraulic conductivity hence poorly productive aquifer zones. This is in consonant with the geology of the area under study.

Keywords: Vertical Electrical Sounding, Aquifer Curve Types, Aquifer Thickness, Aquifer Depth, Electrical Logging and Aquifer Resistivity.

1. Introduction

Researchers from relevant professional fields have carried out geological and geophysical on groundwater resources in similar areas like Njikoka and environs to ascertain aquifer productivity and basic parameters [1]. Though contributions made by these researchers are remarkable, there is need for more work. Therefore, in order to satisfy this high demand for water in the study area the research posed on unveiling the basic aquifer parameters in the study area. The aim of this study is to employ the use of the electrical resistivity method to estimate the aquifer parameters such as hydraulic conductivity, longitudinal conductance, transmissivity, depth, thickness, and transverse resistance in Njikoka and environs. Fig. 1 presented the need for adequate exploration and exploitation of groundwater to serve various purposes of the growing populace within Njikoka and its environs has become pertinent since the record of massive borehole failures due to indiscriminate drilling seems to be on the increase.

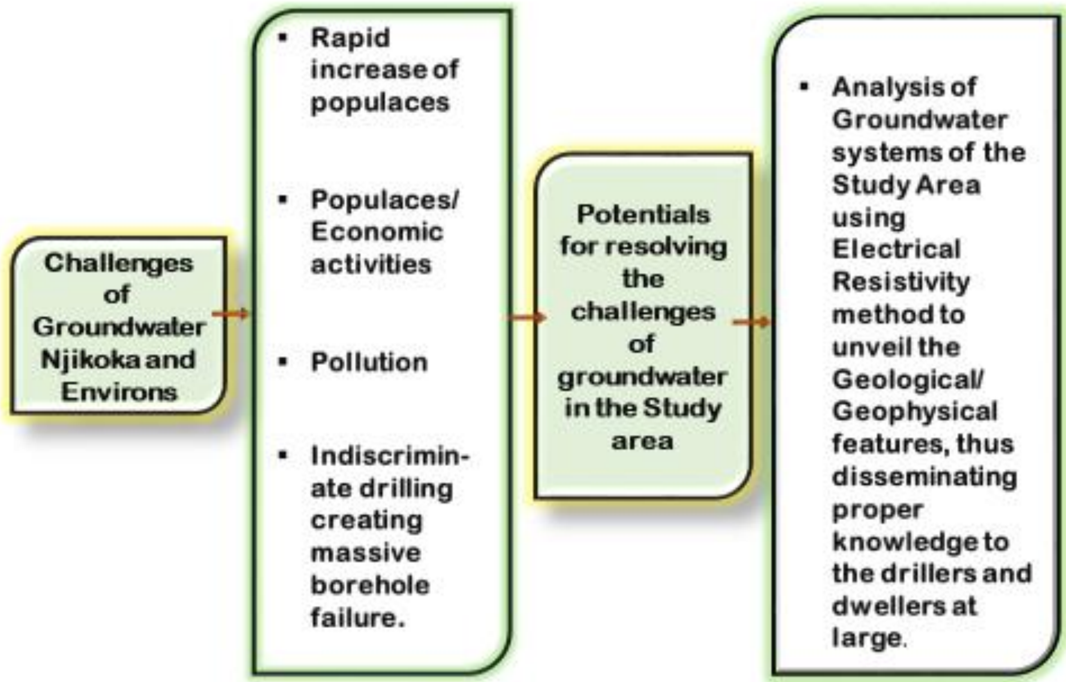

Figure 1: Background Flow Chart of the Problem and Justification of the Study Area

1.2 Topographical and Geological of the Study Area

Njikoka and its environs are one of the Local Government Areas in Anambra State as shown below (Fig. 2). The study area covers six major communities namely Abba, Enugwu-Agidi, Nawfia, Abagana, Enugwu-Ukwu and Nimo. The study area lies within the Latitude: 6° 11' 3.10" N and Longitude: 6° 58' 35.60" E. The land area occupied is about 84.4 km² [2]. The entire area can be majorly accessed through the Enugu-Onitsha Express and the old Enugu-Onitsha road with secondary connecting roads among the communities hence an improved road network. Only Nimo can also be accessed from Neni – Nnewi road junction.

The topography of Njikoka and its environs is generally characterized by broad ridges and fairly broad hills. It is also dominated by the presence of relief lateritic crust hence said to be undulating topography [3]. The study area tends to be situated within two major landforms, namely the Eastern Lowland and Western Upland, which is mostly covered with negative relief features by the occurrences of geohydrologic resources of the Eastern Lowland and groundwater discharge from the prolific Nanka Sand. Anambra Basin is believed to be a Cretaceous depocentre that received Campanian to Tertiary sediments [4]. The stratigraphic setting of Southern Nigeria comprises sediments of three major sedimentary cycles. The first two cycles belong to the Pre-Santonian sediments while the third cycle belongs to Post-Santonian sediments, which are found in the Anambra Basin and Afikpo Syncline. Njikoka falls within part of the Southern Benue Trough and Anambra Basin which is underlain by Eocene Ameki and Nanka formations, figure.3. According to Nwajide 1979, the Abakiliki Anticlinorium forms one of the sources of sediments for Anambra and Abakiliki (Afikpo) Basins that eventually turns to deposit source to the Cenozoic Niger Delta Basin fills [5]. The Ameki Group consists of three stratigraphic units, Nsugbe, Ameki and Nanka Sandstone. The Ameki Group sediments formed in an estuarine, tidal, barrier ridge lagoon complex and open marine system, after the major Paleocene marine transgression of the second depositional cycle at the site of the rift triple junction. In addition, the Ameki Group and Ogwashi Formation are the mapable equivalents of Agbada Formation of the subsurface stratigraphic units of the Niger Delta Basin.

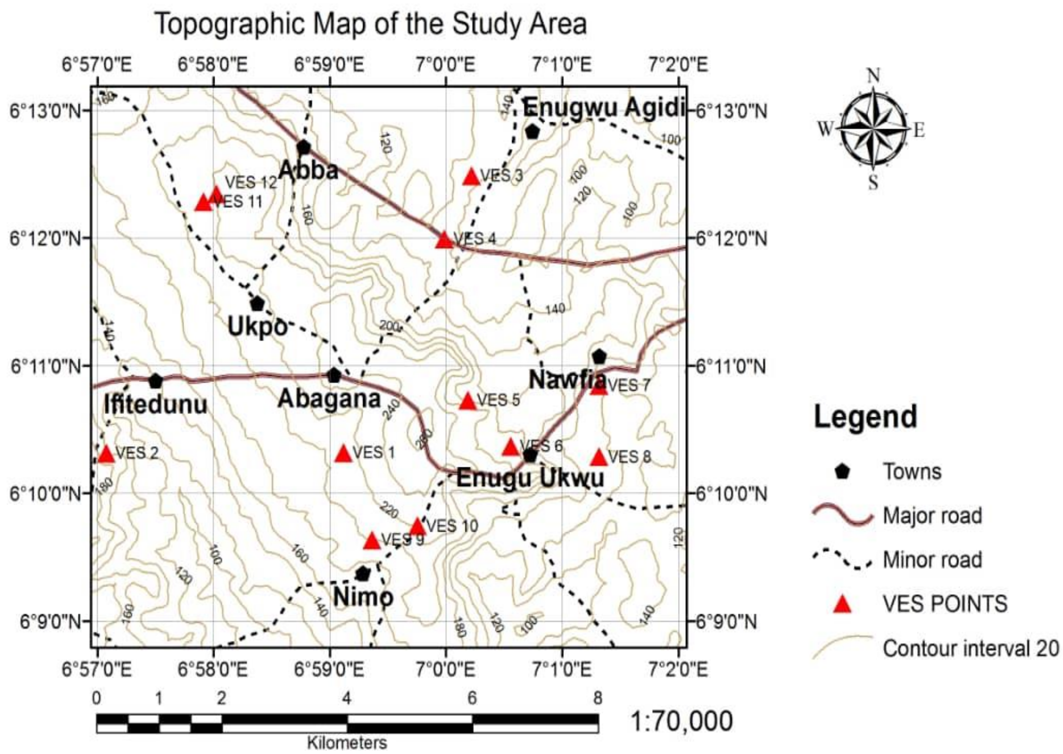

Figure 2: Topographical Setting of the Study Area Modelled Using Geographic Information System (GIS Software)

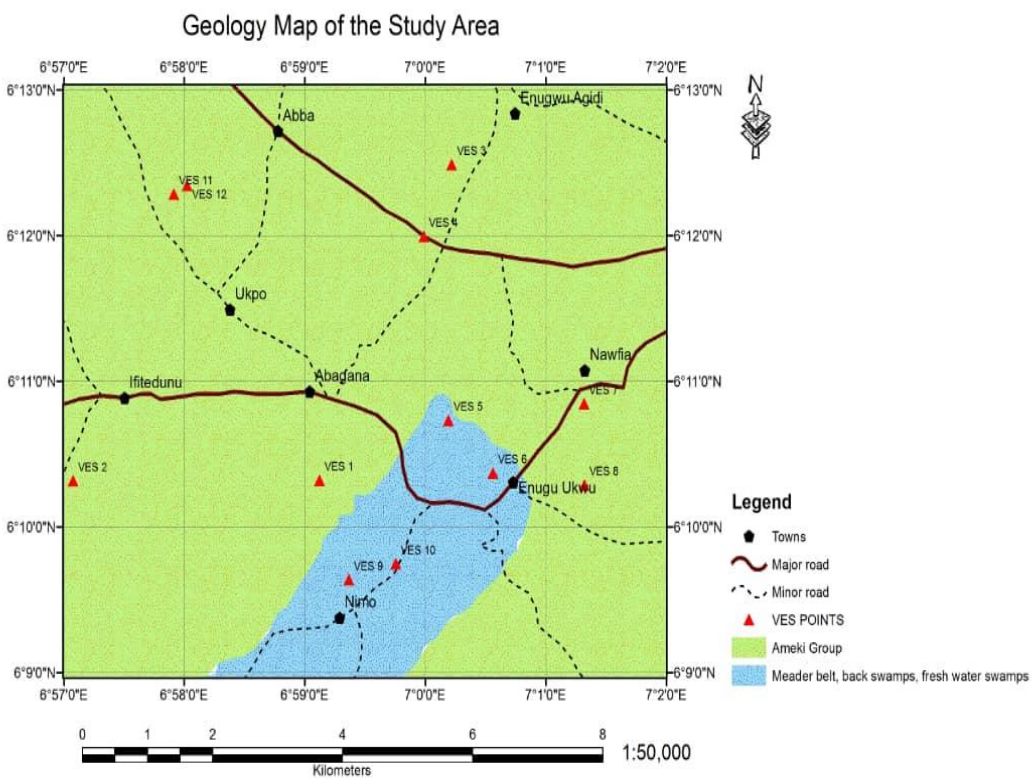

Figure 3: Geological Map of Njikoka and Environs Modelled Using Geographic Information System (GIS Software)

2. Method and Scope of the Study

The scope of this research covered the use of electrical resistivity methods (Schlumberger Array) to determine the geo-electrical sections of the subsurface in all the six communities of Njikoka and environs. Each of the towns (Abba, Enugwuagidi, Nawfia, Abagana, Enugwukwu and Nimo) had two Vertical Electrical Sounding (VES) points in such a way that the entire geographical area was covered. There was Pump test analysis in two grouped locations using existing boreholes to aid estimation of transmissivity, hydraulic conductivity and other aquifer parameters in the study area [6,7].

The use of Vertical Electrical Sounding method to estimate the aquifer parameters of Njikoka and environs was embarked upon to highlight on the need for appropriate knowledge of the subsurface aquifer units to ensure successful exploitation of groundwater in the study area. The major parameters of aquifer productivity for sustainable groundwater development were delineated; such as aquifer thickness, hydraulic conductivity, transmissivity, resistivity, depth, transverse resistance, longitudinal conductance. The groundwater hydrology indices displayed potentials to support the growing population in terms of availability of pipe borne water which must involve professionals for Njikoka and environs. Surface Geophysical method of investigation for groundwater exploration and aquifer parameter estimation had shown to be preferred than hydrogeological methods. It is faster, more convenient and cost effective unlike the hydrogeological method, Onyekwelu et al, 2021. According to, location of engineering structures, assessment of land contamination and groundwater exploration can be achieved from hydraulic characterization of aquifer. The linear relationship between the hydraulic and resistivity parameters in a porous layer determines the gradual variation in the hydrological parameters of the aquiferous unit.

Whereas K is the scientific representation of hydraulic conductivity, it is also dependent on the amount of intrinsic permeability ratio of the medium and the level of saturation. The interconnectivity flow of water within aquifer is determined by the saturated hydraulic conductivity, Ksat.

$$Kc = 1/p \quad \text{...} \quad (1)$$

Where kc = the calculated hydraulic conductivity, p = resistivity of the saturated unit.

Transverse resistance, Tr (ohm-m^2) and Longitudinal conductance, Lc (ohm-1) are important parameters to delineate the prospective units of the aquifer body.

$$Tr = hp \quad \text{...} \quad (2)$$

$$Lc = h/p \quad \text{...} \quad (3)$$

Where h = aquifer thickness and p = resistivity value of the porous unit.

The integrated analysis of aquifer transmissivity was calculated from the pumping test data as investigated by Cooper-Jacob's method modified by David, 1959.

$$\text{transmissivity, } T = \frac{2.3XQ}{4\pi\Delta S} \text{ (m3/day)} \quad \text{.......................................} \quad (4)$$

Where 2.3 is constant, Q= yield of borehole for a known average flow rate in m3/day, 4 is a constant, ΔS = difference in best fit line before equilibrium from drawdown vs logarithm of time plots after pumping test.

$$\text{Furthermore, hydraulic conductivity, } K=T/h \quad \text{..} \quad (5)$$

Where T is transmissivity and h is saturated aquifer thickness.

Geophysical survey resistivity parameters which were as a result of surface electrical measurements can be highly useful not only in aquifer hydraulic characterization but also to a collective number of hydraulic estimations (Ekwe et al. 2006; Corriols and Dahlin, 2008). Accurate correlation between hydraulic conductivity and electrical aquifer properties can be possible since the properties are related to the structure of the pore space and heterogeneity of the unit under investigation. The classification of aquifers with consideration to their transmissivity values were investigated by Freeze and Cherry (1979) while the Hydraulic Conductivity range as classified by Smedema and Rycroft (1983) can be seen in Table.1 and Table.2 below.

Aquifer Rating	Transmissivity Value (m2/day
Very Good	$T > 500$
Good	$150 < T \leq 500$
Moderately Good	$50 < T \leq 150$
Low/Fairly Good	$10 < T \leq 50$
Poor	$1 < T \leq 10$

Table 1: Aquifer Transmissivity as classified (Freeze and Cherry 1979)

Range of K (m day^{-1})	Texture
10 – 50	Gravelly coarse sand
1 – 5	Medium sand
1 – 3	Sandy loam, fine sand
0.5 – 2	Clay (well structured)
0.2 – 0.5	Very fine sand
0.002 – 0.2	Clay (poorly structured)
≤ 0.002	Dense clay (no pores)

Table 2: Texture Range of Hydraulic Conductivity K-values (Smedema and Rycroft 1983)

3. Results and Discussion

3.1 Lithology of the Study Area

The type of lithological formation that underlain Njikoka and environs was Ameki Group which is made up of other sub-stratigraphic units like Ameki Formation, Nanka Sand inclusion and Nsugbe Formation. Ameki Group is characterized by quality of the component formations fine to coarse sandstone embedded with calcareous shale, sandy clay, shaly limestone, calcareous concretions and white or yellow clayey sandstone. The Vertical Electrical Sounding lithological inference and geoelectric section interpretations revealed three (3) to five (5) different rock layers thus; top soil, dry sand, shaly sand, shale and water saturated sand unit. The various lithologic layers were identified according to their depth locations within the subsurface hence the existence of different lithological characteristics within the same geological setting as confirmed in the study area.

3.2 Correlation of Geoelectric Sections of the Study Area

In order to have coordinated correlation of the various VES soundings of the study area, there exist two groups such as Group A and Group B (Fig.4). Each of the groups has an existing borehole pumping testing location. Then in group A, we have the following data; VES 1, VES 2, VES 3, and VES 4 while the second group B, has different set of VES data such as; VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11, and VES 12 as shown in figure 5 and figure 6 Qualitative correlation of interpreted vertical electrical sounding data with pumping test results revealed better method for estimation of groundwater parameters. The hydraulic conductivity and transmissivity as exposed in the two groups of VES data were close in range to the counterpart from the pumping test results.

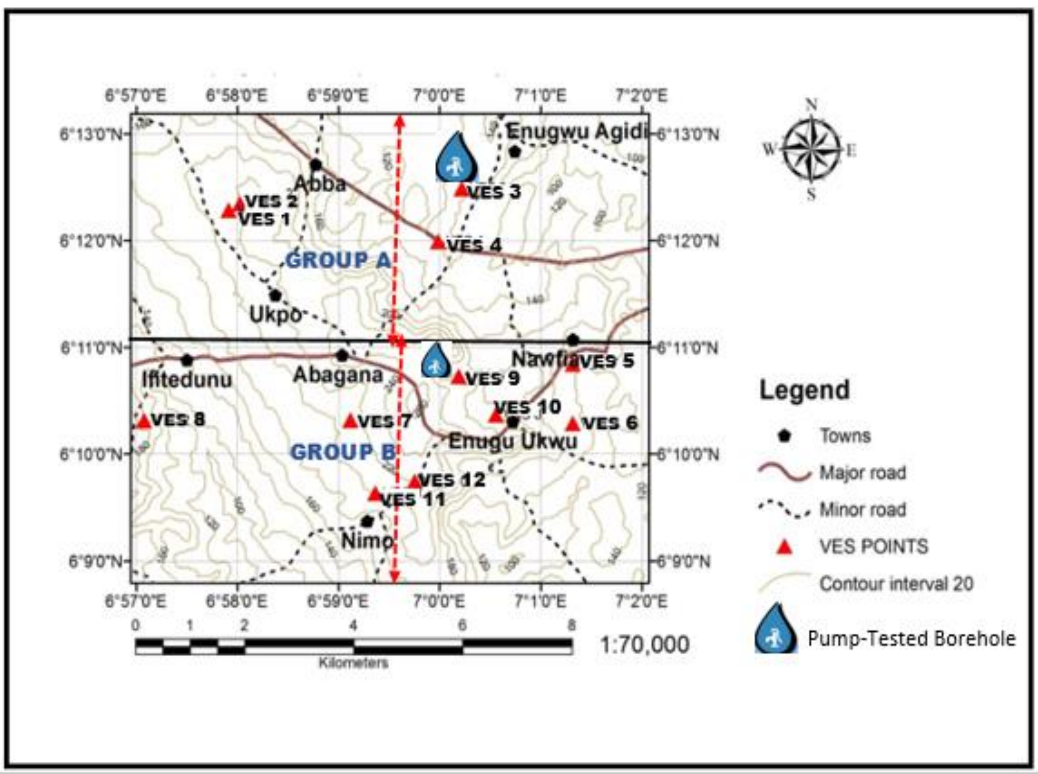

Figure 4: Topographic Map showing Grouped VES Locations with Pump-Tested Boreholes

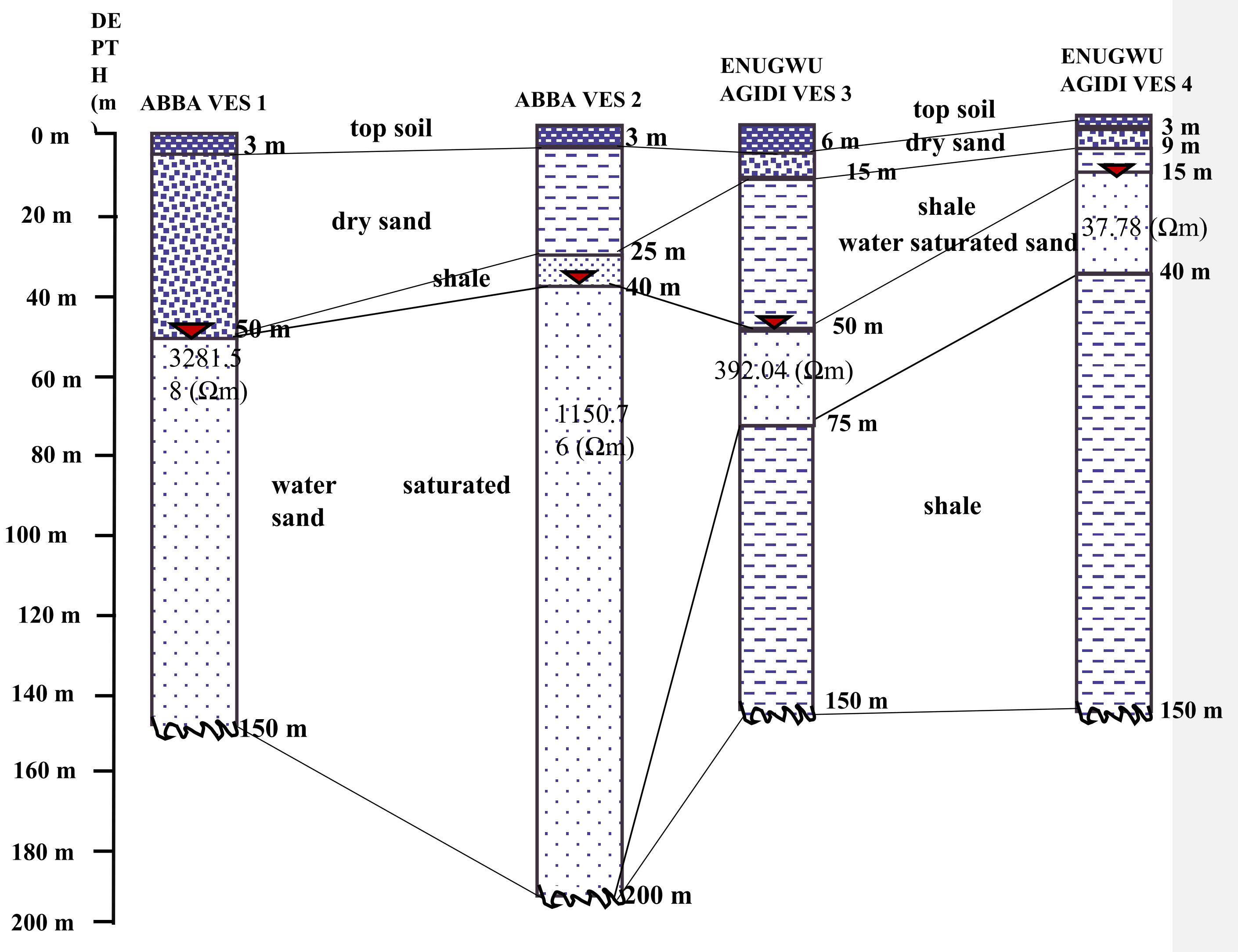

Figure 5: Geoelectric Sections of VES 1, VES 2, VES 3 and VES 4 in Group A

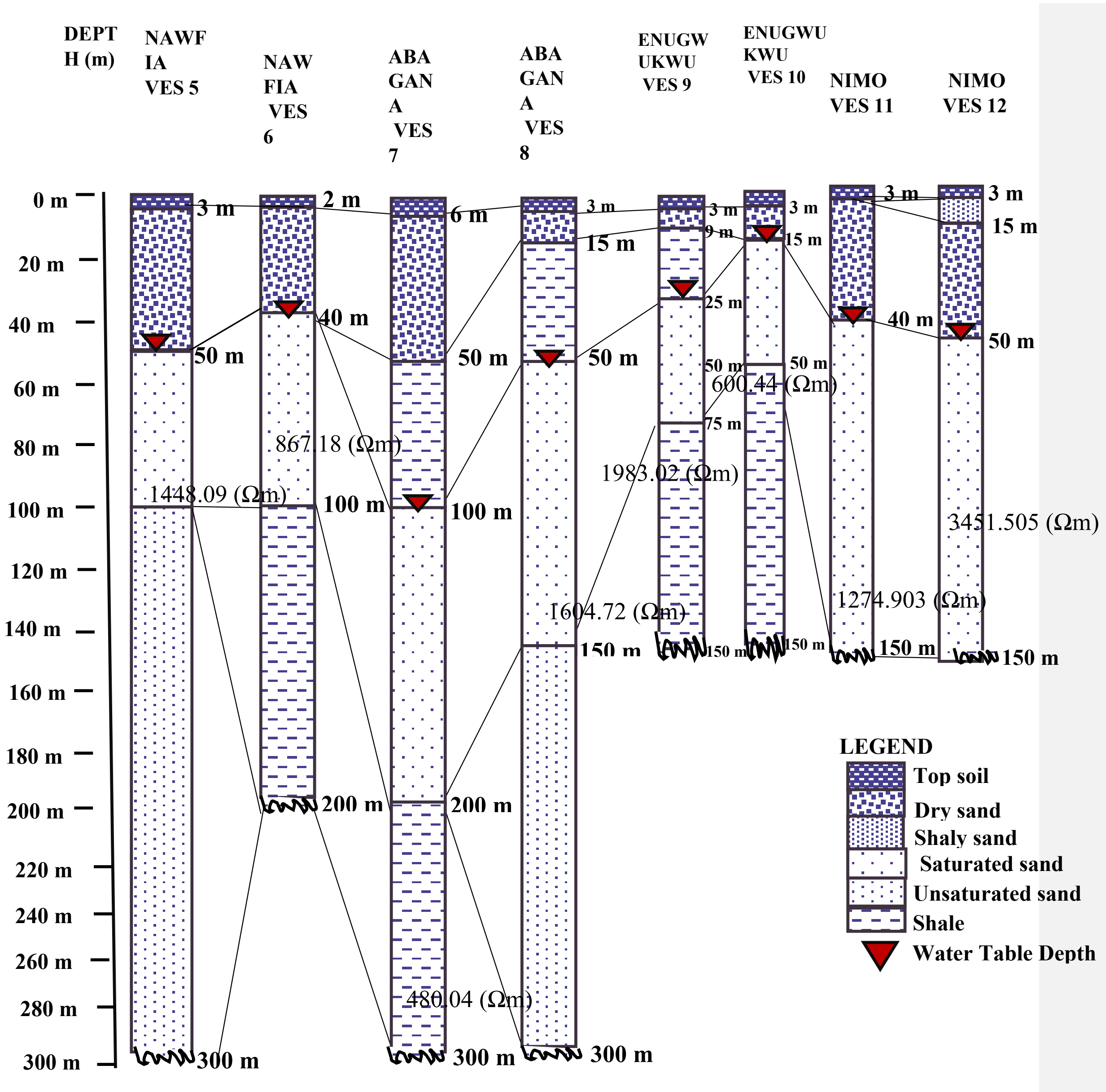

Figure 6: Geoelectric Sections of VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11 and VES 12 in Group B

3.3 Pumping Test Analysis and Calculations

3.3.1 Presentation of Pumping Test Field Data

The pumping test involved in this study is Constant and Recovery tests of the two existing borehole, Enugwuagidi VES 3 and Enugwuukwu VES 9. The two tests were conducted using submersible pump, water level indicator and stop watch to obtain values of the two existing well. Constant discharge test was carried out first, readings were taken as the observation of the level of water made per specified time. Recovery test was also carried out during which water level is measured starting from the time of stoppage of pumping. When pumping stopped in recovery test, the data were recorded from the subsurface water level to the top of the tape marking the water level. Recovery test is calibrated as the level of water when pumping stopped within a given period of time. At 0 minute, constant discharge test (time when pumping started) the water level of Enugwuagidi and Enugwuukwu is 40.55 m and 61.50 m respectively, then get at equilibrium in 7 and 45 minutes to water level of 47.45 m and 72.38 m respectively till pumping stopped. The recovery test which starts from when pumping stopped is the reverse of the constant discharge test. In recovery test of Enugwuagidi and Enugwuukwu, the water level is 47.45 m and 72.38 m at 0 minute at state of equilibrium of 40.55 m and 61.50 m respectively (Table 3.).

CONSTANT DISCHARGE TEST			RECOVERY TEST		CONSTANT DISCHARGE TEST			RECOVERY TEST	
VES Location and Group	**Time since Pumping Started (min)**	**Water Level (m)**	**Time since Pumping stopped (m)**	**Water Level (m)**	**VES Location and Group**	**Time since Pumping Started (min)**	**Water Level (m)**	**Time since Pumping stopped (m)**	**Water Level (m)**
VES 3 Group A	0	40.55	0	47.45	**VES 9 Group B**	0	61.50	0	72.38
	1	41.90	0.3	46.44		1	69.43	1	63.55
	2	46.30	0.7	46.84		2	70.74	2	62.00
	3	46.00	1	46.54		3	71.20	3	61.49
	4	46.58	1.3	44.45		4	71.62	4	61.50
	5	46.70	1.7	44.42		5	71.82	5	61.50
	6	47.40	2	43.36		6	71.90	6	61.50
	7	47.45	3	42.35		7	71.97	7	61.50
	8	47.45	4	41.30		8	72.03	8	61.50
	9	47.45	5	40.77		9	72.04	9	61.50
	10	47.45	6	40.65		15	72.08	10	61.50
	15	47.45	7	40.55		20	72.25	15	61.50
	20	47.45	8	40.55		25	72.35	20	61.50
	25	47.45	9	40.55		30	72.42	25	61.50
	30	47.45	10	40.55		35	72.45	30	61.50
	35	47.45	15	40.55		40	72.48	35	61.50
	40	47.45	20	40.55		45	72.38	40	61.50
	45	47.45	25	40.55		50	72.38	45	61.50
	50	47.45	30	40.55		55	72.38	50	61.50
	55	47.45	40	40.55		60	72.38	55	61.50
	80	47.45	45	40.55		80	72.38	-	-
	90	47.45	50	40.55		90	72.38	-	-
	100	47.45	55	40.55		100	72.38	-	-
	110	47.45	60	40.55		110	72.38	-	-
	120	47.45	-	-		120	72.38	-	-
	140	47.45	-	-		140	72.38	-	-
	160	47.45	-	-		160	72.38	-	-
	180	47.45	-	-		180	72.38	-	-
	210	47.45	-	-		210	72.38	-	-
	240	47.45	-	-		240	72.38	-	-

Table 3: Pumping Test Field Data at VES 3 –Enugwu-agidi and VES 9- Enugwu-ukwu Respectively

The need for pump testing is to check the pumping rate of the well and know the suitable submersible pump to be installed in the drilled well of the study area. The field data obtained from constant discharge and recovery test were presented in water level verses logarithm of time plots. The graphical interpretations of plots revealed the static water level and final water level of the drilled well in the study area. Static water level (SWL) is the distance from the measuring point to the level of water in the well under non-pumping (static) state. In constant discharge test, the static water level of Enugwuagidi VES 3 resulted 40.55 m and the final water level 47.45 m while in Enugwukwu VES 9 static water level revealed 61.5 m and the final water level read 72.38 m (Figure 5and Figure 6). Measuring the water level from the subsurface which is the recovery, hence when pumping stopped, the static water level (SWL) of Enugwuagidi VES 3 revealed 40.55 m and the final water level 47.45 m while Enugwukwu VES 9 static water level proved 61.5 m and the final water level read 72.38 m (Figure 5and Figure .6). The plots of water level verses time for constant discharge and recovery test revealed the flowrate of the existing wells during pump testing which is in consistency with the geological characterizes of the water table of the study area.

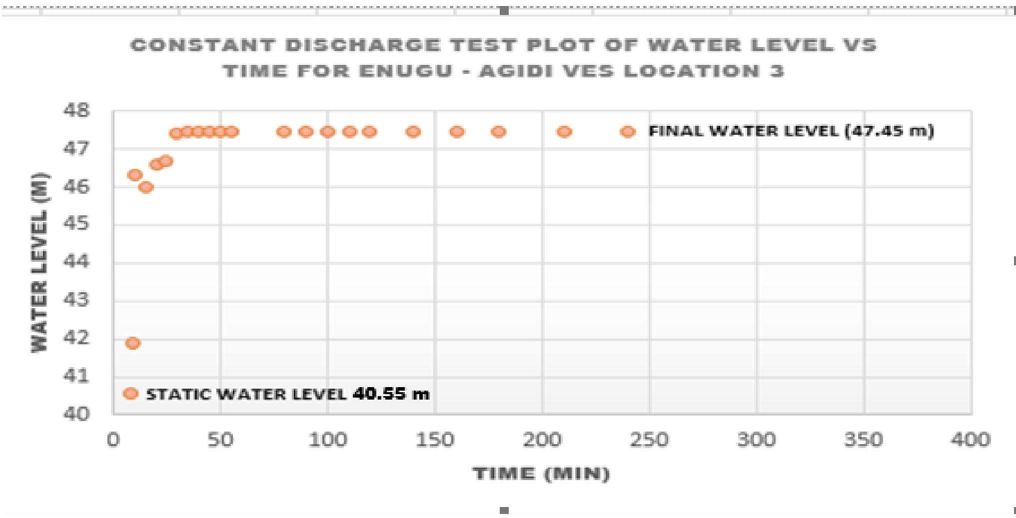

Figure 7: Graph of Constant Discharge Test Water Level Against Time for Enugwu-Agidi VES 3

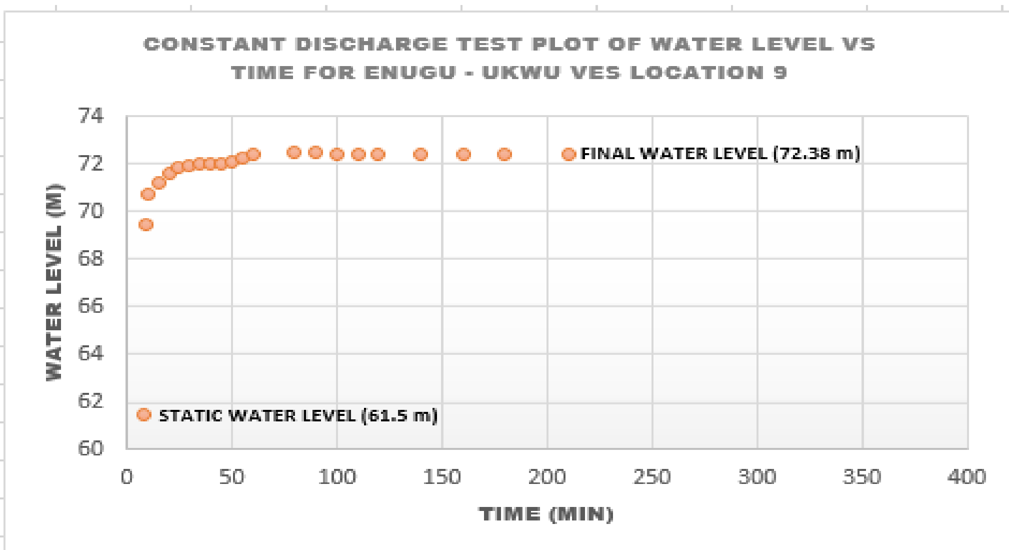

Figure 8: Graph of Constant Discharge Test Water Level Against Time for Enugwu-ukwu VES 9

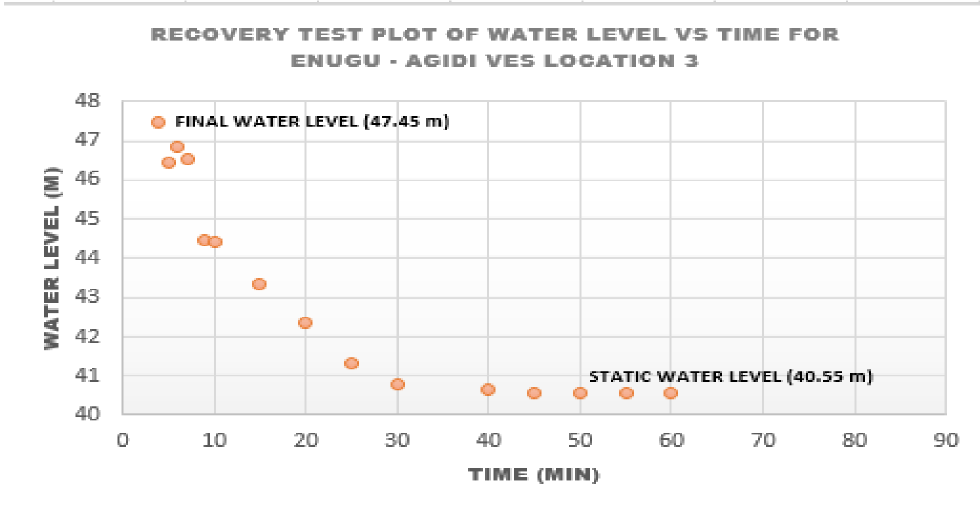

Figure 9: Graph of Recovery Test Water Level Against Time for Enugwu-Agidi VES 3

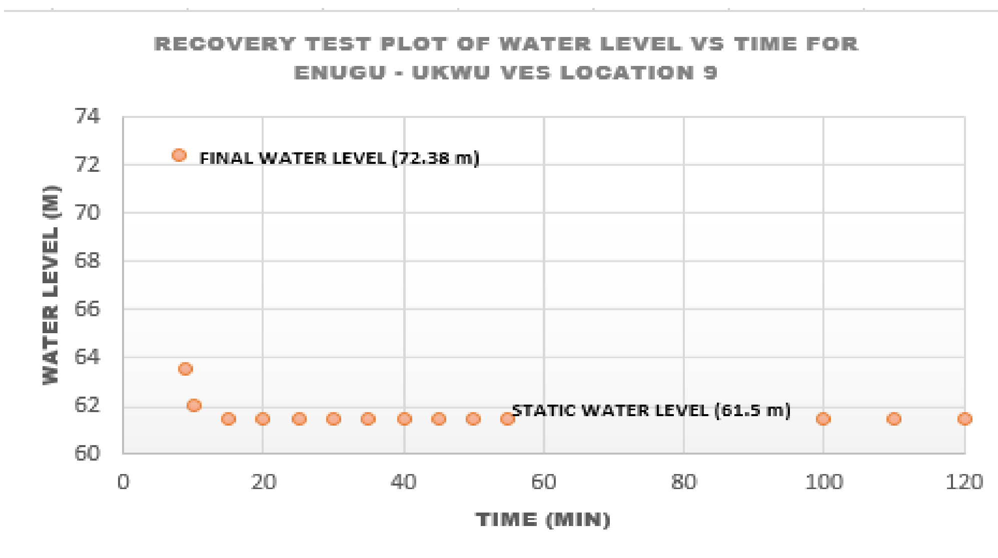

Figure 10: Graph of Recovery Test Water Level Against Time for Enugwu-ukwu VES 9

3.3.2 Integrated Analysis and Results of Pumping Test

The application of Cooper – Jacob methods which was modified by helped in the quantitative analysis and interpretation of water table parameters [8]. The quantitative interpretation of constant discharge and recovery test of the field data were carried out which gave rise to another column called drawdown (`S`) in the table. The estimation of the drawdown was achieved by working out the difference between the static water level and measured water level at every time of complete cycle. The flowrate is derived as the volume of bucket/container divided by specific interval of time invariably the volume of bucket/container is the product of flowrate and time as shown in Table 4 and Table 5 respectively. The average flowrate of water table in existing well of zone A Enugwuagidi VES 3 rated 0.80804 L/S within 76.2577 L average volume of bucket used at static water level of 40.55 m. In zone B Enugwukwu VES 9, with an average volume of bucket 273.813 L the flowrate of the existing well rated 2.77346 L/s at 61.50 m static water level.

CONSTANT DISCHARGE TEST						RECOVERY TEST			
Time since Pumping Started (min)	**Water Level (m)**	**Drawdown S'(m)**	**Volume of bucket used (L)**	**Flow rate L/s**	**Remarks**	**Time since Pumping stopped (m)**	**Water Level (m)**	**Drawdown S'(m)**	**Remarks**
0	40.55	0			Water is observed clear and silt free	0	47.45	6.90	Well was fully recovered at 7th minutes
1	41.90	1.35				0.3	46.44	1.21	
2	46.30	5.75				0.7	46.84	0.46	
3	46.00	5.45				1	46.54	0.35	
4	46.58	6.03				1.3	44.45	0.26	
5	46.70	6.15				1.7	44.42	0.23	
6	47.40	6.85				2	43.36	0.17	
7	47.45	6.90				3	42.35	0.16	
8	47.45	6.90				4	41.30	0.11	
9	47.45	6.90				5	40.77	0.08	
10	47.45	6.90				6	40.65	0.06	
15	47.45	6.90	12.057	0.8038		7	40.55	0.00	
20	47.45	6.90				8	40.55	0.00	
25	47.45	6.90				9	40.55	0.00	
30	47.45	6.90				10	40.55	0.00	
35	47.45	6.90				15	40.55	0.00	
40	47.45	6.90				20	40.55	0.00	
45	47.45	6.90				25	40.55	0.00	
50	47.45	6.90				30	40.55	0.00	
55	47.45	6.90	43.1255	0.7841		40	40.55	0.00	
80	47.45	6.90	64.392	0.8049		45	40.55	0.00	
90	47.45	6.90				50	40.55	0.00	
100	47.45	6.90				55	40.55	0.00	
110	47.45	6.90	92.664	0.8424		60	40.55	0.00	
120	47.45	6.90				-	-	-	
140	47.45	6.90				-	-	-	
160	47.45	6.90				-	-	-	
180	47.45	6.90				-	-	-	
210	47.45	6.90	169.05	0.8050		-	-	-	
240	47.45	6.90				-	-	-	
Summary; Static water level = 40.55 m **Average Flow rate = 0.80804 L/s** **Average Volume of bucket used = 76.2577 L**									

Table 4: Pumping Test Data Interpretation for Enugwuagidi VES 3 (Existing well of VES location in Zone A)

CONSTANT DISCHARGE TEST						RECOVERY TEST			
Time since Pumping Started (min)	**Water Level (m)**	**Draw down S'(m)**	**Volume of bucket used (L)**	**Flow rate L/s**	**Remarks**	**Time since Pumping stopped (m)**	**Water Level (m)**	**Drawdown S'(m)**	**Remarks**
0	61.50	0.00				0	72.38	10.88	
1	69.43	7.92				1	63.55	2.05	
2	70.74	9.24				2	62.00	0.50	
3	71.20	9.70				3	61.49	0.01	
4	71.62	10.12				4	61.50	0.00	
5	71.82	10.32				5	61.50	0.00	
6	71.90	10.40				6	61.50	0.00	
7	71.97	10.47				7	61.50	0.00	
8	72.03	10.53				8	61.50	0.00	
9	72.04	10.54				9	61.50	0.00	
15	72.08	10.58	39.969	2.6646		10	61.50	0.00	
20	72.25	10.75				15	61.50	0.00	
25	72.35	10.85			Water was observed clear and silt free	20	61.50	0.00	Well was fully recovered at 7th minutes
30	72.42	10.92				25	61.50	0.00	
35	72.45	10.98				30	61.50	0.00	
40	72.48	10.88				35	61.50	0.00	
45	72.38	10.88				40	61.50	0.00	
50	72.38	10.88				45	61.50	0.00	
55	72.38	10.88				50	61.50	0.00	
60	72.38	10.88	155.724	2.5954		55	61.50	0.00	
80	72.38	10.88	214.848	2.6856		-	-	-	
90	72.38	10.88				-	-	-	
100	72.38	10.88				-	-	-	
110	72.38	10.88	313.236	2.8476		-	-	-	
120	72.38	10.88				-	-	-	
140	72.38	10.88				-	-	-	
160	72.38	10.88				-	-	-	
180	72.38	10.88				-	-	-	
210	72.38	10.88	645.561	3.0741		-	-	-	
240	72.38	10.88				-	-	-	

Summary; Static Water Level = 61.50 m
Average Flow rate = 2.77346 L/s
Average Volume of bucket used = 273.813 L

Table 5: Pumping Test Data Interpretation for Enugwuukwu VES 9 (Existing well of VES location in Zone B)

3.3.3 Calculation of Volume of Bucket and Flow Rate for Group A

Flowrate = volume of bucket/Time (7)

0.8038L/s = volume of bucket/15

1. Volume of bucket at 15 minutes = 12.057 L, to get the flowrate; where volume of bucket is 12.057 L at time of 15 (s), flowrate = 12.057 (L)/ 15 (m). Therefore, flowrate = 0.8038 L.
2. Calculation of volume of bucket used at 55th minutes within the flowrate of 0.784 L/S at 55 minutes. Substitute the values in Equation (7) above, flowrate = volume of bucket/Time, 0.7841 L/s

= volume of bucket/55 (m), cross multiplying, Volume of bucket = 0.7841 × 55 = 43.1255 L

3. Calculation of volume of bucket used at 80th minutes within the flowrate of 0.8049 L/S at 80th minutes. Substitute the values in equation above, flowrate = volume of bucket / Time, 0.8049 (L/s) = volume of bucket /80, therefore, volume of bucket = 0.8049 × 80 = 64 L.

4. Calculation of volume of bucket used at 110th minutes, having that flowrate at 110th minutes is 0.8424 L/s, volume of bucket = 92.664 L.

4 Calculation of volume of bucket used at 210th minutes, having that flowrate at 210th minutes is 0.8050 L/S, the volume of bucket used is calculated as thus; 0.8050 × volume of bucket/210 volume of bucket = 169.05 L

Therefore, Group A with the existing borehole at VES 3-Enugwuagidi consists of average flowrate of 0.80804 L/s, static water level to be 40.55 m and the average volume of the bucket as 76.2577 L.

3.3.3 Calculation of Volume of Bucket and Flowrate for Group B

1. Having flow rate at 15th minutes as 2.6646 L/s, Substitute in equation (7) above, 2.6646 = volume of bucket/15. At 15th minutes the volume of bucket = 2.6646 × 15 = 39.969 L.

2. Calculation of volume of bucket used at 2.5954 within the flowrate of 2.5954 at 60th minutes.
Flowrate = volume of bucket / time = volume of bucket/ 60. At 60th minutes, volume of bucket = 2.5954× 60 = 155.724 L.

3. Calculation of volume of bucket at 80th minutes within the flowrate of 2.6856 L/S at 80th minutes.
Therefore, 2.6856 = volume of bucket /80. At 80th minutes volume of bucket = 214.848 L.

4. Calculation of volume of bucket used at 110th minutes within 2.8476 L/S flowrate at 110th minutes. Therefore, 2.8476 = volume of bucket / 110, Volume of bucket used at 110th minutes = 313.236 L

5. Calculation of volume of bucket used at 210th minutes within 3.074 L/S flowrate at 210th minutes. Therefore, 3.0741 = volume of bucket /210, At 210th minutes, volume of bucket used = 645.561 L.

Thus, the group B of the VES 9 – Enugwu-ukwu existing borehole revealed average flowrate to be 2.77346 L/S, Static water level 61.50 m and Average volume of bucket used as 273.813 L.

3.4 Estimation of Parameters From Pumping Test Analysis

3.4.1. Calculated Results of the Two Existing Boreholes From Group A-VES 3 and B-VES 9 of the Study Area

With reference to Equations (5) and (6) above, the transmissivity T and hydraulic conductivity K of the two existing boreholes VES 3 – Enugwuagidi and VES 9 – Enugwu- ukwu, were calculated with important variables of pumping test analysis such as; borehole yield `Q', difference in drawdown intercept ΔS and average flowrate. The drawdown intercept (ΔS) of VES 3 location – Enugwuagidi was calculated to be 5.7 m as shown in the plot of drawdown against log of time figure 9 while the drawdown intercept (ΔS) of VES 9 location – Enugwukwu value was 2.8 m in the plot of the drawdown against log of time (Figure 10).

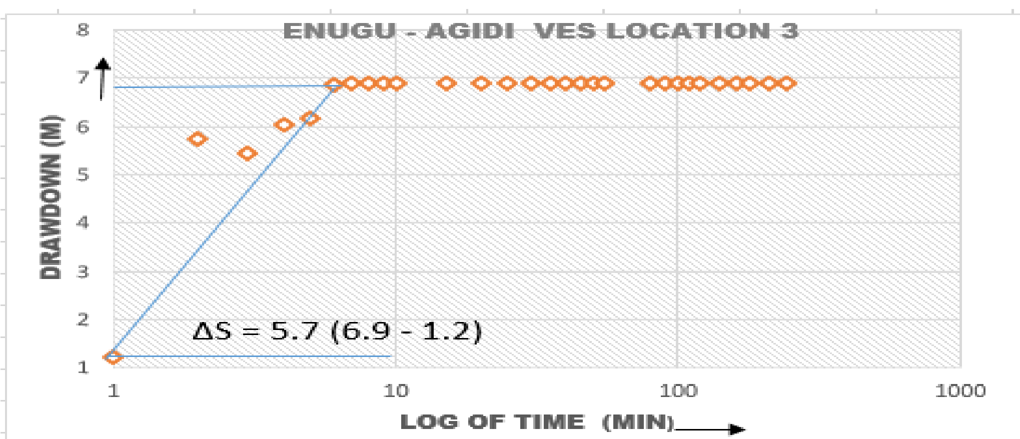

Figure 11: Graph of Drawdown Against Log of Time For Enugwuagidi VES 3

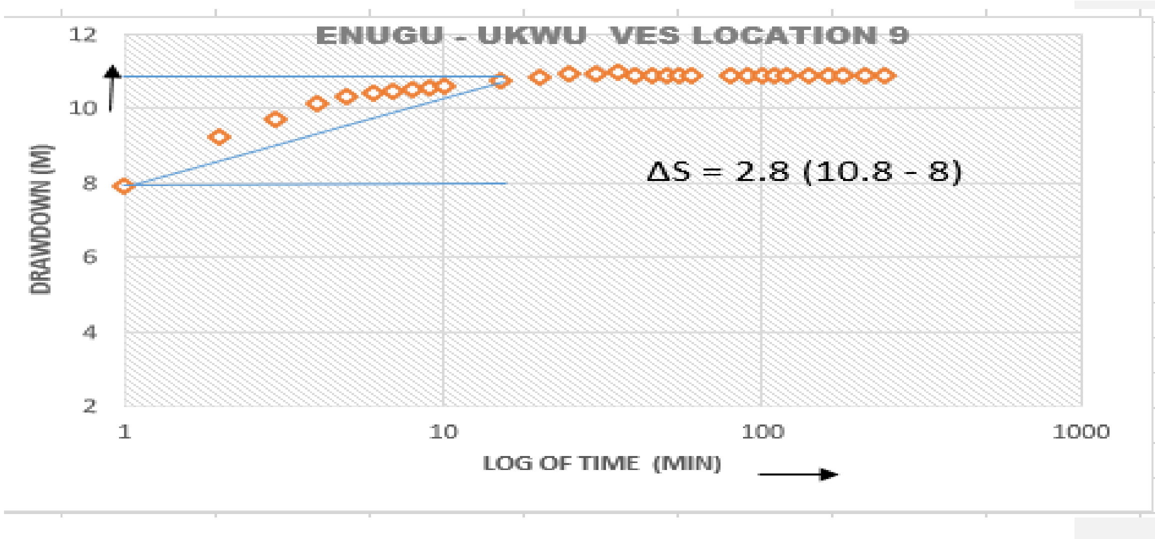

Figure 12: Graph of Drawdown Against Log of Time for Enugwukwu VES 9

The Dar-Zarouk relationship was applied to obtain transmissivity and hydraulic conductivity of the entire remaining VES soundings using aquifer constants of the reference locations of the study area (Table 6). According to pumping test analysis results, in group A of the study area VES 3 Enugwuagidi transmissivity T was estimated to be 2.24 m2/day and hydraulic conductivity was 0.09 m/day whereas the group B of VES 9 – Enugwukwu has transmissivity as 15.66 m2/day and the hydraulic conductivity revealed 0.31 m/day.

From Dar-Zarrouk relationship of transverse resistance and transmissivity

thus; T= KʊR …………………… (8),

where T= Aquifer transmissivity,

R = Transverse resistance of the aquifer, Kʊ= A= Constant of proportionality (Niwas and Singhal, 1981). To estimate the value of the constant of proportionality A, consequently in the group A, Kʊ= A = 0.09 m/day x 1/392.04 Ωm = 2.2956, therefore A= 2.2956 which helped to calculate the values of transmissivity for other VES locations since individual transverse resistance R has been determined earlier using Equation (8) above. However, the process above was repeated in group B to the VES 9 of the study area. The hydraulic conductivity from the existing borehole analysis was 0.31 m/day, while the interpreted average resistivity of the corresponding aquiferous unit was given as 1983.02 Ωm. These values helped to calculate for the value of constant of proportionality A, which was substituted into the equation T= KʊR to estimate the value of transmissivity for the rest of other VES. points in group B of the study area. Since Kʊ= A and T= KʊR, therefore A= 0.31 m/day x 1/1983.02 Ωm = 0.0002. Table 6 shows the ranges of aquifer parameters of the study area calculated from geophysical approach.

Group	VES	Location	Aquifer Thickness (m)	Aquifer Average Resistivity (Ωm)	Depth of Water table (m) from SL	Transverse resistance (Ωm^2)	Longitudinal Conductance (ohm^{-1})	Average Flowrate L/S	Transmissivity from Pumping Test m^2/day)	Hydraulic Conductivity from Pumping Test (m/day)	Aquifer Constant (A)	Calculated Transmissivity (m^2/day)	Calculated Hydraulic Conductivity(m/day)
Group A	1	Abba	100	3281.58	50	3282	0.031	-	-	-	-	7.55	0.08
	2	Abba	160	1150.76	40	1841	0.139					4.23	0.03
	3	Enugwuagidi	25	392.04	50	9801	0.064	0.80804	2.29	0.09	0.0023	22.54	0.90
	4	Enugwuagidi	25	37.78	15	1698	0.368	-	-	-	-	3.91	0.16
Group B	5	Nawfia	50	1448.09	50	7240	0.035	-	-	-	-	1.44	0.03
	6	Nawfia	60	867.18	40	5203	0.069					1.04	0.02
	7	Abagana	100	480.04	100	4800	0.208					0.96	0.01
	8	Abagana	100	1604.72	50	1605	0.062					0.32	0.003
	9	Enugwukwu	50	1983.02	25	9915	0.259	2.7734	15.66	0.31	0.0002	1.98	0.04
	10	Enugwukwu	35	600.44	15	2102	0.058	-	-	-	-	0.42	0.01
	11	Nimo	110	1274.903	40	1402	0.086					0.28	0.003
	12	Nimo	100	3451.505	50	3452	0.029					0.69	0.01

Table 6: Aquifer Parameters Deduced from the Geophysical and Geological Analysis of the Study Area

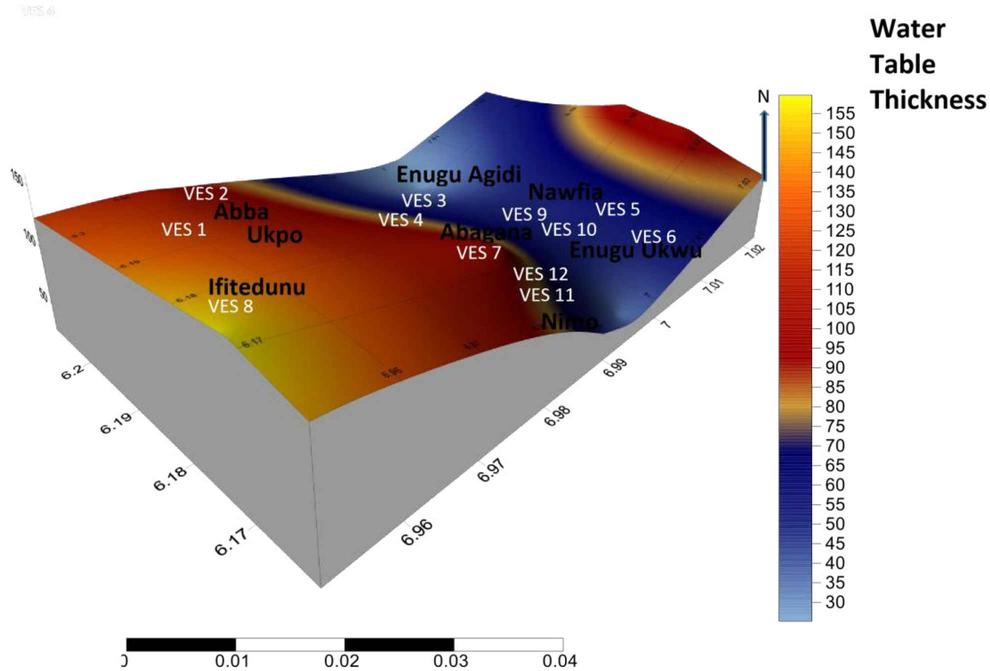

Figure 13: Contour Maps Showing the Aquifer Thickness of the Study Area Modelled Using Surfer 16 Software

The figure 13 above show that the aquifer thickness of the study area trends through SW – NE direction. The thickness of rock layers from the surface to the subsurface water table is called vadose zone and it is usually unsaturated or discontinuously saturated. The thickness varies from 25 m to 160 m within the respective communities. The hydrologic parameters of the Njikoka and environs increased from Enugwu- agidi region to very low values in other communities. Increased aquifer productivity in Enugwu-agidi could be attributed to better aquifer recharge system provided by the presence of many stream channels available in the area.

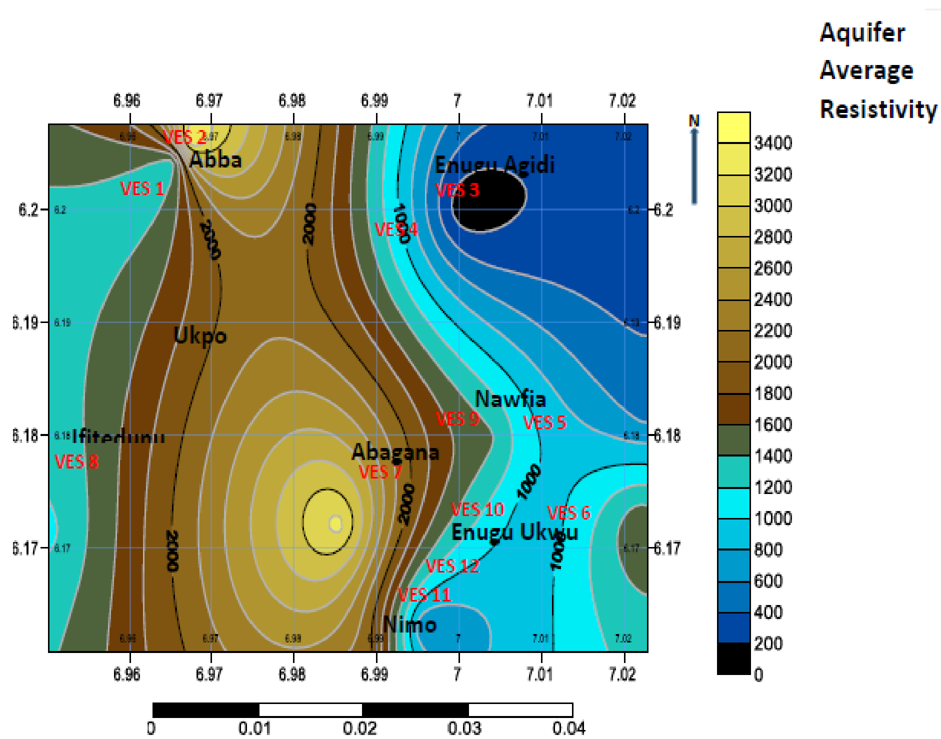

Figure 14: Map of Average Aquifer Resistivity of the Study Area Modelled Using Surfer 16 Software

The resistivity of the area according to the map shows a vertical trend from the left part of North to the South cutting across parts Abba, Abagana, Nawfia and Nimo with values higher than the rest of other communities. The value range of the resistivity of the study area is 37.7 Ωm to 3451 Ωm figure 14. The resistivity values were deduced from the average apparent resistivity of the individual water saturated units for all the VES location. The parameter forms major part of the determination of groundwater existence and hydrologic characteristics of an aquiferous layer in the study area.

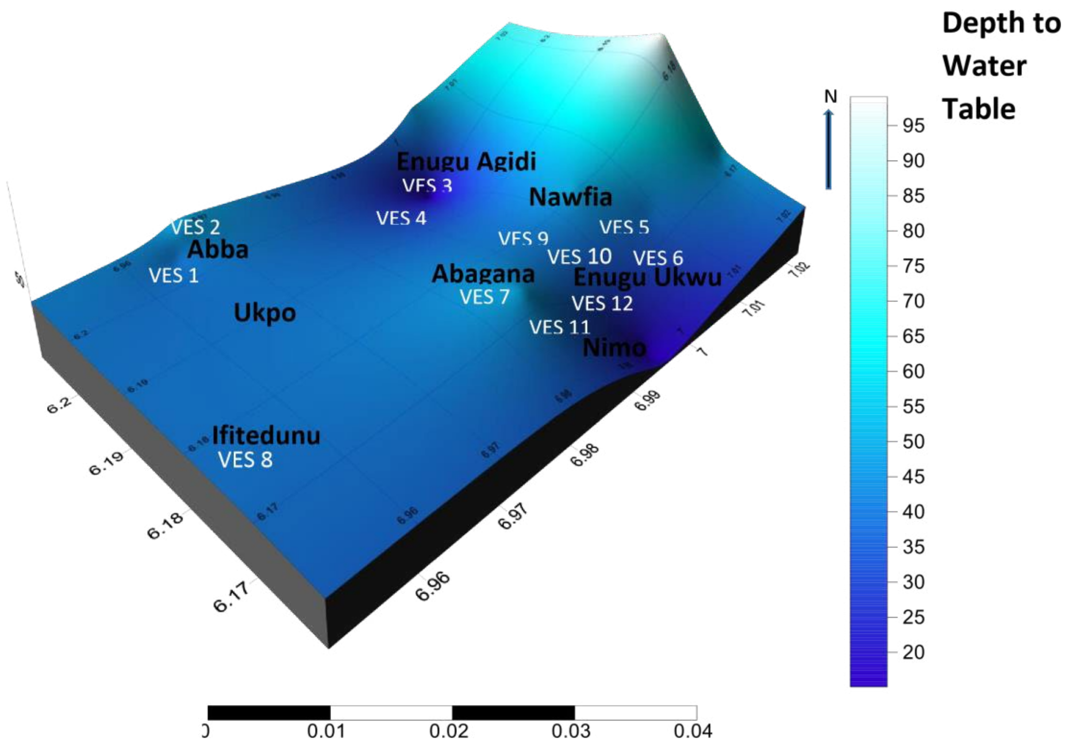

Figure 15: Contour Maps showing Depth to Aquifer with reference to Ground Surface (G.S) of the Study Area modelled using Surfer 16 software.

The contour map in figure 15 below show that the depths of water table in the study area tend geographically low towards the south – western part at the range of 15 m – 100 m. Abba VES location 1 and 2 has aquifer depth of 50 m – 40 m within the coordinates of E0060 58.046' - N060 12.367' and E0060 57.918' - N060 12.257' respectively, Enugwuagidi aquifer depths tend relatively shallower at some parts at range of 50 m – 15 m within a coordinate variation of E0070 00.233' - N060 12.460' and E0070 00.013' - N060 12.013'. Nawfia and Nimo proved the same aquifer depth with Abba VES locations. Among all the VES locations that have close depth of 50 m – 100 m, Enugwukwu has aquifer depth of 15 m – 25 m with reference to coordinates E0070 00.541' - N060 10.382' which is predominantly shallow.

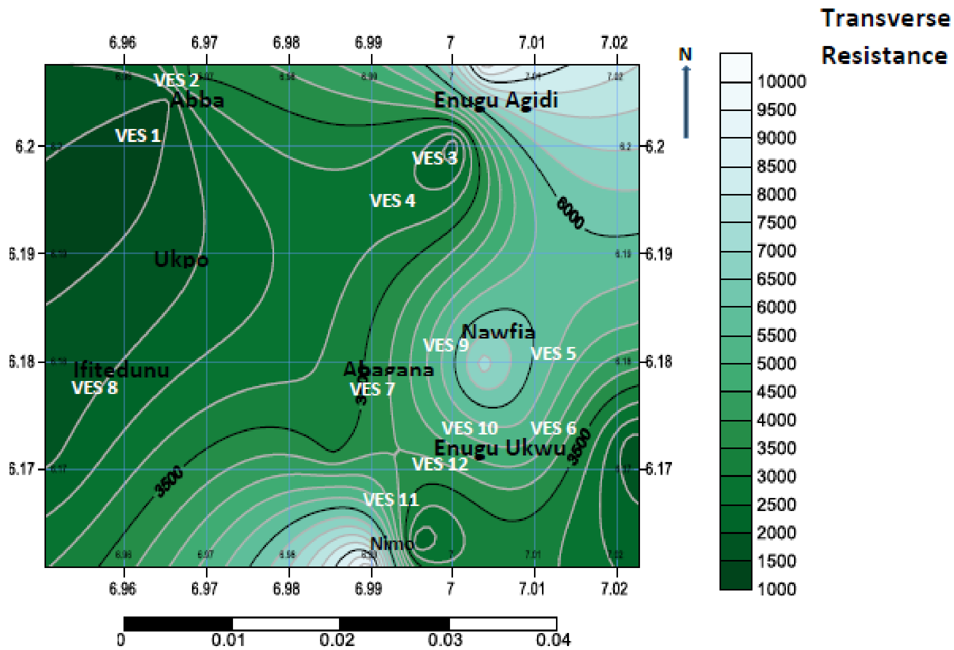

Figure 16: Map of Transverse Resistance of the Study Area Modelled Using Surfer 16 Software

The VES layers resistivity multiplied by its respective thickness gave rise to the distribution of transverse resistance of the study area. The higher values of the transverse resistance were observed in part communities such as Enugwu-agidi, Enugwu-ukwu, Nawfia, Abagana and Nimo respectively. The trending of the transverse resistance tends toward Northeastern to Southeastern axis of the map (Figure 16).

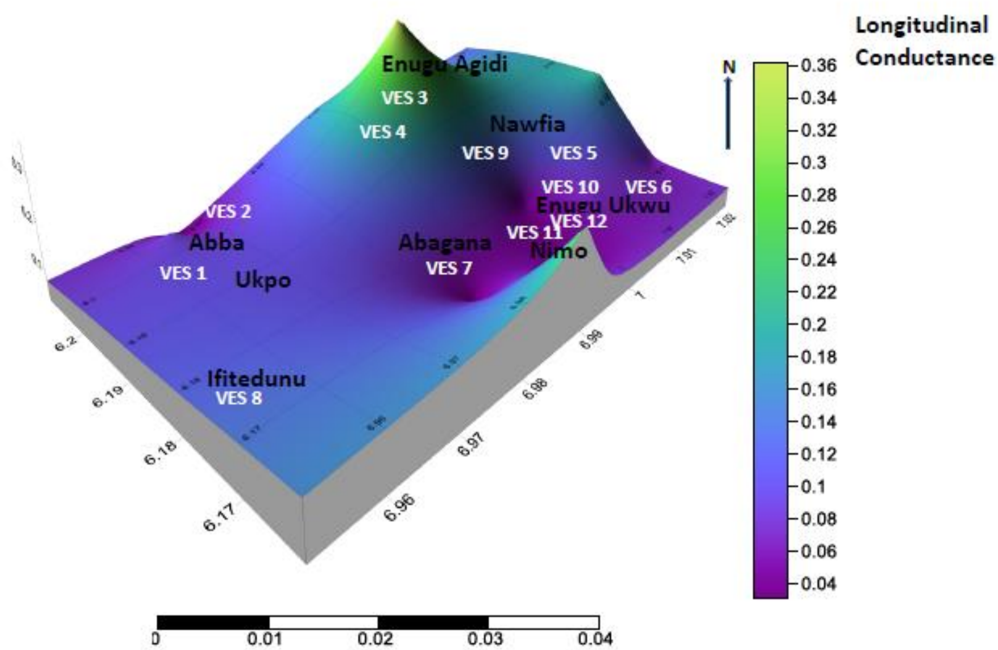

Figure 17: Map showing the Longitudinal Conductance Distribution of the Study Area Modelled Using Surfer 16 Software

In order to get the values of the longitudinal conductance, the aquifer thickness was divided by its VES resistivity value of the location thus applied throughout the study area. Enugwu-agidi shows the highest pyramid shape of the longitudinal conductance with respect to other communities of Njikoka and environs. The calculated values of longitudinal conductance ranges from 0.029 Ω-1 to 0.368 Ω-1 for the entire area under study (Figure 17).

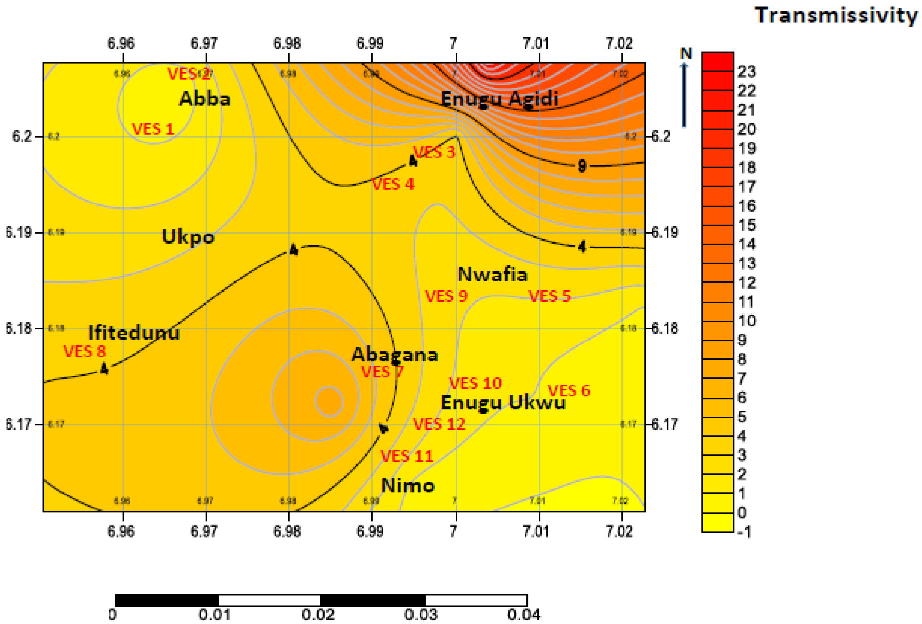

Figure 18: Contour Maps of Aquifer Transmissivity of the Study Area Modelled Using Surfer 16 Software.

The product of the aquifer constant (A) and transverse resistance resulted in aquifer transmissivity for the study area. The tendency of the aquifer to allow the free flow of water within the saturated layer can be termed transmissivity. The value of the transmissivity in part of Enugwuagidi was high relatively to other locations in the area, hence higher aquifer productivity. The map supported the aquifer transmissivity classification by Freeze and Cheery, 1979 which rated the VES 3 of Enugwuagidi low/fairly good in groundwater potentials (Figure 18).

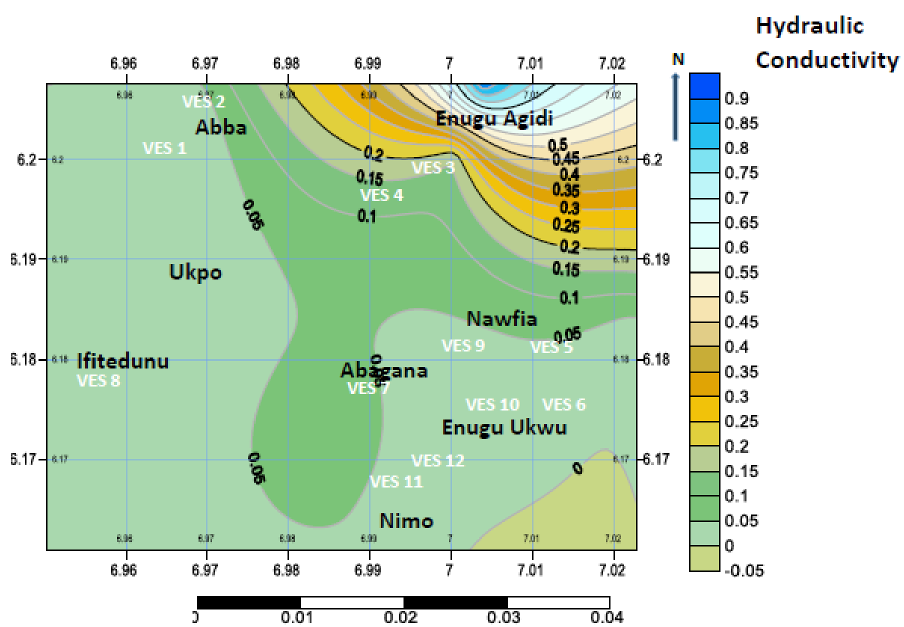

Figure 19: Contour Map of the Hydraulic Conductivity of the Study Area Modelled Using Surfer 16 software.

Hydraulic Conductivity is a function of the aquifer pore spaces connectivity within the rock formation. Its values calculated from the interpreted VES data varies from 0.003 m/day to 0.9 m/day which shows the distribution of hydraulic conductivity for the study area. The Northeastern part of the map displayed the location with high hydraulic conductivity values which was rated clay (well structured) aquifer. Majority of the locations in the study area fall within the map zone rated as clay poorly structured aquifer, Smedema and Rycroft 1983, except part of Enugwuagidi VES-3 location (Figure 19).

3.5 Transmissivity and Hydraulic Conductivity of the Study Area

From aquifer parameter calculations, the transmissivity values of the entire VES points vary from 0.28 m2/day to 22.54 m2/day while the hydraulic conductivity ranges from 0.003 m/day to 0.9 m/day within the study area. The percentage of the aquifer rating shows that 8.33% of the entire spread represents area with low/fair to good transmissivity parameter values Table 6 (VES 3 – Enugwuagidi) and 91.67% of the aquifer layers have poor transmissivity rating which are VES 1, VES2, VES 4, VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11 and VES 12 respectively. Also, the hydraulic conductivity rating of the areas under study displayed that only 8.33% of the aquifer layers were well structured clay texture while other VES locations with percentage of 91.67% were rated as poorly structured clay Table 7 Therefore, Enugwuagidi has better aquifer connectivity tendency than the rest of other towns that make up Njikoka and its environs.

Transmissivity Value (m^2/day)	Aquifer Rating	Affected VES Locations		Distribution Frequency	Frequency Percentage (%)
		Group A / North	Group B / South		
>500	Very Good	-	-	-	-
151 – 500	Good	-	-	-	-
51 – 150	Moderately good	-	-	-	-
11- 50	Low/fairly good	VES 3	-	1	8.33
2 – 10	Poor	VES 1, VES 2, VES 4.	VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11, VES 12	11	91.67

Table 7: Aquifer Classification of the Study Area based on Transmissivity Value (Modified after Freeze & Cheery, 1979)

Range of K (m day^{-1})	Texture	Affected VES Locations		Distribution Frequency	Frequency Percentage (%)
		Group A / North	Group B / South		
10 – 50	Gravelly coarse sand	-	-	-	-
1 – 5	Medium sand	-	-	-	-
1 – 3	Sandy loam, fine sand	-	-	-	-
0.5 – 2	Clay (well structured)	VES 3,		1	8.33
0.2 – 0.5	Very fine sand	-	-	-	-
0.002 – 0.2	Clay (poorly structured)	VES 1, VES 2,			
VES 4	VES 5, VES 6, VES 7, VES 8, VES 9, VES 10, VES 11, VES 12	11	91.67		
≤ 0.002	Dense clay (no pores)	-	-	-	-

Table 8: Hydraulic Conductivity Values of the Study Area (Smedema and Rycroft, 1983)

4. Conclusion and Recommendation

Geophysical methods of Vertical Electrical Sounding were applied in the investigation of ground water system of Njikoka and Environs. The findings show that the study area is predominantly unconfined aquifer system with depth range of 15 m to 100 m. From the results obtained, the transmissivity ranges from 0.28 m2/day to 22.54 m2/day while the hydraulic conductivity was calculated to range from 0.003 m/day to 0.90 m/day in both group A and group B of the study area. The majority of the sounding locations fall within value range of poor transmissivity and poorly structured clay hydraulic conductivity which explains the challenge posed by availability of pipe borne water in the study area. Only part of Enuguagidi showed evidence of little ground water potentials where the transmissivity and hydraulic conductivity rating were low fairly good and well-structured clay respectively. The investigation revealed that exploration and exploitation of ground water in the study area is beyond the indiscriminate drillers hence the professionalism of geophysicist before and after drilling becomes indispensable. In this research the essential aquifer parameters which should form the guide for sustainable ground water development in Njikoka and environs were explored. For a successful exploration and exploitation, geophysicist professionals who can understand the subsurface conditions and characteristics are highly recommended. For commercial purpose drillings the areas with reasonable depth, transmissivity and hydraulic ratings are recommended unlike the failed boreholes created by indiscriminate drillers in many of the study area. Proper pumping test exercise and analysis should be enforced; this will guide in the adequate development of the borehole for sustainable performance. Non-invasive approach to spread the result of this research to the major stake holders to reduce their economic wastage in the study area is also recommended [9-20].

Data Availability

Not Applicable.

Declaration

The authors declared no conflict of interest.

References

1. Dor, N., Syafalni, S., Abustan, I., Rahman, M. T. A., Nazri, M. A. A., Mostafa, R., & Mejus, L. (2011). Verification of surface-groundwater connectivity in an irrigation canal using geophysical, water balance and stable isotope approaches. Water resources management, 25, 2837-2853.
2. Eboagu, N. C., Ajiwe, V. I. E., Ochiagha, K. E., & Odidika, C. (2020). Elemental assessment of borehole waters in Njikoka Local Government Area of Anambra state, Nigeria. Anachem Journal, 10(1), 1881-1891.
3. Ayadiuno, R. U., Ndulue, D. C., & Mozie, A. T. (2022). A Geomorphological Survey and Landscape Analysis of Anambra State Southeast Nigeria. Journal of Geography, Environment and Earth Science International, 26(2), 39-58.
4. George, N. J., Obianwu, V. I., & Obot, I. B. (2011). Estimation of groundwater reserve in unconfined frequently exploited depth of aquifer using a combined surficial geophysical and laboratory techniques in the Niger Delta, South-South, Nigeria. Advances in applied science research, 2(1), 163-177.
5. Ekwe, A. C., Onu, N. N., & Onuoha, K. M. (2006). Estimation of aquifer hydraulic characteristics from electrical sounding data: the case of middle Imo River basin aquifers, south-eastern Nigeria. Journal of spatial hydrology, 6(2).
6. Massoud, U., Santos, F., Khalil, M. A., Taha, A., & Abbas, A. M. (2010). Estimativa de parâmetros hidráulicos do aquífero a partir de medições geofísicas superficiais: um caso de estudo do aquífero Cretácico Superior, Sinai central, Egipto. Hydrogeology Journal, 18, 699-710.
7. Akhter, G., & Hasan, M. J. O. G. (2016). Determination of aquifer parameters using geoelectrical sounding and pumping test data in Khanewal District, Pakistan. Open Geosciences, 8(1), 630-638.
8. David, K. T. (1959). The integrated analysis of aquifer transmmissivity was calculated from the pumping test data according to Cooper – Jacob's method. Ground water hydrology 2nd edition 1 -560.
9. Anizoba, D. C., Chukwuma, G. O., Chukwuma, E. C., & Chinwuko, E. C. (2015). Determination of aquifer characteristics from geo-electrical sounding data in parts of Anambra State, Nigeria. International Journal of Innovation and Applied Studies, 11(4), 832.
10. Anizoba, D. C., Chukwuma, G. O., Chukwuma, E. C., & Chinwuko, E. C. (2015). Determination of aquifer characteristics from geo-electrical sounding data in parts of Anambra State, Nigeria. International Journal of Innovation and Applied Studies, 11(4), 832.
11. Aweto, K., & Akpoborie, I. (2015). Estimating aquifer parameters with geoelectric soundings: Case study from the shallow Benin Formation at Orerokpe, Western Niger Delta, Nigeria. British Journal of Applied Science & Technology, 6(5), 486-496.
12. Aweto, K., & Akpoborie, I. (2015). Estimating aquifer parameters with geoelectric soundings: Case study from the shallow Benin Formation at Orerokpe, Western Niger Delta, Nigeria. British Journal of Applied Science & Technology, 6(5), 486-496.
13. Corriols, M., & Dahlin, T. (2008). Geophysical characterization of the León-Chinandega aquifer, Nicaragua. Hydrogeology Journal, 16, 349-362.
14. Ezeh, C. C. (2012). Hydrogeophysical studies for the delineation of potential groundwater zones in Enugu state, Nigeria. Int. Res. J. Geol. Min, 2(5), 103-112.
15. Ezeigbo, H. I., & Ozoko, D. C. (1989). An evaluation of the water resources of Nsukka and environs, Anambra State, Nigeria. Water Resources Journal of Nigeria Association of Hydrogeologists. Vol, 2(2), 20-25.
16. Freeze, R. A., & Cherry, A. J. (1979). Groundwater, Prantice Hall. Inc. New Jersey, 262-265.
17. Ndubuisi, I. G., Alex, N. N., Austin, O. C., & Sunday, A. A. (2014). Evaluation of Aquifer Hydraulics using Electrical Resistivity Method: A case of Nsugbe sandstone, Anambra

State, Southeastern Nigeria. International Research Journal of Geology and Mining, 4(3), 64-75.
18. Louis, I. F., Karantonis, G. A., Voulgaris, N. S., & Louis, F. I. (2004). The contribution of geophysical methods in the determination of aquifer parameters: the case of Mornos River delta, Greece. Research Journal of Chemistry and Environment, 8(4), 41-49.
19. Mendoza, G. F., Steenhuis, T. S., Walter, M. T., & Parlange, J. Y. (2003). Estimating basin-wide hydraulic parameters of a semi-arid mountainous watershed by recession-flow analysis. Journal of Hydrology, 279(1-4), 57-69.
20. Niwas, S., & Singhal, D. C. (1981). Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. Journal of hydrology, 50, 393-399.