OPEN ACCESS

Saudi Journal of Civil Engineering
Abbreviated Key Title: Saudi J Civ Eng
ISSN 2523-2657 (Print) |ISSN 2523-2231 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com/journal/sjce/home

Original Research Article

Exploration of Ground Water Potential of Federal University of Technology, Owerri and Its Environs Using Resistivity Survey

Nwachukwu, I. N[1*], Dike, B. U[1], Nwoke, H. U[1], Nwakwasi L.N [1]

[1]Department of Civil engineering, Federal University of technology, PMB 1526, Owerri, Imo state, Nigeria

DOI: 10.36348/sjce.2023.v07i09.002 | **Received:** 29.08.2023 | **Accepted:** 03.10.2023 | **Published:** 17.10.2023

***Corresponding author:** Nwachukwu, I. N
Department of Civil engineering, Federal University of technology, PMB 1526, Owerri, Imo state, Nigeria

Abstract

The research focused on evaluating the groundwater potential in the vicinity of Federal University of Technology Owerri (FUTO) using a resistivity survey method. The investigation involved the utilization of eleven Schlumberger vertical electrical soundings (VES). The data collection was conducted using an ABEM Terrameter SAS4000 and then processed with IPI2Win Software, which relies on the conventional theory of curve matching. This process aimed to determine the depth, quality, and subsurface formations of the groundwater. The VES interpretation results revealed the presence of 3-5 geoelectric layers above the aquiferous layers. Various curve types were identified in the study area, including monotonically ascending (AA), bowed-ascending (HA), bowl-bell (HK), and ascending-bell (AK) curves. The majority of the field curves were found to be of the A-shaped type, signifying specific aquifer characteristics. The study indicated that the depth to the water table is relatively shallow in the Ihiagwa area, with an average depth of 7.26 meters. In contrast, the aquifer's depth is deeper around Avu, Nekede, and Eziobodo areas, with a mean depth of 32.33 meters. Obinze had very deep aquifers, with an average depth of 57.75 meters. Furthermore, the study established a relationship between aquifer characteristics and geoelectric parameters, allowing for the estimation of hydraulic conductivity and transmissivity values at all the sounding locations, even in areas lacking boreholes. These hydraulic characteristics showed that the aquifer had protective capacities ranging from 0.036 to 0.509 mhos, transmissivity values ranging from 11856.32 to 28661.28 m2/day, and hydraulic conductivity ranging from 13.47 to 1009.2 m/day. These values suggested that the aquifer materials are highly permeable, facilitating fluid movement within the aquifer. This research demonstrated the effectiveness of surface geophysics in estimating aquifer hydraulic characteristics, particularly in situations where pumping test data are unavailable. It also highlighted the vulnerability of the aquifer to surface contaminants. The findings are expected to be valuable for the long-term planning of groundwater exploitation projects in the study area.

Keywords: Vertical electrical soundings (VES), Electrical Resistivity, Geophysical Properties, Transmissivity and Hydraulic Conductivity.

1.0 INTRODUCTION

Groundwater plays a significant role in supplying fresh water globally, constituting nearly 99% of the total volume of available fresh water in circulation today, as noted by Younger in 2007. This is because water has the remarkable ability to transform into vapor (a gas), enabling its movement through the atmosphere from the ocean to inland areas. There, it condenses and falls as rain, sustaining both plant and animal life (Zumdahl, 2018). When we consider the distribution of water on Earth's surface, the majority resides in oceans (approximately 97.25%), while polar ice caps and glaciers account for about 2.05%. The remaining portion exists in freshwater lakes, rivers, and groundwater sources. With the global population steadily increasing and the demand for fresh water on the rise, the importance of water purification and recycling becomes increasingly evident (Zumdahl, 2018).

Water quality encompasses the various attributes of water, including its chemical, physical, biological, and radiological characteristics. It serves as an indicator of water's condition concerning the needs of living organisms and human requirements. Water quality varies depending on its intended use, whether it is for consumption, industrial processes, or environmental purposes. Prior to selecting drilling sites, it is essential to conduct comprehensive geophysical and hydrogeological investigations. The significance of maintaining water quality lies in safeguarding both human health and the well-being of ecosystems. Ensuring the safety of our drinking water and preventing harm to the environment are paramount concerns. Dissolved minerals in water can lead to pipe corrosion, staining of bathroom fixtures, and affect the performance of washing machines (Kelly, Cronk, Kumpel & Howard, 2010).

Groundwater is typically found in the saturated zone, where voids between sedimentary materials or fractures in rocks are filled with pore water at pressures exceeding atmospheric pressure. It is often regarded as a concealed natural treasure, and its exploitation remains essential due to its numerous, uncompromised uses. While other water sources like streams, rivers, and ponds exist, groundwater stands out for its exceptional natural microbiological quality and generally suitable chemical composition for most applications (Pudentiana and Luke Mamah, 2012).

Effective groundwater resource management necessitates a deep understanding of aquifer recharge, bearing capacity, and discharge rates. Addressing various hydrological and hydrogeological challenges associated with groundwater exploration and exploitation is crucial. In this project, we employed the electrical resistivity method for groundwater exploration, a geophysical approach that involves the scientific measurement of the physical properties of the Earth's crust to investigate mineral deposits. Field parameter estimations were also conducted.

2. MATERIALS AND METHODS

2.1 Materials

The materials that were used for this research are highlighted below.

i. Terrameter SAS 4000
ii. ABEM Terrameter SAS 1000
iii. External Battery Connector
iv. deep penetration resistivity meter.
v. Two potential electrodes
vi. Two current electrodes
vii. A 12-volt car battery (power source).
viii. Four electrical cable rims, two each for the potential and current electrodes.
ix. Two 100m tapes
x. Four geological hammers.
xi. GPS for measuring Co-ordinates and Altitude

2.1.1 Study area

The communities of Eziobodo, Umuchima, Ihiagwa, Okolochi, Emeabiam, and Obinze in Imo State, Nigeria, form the Federal University's boundary. The study's locations were chosen at a variety of locations within the Federal University of Technology Owerri (FUTO) and its environs between longitudes 6°56'E and 7°03'E and latitudes 5°21'N and 5°27. The given guide in Plate 2.6 shows the various places of the profiles reviewed alongside their direction. Accessibility and field logistics were taken into consideration when selecting the study locations throughout FUTO. Ten locations were chosen for the survey.

The region has a mean daily temperature range of 19 to 24 degrees Celsius, a mean daily temperature ranges of 28 to 35 degrees Celsius, an average relative humidity of up to 80 percent, and a longer wet season that runs from April to November. Despite being dominated by semi-deciduous forest, agriculture and other human activities have altered the vegetation, resulting in predominant topsoil with moderate humus content. Road networks provide access to the study area. The Owerri Port-Harcourt road via Obinze and the Owerri Aba road via Naze provide access to the area. Plate 2.1 displays the map of the general survey area that was derived from the Google map. Colored dots and the coordinates are used to identify the VES points. Additionally, the map of FUTO is depicted on Plate 2.2, and a red pointer marks the survey's location.

2.2 Methods

The methods used for achieving the results for this research are discussed below.

2.2.1 Collection and Process of resistivity survey data

Data Acquisition

The data were gathered at a number of pre-selected locations. On the instrument's two sides, the system was set up. The data were then analyzed using IPISW, a resistivity data analysis program, on a straightforward data entry sheet. Curve matching and computer iterative techniques were used for quantitative data interpretation. An automated computer program that was written in accordance with the Schlumberger theory was fed the resistivities and the electrode spacing data that corresponded to them. For each station, logarithmic-scale graphs of apparent resistivity versus depth based on computer results were plotted.

Data Analysis

The model that was mentioned earlier was used to analyze the data that were collected. The standard theory of curve matching is its fundamental operating principle. Based on the data that was collected, the depth to the water table was calculated. In some locations, the values that were calculated using a resistivity survey were also compared to the depths of the water table that were previously recorded from wells in the area.

The VES curves were iterated using an iteration program called IPI2WIN. The technique of partial curve matching was used to quantitatively interpret the set of smooth curves that were taken through the data points. Layer thickness and resistivity were derived from the VES1 to VES11 diagram. The resistivity, thickness, and depth of the water table of each of the delineated layers were determined by interpreting these curves using the partial curve matching method and the auxiliary curves that corresponded to them. The IPI2Win Program for inverting the 1 D dimension was used to analyze the quasi-computed resistivity values. A 1 D curve depicting the underground electrical resistivity distribution is produced as a result of this inversion.

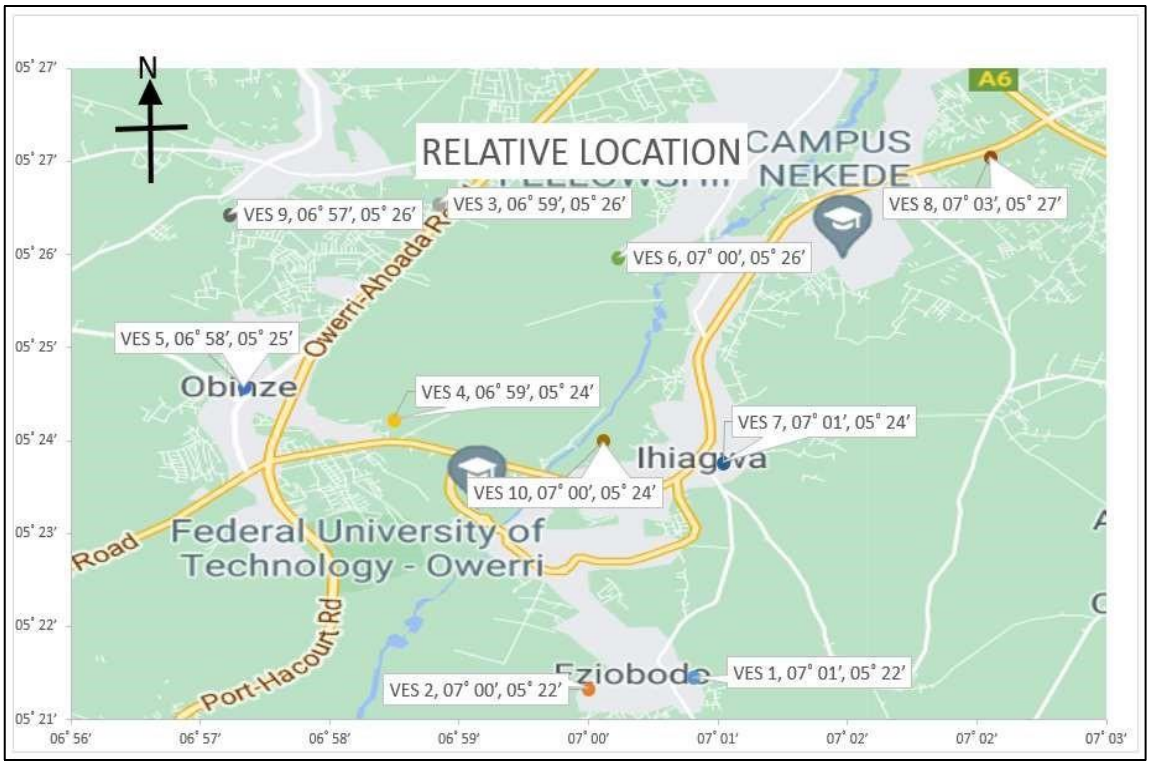

Plate 2.1: Location Map of the survey Area Showing Points the VES

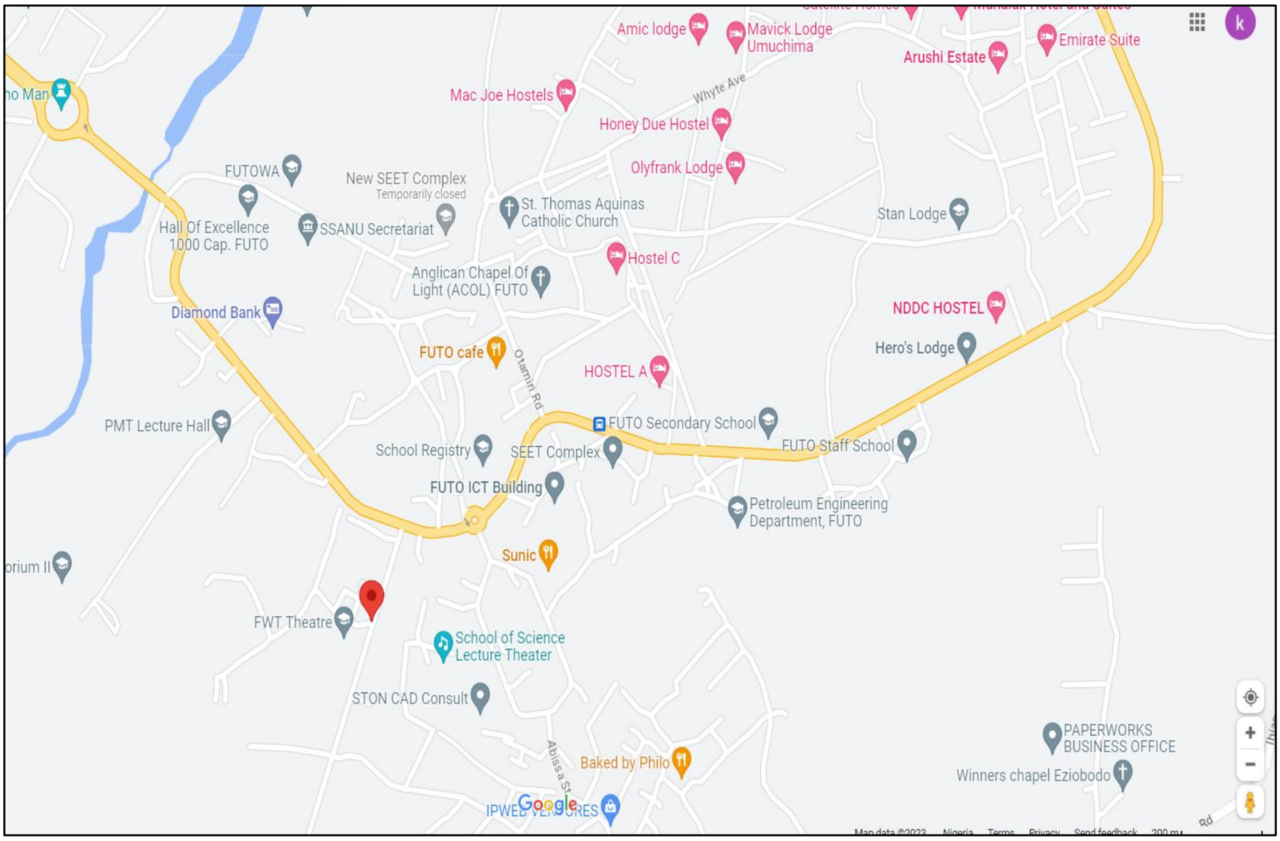

Plate 2.2: FUTO Map showing the survey area indicated in red pointer

Electrical Resistivity Profiling

The topic of interest is electrical resistivity. The process of conducting a linear grid survey allows for the examination of lateral changes in detail, often accompanied by limited insights into vertical variations.

Data profiling involves the systematic collection of data recordings at consistent intervals along a designated profile. The profile is often marked at regular intervals of predetermined distances. In the context of a geometrically ideal scenario, we consider a current flowing through a homogeneous medium inside a well-defined uniform cross section, situated between two electrodes with distinct potentials. The resistance R is determined using the ohm's law as given below.

$$R = \frac{V}{I} \quad \text{………………… Equation 1}$$

Where R is the resistance of the current carrying conductor, V is the voltage of the battery and I is current passing through conductor.

The conductor's cross-sectional area and the electrode distance L also have an impact on the offered resistance. Since the field-measured values correspond to potentials or resistances, the first step in processing the data was to calculate the apparent resistivities. The electrode configuration-specific formula was used to calculate these. 11 locations were surveyed for resistivity.

2.2.2 Subsurface Geologic and Hydrogeologic Characteristics of the Aquifer in the Study Area using Resistivity Survey

Prior to Collecting the In-Depth Data, the Study Area was In-Depth Assessed to Determine the Special Features and Characteristics That Influence the Ground Level of the Area. For the purpose of carrying out a practical resistivity survey, profiles were carefully chosen keeping in mind all of the possible means of transportation and accessibility. The primary objective of the feasibility survey was to avoid data collection difficulties.

2.2.3 Comparison of the Results gotten from the Resistivity Survey to Borehole Logging

The data were gathered using the standard Schlumberger configuration, which states that the current electrodes vary in both directions in a straight line. However, in the event of weak signals, the potential electrodes are moved when better subsurface start results are required.

Although there are a variety of electrode configurations to choose from, such as wenner array, dipole-dipole, pole-pole, and pole-dipole, the Schlumberger electrode configuration was chosen because of its adaptability as well as its precision in data collection and results.

2.2.4 Subsurface and Aquifer Characteristics
Hydraulic Conductivity

According to Kosinki and Kelly (1981), the hydraulic conductivity K is directly proportional to the layer resistivity. According to Hilmi S. Salem (1999), hydraulic conductivity is inversely correlated with permeability. According to Johasem (1977), the following equation describes the relationship between hydraulic conductivity and layer resistivity in a porous aquifer medium:

$K(m/s) = 10^{-5} \times 97.5^{-1} \times \rho^{1.195}$ ……………. Equation 2

$K(m/day) = 60 \times 60 \times 24 \times K\,(m/s)$ ……… Equation 3

Transmissivity of the aquifer

Transmissivity is a major property of an aquifer which helps in the characterization of rocks as water conducting media.

$T = Kh$ ………………………….. Equation 4

Where T is the aquifer transmissivity, K is aquifer hydraulic conductivity and h is the aquifer thickness.

Protective Capacity

The values of the total longitudinal conductance of the overburden layers of an aquifer were used in evaluation of the protective capacity of the aquifer.

$\boldsymbol{PC} = \Sigma \boldsymbol{LC} = \Sigma \boldsymbol{h}_i/\boldsymbol{\rho}_I$ ……………… Equation 5

Where PC is protective capacity, LC is longitudinal conductance, hi is thickness of ith layer and ρi is resistivity of ith layer. The rating of protective capacity of an aquifer was described by Oladapo and Akintorinwa (2007) as expressed below.

3.0 RESULTS AND DISCUSSION

3.1. RESULTS

The results from this research are presented here.

Rating	Remarks
Greater than 10	Excellent
5–10	Very good
0.2–4.9	Moderate
0.1–0.19	Weak
Less than 0.1	Poor

Source: Oladapo and Akintorinwa (2007)

3.1.1 Location of sites

The sites (represented using VES), the coordinates in the longitude and latitude directions and the altitude of the sites are shown below in Table 3.1.

Table 3.1: Locations, coordinates and heights

Stations	Location	Lat	Log	Height
VES 1	Church Eziobodo	07˚ 01’	05˚ 22’	177m
VES 2	Girls sec school, Eziobodo	07˚ 00’	05˚ 22’	210m
VES 3	Gas plant Avu	06˚ 59’	05˚ 26’	178m
VES 4	Futo road Obinze	06˚ 59’	05˚ 24’	185m
VES 5	Church Obinze	06˚ 58’	05˚ 25’	170m
VES 6	Micoh guest house junction Okowu village Nekede	07˚ 00’	05˚ 26’	216m
VES 7	Magistrate court Ihiagwa	07˚ 01’	05˚ 24’	197m
VES 8	Industrial cluster Nekede	07˚ 03’	05˚ 27’	229m
VES 9	Primary school Avu	06˚ 57’	05˚ 26’	159m
VES 10	Umuchimma village gate Ihiagwa	07˚ 00’	05˚ 24’	210m
VES 11	Behind Geology Building, FUTO	07˚ 00’	05˚ 23’	194m

3.1.2 Resistivity

The resistance gotten form the display of the terrameter was recorded on a custom-made data sheet and the resistivity was calculated using a software and summarized. The results are summarized in Table 3.2. The resistivity was gotten using the formula ($p = \frac{KV}{I}$)

Table 3.2: Summary of Calculated resistivity values of the VES locations

SN	AB/2	MN/2	Resistivity										
			VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10	VES 11
	M	M	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM	ΩM
1	1.5	0.5	44.4	33.9	176.0	189.3	48.6	93.0	35.5	618.1	317.3	87.2	194.5
2	2	0.5	51.8	39.0	218.4	185.4	53.6	104.0	23.7	563.0	226.2	95.8	187.6
3	2.6	0.5	63.0	43.8	190.4	144.4	76.1	110.6	37.8	548.9	321.5	108.0	135.2
4	3.4	0.5	66.4	44.4	286.1	118.2	94.4	107.2	40.1	510.1	298.6	106.9	111.1
5	4.5	0.5	79.1	49.0	192.8	101.7	109.9	117.4	44.0	495.5	281.3	115.6	78.0
6	6	0.5	110.1	53.9	204.4	82.0	121.3	161.7	48.3	320.1	284.1	131.4	101.0
7	8	0.5	104.0	64.0	252.0	104.0	120.0	178.0	44.0	314.0	370.0	170.0	120.4
8	10.5	0.5	138.4	76.1	280.3	124.6	128.0	193.8	62.3	266.4	415.2	183.4	160.6
9	14	0.5	209.1	92.3	307.5	153.8	123.0	190.7	49.2	289.1	424.4	233.7	132.4
10	10.5	3.5	94.6	78.3	203.3	120.1	109.6	77.4	36.1	193.2	181.3	126.3	159.0
11	14	3.5	136.1	95.7	264.8	151.8	105.6	104.8	46.2	236.8	252.5	170.0	177.0
12	18	3.5	179.2	112.0	302.4	179.2	144.2	130.2	53.2	246.4	239.4	235.2	208.9
13	24	3.5	199.9	131.6	346.6	237.8	179.6	189.8	83.5	331.4	293.5	225.2	214.3
14	32	3.5	190.7	109.0	413.1	236.1	208.8	190.7	118.0	463.1	331.4	281.5	240.4
15	42	3.5	235.8	157.2	471.6	290.8	235.8	220.1	133.6	495.2	361.6	314.4	321.2
16	55	3.5	351.5	189.3	513.8	405.6	351.5	270.4	162.2	459.7	419.1	378.6	251.0
17	42	14	261.7	158.4	526.9	270.6	306.2	240.3	99.7	402.3	580.3	402.3	310.6
18	55	14	367.7	177.5	681.6	317.0	310.7	259.9	126.8	516.7	687.9	478.7	328.7
19	72.5	14	397.6	238.6	721.4	386.2	301.0	289.7	159.0	704.3	920.2	505.5	358.0
20	95	14	465.8	208.1	763.1	446.0	366.7	356.8	198.2	991.0	1248.7	594.6	370.2
21	125	14	536.3	311.4	795.8	536.3	484.4	432.5	259.5	1332.1	1522.4	605.5	401.0
22	165	14	757.5	454.5	909.0	848.4	666.6	636.3	242.4	1181.7	1757.4	606.0	459.7
23	215	14	1032.0	619.2	1290.0	1135.2	1032.0	774.0	309.6	1702.8	1806.0	619.2	536.3
24	165	55	732.5	469.9	1236.9	815.4	856.8	601.2	186.6	1078.0	1326.7	877.6	422.4
25	215	55	1048.9	567.6	1579.5	863.8	863.8	814.4	209.8	1431.4	1838.7	1184.6	430.2
26	280	55	1010.5	602.0	1913.5	1204.0	1118.0	817.0	301.0	1505.0	1806.0	1032.0	
27	370	55	1069.6	764.0	2292.0	1222.4	1528.0	840.4	305.6	1298.8	1986.4	916.8	

3.1.3 Processing of resistivity data

The resistivity results were plotted using IPI2Win on a logarithmic graph and a smooth curve that can be easily understood by the software and the equivalent soil layers and their resistivity calculated by the software. The computer software was used to get an optimum solution having the least layer possible and the least error possible.

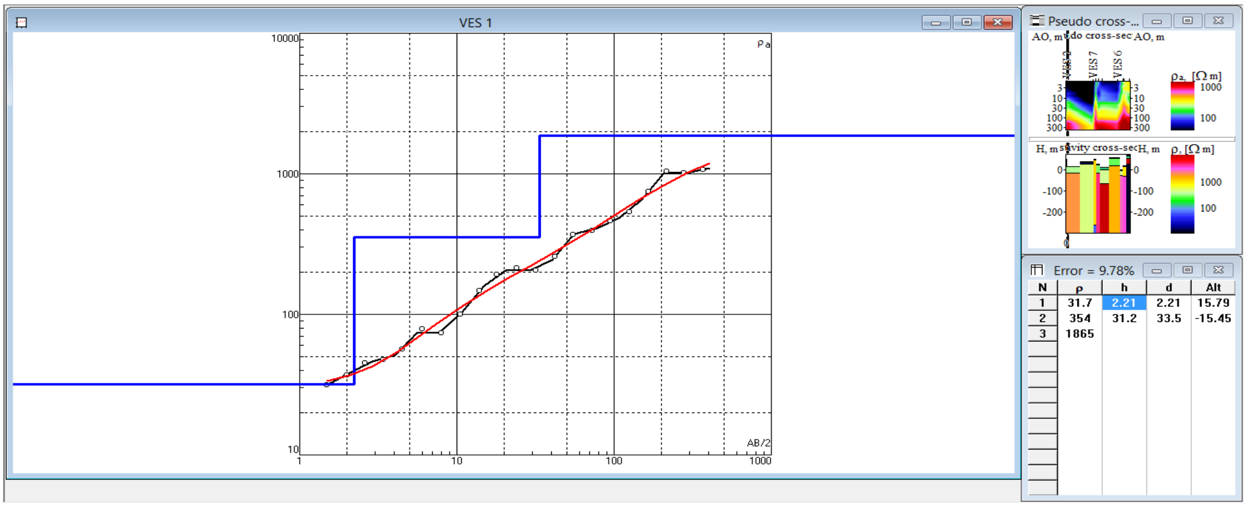

Figure 3.1: Curve marching charts of VES 1 (Church Eziobodo)

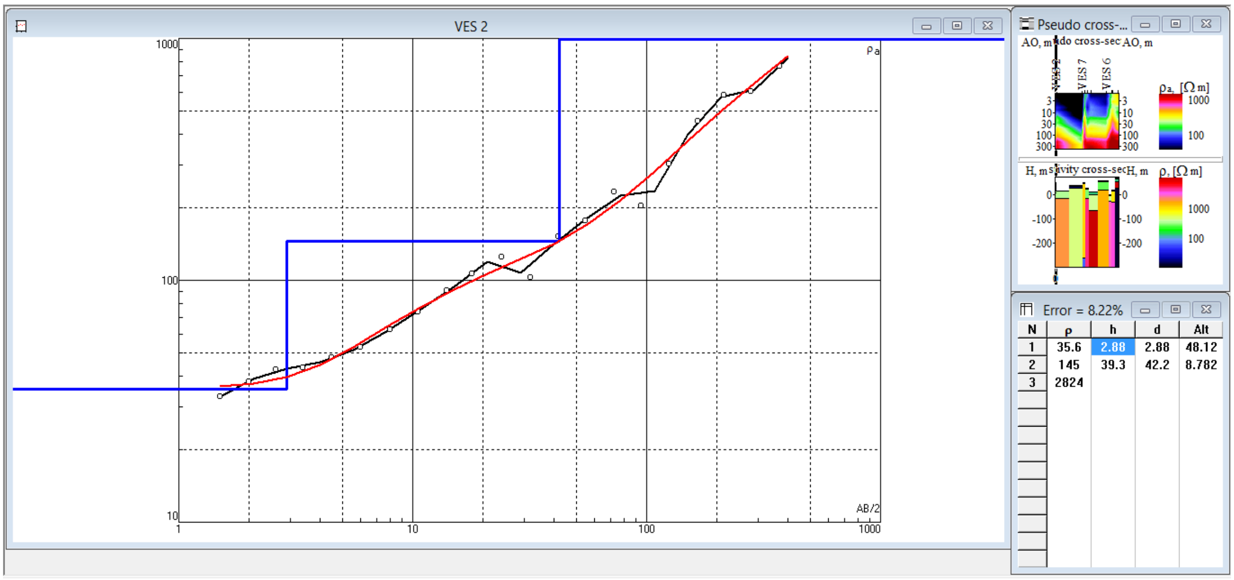

Figure 3.2: Curve marching charts of VES 2 (Girls Sec School, Eziobodo)

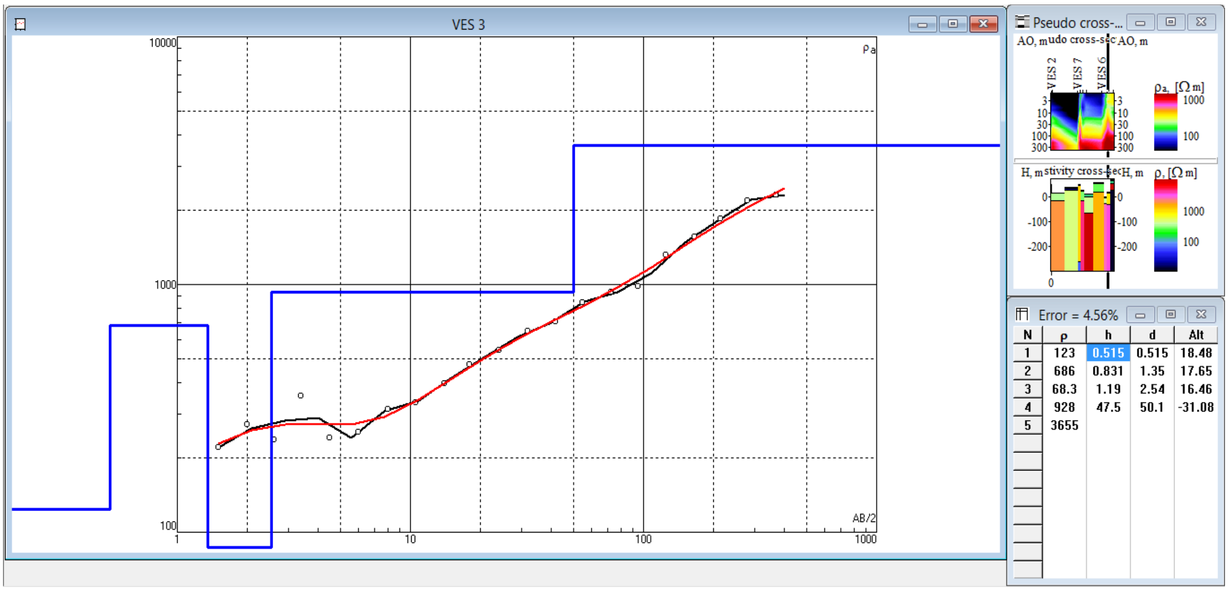

Figure 3.3: Curve marching charts of VES 3 (Gas plant Avu)

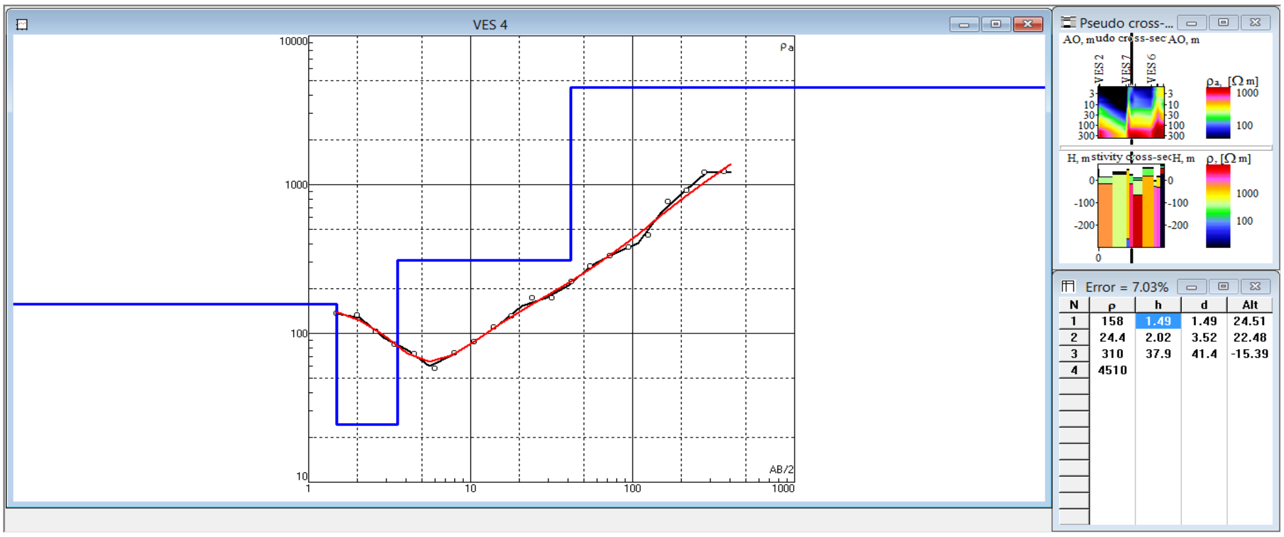

Figure 3.4: Curve marching charts of VES 4 (Futo road Obinze)

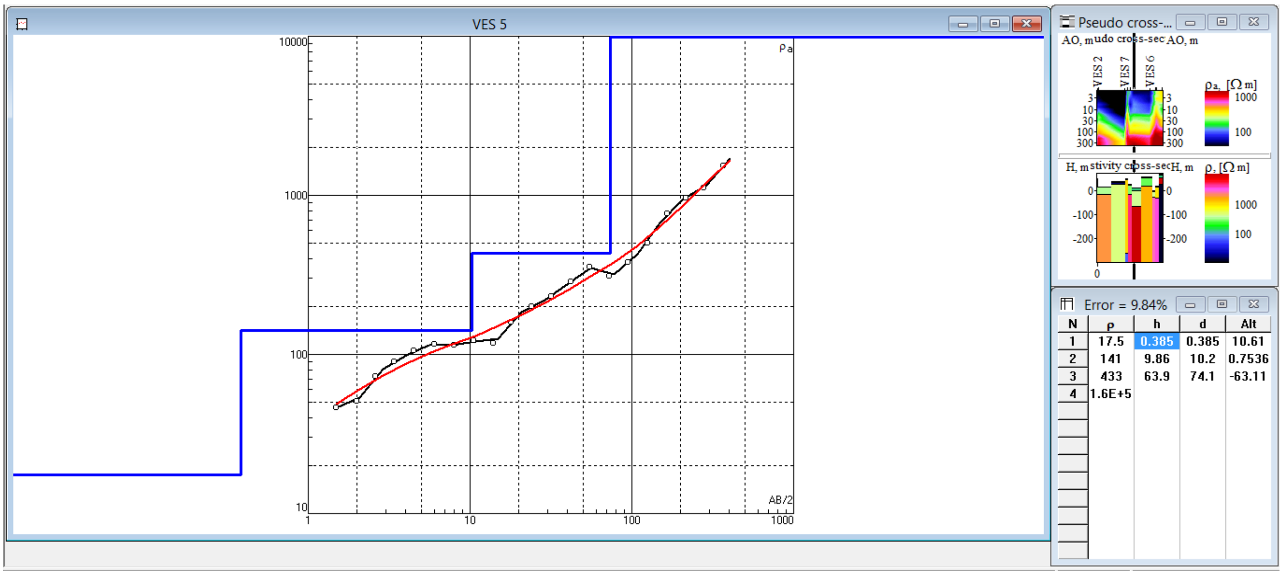

Figure 3.5: Curve marching charts of VES 5 (Church Obinze)

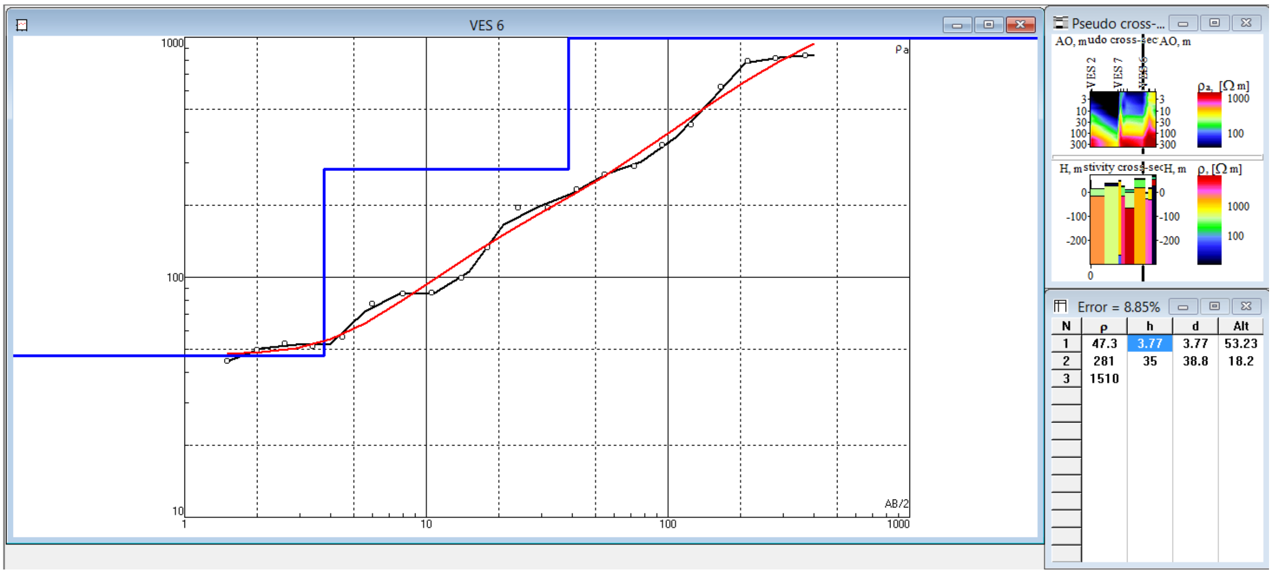

Figure 3.6: Curve marching charts of VES 6 (Micoh guest house junction Okowu village Nekede)

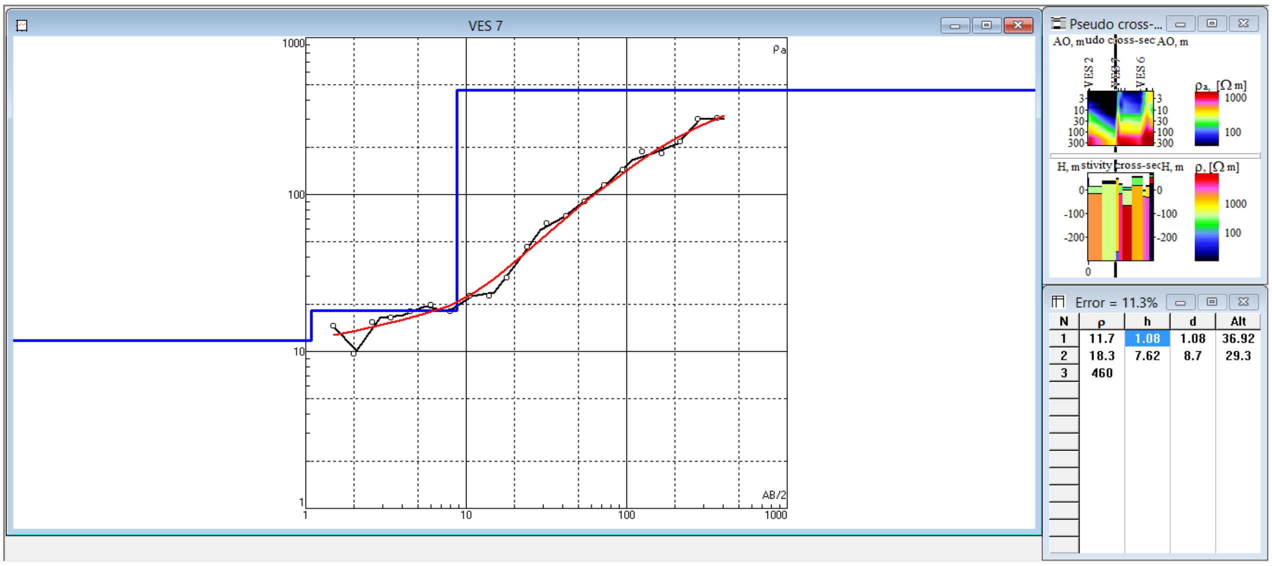

Figure 3.7: Curve marching charts of VES 7 (Magistrate court Ihiagwa)

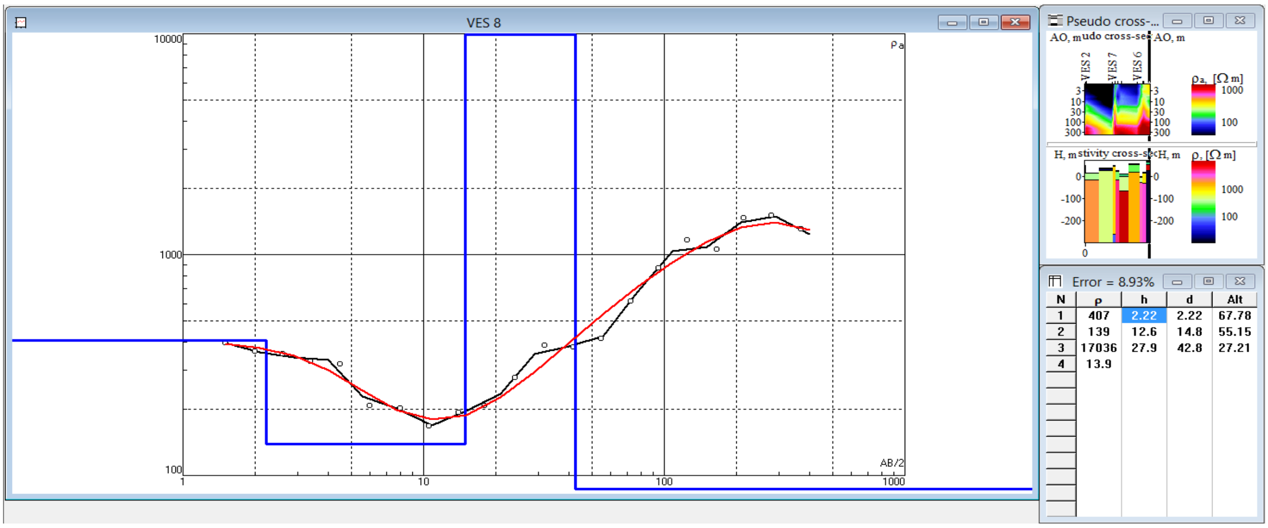

Figure 3.8: Curve marching charts of VES 8 (Industrial Cluster Nekede)

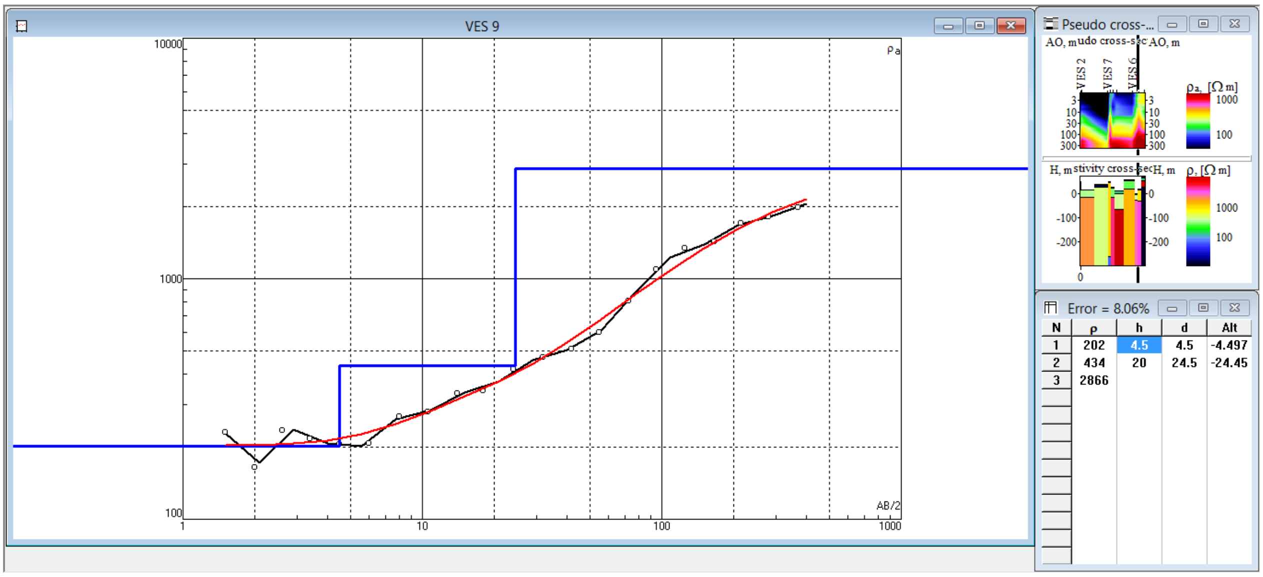

Figure 3.9: Curve marching charts of VES 9 (Primary school Avu)

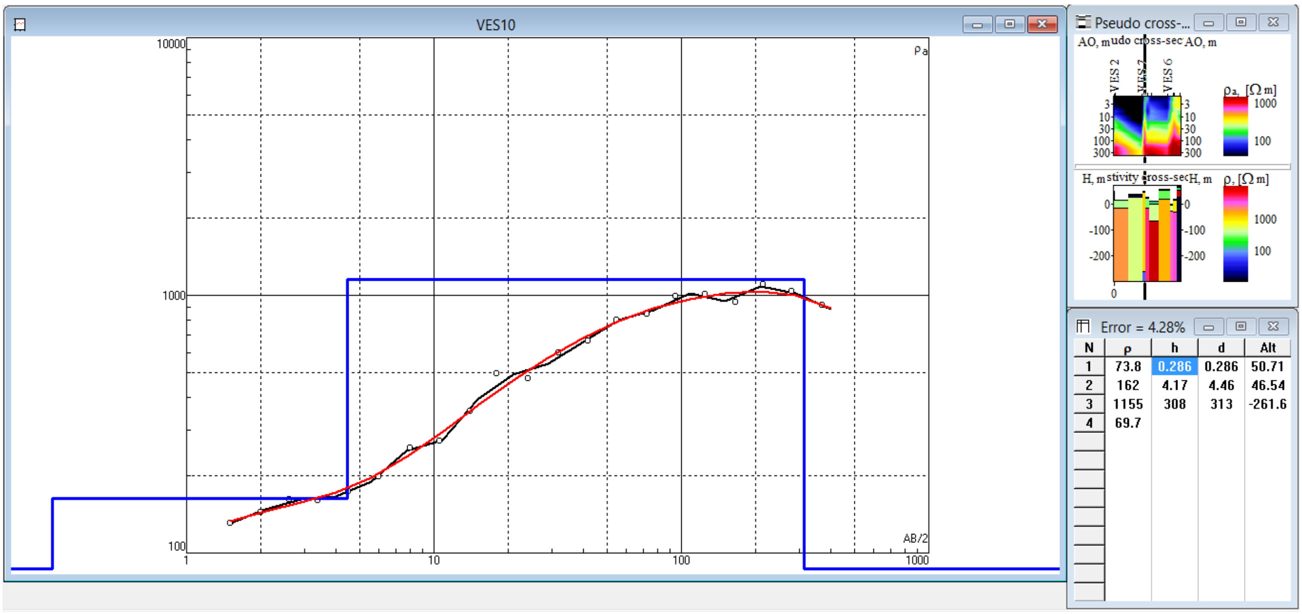

Figure 3.10: Curve marching charts of VES 10 (Umuchima village gate Ihiagwa)

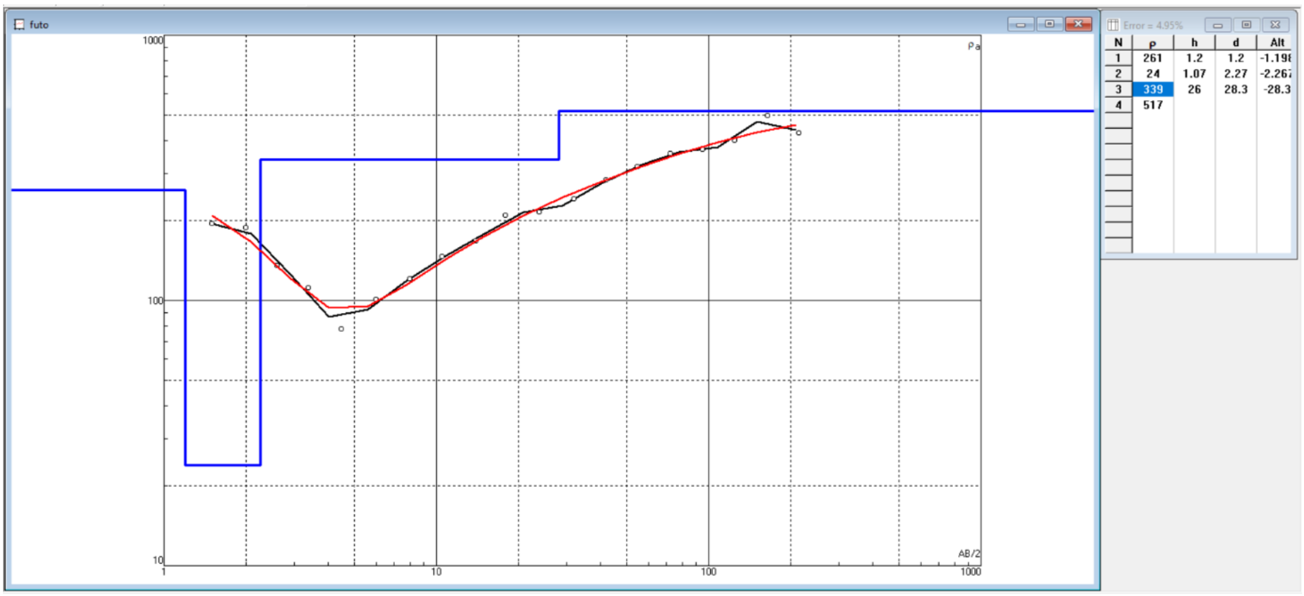

Figure 3.11: Curve marching charts of VES 11 (FUTO)

The layers of the ground were predicted using the solutions from the software. Table 3 shows the ground layers, the thickness and the percentage error between the field data and the estimated computer data for each VES station. Figure 2.12 also show the layers in a cross-section from south to north.

Table 3.3: The ground layers and their resistivity value

		Soil layers and their resistivity value				
		Layer 1	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**
VES 1	Ro	31.7	354	1865		
10.60%	H	2.21	31.2			
VES 2	Ro	35.6	145	2824		
8.22%	H	2.88	39.3			
VES 3	Ro	123	686	68.3	928	3655
4.56%	H	0.515	0.831	1.19	47.5	
VES 4	Ro	158	24.4	310	4510	
7.03%	H	1.49	2.02	37.9		
VES 5	Ro	17.5	141	433	160000	

		Soil layers and their resistivity value				
		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
9.84%	H	0.385	9.86	63.9		
VES 6	Ro	47.3	281	1510		
8.85%	H	3.77	35			
VES 7	Ro	11.7	18.3	460		
11.30%	H	1.08	7.62			
VES 8	Ro	407	139	17036	13.9	
8.93%	H	2.22	12.6	27.9		
VES 9	Ro	202	434	2866		
8.06%	H	4.5	20			
VES 10	Ro	73.8	162	1155	69.7	
5.76%	H	0.286	4.17	308		
VES 11	Ro	261	24	339	517	
5.76%	H	1.2	2.27	28.3		

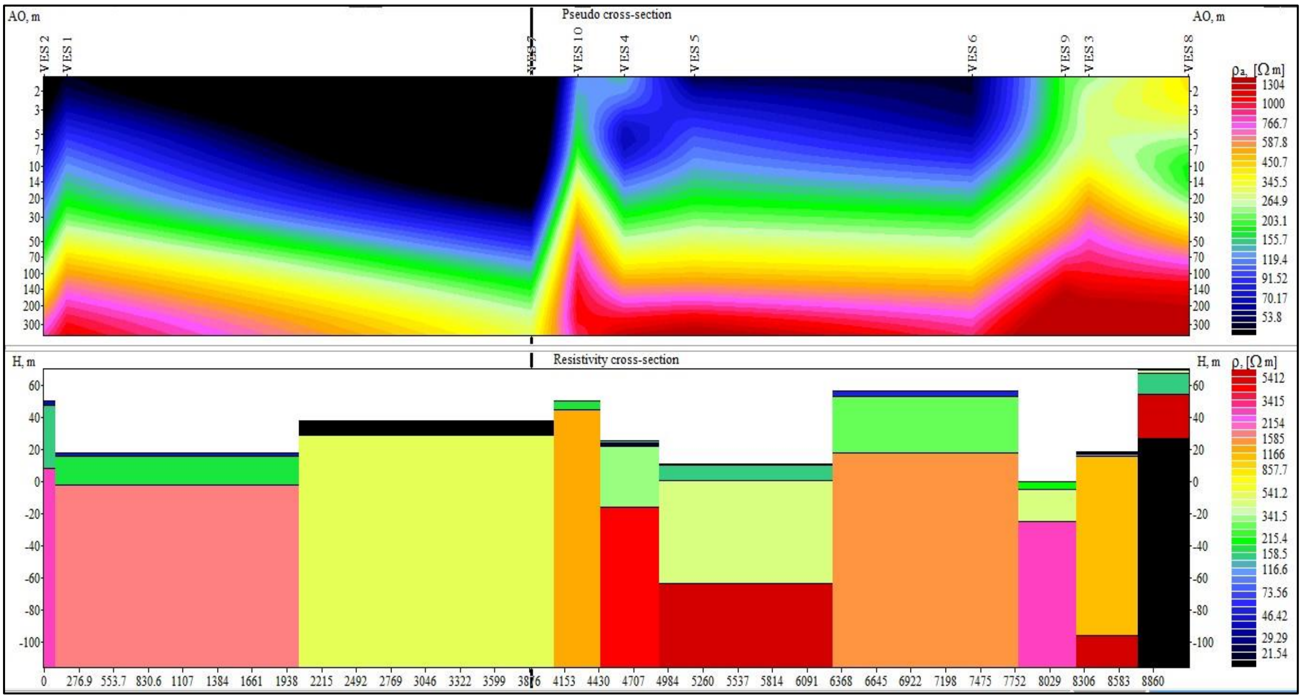

Figure 3.12: S-N Axis Cross-section

From the analysis of the VES data, the layers were predicted and also the thickness. Table 2.4 shows the depth and thickness for each borehole.

Table 3.4: Location, estimated depth and thickness of aquifer

Label	Location	Depth of Aquifer (m)	Thickness (m)
Ves 1	Church Eziobodo	33.5	267
Ves 2	Girls sec school, Eziobodo	42.19	-
Ves 3	Gas plant Avu	50.1	-
Ves 4	FUTO road Obinze	41.39	-
Ves 5	Church Obinze	74.11	-
Ves 6	Micoh guest house junction Okowu village Nekede	38.8	-
Ves 7	Magistrate court Ihiagwa	8.858	-
Ves 8	Industrial cluster Nekede	14.85	27.9
Ves 9	Primary school Avu	24.45	-
Ves 10	Umuchima village gate Ihiagwa	5.673	308
Ves 11	Behind Geology Building, FUTO	28.3	-

3.1.4 The geoelectric and hydraulic parameter

The geoelectric and hydraulic parameter for estimation of aquifer potential where calculated using the formulas below and are presented in table 2.5. From equation 3, the formula used to calculate for hydraulic conductivity is

$$\mathbf{K}\ (m/day) = 60 \times 60 \times 24 \times \mathbf{K}\ (m/s),$$

From equation 4, the formula used to calculate for Transmissivity is

$$\mathbf{T = Kh,}$$

And, from equation 5, the formula used to calculate for Protective Capacity is

$$PC = \Sigma LC = \Sigma h_i/\rho_i$$

Table 3.5: Geoelectric and hydraulic parameter

VES	Location	Curve Type	Resistivity	Thickness	Hydraulic Conductivity	Depth	Transmissivity	Protective Capacity
			(ohm-m)	(m)	(m/day)	(m)	(m^2/day)	(mhos)
1	Eziobodo	AA	1648	267	61.91	23.6	16529.97	0.227
2	Eziobodo	AA	2827		117.99	42.2		0.353
3	Avu	HA	3655		160.38	50.1		0.096
4	Obinze	HA	4510		206.18	41.4		0.215
5	Obinze	AA	15000		866.84	74.1		0.24
6	Nekede	AA	1510		55.77	38.8		0.206
7	Ihiagwa	AA	460		13.47	8.9		0.509
8	Nekede	HK	17036	28.4	1009.2	14.9	28661.28	0.074
9	Avu	AA	2866		119.94	24.5		0.068
10	Ihiagwa	AK	1244	268	44.24	5.7	11856.32	0.038
11	FUTO	HA	517		15.49	28.3		0.126

Legend: Monotonically ascending curve (AA), Bowed-ascending curve (HA), Bowl-bell curve (HK) and Ascending-bell curve (AK)

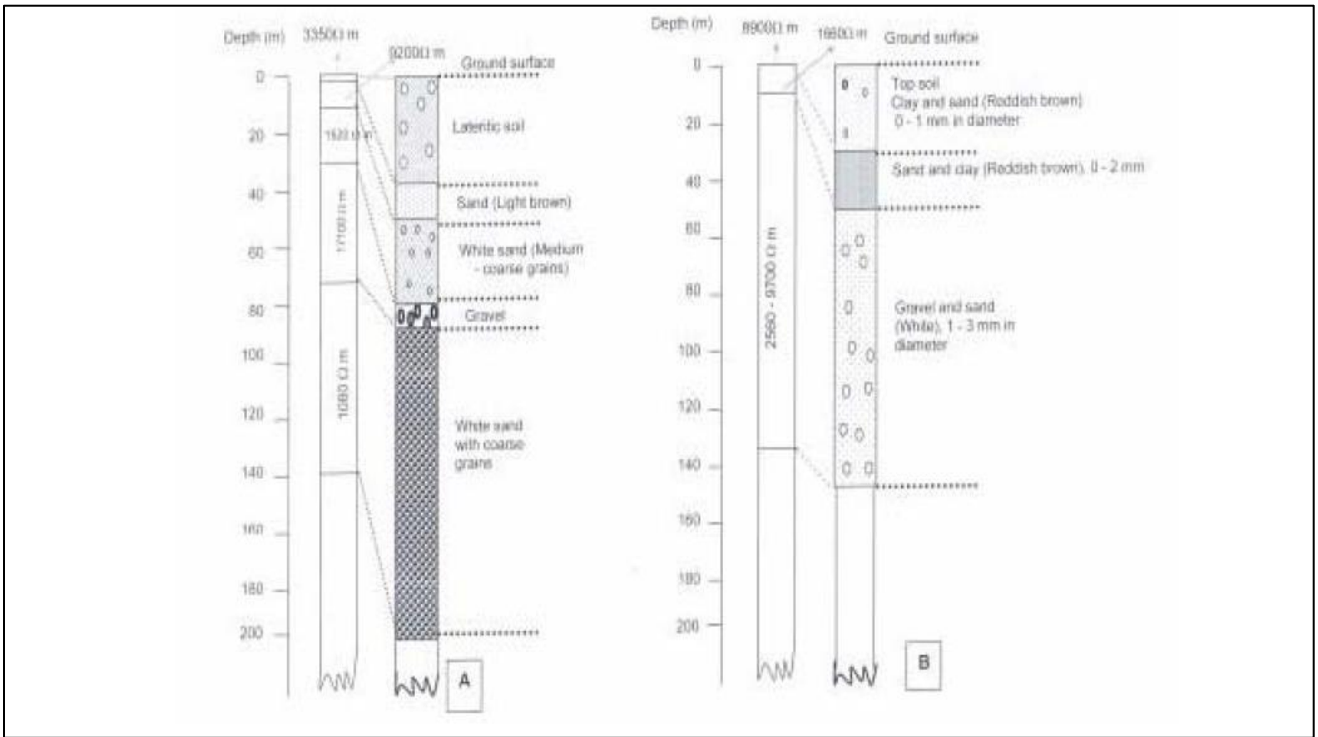

Figure 3.13: Illustration of borehole logging gotten from Kennedy (2020)

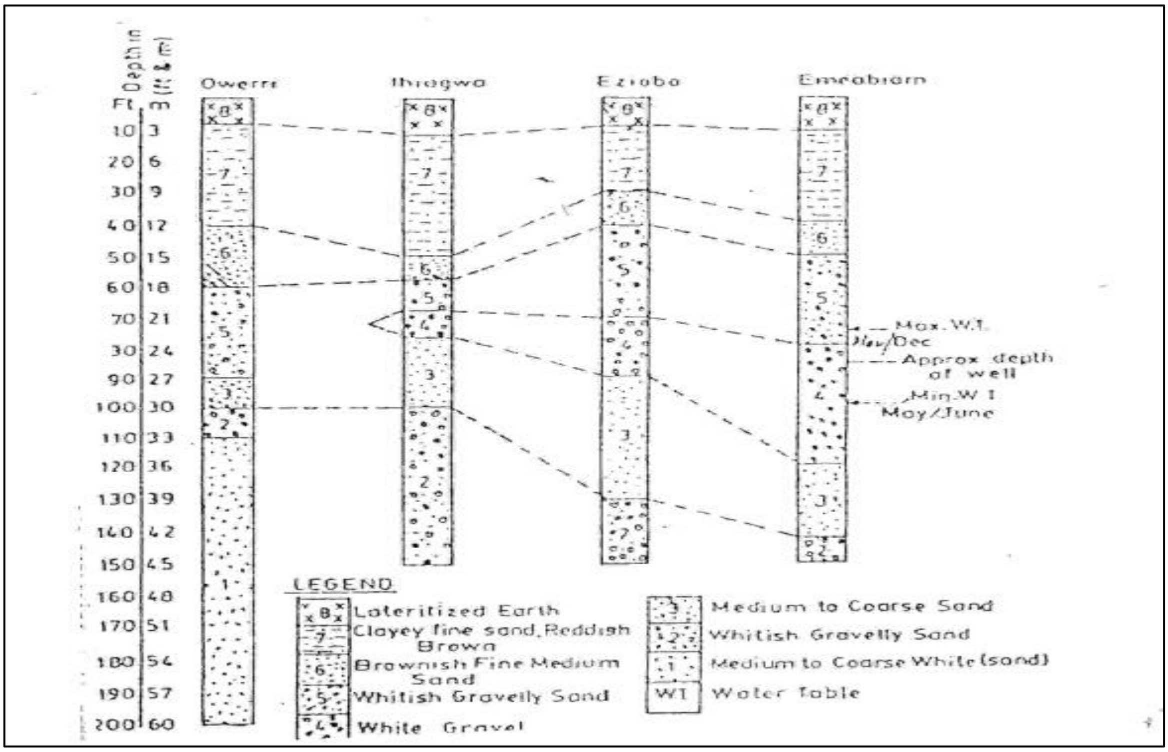

Figure 3.14: Illustration of borehole logging gotten from Amadi (2008)

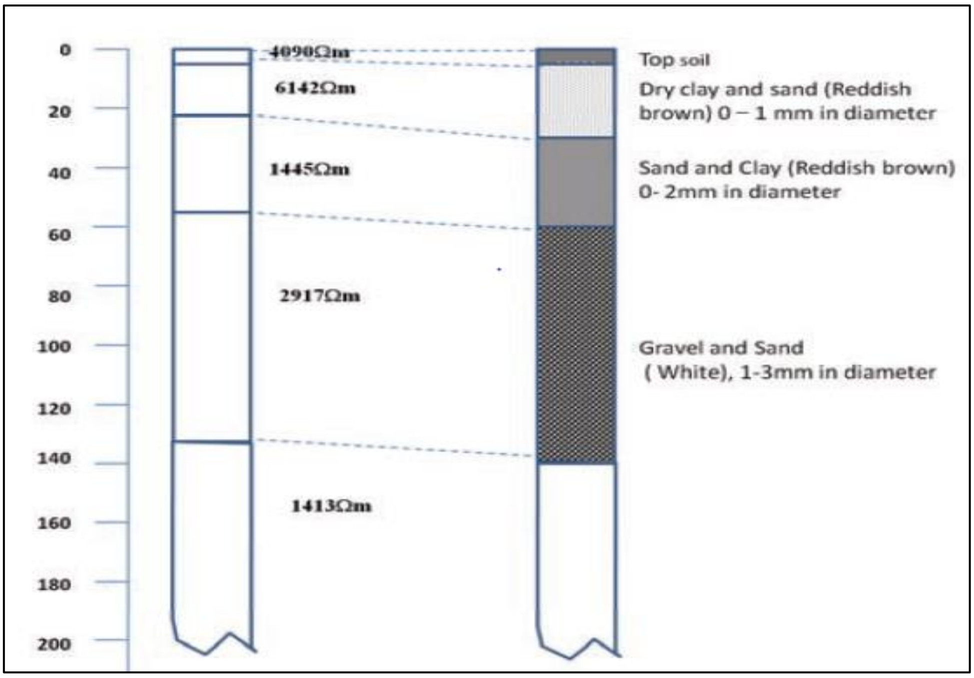

Figure 3.15: Illustration of borehole logging gotten from Ekwe and Opara (2012)

3.2. DISCUSSION

The results obtained above have been discussed in this section.

3.2.1 The processed resistivity data

According to the literature, the few layers of Owerri soil necessitated the use of the fewest layers when plotting the curves. The calculated groundwater depths were also compared to other studies that had been done nearby by various agencies using destructive methods and showed a close resemblance. The observed data's resistivity-depth transformations are depicted on the right side of each curve, while the calculated responses and observed data are depicted on the left. The calculated VES curves show that the number of interpreted layers in the study area ranges from three to five.

According to Table 3.5, the A-type curves dominate the majority of the study area: VES1, VES2, VES5, VES6, VES7, and VES9 have AA-type curves, VES3, VES4, and VES11 have HA-type curves, VES8 has HK-type curves, and VES10 has AK-type curves. The result is difficult to understand due to the type curves' resistivity increasing with depth, but the aquifer parameters were estimated using secondary information from borehole logging. Additionally, these layers' actual resistivities range from one to more than 10,000. m. They reveal that the varying resistivity values of the Quaternary deposits, which primarily consist of gravel, sand, and clay, set them apart. Due to the low salinity of the groundwater, resistivity imaging cannot determine whether deeper layers (>15 meters) are also wet because they are resistive in the unsaturated zone and below the water table. To confirm the salinity and moisture status of these deeper materials, deeper coring is required.

3.2.2 The geoelectric and hydraulic parameter

The established relationship between the characteristics of the aquifer and the geoelectric parameters has also been used to estimate the hydraulic conductivity and transmissivity values of all of the sounding locations, including those where there were no boreholes. The geoelectric parameters were used to estimate the hydraulic characteristics of the aquifer, which revealed that the aquifer has transmissivity values of 11856.32 to 28661.28 m^2/day, hydraulic conductivity values of 13.47 to 1009.2 m/day, and protective capacities of between 0.036 and 0.509 mhos.

The cost of drilling wells to measure the hydraulic parameters of an aquifer is frequently prohibitive. As a result, the Dar Zarrauk transmissivity method presented in this study is an economical alternative for determining the aquifer transmissivity from VES. The non-uniqueness of interpreting resistivity data is minimized when Dar-zarouk parameters are used to estimate transmissivity. The results can be used to locate exploratory boreholes and provide a useful first approximation of the transmissivity variation.

3.2.3 Compilation of Correlated Resistivity Survey Results with Borehole Logging

The software's layers were used to determine the aquifers' depths and thicknesses. Borehole logging obtained from some published sources is still crucial for confirming the results because the resistivity data were insufficient to obtain the aquifer properties. These findings were derived from the work of a few researchers who conducted resistivity surveys or subsurface straters in Owerri.

The borehole logging in new Owerri (A) and Ihiagwa (B) is depicted in Figure 3.12; Figure 3.13 also depicts the logging of various boreholes in Owerri, with the locations labeled, and Figure 3.14 depicts the logging of a borehole in Ihiagwa.

While the soil strata's' resistivity is comparable to that of other researchers, the values of the resistivity did not exactly match the results of the borehole logging.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The electrical resistivity method with VES has been effective in assessing the study area's overburden protective capacity and groundwater potential. Using partial curve matching, the VES data were quantitatively interpreted, and IPIW software was used to refine the findings. The study area's fundamental properties of fluid transmissivity, transverse resistance, protective capacity, hydraulic conductivity, aquifer resistivity, and depth have been determined. This study successfully used electrical resistivity imaging to identify the study area's subsurface layers. However, due to the irregular properties of the soil, these layers are not clearly separated. This study successfully used electrical resistivity imaging to identify the study area's subsurface saturated and unsaturated layers. The resistivity image aquifer properties study area, in conjunction with borehole data. The transmissibility and hydraulic conductivity values show that the area has a good potential for ground water. Amadi (2008) also made this observation based on his data.

The thicknesses, resistivities, and depths of the aquiferous zones have been resolved with the assistance of computer-modelled interpretation methods. Around Ihiagwa areas, the average depth to the water is 7.26 meters. The aquifer has a mean depth of 32.33 meters around the Avu, Nekede, and Eziobodo areas. At Obinze, very deep aquifers with a mean depth of 57.75 meters were detected.

These mean K values were used to calculate the transmissivity values. Transmissivity values range from 11856.32 to 28661.28 m^2/day. This finding demonstrates that the aquifer is made up of coarse, unconsolidated sand. In most of the places that were looked at, it is most likely to be possible to drill productive boreholes if the transmissivities are high enough and the aquifer thicknesses are good. The precision of the hydraulic conductivity calculated using the resistivity method is critical to the transmissivity values derived from electrical resistivity measurements. The ability to estimate hydraulic parameters, which cuts down on the additional costs associated with pumping tests, is one of this method's strengths.

Using a one-dimension resistivity survey, it is extremely difficult to determine whether an aquifer is confined or unconfined; however, additional data from borehole logging obtained from secondary sources can confirm that the boreholes are not confined. The fact that almost all of the loggings show soil layers with clayey sand close to the surface to clear sand very deep in the ground is the reason for this conclusion; however, the variation is almost constant.

To check the study's credibility, alternative geophysical exploration techniques like seismic refraction could be used to draw lines between the subsurface layers. However, as it is in close agreement with regional geology and litologic data gathered from the area, this would not significantly alter the sounding's outcome. In the process of analyzing the field data, the appropriate computer program took care of the issue of human bias that is inherent in conventional matching methods. With the help of additional geological and geophysical data gathered from the region, the ambiguity in the interpretation of resistivity data was resolved.

4.2 RECOMMENDATIONS

Following careful research, the following recommendations are possible:

i. The public should be educated about the negative health effects of poor groundwater management and the necessary laws should be enforced to manage the quality of the groundwater.

ii. Engineers should investigate the theory and application of the resistivity method in depth to obtain more trustworthy data.

iii. It is suggested that a hydro chemical study be carried out to ascertain whether the water can be transported for use in both domestic and industrial settings.

iv. It is necessary to establish a long-term record of groundwater levels around FUTO and its surroundings. This could be used to look for patterns and keep track of how big groundwater abstractions affect things. Continuously recording and storing the aquifer's hydraulic parameters, such as transmissivity, specific yield, and hydraulic conductivity, is also recommended. Future hydrologic models for the region could benefit from this data. In order to predict the movement of chemical and variation in ground water chemistry in response to groundwater abstraction, hydrologic modeling should be combined with in-depth field investigations.

v. It is crucial to create an aquifer vulnerability map of the region to identify areas where aquifers are protected by thick, low-permeability cover and isolated from contaminated sources.

REFERENCES

- Amadi, A. N. (2008). Evaluation of Aquifer Characteristics In Southern Part of Imo State, Southeastern Nigeria. *Nigerian Journal of Technological Research*, 12-26.
- Heather, L. R., Beth, A. S., Jeffrey, L., Leberfinger, P. G., & Jeffrey, J. (1999). Electrical Imageing: A Method for Identifying Potential Collapse and Other Karst Features Near Road Way. Science Applications International Corporation, Middletown, Pensylvania. *50th Annual Highway Geology Symposium*.
- Kelly, E., Cronk, R., Kumpel, E., & Howard, G. (2010). How We Assess Water Safety: A Critical Review of Sanitary Inspection and Water Quality Analysis. *Science of the Total Enviroment*.
- Kelly, E. W. (1977). Geological Sounding for Estimating aquifer Hydraulic Conductivity. *Ground Water*, *15*(6), 420-425.
- Larson, D. R., & Mayer, S. C. (1993). Summary: Hydrogeological Investigation for a Manicipal Groundwater Supply, Danville, Illinois. *Illinois State Geological Survey Open File Series*.
- Loke, H. M. (2001). *Constrained Time-Lapse Resistivity Imaging Inversion.* Symposium on the Application of Geophysics to Engineering and Enviromental Problem.
- Pudentiana, O., & Mamah, L. (2012). Integration of Geophysical Techniques for Groundwater Potential Investigation in Katshina-ala, Benue State, Nigeria. *The Pacific Journal of Science and Engineering*.
- Younger, L. P. (2007). *Groundwater in the Enviroment: An Introduction.* Oxford, UK: Blackwell Publisher.
- Zumdahl, S. (2018). *Ammonia.* Encyclopaedia Britannica.