GEOPHYSICAL INVESTIGATION FOR GROUNDWATER DEVELOPMENT USING VERTICAL ELECTRICAL SOUNDING IN EDO STATE DEVELOPMENT AND PROPERTY AGENCY AREA BENIN CITY NIGERIA

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CERTIFICATION

This is to certify that this project work was submitted and approved by the Department of Geology in partial fulfillment for the requirement for the award of Bachelor of Science in Geology, University of Benin, Benin city.

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(Head of Department)	(Signature)	(Date)

DEDICATION

This project is dedicated to Mr. and Mrs. Daigbe for making my education possible.

ACKNOWLEDGEMENT

First, my acknowledgement goes to God almighty for his never-ending love, kindness, and faithfulness to me and my family.

The execution of this project was made possible by the input of so many people who I love and appreciate. Topping the list is Dr S.A. Salami, my project supervisor, for his never say die attitude towards the execution of this project. I am also grateful for his constructive criticism, ideas, and the fatherly role he played in the successful completion of this project. My external supervisor, Mr. B.M. Emmanuel, also deserves special recognition as his selfless sacrifices of time, money, and energy were powerful drivers of this project. The Head of Department, Prof I.S. Imasuen, also commands a special mention. His organization of the department to accommodate project work and regular lectures was nothing short of genius.

I also want to specially mention my predecessor, Master Emmanuel Egbon, for sharing his experience which proved invaluable in the execution of this project. I am also indebted to my colleagues Seun 'Calcite' Martins, Ebenezer 'Zibapiano' Osaruyi, Evans 'Big brother' Amenze, Ofonze 'Fozzy' Chinemerem, and Samuel 'Obirim' Akiode for lending me their manpower during the acquisition phase of this project.

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ABSTRACT

A geophysical survey was carried out at Edo State Development and Property Agency (EDPA) Housing Estate, Benin City to determine the depth to water table at four points within the study area. The Geophysical method used was the Electrical Resistivity Method. The Vertical Electrical Sounding technique was used in the survey with the Schlumberger Array being the electrode setup of choice.

Four electrical soundings were carried out with the aid of ABEM SAS 300 terrameter set. The reduction of the acquired data was done with a spreadsheet software. The Interpretation was done using software such as IX1D. 3D field was used to generate subsurface maps.

The results of our interpretation show that in every VES sounding a prolific aquifer was located at relatively shallow depths. The depth to groundwater values from VES 1, 2, 3, and 4 show us a depth to water table of 87, 107, 85, and 93 metres respectively. The groundwater flow direction was also determined and the groundwater is considered to be safe as the depth to groundwater is high enough to be out of contact with underground sewage storages and also, the clay beds above the aquifers serve as filtering medium for infiltrating groundwater and escaping sewage.

CHAPTER 1

INTRODUCTION

1.1 GROUNDWATER

Groundwater is found in pore spaces of subsurface rocks. After polar ice caps, groundwater is the next largest reservoir of freshwater on Earth, containing more than 100 times the volume of streams and freshwater lakes (Shiklomanov, 1993.). According to Plummer et al. (2001), the source of groundwater is rainfall and snowmelt. It is one of the major components of the hydrological cycle. A French hydrologist, Pierre Perrault, from the result of hydrologic investigations in the basins of Seine River was the first to prove that the water contained within earth was not drawn up from the oceans but rather was provided by rainfall and snowmelt. In his assertion, about 97% of all water is contained within the ocean basins while of the 3% outside the basins, nearly 80% is contained within the glacier and polar ice. About 0.7% is represented by the more visible surface accumulations of water and 20% of all the water outside the ocean basins resides underground. Hydrologists estimate that more than 8 million cubic kilometers of water exists below the surface as groundwater (Renton, 1994).

Groundwater is one of the most important natural resources (Singh, 2007). It is accumulated and held in geological bodies called aquifers. These bodies may be sedimentary deposits or rocks that are permeable enough to transmit economically significant quantities of water. These aquifers include sandstone, well-jointed limestone, conglomerates, and some well-fractured volcanic rocks (such as columnar basalt) as well as well-fractured crystalline rocks.

Aquifers are broadly categorized into two: confined and unconfined aquifers. Confined aquifers are completely filled with water under confining pressure. The source of confining pressure is usually a relatively impermeable layer called aquitard. An example of such a confining layer is clay.

An unconfined aquifer is one in which water table condition prevails owing to the absence of layer of relatively impermeable material on top. The conditions for the Formation of unconfined aquifer are specific. First, there is no impermeable confining layer e.g., clay. Second, the water in the aquifer is not under pressure. Third, an unconfined aquifer is rapidly recharged by precipitation hence, it has rising and falling water table according to seasons.

Hanging or perched aquifer also exists. This occurs when a relatively impermeable layer occurs above the water table and holds up infiltrating water to form a saturated lens of limited extent above the saturated zone of the aquifer.

1.2 AIM AND OBJECTIVES

This project aims to investigate the hydrogeological parameters of the chosen areas using the Vertical Electrical Sounding (VES) technique of Electrical Resistivity Method of geophysical exploration. The following are the objectives of the study.

1. Delineation of groundwater horizon at different locations and estimation of aquifer thickness.
2. Stratigraphic delineation of lithology in terms of the different resistivity values.

1.3 LOCATION OF STUDY AREA

The study area is located within latitudes 6°22'N and longitudes 005°36'E and covers an area of about 40.825 square kilometers in Egor Local Government Areas of Edo State. It covers Adolor in Egor L.G.A. The region has a gently undulating topography and the elevation varies between 98m and 118m above sea level.

The study area is accessible through a network of major and minor roads in addition to several foot paths. The major access roads are the technical Road, Federal Girls Government College and Ugbowo.

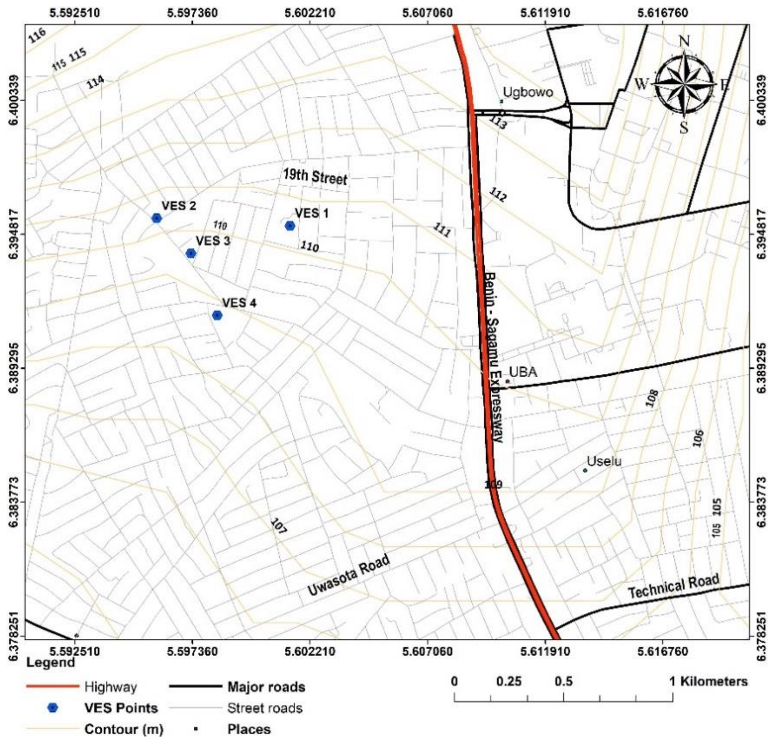


Figure 1.1: Location Map of Study Area.

1.4 ELECTRODE ARRAYS

An electrode array is a configuration of electrodes used for measuring either an electric current or voltage. Some electrode arrays can operate in a bidirectional fashion, in that they can also be used to provide a stimulating pattern of electric current or voltage. Some examples of electrode arrays include: schlumberger array, wenner alpha array, pole-pole array, pole-dipole array etc. (Wikipedia, 2022). For the purpose of the project, the Schlumberger array was used.

THE SCHLUMBERGER ARRAY

The electrode arrangement used in this work is the Schlumberger configuration. The choice of Schlumberger array for this work is due to the fact that it has the highest resolution and involves minimal labour cost than other configurations, like Wenner array, Lee partitioning method, pole-dipole method and others.

In this method, four collinear electrodes are used with the outer two being current electrodes (C1 and C2) and the inner two (P1, P2) the potential electrodes (Fig. 2.6c). C1 and C2 are spaced far apart symmetrically about the center 0 and are at separation ‘a’ each from the center. The inner potential electrodes are more closely spaced and are equidistant about 0 at different separations depending on the value of the readings taken. When the readings become too small to be significant, a shift in potential electrodes becomes important.

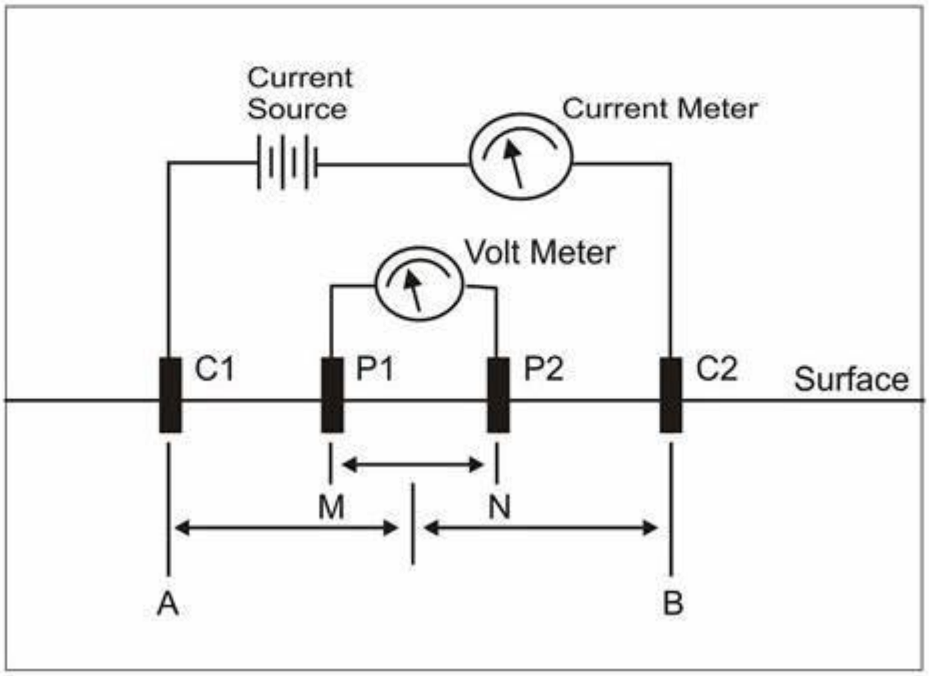


Figure 1.2: The Schematic Diagram of the Schlumberger Array (After Stanley (2012)).

CHAPTER 2

LITERATURE REVIEW

2.1 REGIONAL GEOLOGY OF STUDY AREA

The area under study falls within the Niger Delta sedimentary basin. The Niger Delta has an aerial extent of 75,000 km^2 and is located between latitude 4°30' and 5° 20' N and longitude 3° and 9°E. It is the second largest delta in the world with a coastline spanning about 450 km terminating at the Imo River entrance (Awosika, 1995). The Niger Delta is underlain by three principal Formations, namely: Akata, Agbada and Benin Formations. The Akata Formation, which is predominantly shale and clay and the Agbada Formation which is generally fluviatile and fluvio-marine are primarily of interest to the hydrocarbon industry. The Benin Formation is the youngest Formation in the Niger Delta Basin which was deposited in the Oligocene, and it is still being deposited now. (Tuttle *et al.*, 1999).

These three geologic Formations in the Niger Delta Basin are further discussed below:

BENIN FORMATION

It is assigned to the Oligocene-Pleistocene period in the continent of Africa and to the Oligocene-Pleistocene recent at the sub-oceanic (Short and Stauble, 1967). The formation is characterized by top reddish to reddish brown lateritic massive fairly indurate clay and sand. This is often marked with reticulate mud cracks. This caps the underlying more friable pinkish-yellowish white often gravelly-pebble sands clayey soils, sands and clay (Akujieze, 2004). The sedimentary sequences are poorly bedded with discontinuous clay horizons at various depths. It is estimated to be about 800m thick under Benin City and about 1,830m near the sea shore sections of the formation. They are exposed at various erosion sites, sand quarry sites, and road cuttings. The Benin formation covers 95% of the region (Catherine, 2015).

AGBADA FORMATION

The Agbada Formation occurs as a paralic sequence of shale and sand interbeds throughout the

Niger Delta clastic wedge. It increases in shale thickness and decreases in sand thickness with depth. It has a maximum thickness of about 3,900m and ranges in age from Eocene to Pleistocene 5. It can be found in southern Nigeria, where it is known as the Ogwashi-Asaba and Ameki Formations. The lithologies are mostly made up of alternating sands, silts, and shales with progressive grain size and bed thickness changes. The strata are generally interpreted to have formed in fluvial-deltaic environments 5, 10. The Agbada Formation, which lies beneath the Benin Formation, is made up of interbedded fluvio-marine sands, sandstones, and siltstones of varying proportions and thicknesses that represent a cyclic sequence of offlap units. 8. The sandstone varies in texture from coarse to fine grain, from poorly sorted to very well sorted, and from unconsolidated to slightly consolidated. Some shell fragments and glauconites have a limonite streak and a limonite coating. 1. The shales are medium to dark grey in color, well-consolidated, and silty, with glauconites scattered throughout. The Formation gradually passes into the Akata Formation as the shale content rises. The Agbada Formation is made up of a complicated series of deposits that were deposited in at least five different environments: holomarine, barrier bar, barrier foot, tidal coastal plain, and lower deltaic flood plain.9. The thickness ranges from 0-4500m.

AKATA FORMATION

In the central portion of this clastic wedge, the Akata Formation, which consists of prodeltaic dark grey shales and silts with uncommon streaks of sand of possible turbidite flow origin, is estimated to be 6,400m thick. Sea planktonic foraminifera represent a Paleocene to Recent depositional context on a shallow marine shelf. The Imo shale, which is exposed onshore in the northeastern section of the delta, is the name given to these shales. This Formation can also be found offshore in diapers along continental slopes where it is heavily buried; Akata shales are often overpressured. Prodelta and deeper water deposits shoal vertically into the Agbada Formation, according to the Akata shales. It is assumed to be the Niger delta complex's source rock.

2.2 LOCAL GEOLOGY OF STUDY AREA

The study area (Benin City) is underlain by sedimentary Formation of the South Sedimentary Basin. The geology is generally marked by top reddish earth, composed of ferruginized or literalized clay sand. Parkinson (1907) first used the term Benin sand to describe the reddish earth underlain by sands, sandy clays and ferruginized sandstone that mark the Paleo-Coastal Environment of Paleocene-Pleistocene Age. These sediments spread across the southern fringes of the Anambra Basin and marking the upper fancies off-flaps of the Niger Delta (Catherine, 2015). Tattam, (1943) used the name Coastal plain sands to describe the Formation of red earth underlain by sands and clays that mark an ancient coastal plain environment now exposed in Calabar, Owerri, Onitsha and the Benin Region with the age Oligocene-Pleistocene.

2.3 ELECTRICAL PROPERTIES OF ROCK MATERIALS

There are many factors affecting the resistivity of rocks, some of which include mineral content, porosity and permeability, fluid content, and so on. However, the differences in resistivity values for different rock types is greatly controlled by the amount of water in the pore spaces and layers of rocks (Telford et al., 1990). Table 2.1(a) shows the resistivity as a function of the percentage water content. The resistivity values of some common rocks are given in Table 2.1(b). Basement (Igneous and Metamorphic) rocks generally have higher resistivity values. The resistivity of these rocks is greatly dependent on the degree of fracturing and the percentage of fracture filled with groundwater. Sedimentary rocks usually have lesser resistance values due to their higher porosities, permeabilities, and water content when compared to basement rocks.

Porosity is also a major factor controlling the resistivity of rocks. Generally, resistivityincreases as porosity decreases. The shapes and arrangement of pores can greatly influence resistivity.

Table 2.1 (a): Resistivity of rock as function of percentage water content (Telford et al., 1990).

Rock/sediment	**Percentage (%)**	**Resistivity**
Granite	0	10^{lu}
Granite	0.19	1.8xl0^{6}
Basalt	0	6.0xl0^{6}
Basalt	0.95	4xl0^{4}
Coarse grained	0.39	9.6xl0^{5}
Coarse grained	0.18	10^{s}
Medium grained	1.0	4.2xl0^{3}
Medium grained	0.1	1.4xl0^{8}
Greywacke sandstone	0.16	4.7xl0^{3}
Greywacke sandstone	0.45	5.8xl0^{4}
Arkosic sandstone	1.0	1.4xl0^{3}

Table 2.1 (b): Bulk resistivity of some rock types (Loke, 1997)

	Rock types	**Resistivity (ohm metre)**
Igneous	Basalt	5.Ox 10^{3}-1.0x10’
	Granite	4.5xl0^{3} -1.3xl0^{6}
Metamorphic	Slate	6.0xl0^{2}-4.0x10’
	Quartzite	1.0x10^{2}-2.0x10^{8}
	Marble	1.0x10^{2}-2.5x10^{8}
Sedimentary	Conglomerate	2.0xl0<1.0xl0^{4}
	Sand stone	8.4x10^{3}-1.0x10^{5}
	Shale	20-2.0x10^{3}
	Lime stone	50-4.0xl0^{3}

2.4 PRINCIPLE OF ELECTRICAL RESISTIVITY SURVEY

The principle of every electrical survey method is Potential Difference (PD). It is the difference in electrical potential between two charged bodies. Potential Difference is also called voltage. Current is sent into the ground and the resistance is measured with a device called a Terrameter. The relationship between the voltage, current sent into the ground, and the resistance of the rock is given by the equation:

2.5 VERTICAL ELECTRICAL SOUNDING (VES)

When it comes to groundwater investigation, there aren't many techniques that rival Vertical Electrical Sounding. This method of electrical resistivity investigation has been favourably applied in areas of groundwater potential studies, determination of faults, depth to bedrock and as well as in the search for geothermal reservoirs. Obiakor (1984) used this method in establishing the best area to harvest groundwater in Idemili and Anambra L.G.A of Anambra state. Adetola and Igbedi (2000) used VES method to establish successfully the site for successful borehole location and the confirmation of the Bende-Ameki Formation in Agbede, Southwestern Nigeria. VES method has also been successfully used to map the subsurface Formation on the Eastern red sea coast of Jordan (Awni, 2007) and in quantitative assessment of groundwater reserve of unconfined aquifer in Burkit Jalil- Serdang area, Malaysia (Hago, 2000). Okolie (2005) estimated the groundwater potential in parts of Niger Delta using VES method. Basically, vertical electrical sounding is one of the best methods of investigating the electrical properties of the subsurface such as resistivity/conductivity variation with depth and is the best geophysical method known and applied for groundwater prospecting in many areas (Parasnis, 1986; Emenike, 2001). VES is a technique that vertically probes the subsurface from a fixed point on the surface. The electrodes are arranged equidistant from this fixed point and are spread farther as greater depths are being investigated.

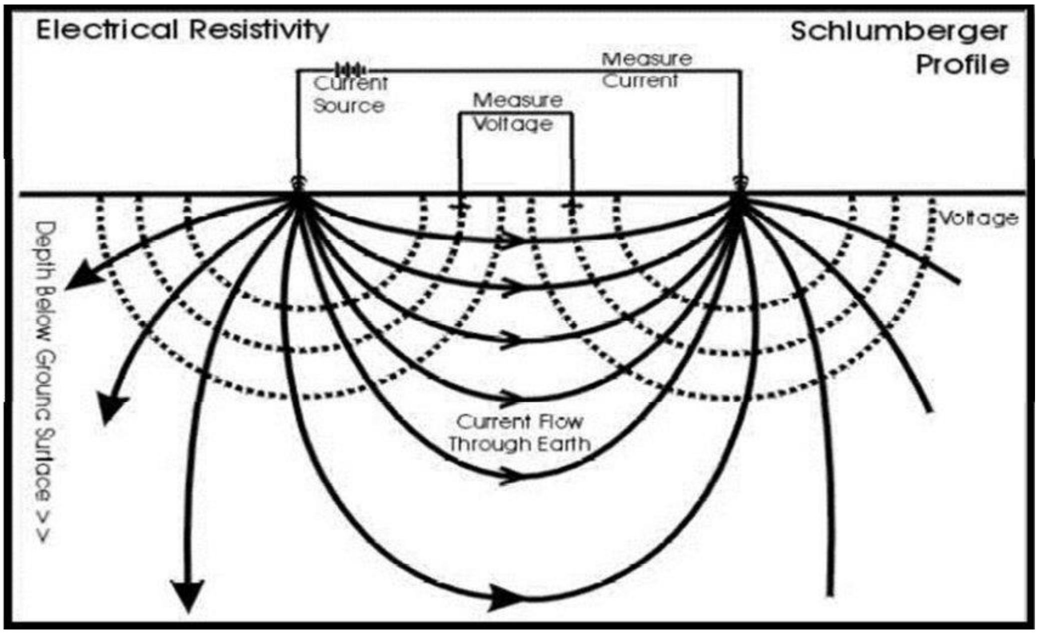


Figure 2.2: Schematic Diagram Showing the Probing of the VES technique (After Cyril (2019)).

CHAPTER THREE

MATERIALS AND METHODS

3.1 LIST OF EQUIPMENTS

The equipment used for the field work was provided by the geology department and it consisted of:

1. ABEM Digital Terrameter: This instrument is a signal averaging system branded SAS300. It measures in different modes and run in four cycles (Fig 3.1).

In the resistivity mode, it comprises a battery-powered deep penetrating resistivity meter with an output sufficient for current electrode separation of up to 2km under good surveying conditions. The ratio of the developed potential (V) to the current (I) supplied (AF) is automatically calculated and averaged over the selected number of cycles and the value is digitally displayed in milliohms, ohms or kilohms. The overall ranges extend from 0.5 milliohm to 1999 kilohms.

SAS300 is a three-unit compact piece of measuring instrument housed in a single casing. These units are the transmitter, the receiver and the microprocessor. These units work together as a single unit to produce the reading which is displayed on the screen. The voltage signal created by the transmitted current signal is received by the receiver after discrimination between noise and the signal. The microprocessor controls and monitors all measurements to ensure optimal accuracy. It runs a one second thorough check on the circuit and switch position.

Figure 3.1: Picture of ABEM Terrameter.

2. Cable Reels: The instruments are used to connect the electrodes to the terrameter which gives reading

Figure 3.2: Picture of Cable Reels

3. Connecting cables: They are used to connect the terrameter to the current reels and potential reels They are usually connected according to indicators P_1, C_1, P_2, and C_2.

Figure 3.3: Picture of Connecting Cables.

4.hammer: The instrument was used to nail electrodes into the ground

Figure 3.4: Picture of a Hammer

5.Electrodes: The instrument is used to collect data and also marking points

Figure 3.5: Picture of Electrodes

6.measuring tapes: The instrument is used to measure distance in the field

Figure 3.6: Picture of Measuring tape.

7. GPS: The instrument is used to get GPS coordinates and take the elevation of the area where readings were taken from

Figure 3.7: Picture of GPS

8. Car Battery: This is used to power the terrameter

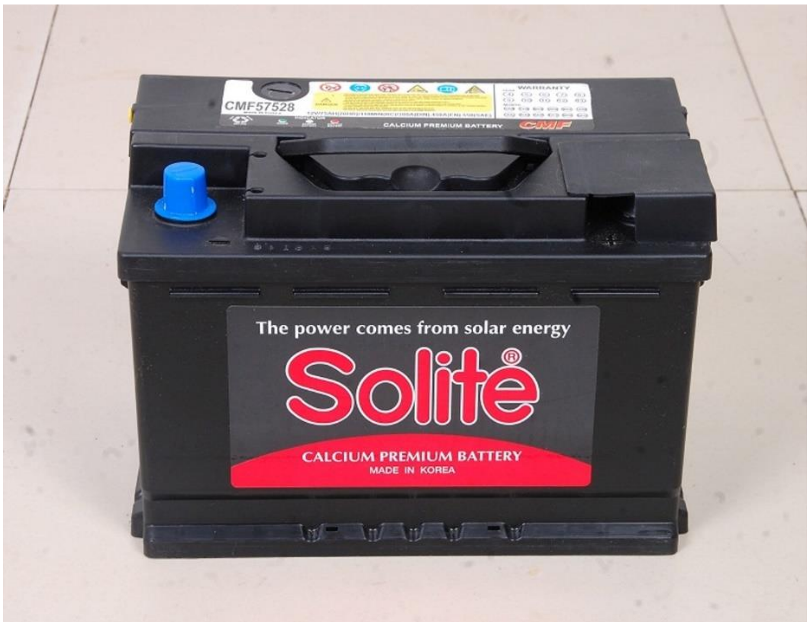


Figure 3.8: Picture of Car Battery

3.2 RECONAISSANCE SURVEY

The field work proceeded in two stages. The first stage was the reconnaissance studies. The second was the field work proper. The reconnaissance studies were done remotely in the office using Google Earth to determine elevation, road length, and uniformity of terrain.

3.3 FIELD PROCEDURE

The actual field work was more involving and entailed running VES traverses in locations selected within the area of study. It started on 19th June and ended on 20th June, 2023.

Six people were involved in the traversing work. These included one geophysics technician who brought the terramter and operated it and five students (two operated on either flank of the profile centre). A student worked at the centre of the spread with the operator and they operated the equipment and read out the value of the resistance displayed. The writer also worked with the technician from the centre to expand the potential electrode separation during looping. He also carried out checks on the continuity of the traverse line on either side from the centre.

3.4 THEORY OF ELECTRICAL RESISTIVITY METHOD

The electrical resistivity method is an active geophysical method. It employs an artificial source (a Direct Current or a low frequency Alternating Current) which is introduced into the ground through a pair of electrodes. The procedure involves measurement of potential difference between the two electrodes in the vicinity of current flow.

Apparent resistivity is calculated by using the potential difference for interpretation. The electrodes by which current is introduced into the ground are called Current electrodes and electrodes which the potential difference is measured are called Potential electrodes.

3.5 DATA ACQUISITION

The data acquisition process commenced with the establishment of a centre point from which both current and potential electrodes were equally spaced. Next was the connection of reel wires to the electrodes. Following that was the establishment of connection between the terrameter and external battery. Immediately after was the linking of the terrameter with the current and potential reels.

The readings were gotten by sending current into the ground using hammered-down electrodes at different length intervals corresponding to equal depth penetrations. Readings taken were then recorded on a special sheet of paper designed for recording VES readings using the Schlumberger array.

3.6 FIELD PRECAUTIONS

The following were adhered to in order to avoid errors during the acquisition of data:

- The electrodes were properly hammered down to ensure good contact with the ground.
- The reel wires were firmly tied to the potential and current electrodes.
- The VES was setup away from power lines to prevent distortions in readings.
- The potential and current reels were moved parallel to each other to prevent tangling.

3.7 ADJUSTED DATA

To smoothen the generated curve on Microsoft Excel, the resistivity results had to be amended so as to follow the overall resistivity trend of the VES survey. This adjustment helped us get better interpretation results.

3.8 INTERPRETATION TECHNIQUE:

The Interpretation technique involved a number of steps, from generation of tables in Microsoft Excel to the creation of logs using IX1D software. Maps were then generated in a specialized application called 3D field. For Microsoft Excel, the field record was digitized in the software and a 2D graph of Apparent Resistivity against AB/2 was created. Then, a table of Rho and layer thickness is prepared for modelling on the IX1D software. The layers' thickness log and curve are then created. With sound application of geological knowledge, the aquifer can be picked from the software. Third, and optional, the Groundwater Depth Map, Resistivity map, Groundwater flow map, and hydraulic head maps can be generated to further depict the subsurface conditions using the 3D field software. In the generation of maps, we made use of the block kriging method for contour generation for the resistivity, depth to groundwater, and elevation head maps. However, for our groundwater flow map, we made use of the minimum curve technique. The first three maps were colour filled contours while the last map was made with simple contours.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

The results for the four VES soundings are tabulated below with graphical representations of the results. For VES 1-4, the tables of apparent resistivity are presented first, followed by the interpretation results from the IX1D software, and finally, a table from which we inferred lithologies from resistivity values is presented. we see that the depth to groundwater at VES 1 is about 87m, VES 2, 3 and 4 at 107, 85, and 93m respectively. Maps are also generated from the values derived from our data. These maps include the resistivity variation map, topographic map, depth to groundwater map, and the groundwater flow map. Together, these maps give us an insight into the subsurface conditions of the study areas.

VES SOUNDING RESULT TABLES AND GRAPH

DATE: 07/06/2023

COORDINATES: N6º 23’ 42.6” & E5º 36’ 5”

ELEVATION: 108m

SOUNDING NUMBER: 1

Table 4.1 (a): Adjusted Resistivity Values for VES 1

AB/2 (m)	MN/2 (m)	Adjusted Resistivity (Ωm)
1.00	0.20	91.02
1.47	0.20	110.00
2.15	0.20	154.78
3.16	0.20	204.68
4.64	0.20	253.20
6.81	0.20	331.21
10.00	2.00	391.37
14.70	2.00	533.11
21.50	2.00	700.00

31.60	2.00	950.00
46.40	10.00	1183.29
68.10	10.00	1380.00
100.00	10.00	1600.00
133.00	40.00	1700.00
178.00	40.00	1800.00
237.00	40.00	1880.00
316.00	40.00	1700.00
422.00	40.00	1344.69

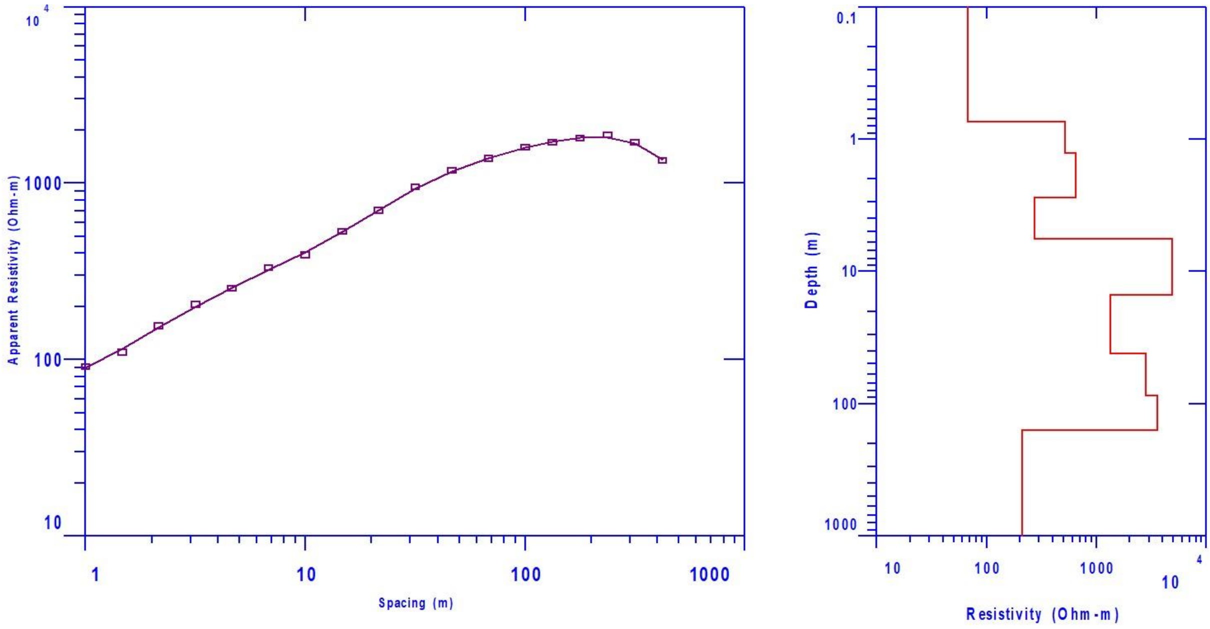


Figure 4.1: Graphical Interpretation of VES 1

Table 4.1 (b): Interpreted values for Depth to Groundwater for VES 1

Layer	Resistivity (Ωm)	Thickness (h)	Depth (m)	Inferred Lithology	Remarks
1	67.973	0.74354	0.74354	Clay	
2	513.72	0.53608	1.2796	Silt	
3	642.27	1.4946	2.7742	Silt	
4	271.95	2.9443	5.7185	Silt	
5	4912.2	9.3605	15.079	Sandstone	
6	1338.9	26.997	42.076	Sandstone	
7	2800.1	45.499	87.575	Sandstone	Aquifer
8	3587.1	71.17	158.75	Sandstone	
9	210.54				

VES SOUNDING RESULT TABLES AND GRAPH

DATE: 07/06/2023

COORDINATES: N6º 23’ 43.7” & E5º 35’ 45.2”

ELEVATION: 109m

SOUNDING NUMBER: 2

Table 4.2 (a): Adjusted Resistivity Values for VES 2

AB/2 (m)	MN/2 (m)	Adjusted Resistivity (Ωm)
1.00	0.20	310.68096
1.47	0.20	324.5303619
2.15	0.20	390
3.16	0.20	520.2971021
4.64	0.20	658.3231512
6.81	0.20	800
10.00	2.00	861.15936
14.70	2.00	916.2818225
21.50	2.00	1101.463448
31.60	2.00	1286.680671
46.40	10.00	1535.195276
68.10	10.00	2031.646813
100.00	10.00	2482.24284
133.00	40.00	2666.518784
178.00	40.00	2700
237.00	40.00	2500
316.00	40.00	1800

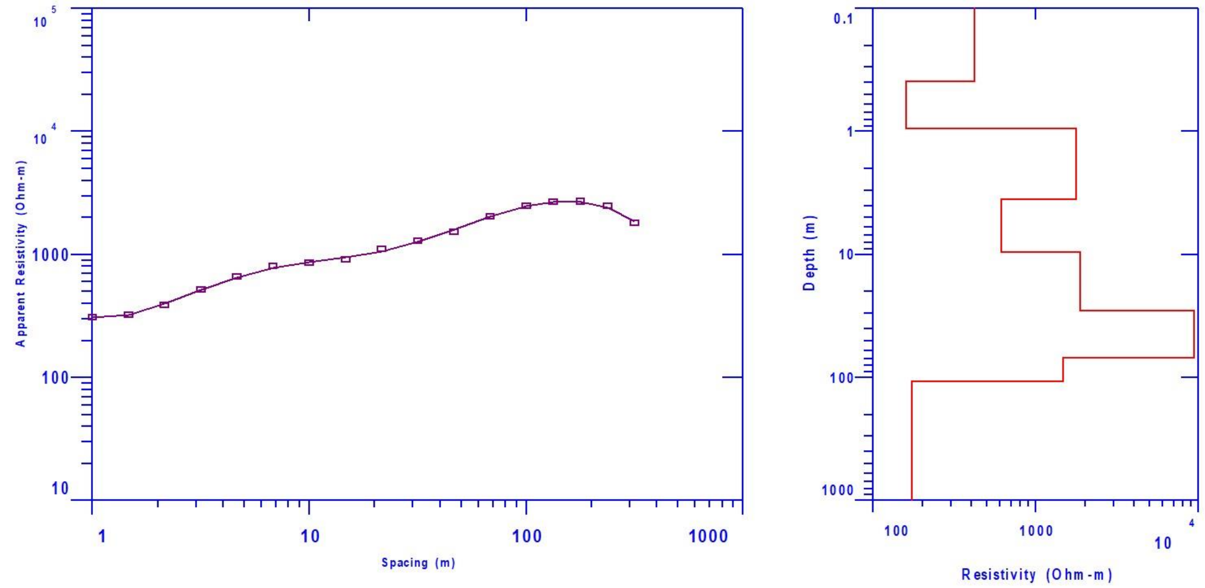


Figure 4.2: Graphical Interpretation of VES 2

Table 4.2 (b): Interpreted values for Depth to Groundwater for VES 2

Layer	Resistivity (Ωm)	Thickness (h)	Depth (m)	Inferred Lithology	Remarks
1	421.3	0.39052	0.39052	Silt	
2	160.07	0.55792	0.94844	Clay	
3	1769.5	2.6233	3.5717	Sandstone	
4	614.91	5.9657	9.5374	Silt	
5	1876.6	18.916	28.454	Sandstone	
6	9420.7	41.01	69.464	Sandstone	
7	1478.1	38.426	107.89	Sandstone	Aquifer
8	171.93				

VES SOUNDING RESULT TABLES AND GRAPH

DATE: 08/06/2023

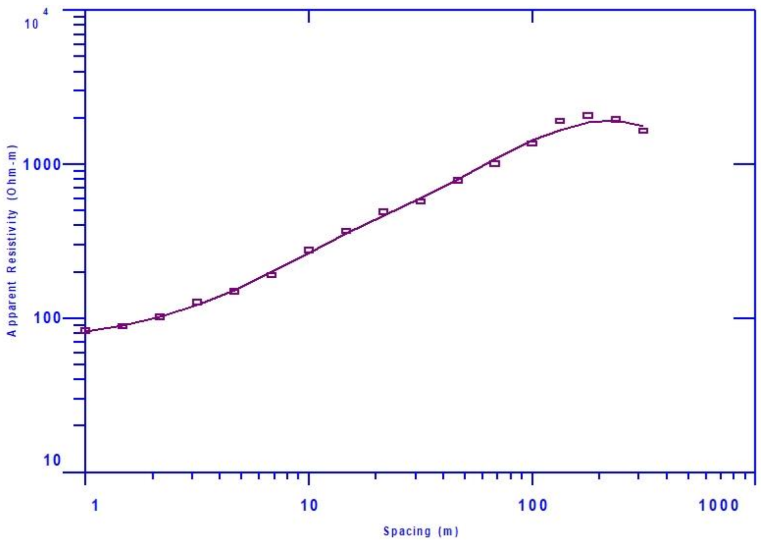
COORDINATES N6º 23’ 38.5” & E5º 35’ 50.3”

ELEVATION: 104m

SOUNDING NUMBER: 3

Table 4.3 (a): Adjusted Resistivity Values for VES 3

AB/2 (m)	MN/2 (m)	Adjusted Resistivity (Ωm)
1.00	0.20	83.32
1.47	0.20	88.63
2.15	0.20	101.50
3.16	0.20	126.56
4.64	0.20	150.00
6.81	0.20	190.00
10.00	2.00	276.75
14.70	2.00	368.18
21.50	2.00	488.45
31.60	2.00	573.42
46.40	10.00	783.72
68.10	10.00	1012.97
100.00	10.00	1359.32
133.00	40.00	1910.00
178.00	40.00	2067.71
237.00	40.00	1950.00
316.00	40.00	1650.00



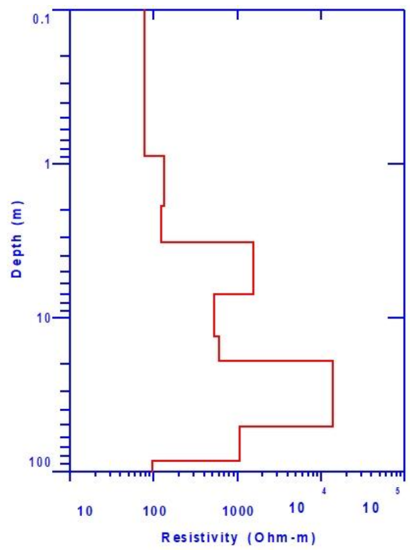


Figure 4.3: Graphical Interpretation of VES 3

Table 4.3 (b): Interpreted values for Depth to Groundwater for VES 3

Layer	Resistivity (Ωm)	Thickness (h)	Depth	Inferred Lithology	Remarks
1	76.949	0.88497	0.88497	Clay	
2	133.59	0.99722	1.8822	Clay	
3	123.81	1.375	3.2572	Clay	
4	1565.1	3.8141	7.0713	Sandstone	
5	523.57	6.2216	13.293	Silt	
6	600.4	5.7153	19.008	Silt	
7	13794	32.545	51.553	Sandstone	
8	1069.2	34.199	85.752	Sandstone	Aquifer
9	95.853				

VES SOUNDING RESULT TABLES AND GRAPH

DATE: 08/06/2023

COORDINATES: N6º 23’ 29.3” & E5º 35’ 54.2”

ELEVATION: 106m

SOUNDING NUMBER: 4

Table 4.4 (a): Adjusted Resistivity Values for VES 4

AB/2 (m)	MN/2 (m)	Adjusted Resistivity (Ωm)
1.00	0.20	157.60
1.47	0.20	191.08
2.15	0.20	224.97
3.16	0.20	240.00
4.64	0.20	214.71
6.81	0.20	238.40
10.00	2.00	377.04
14.70	2.00	526.44
21.50	2.00	600.00
31.60	2.00	703.10
46.40	10.00	900.00
68.10	10.00	1104.93
100.00	10.00	1300.00
133.00	40.00	1700.00
178.00	40.00	2000.00
237.00	40.00	2000.00
316.00	40.00	1512.72

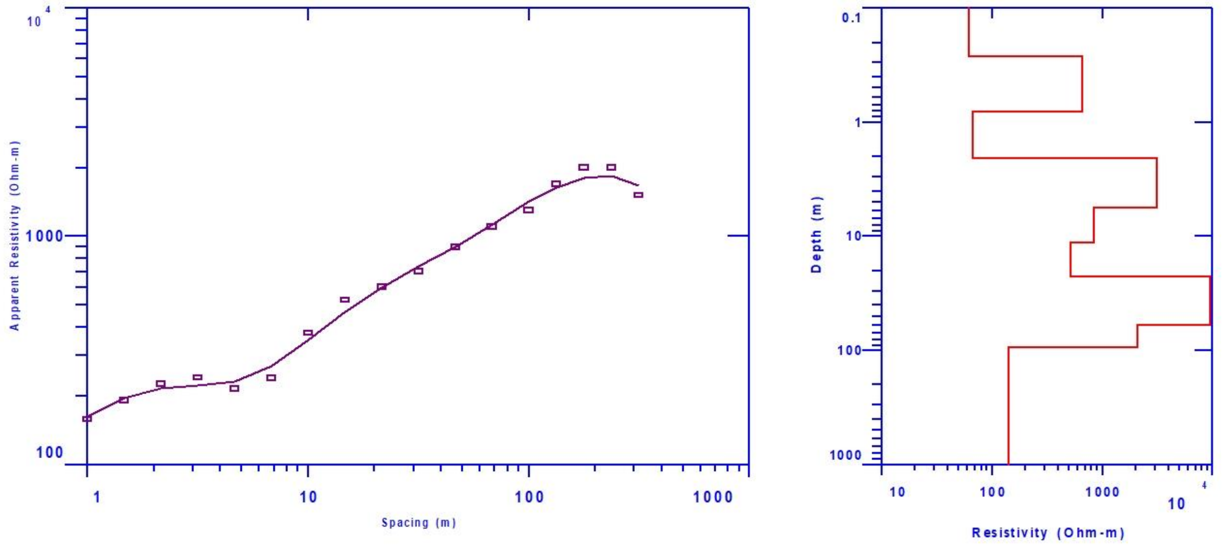


Figure 4.4: Graphical Interpretation of VES 4

Table 4.4 (b): Interpreted values for Depth to Groundwater for VES 4

Layer	Resistivity (Ωm)	Thickness (h)	Depth (m)	Inferred Lithology	Remarks
1	62.08	0.26	0.26	Clay	
2	662.56	0.54	0.81	Silt	
3	66.76	1.24	2.05	Clay	
4	3125.60	3.60	5.66	Sandstone	
5	846.64	5.77	11.43	Silt	
6	517.45	11.15	22.59	Silt	
7	9539.30	37.41	60.01	Sandstone	
8	2093.50	33.41	93.42	Sandstone	Aquifer
9	142.05				

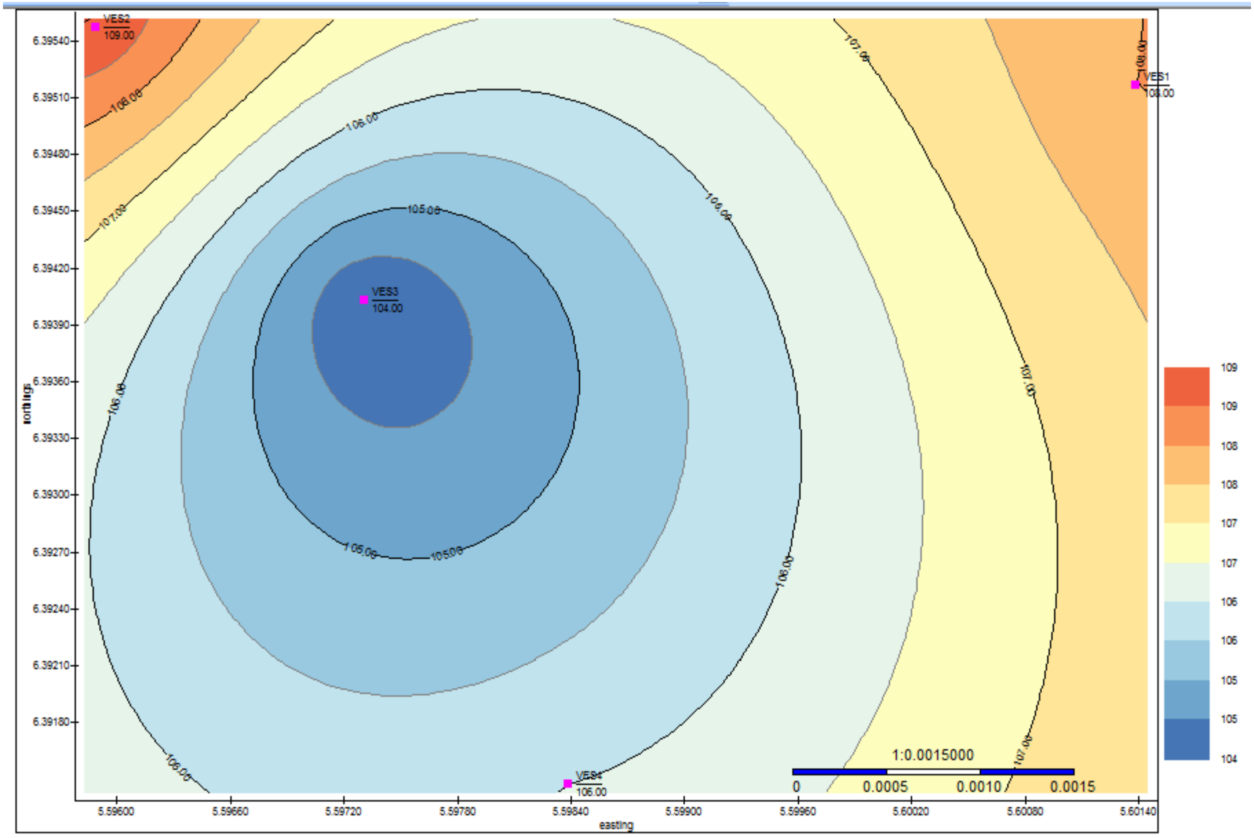


Figure 4.5 (a): 2D Topographic Map of the Study Area.

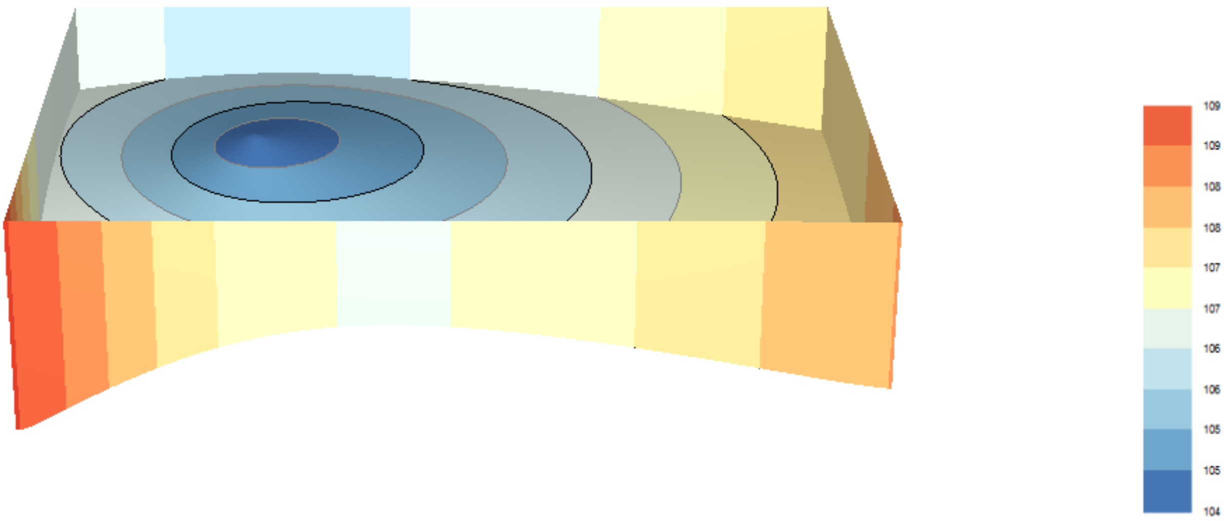


Figure 4.5 (b): 3D Topographic Map of the Study Area.

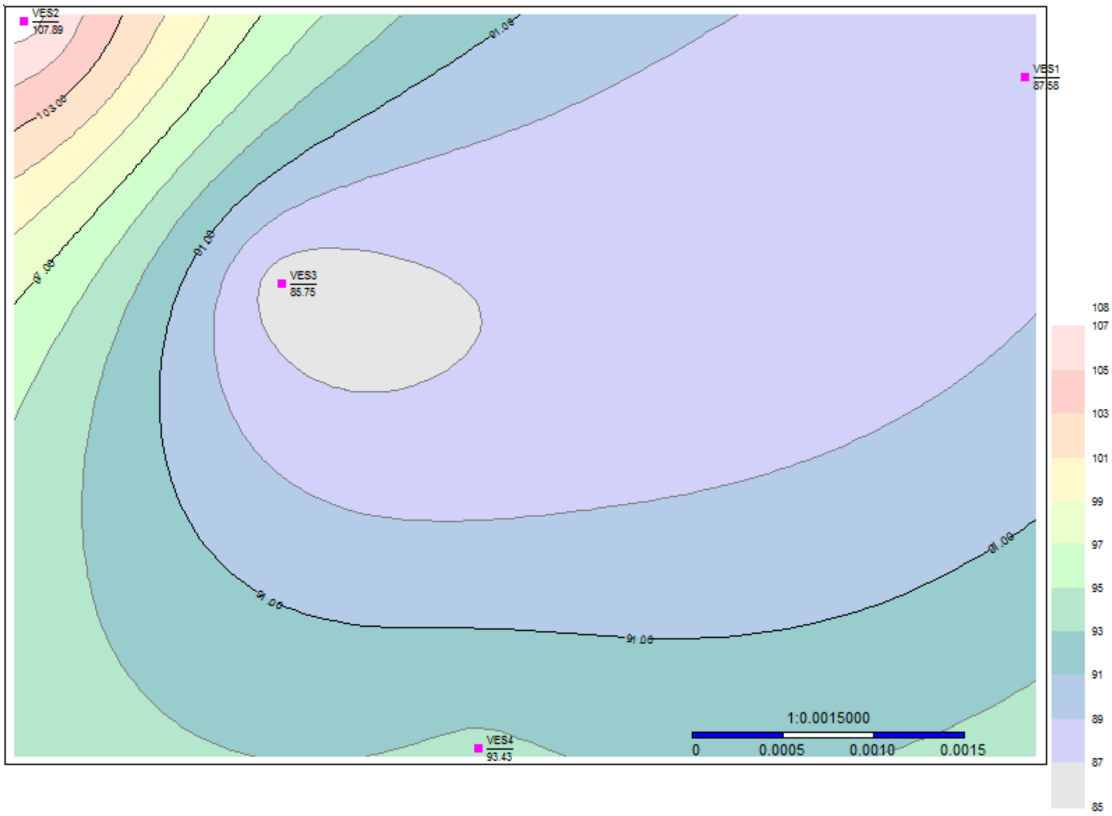


Figure 4.6 (a): 2D Representation of Depth to Groundwater Map.

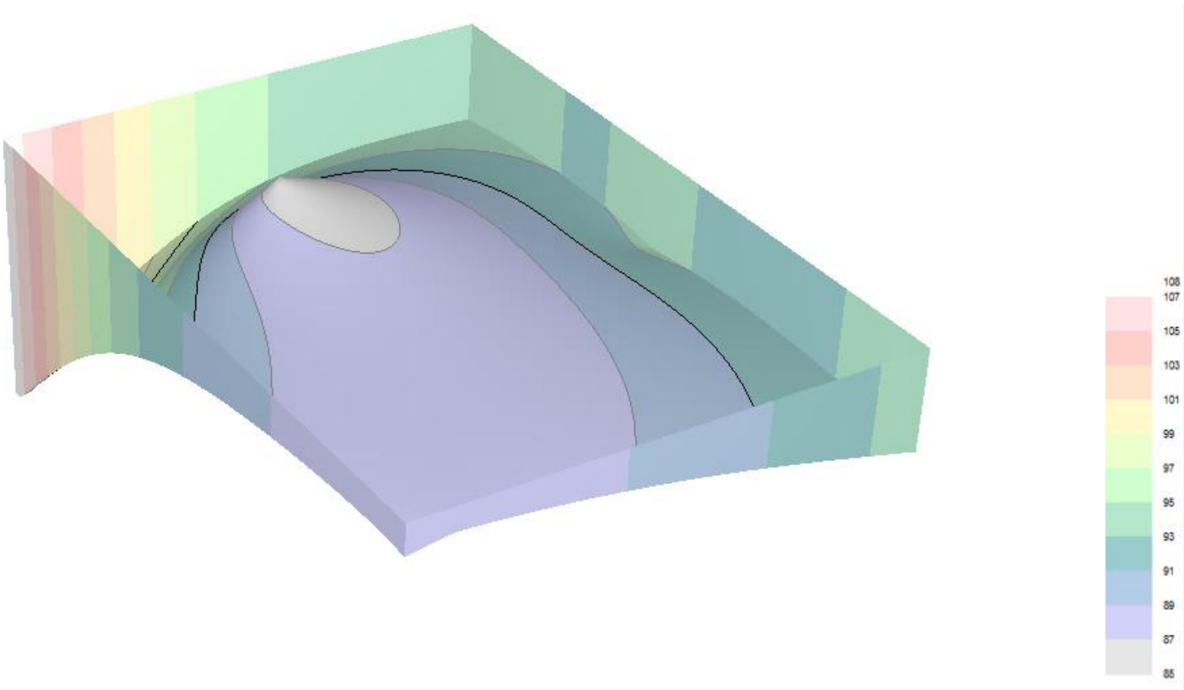


Figure 4.6 (b): 3D Representation of Depth to Groundwater Map.

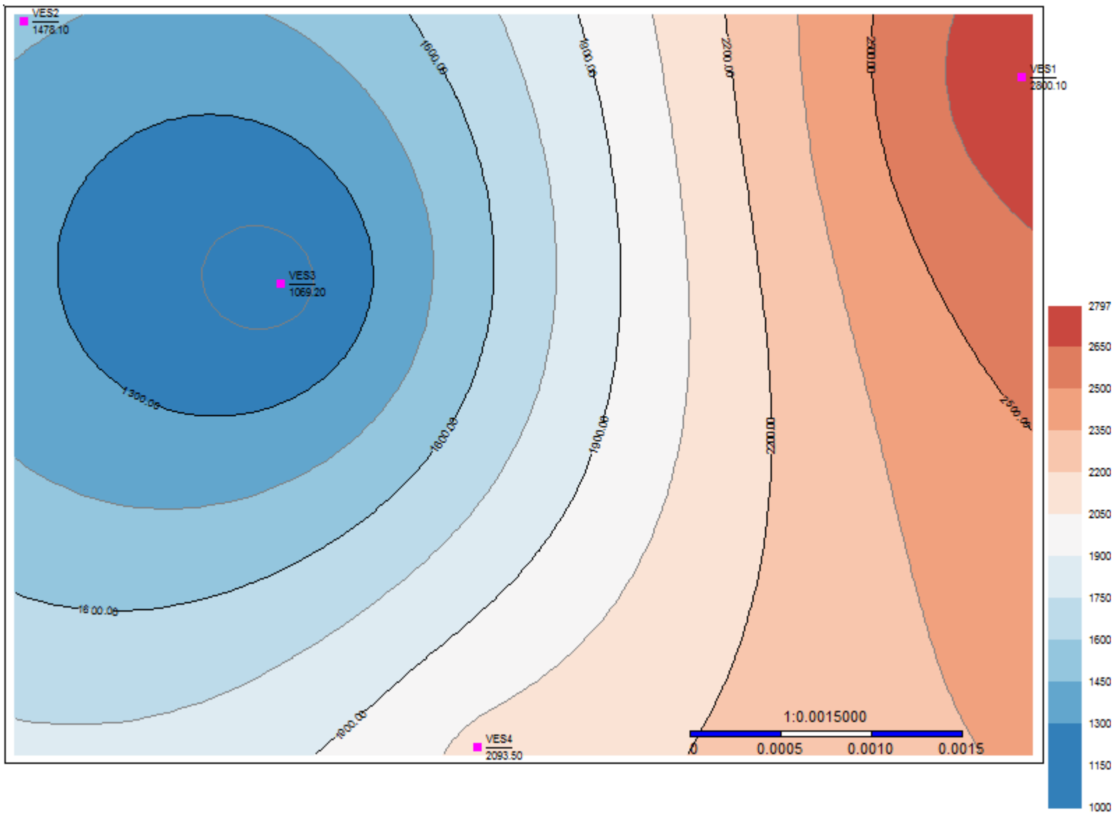


Figure 4.7 (a): 2D Resistivity Variation Map of Saturated Layers.

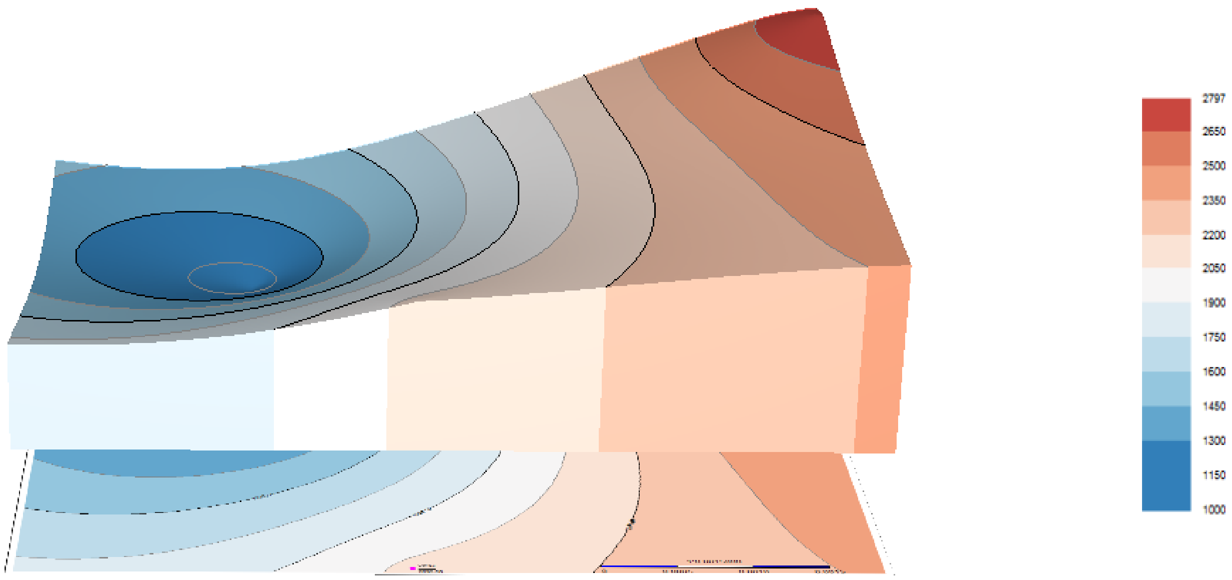


Figure 4.7 (b): 3D Map overlying 2D map of Resistivity Variation of Saturated Layers.

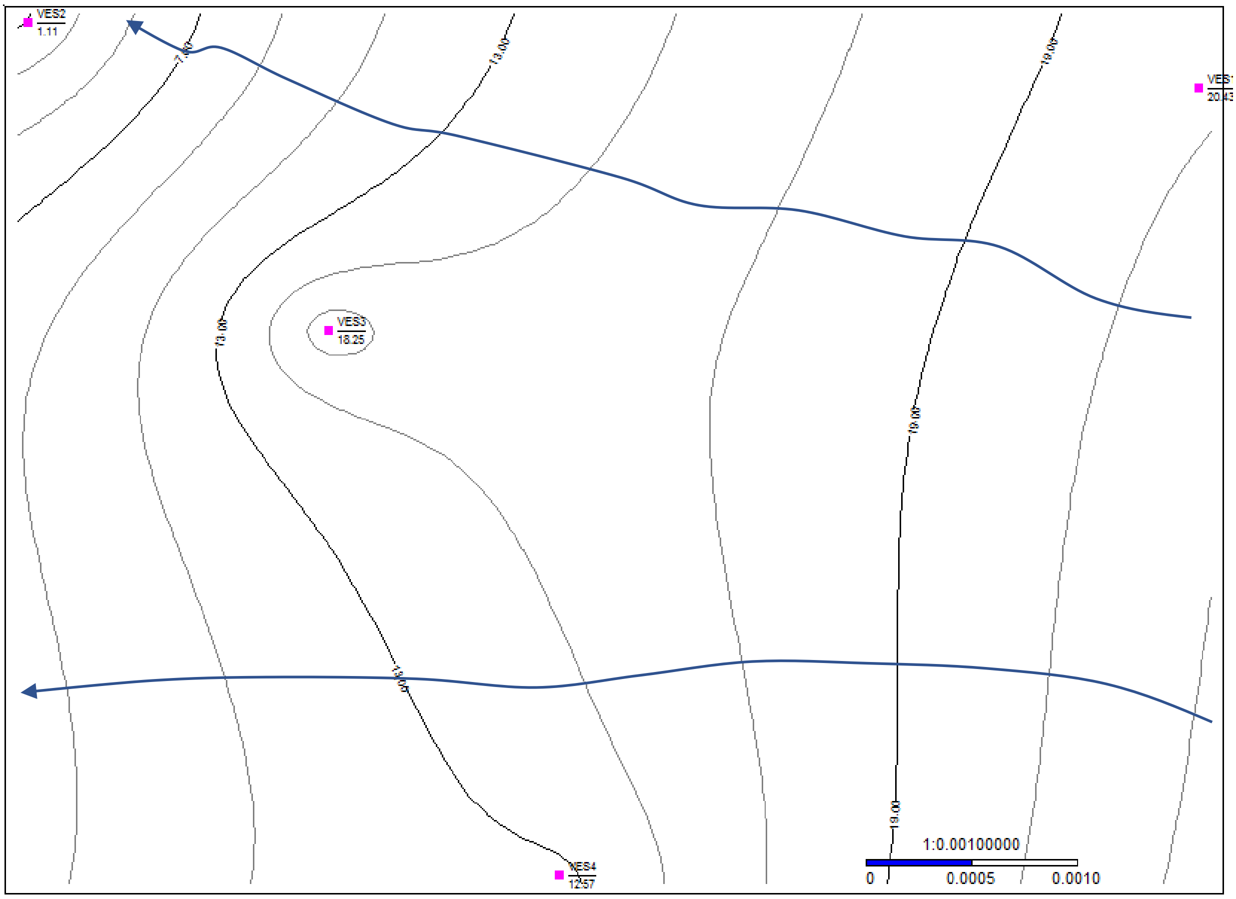


Figure 4.8: Simple Contour Map of Groundwater Flow Direction.

4.2 DISCUSSION

The depths to groundwater at VES 1, 2, 3 and 4 which are 87.575, 107.89, 85.752, 93.426 respectively. A relative analysis of the map shows us that VES 1 and 3 have relatively similar groundwater depths relative to their surface elevations while VES 2 and 4 also have similar depths. Another observation is that the groundwater is shallower from east to west. From South to North to South, the groundwater depth becomes shallower (analyzing from the location map). Interpreting the lithologies, we have three distinct bodies recognized based on resistivity values. However, these values are only inferred, meaning that they may be proved different with further subsurface studies such as borehole cuttings. For VES 1, we have a Succession starting from clay, moving to silt, and then sandstones of different grain sizes (as we move vertically downwards). In VES 2, we have silt, clay, sandstone, silt, and sandstones of varying grain sizes. VES 3 picked up clay, sandstone, silt and sandstone. Finally, VES 4 inferences were clay, silt, clay, sandstone, silt, and sandstone. Something noteworthy about the stratification of the four VES points is that the variation in bed thicknesses and lithologic characteristics is cause for further subsurface studies.

The Groundwater Flow Direction Map shows us that the movement of subsurface water is North-West to west in direction (given the fact that groundwater flows from region of higher elevation to areas of lower elevation.).

Analyzing the resistivity maps, we can see that the areas of lower resistivity (blue in colour) may be contaminated with a bit of salt water. However, from literature review of the Benin Formation, it is safe to assume that the groundwater at VES 3 and 2 is relatively clean and fit for domestic use. Moving to regions of higher resistivity (VES4 and 1 respectively), we can say that the water is quite clean as the likelihood of salt intrusion (which increases the conductivity and reduces the resistivity of the saturated layer).

As regards the quality of the water, geochemically speaking, the clays above the aquifer serve as filters for the infiltrating surface water. Also, groundwater contamination by sewage is highly improbable because the investigation results show that the aquifers are confined. However, should the water be extracted, it should be taken to the lab for further testing.

CHAPTER 5

CONCLUSION

The Benin Formation has been known to be a prolific Aquifer. The results of this ground water survey have reaffirmed this. The depth to groundwater values from VES 1, 2, 3, and 4 show us a depth to water table of 87, 107, 85, and 93 metres respectively which are relatively shallow.

The results also show that the aquifer houses enough groundwater for domestic purposes with EDPA being primarily a Housing Estate.

Further studies should be made for accurate correlation of groundwater depths to understand the subsurface of the Benin Formation better.

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