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Data Acquisation and Interpretation of Hydrogeological Survey in Parts of MALETE, Southwestern Nigeria

[1]Egbeyale G. B., [2]Ogunseye T. T., [3]Ajani A. S.,[4]Bello A. K.,[5]OyeroP. O., and. [6]Odeyem C. S.
[1, 3, 5]Kwara State University, Malete, Kwara State, Nigeria
[2]University of Ibadan, Oyo State, Nigeria
[4]Bell University, Ota, Ogun State, Nigeria
[6]Federal University of Technology Akure, Ondo State, Nigeria
Corresponding authors:godwinegbeyale@gmail.com

Abstract
This study was carried out to acquire hydro-geophysical data and provide detailed interpretation of the data in parts of Malete, Moro local government, Kwara State, Nigeria. The geographical coordinates of the study area are longitude 8˚ 42' 0" East and Latitude 4˚ 28' 0" North. A total of 16 Vertical Electrical Soundings were carried/ estimated out across three profiles using the Schlumberger electrode array configuration, with current electrode separation (AB/2) varying from 1m to 80 m. The data obtained were subjected to interpretation by partial curve matching and then by computer iteration. The interpretation of the VES data also assisted in the characterization of three to four geo-electric layers from which the aquifer unit was delineated. The layers are divided into Topsoil, Laterites, weathered basement and Fresh bed rock. The weathered and fractured basements are the aquifer unit delineated across the area. The thickness of the weathered basement unit varies from 10.1m to 38.3m in the area.

Keywords*: Groundwater, geo-electric, schlumberger, Topsoil, weathered basement*

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I. Introduction

Groundwater is described as the water found beneath the surface of the earth in underground streams and aquifers or the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations (Reynolds 1997, Anomohanran, 2013). The volumes of groundwater are large, however, it is estimated that there is about one hundred times fresher groundwater on earth than all the freshwater in rivers and lakes. Groundwater is a valuable resource both in Nigeria and throughout the world. It is the source of drinking water for about half the total population and nearly all of the rural population, and it provides over 50 billion gallons per day for agricultural needs. Groundwater resources are gaining increasing importance and they represent an increasing proportion of the water supplies used for different applications. Groundwater is a vital natural resource for reliable and economic provision of safe water supplies in both the urban and rural environment. It makes up about twenty percent of the world's fresh water supply, which is about 0.61% of the entire world's water, including oceans and permanent ice (Koefoed, 1979, McNeil, 1980). Global groundwater storage is roughly equal to the total amount of freshwater stored in the snow and ice pack, including the north and south poles (Adelana et al., 2007, Papadopoulos, 2021)). This makes it an important resource that can act as a natural storage that can buffer against shortages of surface water, as in during times of drought. Groundwater development may be primarily restricted to the aquifer in the weathered overburden or completed in the fractured bedrock in locations where the overburden is relatively thin. Viable aquifers wholly within the fractured bedrock are of rare occurrence because of the typically low storability of fracture systems. The occurrence of groundwater in the basement complex terrain of Nigeria is highly unpredictable and hence requires a combination of hydrologic, geophysical and geologic surveys to achieve success in groundwater development programs (Adnan etal , 2019, Olayinka, 2000 abd Mavriou et al, 2019).

The groundwater can be in sedimentary terrain where it is less difficult to exploit except for its chemical composition (Adiat et al, 2009). It can also be in the basement complex terrain where it can be a bit difficult to locate especially in area underlain by crystalline unfractured or unweathered rock. The research for groundwater today has become essential, due to its cheapness and its chance of obtaining quality water from the bedrock. Therefore, the application of geophysics to the successful exploration of underground water in sedimentary terrain requires a proper understanding of its hydro-geological characteristic. Evidence has shown that geophysical methods are the most reliable and the most accurate means of all surveying methods of subsurface structural investigations and rock variation.

Therefore, in the process of exploitation of groundwater a need for well data interpretation of hydro-geological data survey required. Hence, the study aimed at interpreting acquired hydro-geophysical data in Malete.

1.1 Description of the study area

Malete, the study area, is situated in Moro local Government, Kwara State, Nigeria, its geographical coordinates are longitude 8˚ 42' 0" North and Latitude 4˚ 28' 0" East. Moro is a local government in Kwara state, Nigeria. It has an area of 3,272km² and a population of 108,792 at the 2006 census. The project areas were generally accessible by minor roads and several footpaths, it is about 105km from Ilorin and accessible by road. The climate is sub- equatorial with average annual rainfall 2000mm – 2500m and a temperature of about 27˚C - 28˚C. Rainfall is recorded during the rainy season which lasts from April to October with a peak between June and August. The peak temperature is recorded between the months of Jan to March. Most of the rainfall comes in torrential showers resulting in high run-off. In the flat lying areas, rain water is retained for a long time due to the clayey nature of the soil. The harmattan season normally lasts from November to February. During this period and the succeeding dry season the soil and drainage dry up in the study area. The Location map of the study area is shown with the Profile lines in Figure 1.

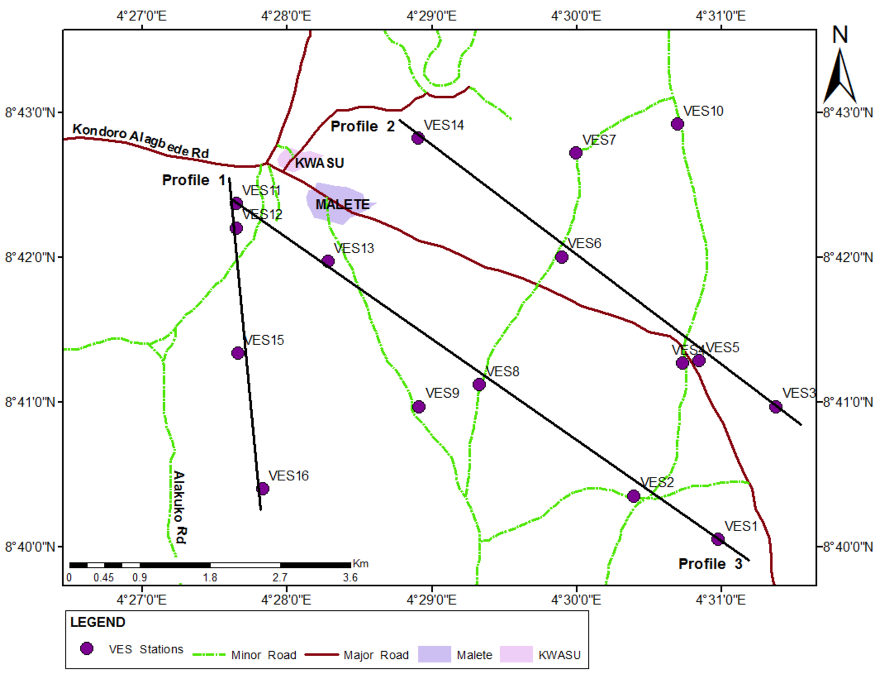


Figure 1: The Location map of the study area showing the Profile lines.

II. Materials and Methods

The data was acquired by the use of the following tools and equipment; electrodes, hammer, cables, resistivity meter, GPS, measuring tapes.

The electrical resistivity method has been the most commonly used geophysical tool for groundwater investigation because of its advantage which include simplicity in field technique and data handling procedure.

Measurement of resistivity were made using ABEM WADI (SAS 300B) terrameter, while Global positioning system (GPS) was used to measure or get the elevation above the sea level, longitude and latitude of the VES position. Measuring tape was used to measure inter-electrode spacing separation. Other accessories to the terrameter include the booster, four metal electrodes, hammers and cables for current and potential electrodes. The first step undertaken on the field was the reconnaissance study of the area. Having established these points, they were marked and Vertical Electrical Sounding was carried out by using Schlumberger array as shown in Figure 2.

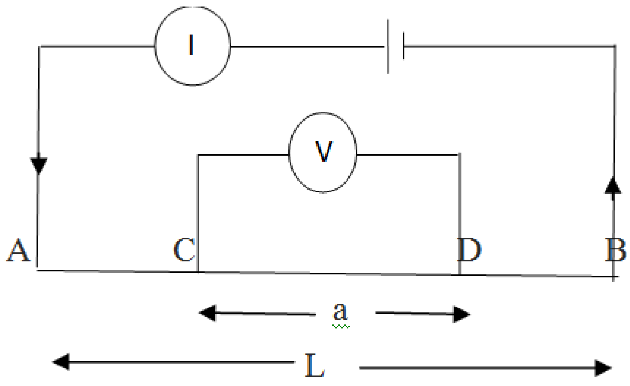


Figure 2: Schlumberger configuration for resistivity measurement, consisting of a pair of current electrodes (A, B) and a pair of potential electrodes (C, D),

Let the separations of the current and potential electrodes be L and a respectively
Then

$r_{DB} = r_{AC}$ and $r_{AD} = r_{CB}$

(1)

and $r_{AD} = r_{CB} = \frac{(L+a)}{2}$, (2)

Substituting in the general formula (Equation ;

$$\rho_a = 2\pi \frac{V}{I}\left[\frac{1}{\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) - \left(\frac{1}{r_{AB}} - \frac{1}{r_{DB}}\right)}\right]$$

(3)

We have

$$\rho_a = \frac{\pi v(L^2 - a^2)}{4Ia}$$

(4)

where r_{DB} is the distance between electrode D and B,

r_{AC} is the distance between electrode A and C

r_{CB} is the distance between electrode C and B

r_{AD} is the distance between electrode A and D

L is the distance between current electrode A and C

a is the distance between potential electrodes C D

v is the potential difference and *I* is the current flow

If the electrode carries a current I, measured in amperes (a), the potential at any point in the medium or on the boundary is given by:

III. Results and Discussion

The resistivity data were interpreted both qualitatively and quantitatively using computer based interpretative modeling. The results gotten from the field were improved upon by the application of an interactive (iterative) computer program. The interpretation of the geo-electric parameters which involves the resistivity and the thickness in terms of subsurface geology and groundwater conditions of the study area were carried out on the basis of the geological and lithological information of the area. In the computer modeling, the field data is input into the computer and the computer theoretically calculated curves are modified until a match is attained between the calculated, and the observed resistivity curves, as illustrated by Koefoed (1979).

The computer displays the resistivity and the layer thickness of the model which was adjusted to approximate or fit the field observations. The computer program employed in the interpretation of the VES data is IP12 WIN while SURFER 11 was used to provide the basement relief map and the iso-resistivity map. The summary of results of Vertical Electrical Sounding is presented on Table 1 while the summary of qualitative interpretation of the VES curve is presented on Table 2. Also the summary showing the Aquifer Thickness is presented on Table 3. Thickness of layers and depth of weathering obtained from resistivity data is on Table 4.

Table 1: Summary of Results of Vertical Electrical Sounding

VES STATION	No. of Layers	Resistivity (Ωm)	Thickness	Depth to Bedrock	Curve Type	Reflection Coefficient	Remark
VES1	3	1997	2.69	19.1	H	0.86	Topsoil
		144	16.4				Weathered Basement
		1847					Fresh Basement.
VES2	3	964	1.89	14.8	H	0.74	Topsoil
		121	12.9				Weathered Basement
		823					Fresh Basement
VES3	3	747	5.04	29.7	H	0.77	Laterites
		183	24.7				Weathered Basement
		1384					Fresh Basement
VES4	3	295	2.5	18.7	H	0.56	Laterites
		69.4	16.2				Weathered Basement
		1033					Fresh Basement.
VES5	3	375	3.16	14.8	H	0.86	Lateritic soil
		104	11.6				Weathered Basement
		1414					Fresh Basement
VES6	4	343	0.826	15.1	QH	0.90	Topsoil
		123	1.89				Laterites
		46.6	12.3				Weathered Basement
		908					Fresh Basement
VES7	4	352	0.517	13.2	QH	0.95	Topsoil
		91.8	2.48				
		18.9	10.2				Weathered Basement
		908					Fresh Basement
VES8	4	26.3	0.206	29.3	KH	0.87	Topsoil
		293	4.71				Laterites
		67.2	24.4				Weathered Basement
		938					Fresh Basement
VES9	4	36.4	1.49	21.7	A	0.93	Topsoil
		134	10.1				Laterites,
		32.7	10.1				Weathered Basement
		927					Fresh Basement
VES10	3	1381	3.64	22.9	H	0.73	Laterites,
		195	19.3				Weathered Basement
		1227					Fresh Basement.
VES11	4	403	1.48	47.9	KH	0.69	Topsoil
		723	8.1				Laterites,
		277	38.3				Weathered Basement
		1509					Fresh Basement
VES12	3	516	3.56	14.7	HA	0.87	Laterite
		195	11.2				Weathered Basement
		2902					Fresh Basement
VES13	3	1500	2.05	16.3	HA	0.96	Topsoil
		34.9	14.2				Sandy Clay
		1802					Laterites,
VES14	3	958	2.79	20.3	H	0.81	Laterites,
		92.4	17.5				Weathered Basement
		918					Fresh Basement.
VES15	4	633	0.423	36.4	KH	0.82	Topsoil
		2840	2.39				Laterites,
		266	33.6				Weathered Basement
		2750					Fresh Basement.
VES16	4	598	0.664	31.6	KH	0.73	Topsoil
		1538	3.61				Laterites,
		330	27.3				Weathered Basement

		2124					Fresh Basement.

Table 2 Summary of qualitative interpretation of the VES curve

S/N	Curve Type	No of Occurrence	VES No
1	A	1	9
2	H	7	1, 2, 3, 4, 5, 10, 14
3	KH	4	8, 11, 15, 16
4	HA	2	12, 13
5	QH	2	6,7

Table 3: Summary showing the Aquifer Thickness

VES STATION	EASTINGS	NORTHINGS	RESTOP SOIL	RES LATERITE	RESWEATHERED BASE	RESFRESHB ASEMENT	AQUIFER THICKNESS
VES1	4.516389	8.6675	-	1997	144	1847	16.4
VES2	4.506667	8.6725	-	964	121	823	12.9
VES3	4.523056	8.682778	-	747	183	1384	24.7
VES4	4.512222	8.687778	-	295	69.4	1033	16.2
VES5	4.514167	8.688056	–	375	104	1414	11.6
VES6	4.498333	8.70000	343	123	46.6	908	12.3
VES7	4.50000	8.711944	352	91.8	18.9	908	10.2
VES8	4.488889	8.685278	26.3	293	67.2	938	24.4
VES9	4.481944	8.682778	36.4	134	32.7	927	10.1
VES10	4.511667	8.715278	-	1381	195	1227	19.3
VES11	4.460833	8.706111	403	723	277	1509	38.3
VES12	4.460833	8.703333	_	516	195	2902	11.2
VES13	4.471389	8.699444	-	1500	34.9	1882	14.2
VES14	4.481806	8.713667	-	958	92.4	918	17.5
VES15	4.461028	8.688914	633	2840	266	2750	33.6
VES16	4.463917	8.673278	598	1538	330	21	27.3

Table 4: Thickness of Layers and Depth of Weathering obtained from Resistivity Data

VES STATION	EASTIN GS	NORTHIN GS	LAYE RS	WEATHER ED BASEMENT	DEPTHOF WEATHERI NG	REFLECTIONCOE FFICIENT	GROUNDWAT ER POTENTIAL
VES1	4.516389	8.66750	3	16.4	19.1	0.86	Moderate
VES2	4.506667	8.67250	3	12.9	14.8	0.74	High
VES3	4.523056	8.682778	3	24.7	29.7	0.77	High
VES4	4.512222	8.687778	3	16.2	18.7	0.56	High
VES5	4.514167	8.688056	3	11.6	14.8	0.86	Moderate
VES6	4.498333	8.700000	4	12.3	15.1	0.90	Low
VES7	4.50000	8.711944	4	10.2	13.2	0.95	Low
VES8	4.488889	8.685278	4	24.4	29.3	0.87	Moderate
VES9	4.481944	8.682778	4	10.1	21.7	0.93	Low
VES10	4.511667	8.715278	3	19.3	22.9	0.73	High
VES11	4.460833	8.706111	4	38.3	47.9	0.69	High
VES12	4.460833	8.703333	3	11.2	14.7	0.87	Moderate
VES13	4.471389	8.699444	3	14.2	16.3	0.96	Low
VES14	4.481806	8.713667	3	17.5	20.3	0.81	Moderate
VES15	4.461028	8.688914	4	33.6	36.4	0.82	Moderate

VES16	4.463917	8.673278	4	27.3	31.6	0.73	High

3.1 Geophysical Data Interpretation

The computer program employed was the IP12WIN (Figure 4.8) geophysical software, Field data are input and then modeled. Hence the computer iteration makes the interpretation of such problems easier. The VES data are shown in Table 1. The data in the table include the current electrode spacing (AB/2), potential electrode spacing (MN/2), the geometric factor (K) and the apparent resistivity values ($p\Omega m$) of each VES point. Calculations of the reflection coefficients (Rc) of the fresh basement rock of the study area were done using the method of Offodile (2002), Keller and Frischknecht (1996), Oyawole (1972), and Senbore (2018): The fractured and fresh basement layers were separated using the values of reflection coefficient gotten from each VES point, which is the measure of competence of the basement layer.(Keary 1991, Omole et al, 2017). The reflection coefficient map has a value range of (0.09 – 0.99). It was discovered that areas of lower reflection coefficient values (<0.8) exhibits weathered or fractured basement rock which favors high water potential i.e. areas with lower reflection coefficients represent areas with fractured/or intensely weathered bedrock.

3.2 Analysis of Electrical Resistivity Data

The VES curves were represented as depth sounding curves as shown in (Figure 4.8). The curves are graphs expressing the variation in apparent resistivity with increasing depth. The shape of the VES curves depends on three factors: the thickness of each layer, the number of layers in the subsurface and the ratio of the resistivity of the layer. Resistivity and thickness of the layers obtained from computer iteration were used to present geo-electric sections, the iso-resistivity map which shows the horizontal layer of the subsurface at varying depth, groundwater potential map and so on.

3.3 Geo Electric Section (Profile 1)

The geo-electric section (profile 1) is made up of data from VES 11, 12, 15, 16 and 5 (Figure 3). The first layer which is called the top soil can be found in VES 11, 15, 16 is characterized with resistivity values within the range of 403Ωm to 633Ωm with a thickness which varies from 0.4m to 1.5m. The second layer has resistivity values ranging from 375Ωm to 1538Ωm and thickness which varies from 2m to 8.1m is called the laterites. The weathered basement which its resistivity values ranges from 104Ωm to 330Ωm and has a thickness range of 11m to 34m is the third layer. The last layer with resistivity values ranging from 21Ωm to 2902Ωm with infinity thickness is presumed the fresh basement.

3.4 Geo Electric Section (Profile 2)

The geo-electric section (Profile 2) is made up data from VES 3, 5, 6 14 (Figure 4). These geo-electric sections consists of three to four layers, VES 3, 5, 14 has three geo-electric layers while VES 6 has four geo-electric layers. The first layer which is the top soil can be found only in VES 6 has a resistivity value of 343Ωm with thickness of 0.83m. The second layer which consists of resistivity values ranging from 123Ωm to 958Ωm and thickness ranging from 1.8m to 5.1m is called the laterites layer. The weathered basement which is the third layer has resistivity values ranging from 46Ωm to 183Ωm with thickness of 1.8m to 25m. The last layer with resistivity values ranging from 908Ωm to 1414Ωm is presumed the fresh basement or fresh bedrock (Offodile, 2002).

3.5 Geo Electric Section (Profile 3)

This geo-electric section is made up of data from VES 1, 2, 8, 11 and 13. (Figure5) The top soil which can be found only in VES 8 and 11 has thickness ranging between 0.2m to 1.5 m and resistivity values from 26Ωm to 403Ωm. The second layer which is the laterites can be found in VES 1, 2, 8, 11, and 13 with resistivity values ranging from 293Ωm to 1997Ωm and thickness of 4.71m. The weathered basement has resistivity values ranging from 34Ωm to 277Ωm with thickness ranging between 12m to 34m. The basal unit which is known as the fresh basement has resistivity values ranging from 823Ωm to 1847Ωm.

3.6 Groundwater Flow Net

A flow net is a graphical representation of two dimensional steady state groundwater flow through aquifers. The construction of a flow net, for example a water table or potentiometric surface map, and the interpretation of groundwater flow lines, requires the implicit assumption that flow is perpendicular to the lines of equal hydraulic head (i.e the porous material is isotropic), with flow in the direction of decreasing head. Flow net was plotted to determine horizontal groundwater flow directions in the study area. Construction of a flow net is often used for solving groundwater flow problems where the geometry makes analytical solutions impractical. The flow net is an important tool in analyzing two dimensional irrotational flow problems. Flow net technique is a graphical representation method. The contour map shown below shows the flow directions (Figure 6).

3.7 Groundwater Potential Evaluation

The groundwater potential of the area is defined by identifying areas with low reflection coefficient, high regolith resistivity and thick weathered basement. Areas with low reflection coefficients represent area where the bedrock is weathered and/or fractured (Olayinka, 2000). Areas where the resistivity is high, the materials are usually essentially sandy and can act as an aquifer, minimum thickness of 10m is recommended by Lowrie (1997) to ensure adequate yields to wells. The groundwater potential of the study area was evaluated based on the following parameters; weathered layer thickness and resistivity overburden thickness, Regolith resistivity and reflection coefficient. The weathered layers or fresh layers constitute the water saturated zones which are aquifer units. Areas where the weathered layer thickness is greater than 15m and of a low clay content as shown by the resistivity range i.e. less than 60Ωm value is categorized to be the areas of high groundwater potentials. The groundwater potential evaluation of the selected parts of Moro the study area is based on various categories of maps: isopach and iso resistivity maps of the weathered layer and the reflection coefficient map. In preparing the groundwater potential map of the area as deduced from the geo-electric parameters (resistivity and thickness) and reflection coefficient obtained from interpreted VES results. According to (Olayinka 2000), he observed that areas with lower reflection coefficient values exhibits a fracture basement rock and hence has high water potential. In the present study, reflection coefficient values less than 0.9 may be indicative of high density water filled fracture (Olayinka 2000). The groundwater potential map shown in Figure 7 was used to classify the study area into high intermediate and low groundwater potential zones, VES 11,12,15 and 16 which are found in the northwestern and southwestern of the study area are characterized as high groundwater potential zones, while VES 10 which falls in the northern part of the study area also shows potentials for high groundwater zones. Also, the southeastern part, and a significant pach of the northern part of the study area could be characterized as intermediate to low groundwater potential zone.

3.8 Vertical electric sounding (ves) curves

In the computer modeling, the field data is input into the computer and the computer theoretically calculated curves are modified until a match is attained between the calculated, and the observed resistivity curves.The computer program employed in the interpretation of the VES data is IP12 WIN, asshown in Figure 8.

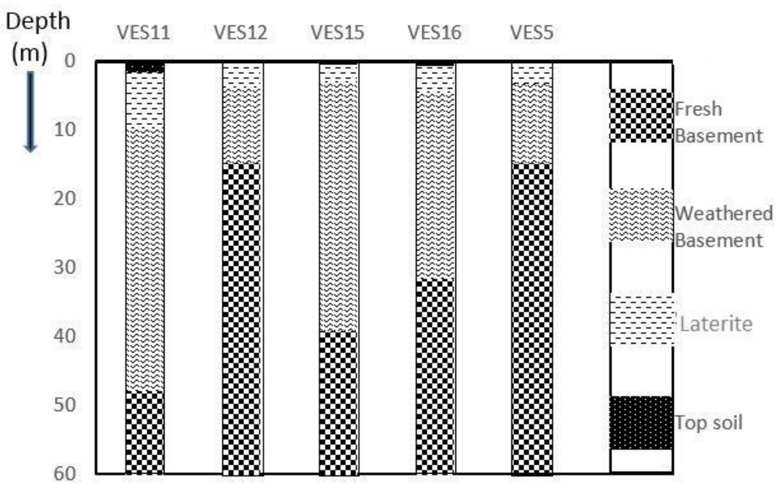


Figure 3: Geo-electric sections along the Profile 1 line across VES 11, 12, 15, 16 and 5

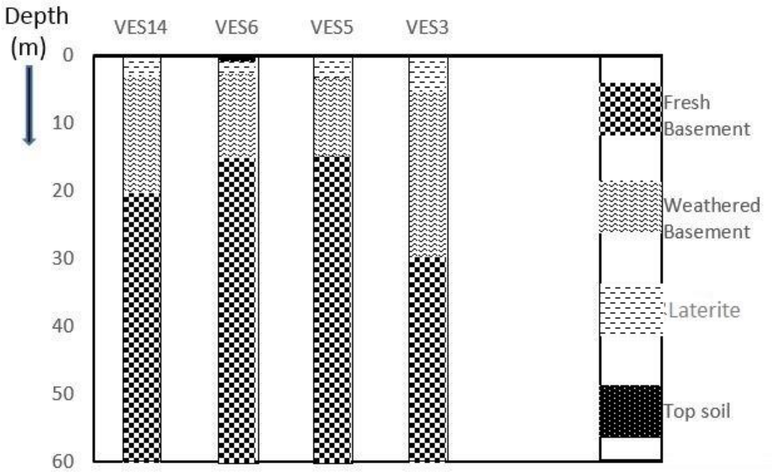


Figure 4: Geo-electric sections along Profile 2 line across VES 3, 5, 6, 14

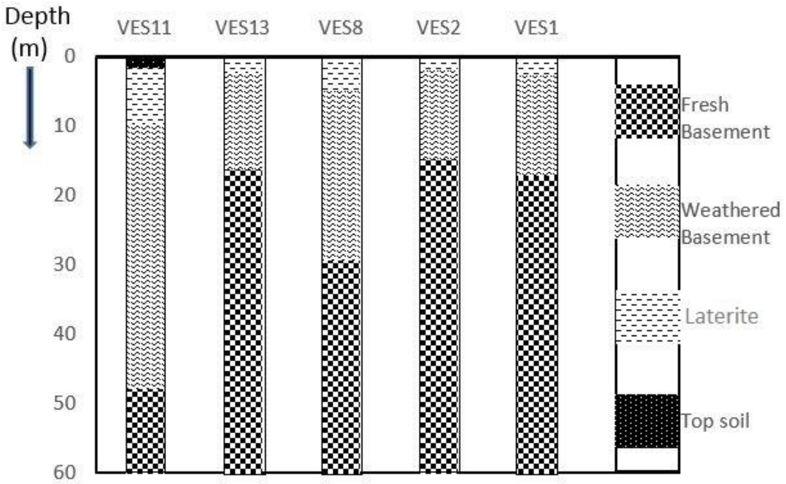


Figure 5: Geo-electric sections along Profile 3 line across VES 1, 2, 8, 11 and 13

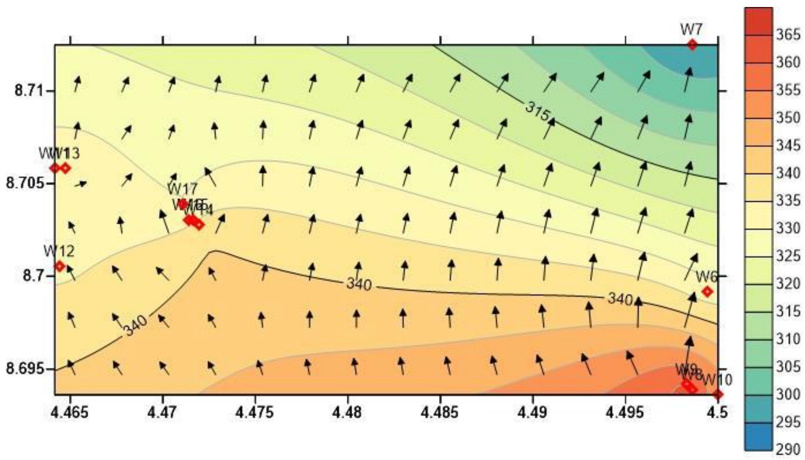


Figure 6: Groundwater Flow Net of the study area.

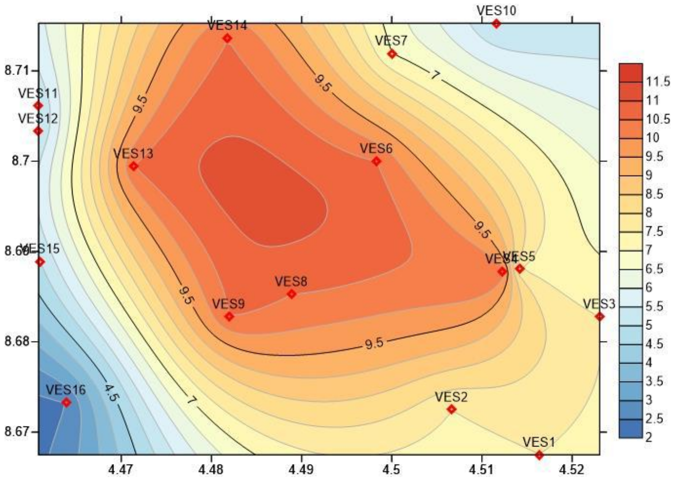
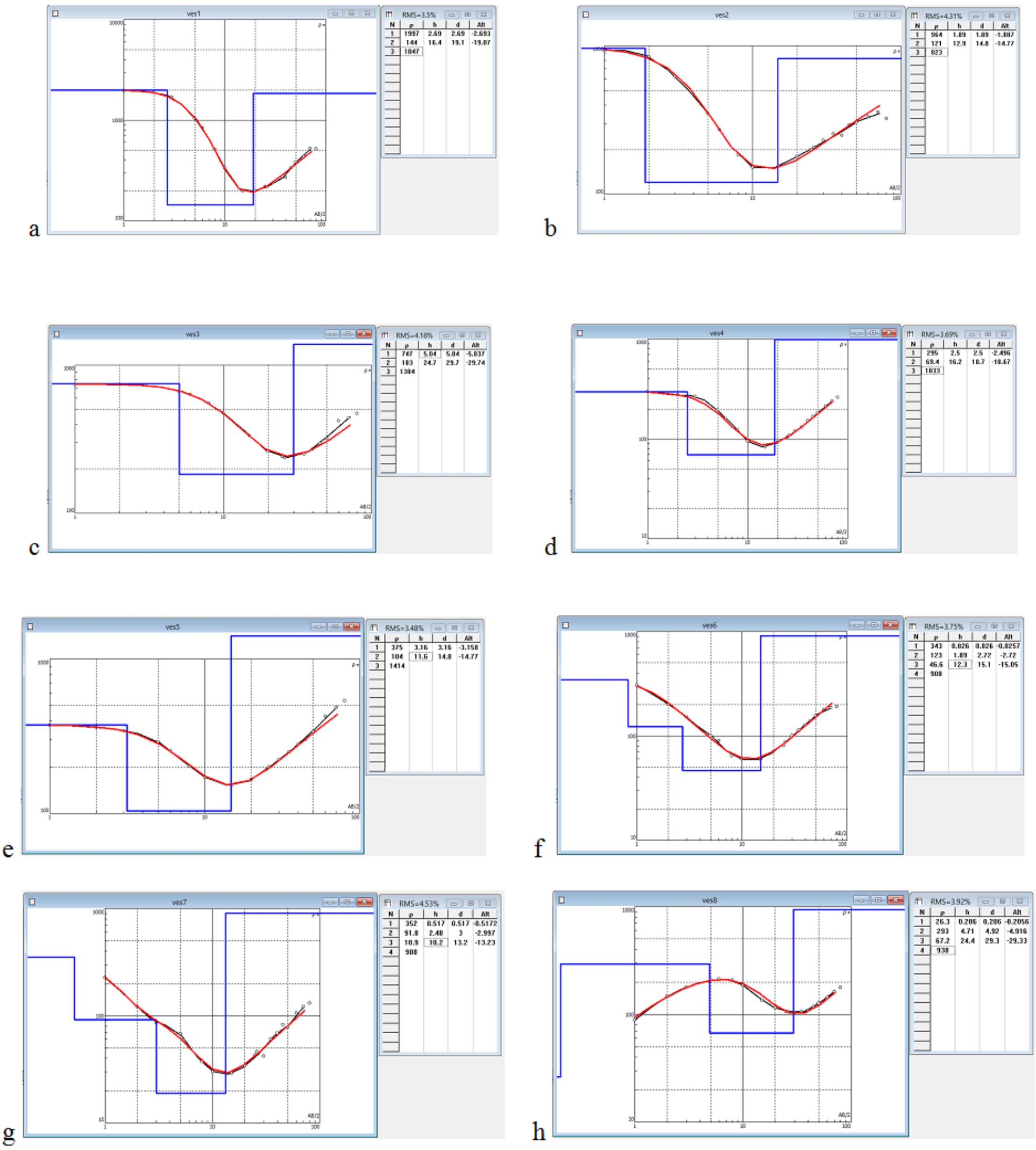


Figure 7 Groundwater potential map of the study area.



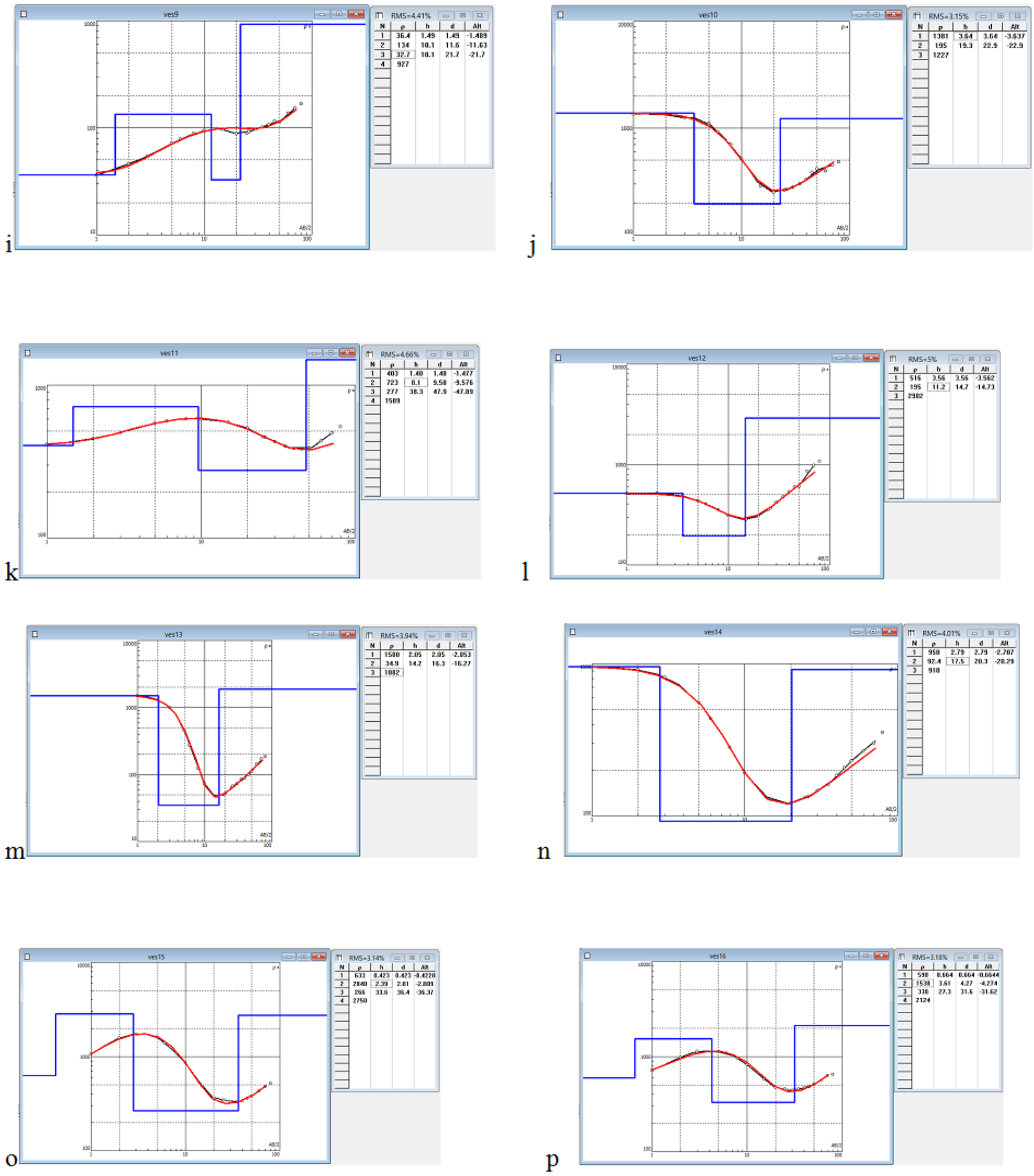


Figure 8(a-p) vertical electric sounding (ves) curves

IV. Conclusions

This study acquired hydro-geophysical data in malete and adequate interpretation was provided to them.The results of the quantitative interpretation of the VES data reveal that the subsurface is characterized by the topsoil, laterites, weathered basement and fresh basement. A Geo-electrical investigation was used to determine the lithological characteristics and groundwater so as to determine the effects of over pumping of groundwater in the study area. The interpreted VES data results also revealed five earth curve models which are A, H, KH, HA, QH. Type H and KH curves which are often associated with groundwater possibilities (Omosuyi, 2010) were found in the study area. Furthermore, the geo-electric parameters (resistivity and thickness) gotten from the VES sounding data were used to delineate the aquifer types of the area as: weathered bedrock and fractured bedrock aquifer types, which are in agreement with Nur and Afa (2002) who are of the opinion that the weathered and/or fractured rocks in the crystalline basement areas are the only places where water could be found throughout the year. Also the resistivity and thickness gotten from the interpreted VES data were used to generate geo-electric sections, isoresistivity contours maps which were analyzed in terms of hydrological importance of the area and lastly the maps were used to differentiate areas with high intermediate groundwater potentials from areas with low intermediate groundwater potential.

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