Nigerian Journal of Water Resources. *Vol. 5, No.1, December 2019.*

DETERMINATION OF HYDRAULIC PROPERTIES OF AN AQUIFER USING ELECTRICAL RESISTIVITY TECHNIQUES- A CASE OF A PART OF NORTHERN KADUNA METROPOLIS

OMOTAYO KAYODE EBENEZER and OZOANI HUMPHREY CHIEDOZIE
Kayodeomotayous2@yahoo.com; humphreyozoani@gmail.com
Groundwater Department, National Water Resources Institute,
Kaduna, Nigeria

ABSTRACT

The research is aimped at the determination of the hydraulic characteristics (K and T) of an aquifer, using only the electrical resistivity method, so that when there is no borehole information, these characteristics can still be determined. Consequently, 11 Vertical Electrical Sounding (VES) points and 4 boreholes were investigated. The boreholes will serve as control or check for the results got from electrical resistivity survey. First, the Singh 2005 formula was used to calculate the Hydraulic Conductivity of the aquiferous zone for each VES point. Thereafter, the Transmissivity was calculated using the Singhal and Niwas 1981 formula. Meanwhile, the thickness of the aquifer used for calculating Transmissivity from Hydraulic Conductivity were determined in three different ways: (a) using the thickness, h= Depth to fractureless fresh basement rock minus Depth to water table and (b) using the thickness h of aquiferous zone derived from VES interpretation and (c) using the thickness h of the screened aquiferous zone of the available boreholes. The Transmissivity values from the three different aquifer thicknesses were now compared to those got from pumping test. And it was observed that the Transmissivity values got from the thickness of screened aquifer correlate fairly with the Transmissivity values from pumping test. While the Transmissivity values from the other two methods are relatively high, which may be as a consequence of the fact that the calculations takes into consideration that the porosity and permeability are constant and continuous throughout the length of the aquifer. And this is rarely so in practice. Finally, using the VES curves interpretation and the corresponding pseudosections, the high groundwater potential zones in the area have been delineated.

KEY WORDS: *Electrical Resistivity Method, Transmissivity, Permeability, Hydraulic Conductivity, Aquifer, Singh, Singhal and Niwas*

1.0 INTRODUCTION

1.1 Statement of the Problem

In order to avoid drilling abortive wells, geophysical investigation is imperative because it helps to delineate aquifer (or potential water bearing geological units) while on the other hand, assessment of water yielding capacity of aquifer are traditionally determined from parameters obtained from well pumping test and well log data. These are time consuming and expensive. A rapid and cost effective means of determining the hydraulic parameters is with resistivity data (Kelly, 1977; Singhal and Niwas, 1981; Singh, 2005; Osumeje et al, 2016, particularly where boreholes are not sufficient (Dharkate and Singh, 2005) or not available

Omotayo and Eduvie 2017).

The hydraulic characteristics of subsurface aquifers are important properties for both groundwater and contaminated land assessments, and also for safe construction of civil engineering structures. Hydraulic conductivity/permeability (K), Transmissivity (T) and Storativity (S) are all commonly applied hydraulic parameters in groundwater flow modeling (Freeze and Cherry, 1979; Fitts, 2002 Singh, 2005). Application of field hydrogeological methods of assessment is a standard technique for evaluating these aquifer properties, however estimating K, T, and S values from field pumping tests and downhole well-log data can be very expensive and time-consuming. In this context, surface geophysical methods may provide rapid and effective techniques for groundwater exploration and aquifer evaluation. Application of geophysical methods is generally proving very effective for water content estimation, water quality assessment, mapping of the depth to the water table and bedrock (Hubbard and Rubin, 2002; Singh, 2005). Although various geophysical techniques currently are being applied to explore and assess water resources, the DC electrical resistivity method still proves the most powerful and cost-effective (Singh, 2005). Recently, attempts have been made by researchers to obtain hydraulic parameter estimates from resistivity measurements (e.g. Brace, 1977; Biella et al., 1983; Bussian, 1983). In porous media and alluvial aquifers per se, transmissivities, formation factors and permeability can be estimated using empirical/semi-empirical correlations, often using simple linear relations (Kelly, 1977a, b; Heigold et al., 1979; Urish, 1981; Chen and Hubbard et al., 2001, Singh, 2005). In fractured and fissured hard rock regions delineation of aquifer properties by geophysical methods can be a particularly very difficult task. For example, if the conductive aquifer is thin and sandwiched between two electrically resistive layers then no indication of its presence will be observed in a resistivity sounding curve (Singh, 2003a). Moreover, groundwater flow in fractured aquifers is very complicated, and accuracy in estimation of the hydraulic parameters depends on the hydraulic behavior in particular fractures, which is site specific. In such situations, non-conventional methods may be useful to detect a hidden aquifer (Singh, 2003a).

1.2 Basic Principles

The depth of investigation in a Schlumberger sounding configuration typically varies between 0.25 AB to 0.5 AB (Roy and Elliot, 1981). Mathematically, electrical current flow (J) in a conducting medium is governed by Ohm's law and groundwater flow in a porous medium by Darcy's law, both having similar forms of equation:

$J = -\sigma\, dV/dr$ ……………………………….(1)

$q = -K\, dh/dr$……………………………….(2)

where J, σ, V, r, q, K, h are respectively the current density (amps per unit area), electrical conductivity (Siemens/m = reciprocal resistivity, ρ ohm.m or Ω.m), electrical potential (volts), distance (metres), specific discharge (discharge per unit area), hydraulic conductivity (or permeability; m/s) and hydraulic head (m). The analogy between these two macroscopic phenomena is widely accepted (Freeze and Cherry, 1979; Fitts, 2002). Thus, the electrical method provides a powerful analogue and tool for groundwater exploration and modeling, and may be useful e.g. in generating analytic flow nets.

For homogeneous and isotropic medium, electric current and groundwater flow both satisfy the Laplace equation: for electrical flow

$d^2V/dr^2 + 2/r\, dV/dr =$ ……..……………….(3)

and for groundwater flow:

$d^2h/dr^2 + 1/r\,dh/dr = 0$……………………....(4)

For a point current source, the solution of Eq. (3) in a semi-infinite, homogeneous medium for (hemispherical earth) electrical flow can be written as

$V = \rho I/2\pi x\ 1/r$……………………………..(5)

and for hydraulic flow a similar equation can be written as:

$h = Q/2\pi T x\ \ln r$ …………………(6)

Transmissivity of an aquifer of saturated thickness b then is expressed by

$T = Kb$……………………......................(7)

and as such, Eq. (6) becomes:

$h = Q/2\pi K b x \ln r$ …………………………..(8)

In general terms, since larger connected pores make for better flow characteristics for both water and electric currents it is expected that at the very least there should be some relationship between electrical and hydraulic parameters. Hydrogeological properties of the aquifers in fractured aquifers generally vary rapidly. As a result, directly linear relations between resistivity and hydraulic parameters (K and T) do not readily exist. Therefore, in present study, nonlinear relations between resistivity and transmissivity and permeability have been used. The empirical relation between K and ρ may be used to compute permeability estimates at VES locations where K data from pumping tests is not directly available. However, it is potentially a very difficult task to generalize the relationships both to alluvial and fractured aquifers. Transmissivity evaluations based on permeability estimates in the former case may be particularly erroneous if the saturated thickness and electrical resistivity of the aquifer are not interpreted accurately. Thus accuracy in estimation of thickness and resistivity of the aquifer must be adequately maintained while interpreting the VES data, and rms error<5%.

According to Singhal and Niwas (1981), the analytical relationship between aquifer Transmissivity (T), hydraulic conductivity (K) and aquifer thickness (h) is given by:

$T = Kh$……………………………………. (9)

And in accordance with Singh (2005)

$K = 8 \times 10^{-6} e^{-0.0013\rho}$…………………………..(10)

where ρ is resistivity of the aquifer.

The relation above is used to estimate hydraulic conductivity (K) and the unit is sandwiched by resistive layers (Singh, 2005). In hydrogeological maps, Transmissivity has been the best hydraulic property to clearly express groundwater potential ((Krasny, 1993; Kudamnya and Osumeje, 2015; Osumeje et al, 2016)

2.0 GEOLOGY AND GEOMORPHOLOGY

The area of study Mando is located in Igabi Local Government Area of Kaduna State, situated in Northern Kaduna Metropolis, and covers the premises of National Water Resources Institute, Kaduna and environs. A sketch map showing the location of the study area with the VES and borehole points is shown in Figures 1 and 2 below. Also, the coordinates of the VES points are given in Table1 below. The area is located on the basement complex, although the terrain is flat, with no visible outcrop.

The study area consists mainly of the migmatite-Gneiss Complex which consists of migmatite, biotites and granitic gneiss. The migmatite gneiss complex represents reactivated metasedments which are characterized by a variety of structures and textures. Now, the basement complex lies in an extensive Pan-African mobile belt situated between the West African and Congo Cratons (Fig. 1). It consists of a wide variety of metamorphic and igneous rocks and has been shown to be polycyclic with ages ranging from 2800M.a to 450M.a. The Pan-African event (600±150M.a) was the latest reactivation that affected the whole region (Fitches et al, 1985), and it caused regional metamorphism and deformation which imposed a generally N-S foliation trend and brought about the emplacement of granitoids. The basement complex can be subdivided into three major lithological units which are Migmatite-Gneiss complex; Older Granite and Schist Belt. The crystalline basement complex can thus be considered to compose mainly of metamorphic rocks. The major rock type in the area of study comprises of migmatite-gneiss complex that underlain most of the area. The metasedimentary series consists of undifferentiated schist, including gneiss, fine grained flaggy quartzite and pegmatites. These are metamorphosed sedimentary and metavolcanic rocks. The area is capped by laterites. The laterites are sometimes highly consolidated especially at the surface and weathered into lateritic nodules mixed with silty and sandy clays.

The storability and hydraulic conductivity of groundwater flow systems in the crystalline basement areas as in the area of study depend on the extent of development of secondary structural features such as the weathered overburden and fractures. These fractures tend to close with depth due to increasing weight of the overburden. In these area groundwater therefore occurs either in the weathered mantle or fractured systems of the unweathered or partly weathered bedrock or both as these two aquifer types mostly interconnected in places culminating in groundwater basins. Due to differential weathering, these groundwater basins are often localized in such a way that it becomes desirable for a geophysical investigation to be carried out prior to drilling to locate them as accurately as possible to avoid abortive wells. This is the justification for the investigations.

The local hydrogeology of the premises investigated is characterized by shallow groundwater conditions as is evidenced by the presence of dug wells (about 6m depth) reflecting encouraging potentials for groundwater development.

Study Area

Figure1. Map of Kaduna State showing the Study Area in Igabi Local Government Area

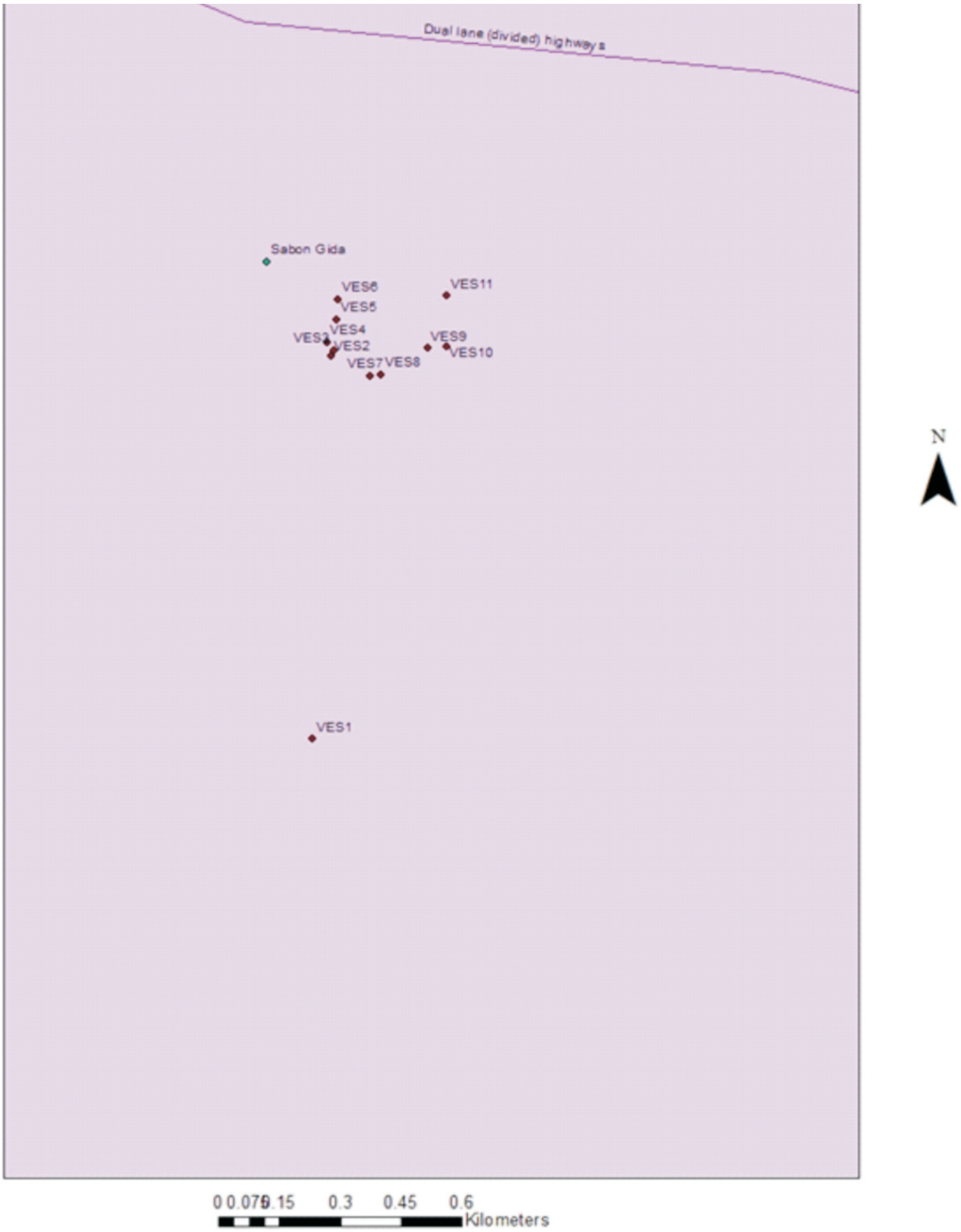


Figure 2 Map of Study Area showing the VES points

Table1. Showing the coordinates of the VES points

Location/VES No	**Latitude**	**Longitude**	**Elevation(AMSLm)**
1	N10^{0}34.364'	E007^{0}25.061'	625
2	N10^{0}34.874'	E007^{0}25.085'	627
3	N10^{0}34.882'	E007^{0}25.089'	626
4	N10^{0}34.893'	E007^{0}25.080'	625
5	N10^{0}34.923'	E007^{0}25.093'	625
6	N10^{0}34.950'	E007^{0}25.095'	624
7	N10^{0}34.848'	E007^{0}25.137'	626
8	N10^{0}34.850'	E007^{0}25.152'	626
9	N10^{0}34.885'	E007^{0}25.214'	630
10	N10^{0}34.888'	E007^{0}25.239'	632
11	N10^{0}34.955	E007^{0}25.240'	630

3.0 MATERIALS AND METHODS

The method of study involves geophysical investigation using resistivity method. In the DC resistivity surveying, an electric current is passed into the ground through two outer electrodes (A and B), and the resultant potential difference is measured across two inner electrodes (M and N) that are arranged in a straight line, symmetrically about a centre point. The ratio of the potential difference to the current is displayed by the Resistivity meter as resistance. A geometric factor in metres is calculated as a function of the electrode spacing. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed (Abubakar et al, 2016). Mc Ohm-EL model was the resistivity meter used. After the resistance is measured, it is multiplied by the geometric factor to get the apparent resistivity for each electrode spread. The apparent resistivity values are subsequently plotted against the electrode spacing AB/2 on a log-log scale to obtain the depth sounding curves. The VES data were interpreted using computer software IPI2win. The interpreted VES data was then analyzed to determine the aquiferous zones with their respective thicknesses and resistivities. Based on the above equations (equations 9 and 10), the Hydraulic Conductivity and Transmissivity values of the study area were calculated as shown in tables 3 and 4 below.

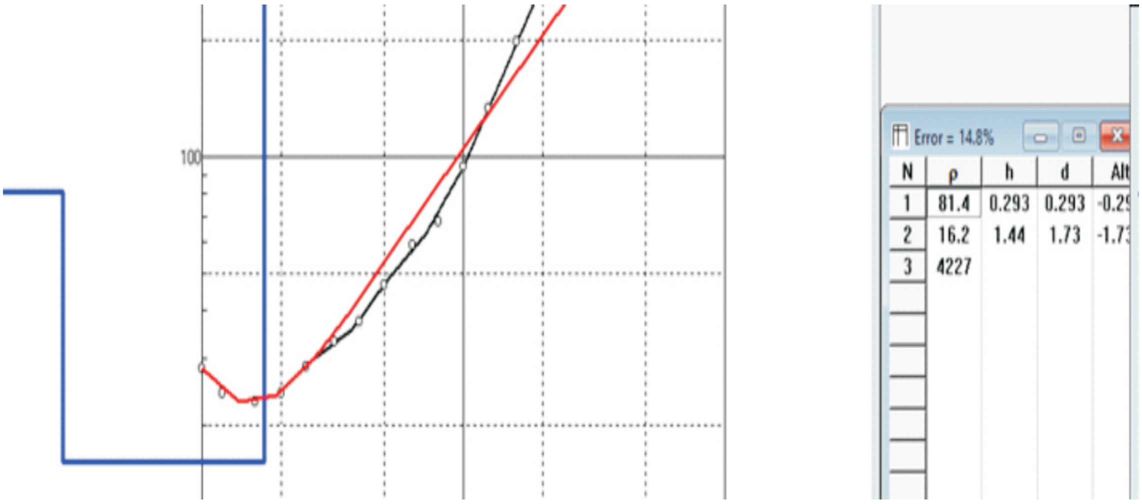
These results are then compared to the ones got from pump test for the two boreholes drilled in the area. The boreholes used in the study were drilled using Korean Rig (KIA Engine). In both boreholes, the drilling was started using 10" clay cutter which was used to drill the overburden. This was changed to 6" Down the Hole hammer to drill the hard rocks. 8" temporary casings were now used to hold the overburden before the hammer was introduced. At the completion of the drilling, screens and casings were installed before removing the temporary casings. Gravel packing and cement grouting then completed the construction process. Pumping test was carried out to determine the hydraulic properties of the aquifer such as transmissivity and hydraulic conductivity for comparison with the values estimated from the VES investigation.

Information on thickness of the aquifer used in the calculation of T from K (see equations 9) is extracted here using the thickness of aquiferous zones got from the VES interpretation, thickness of screened aquiferous zone from existing boreholes along with information on depth to the water table from the dug boreholes in the area. Thickness and resistivity of the aquifer at various observation points are obtained by inversion of VES data. The appropriate information available on hydrological parameters and depth of water table from dug wells and bore well is used to constrain and minimize the ambiguity of interpretation. The root mean square (rms) error between observed and computed VES data is mostly maintained less than 5% while computing the resistivity and thickness of the aquifer by employing inversion scheme proposed by Jupp and Vozoff (1975).

4.0 Results and Discussion

4.1 Results

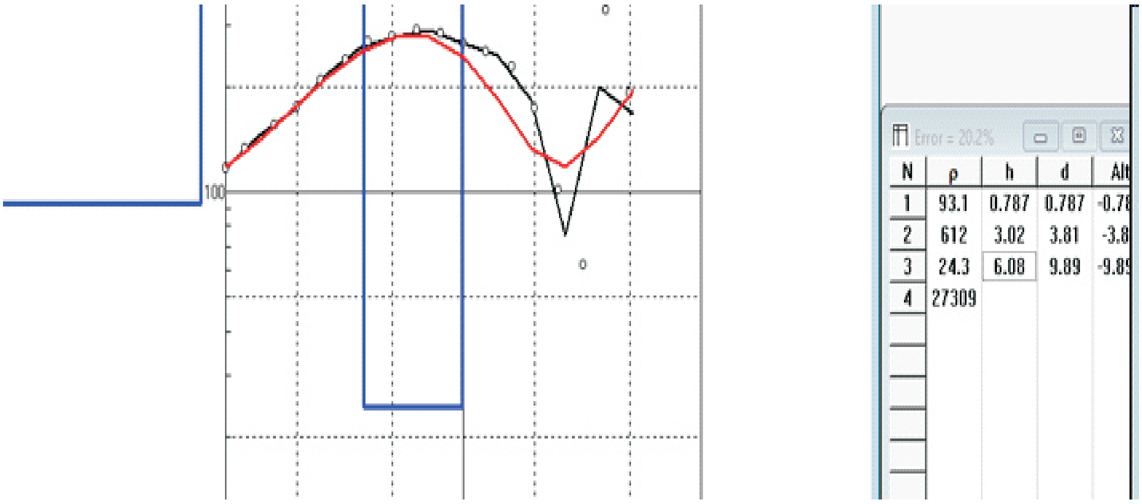
Figures 3 to 15 show the VES Interpretation resistivity sections and Pseudosections of the observed Resistivity data. Also, Table 2 to Table 4 show the aquifer parameters from Geoelectric Interpretation and Pumping Test.



Error = 14.8%

N	ρ	h	d	Alt
1	81.4	0.293	0.293	-0.2
2	16.2	1.44	1.73	-1.7
3	4227			

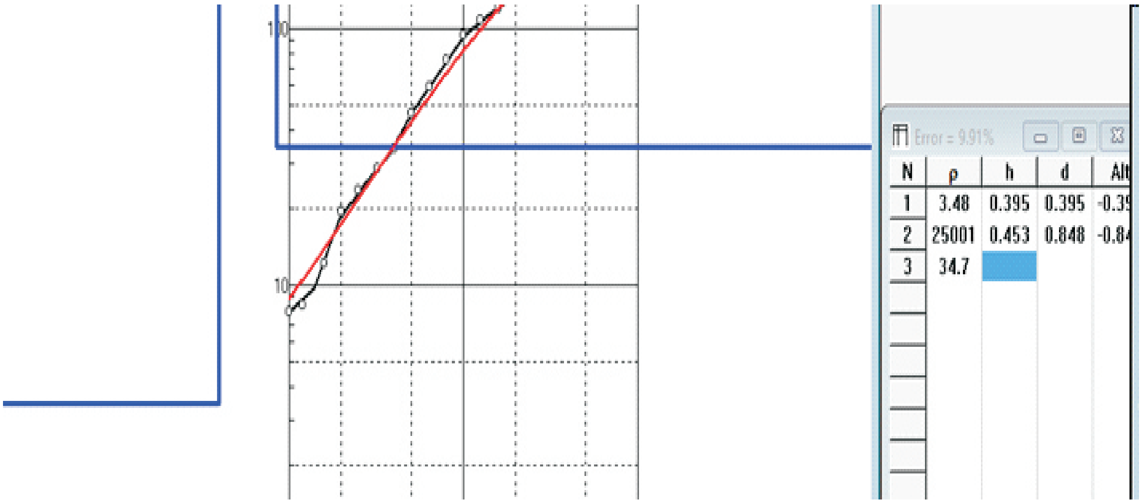
Figure3 VES interpretation at station1 (VES1)



Error = 20.2%

N	ρ	h	d	Alt
1	93.1	0.787	0.787	-0.78
2	612	3.02	3.81	-3.8
3	24.3	6.08	9.89	-9.8
4	27309			

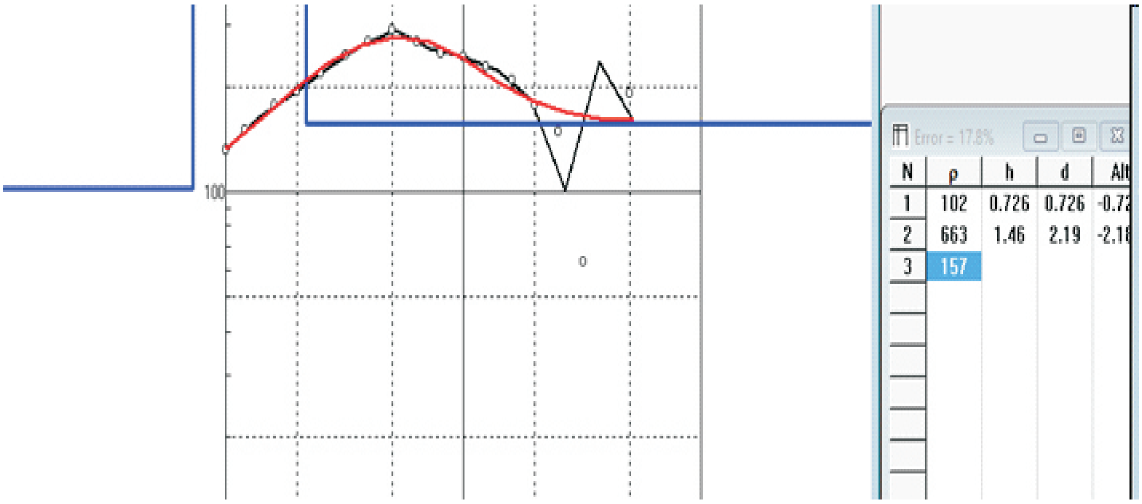
Figure4 VES Interpretation at station 2 (VES2)



Error = 9.91%

N	ρ	h	d	Alt
1	3.48	0.395	0.395	-0.39
2	25001	0.453	0.848	-0.84
3	34.7			

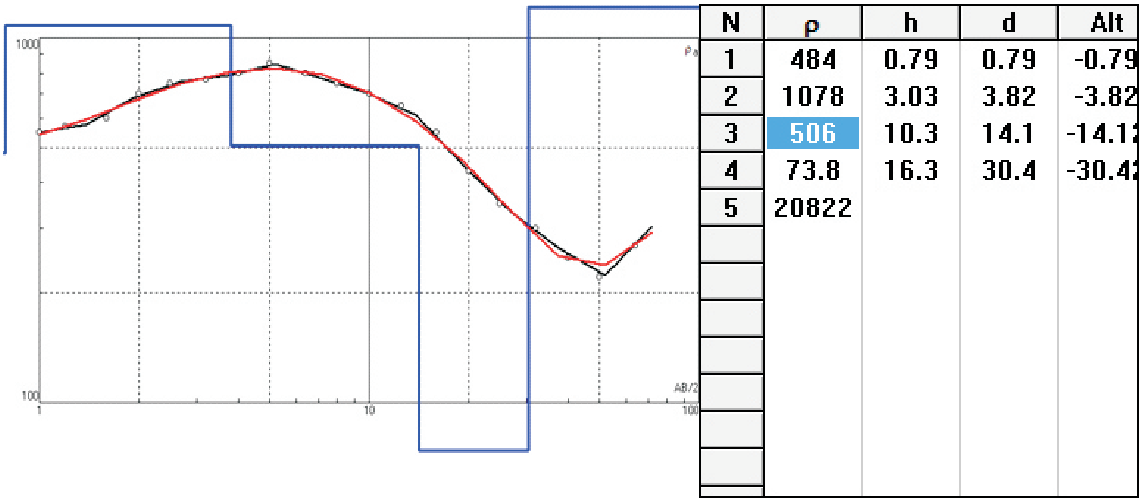
Figure5 VES interpretation at station 3 (VES3)



Error = 17.8%

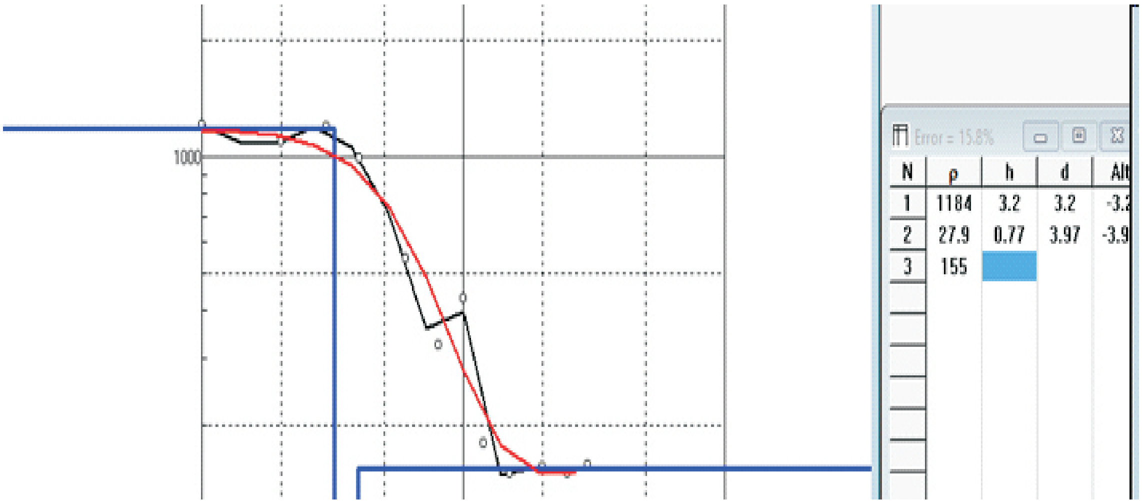
N	ρ	h	d	Alt
1	102	0.726	0.726	-0.72
2	663	1.46	2.19	-2.18
3	157			

Figure6 VES interpretation at station 4 (VES4)



N	ρ	h	d	Alt
1	484	0.79	0.79	-0.79
2	1078	3.03	3.82	-3.82
3	506	10.3	14.1	-14.12
4	73.8	16.3	30.4	-30.42
5	20822			

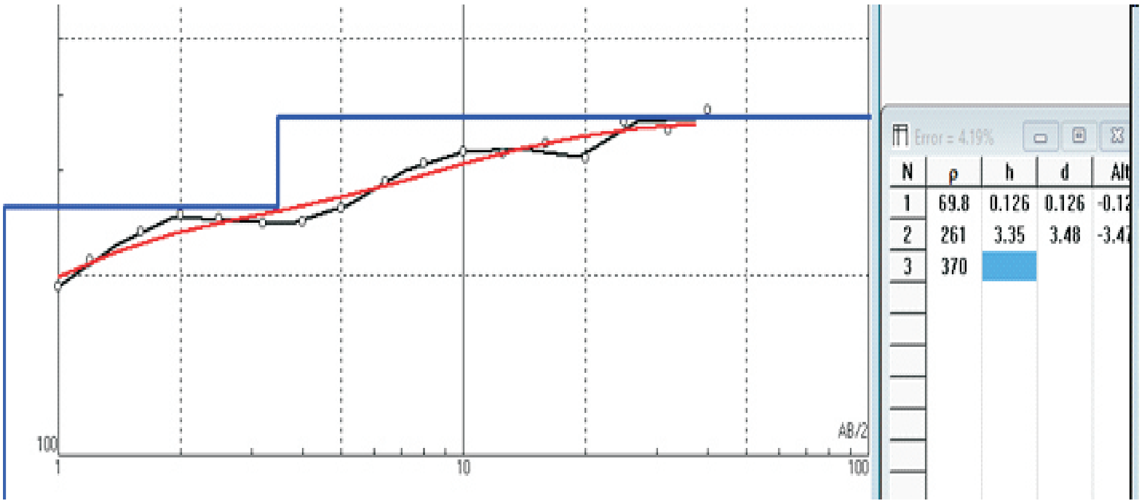
Figure7 VES interpretation at station 5 (VES5)



Error = 15.8%

N	ρ	h	d	Alt
1	1184	3.2	3.2	-3.2
2	27.9	0.77	3.97	-3.9
3	155			

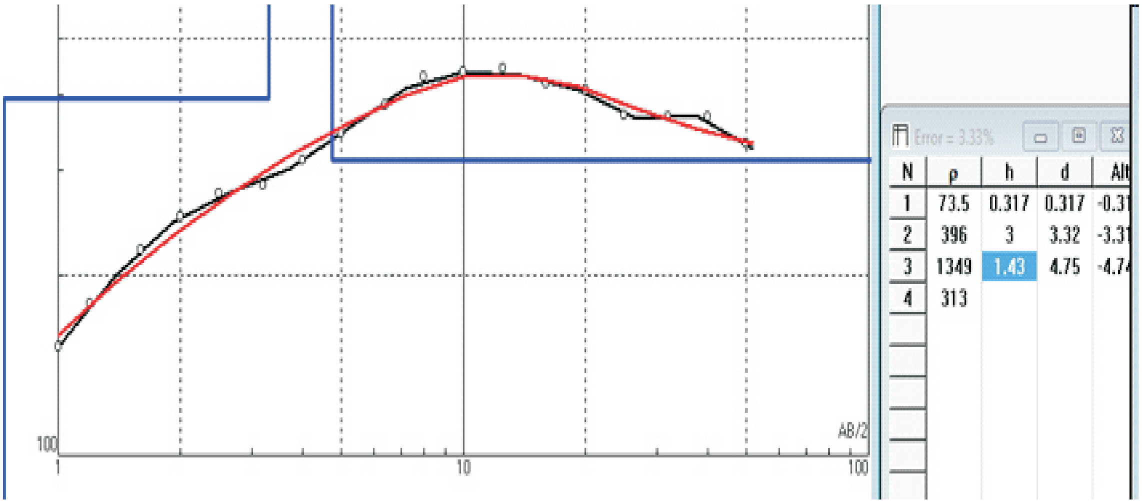
Figure8 VES interpretation at station 6 (VES6)



Error = 4.19%

N	ρ	h	d	Alt
1	69.8	0.126	0.126	-0.12
2	261	3.35	3.48	-3.4
3	370			

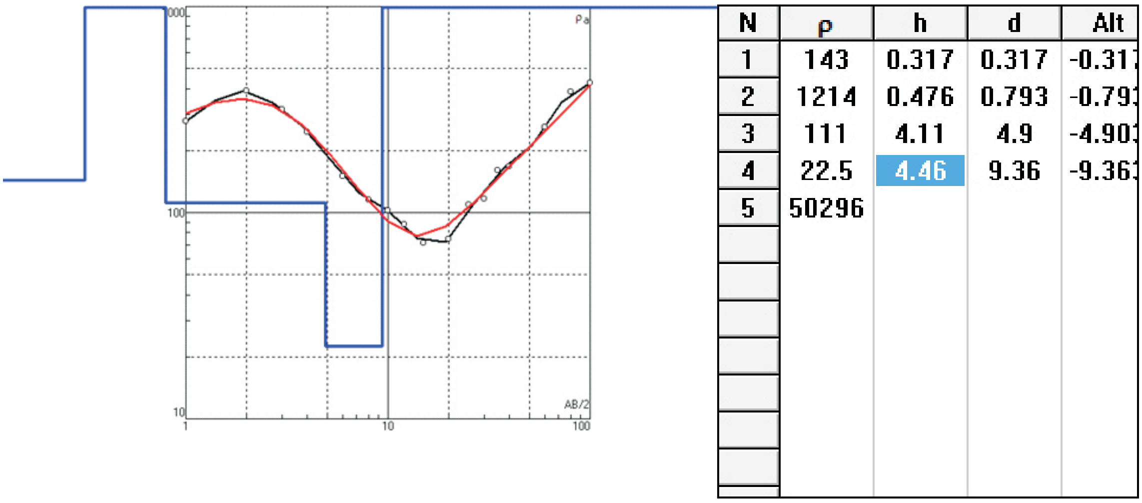
Figure9 VES interpretation at station 7 (VES7)



Error = 3.33%

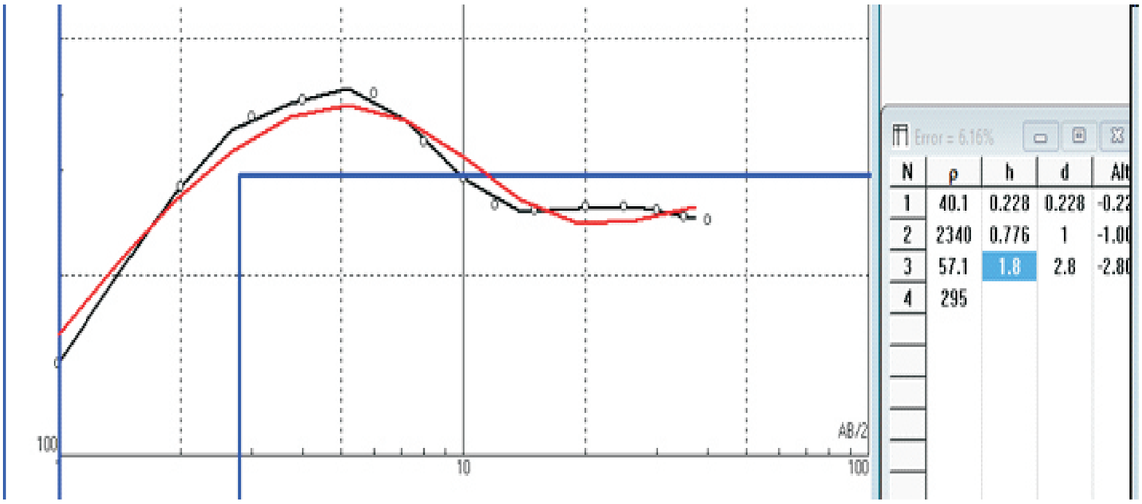
N	ρ	h	d	Alt
1	73.5	0.317	0.317	-0.31
2	396	3	3.32	-3.31
3	1349	1.43	4.75	-4.7
4	313			

Figure10 VES interpretation at station 8 (VES8)



N	ρ	h	d	Alt
1	143	0.317	0.317	-0.31
2	1214	0.476	0.793	-0.79
3	111	4.11	4.9	-4.90
4	22.5	4.46	9.36	-9.36
5	50296			

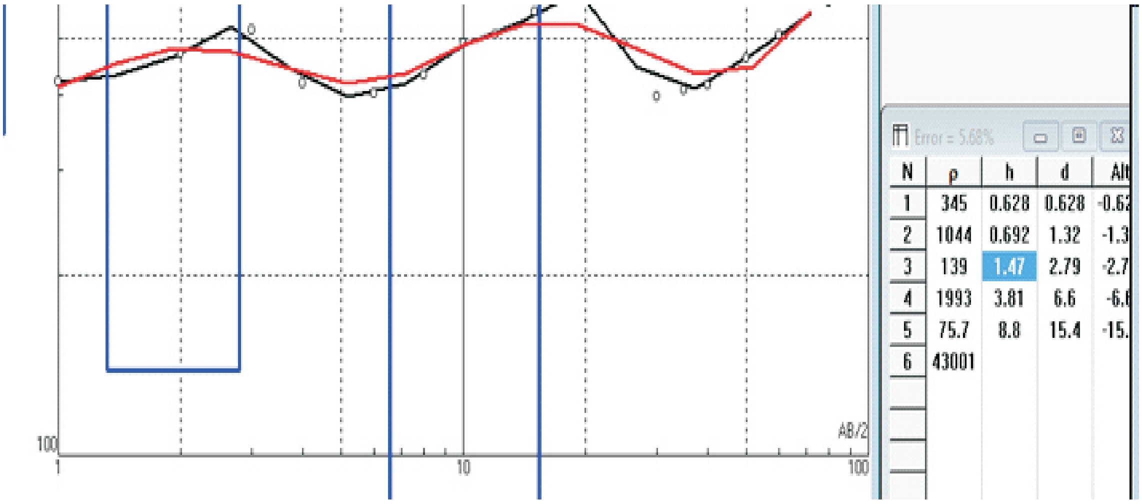
Figure11 VES interpretation at station 9 (VES9)



Error = 6.16%

N	ρ	h	d	Alt
1	40.1	0.228	0.228	-0.22
2	2340	0.776	1	-1.00
3	57.1	1.8	2.8	-2.80
4	295			

Figure12 VES interpretation at station 10 (VES10)



Error = 5.68%

N	ρ	h	d	Alt
1	345	0.628	0.628	-0.62
2	1044	0.692	1.32	-1.3
3	139	1.47	2.79	-2.7
4	1993	3.81	6.6	-6.6
5	75.7	8.8	15.4	-15.
6	43001			

Figure13 VES interpretation at station 11 (VES11)

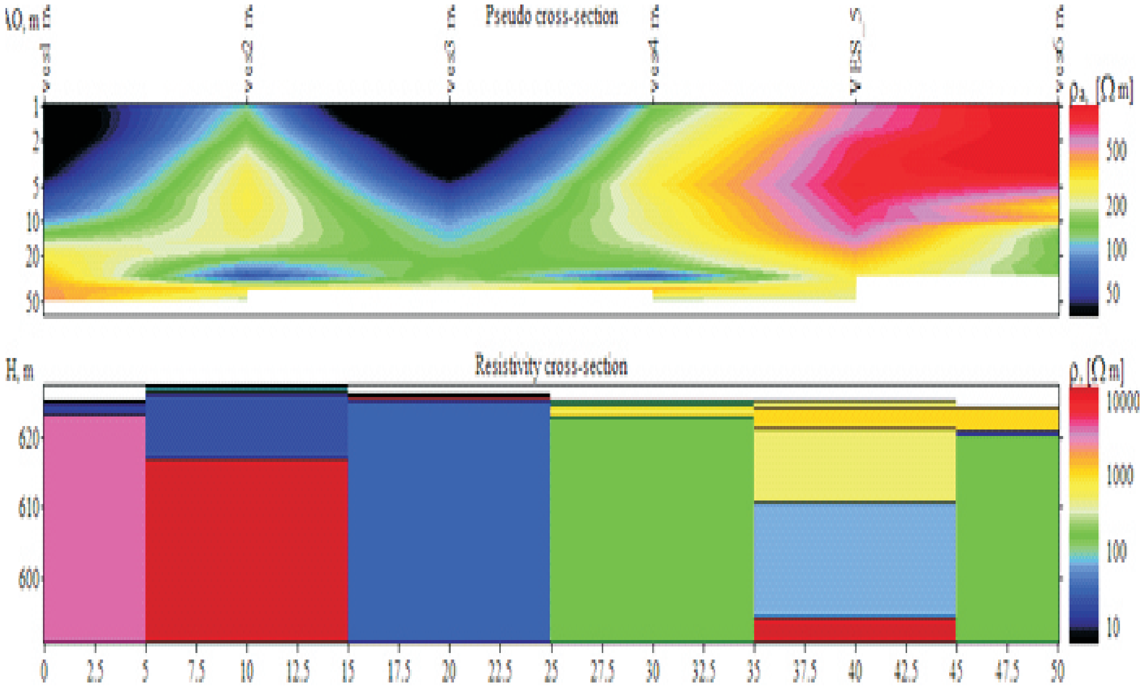


Figure14 Cross section Across VES1- VES6

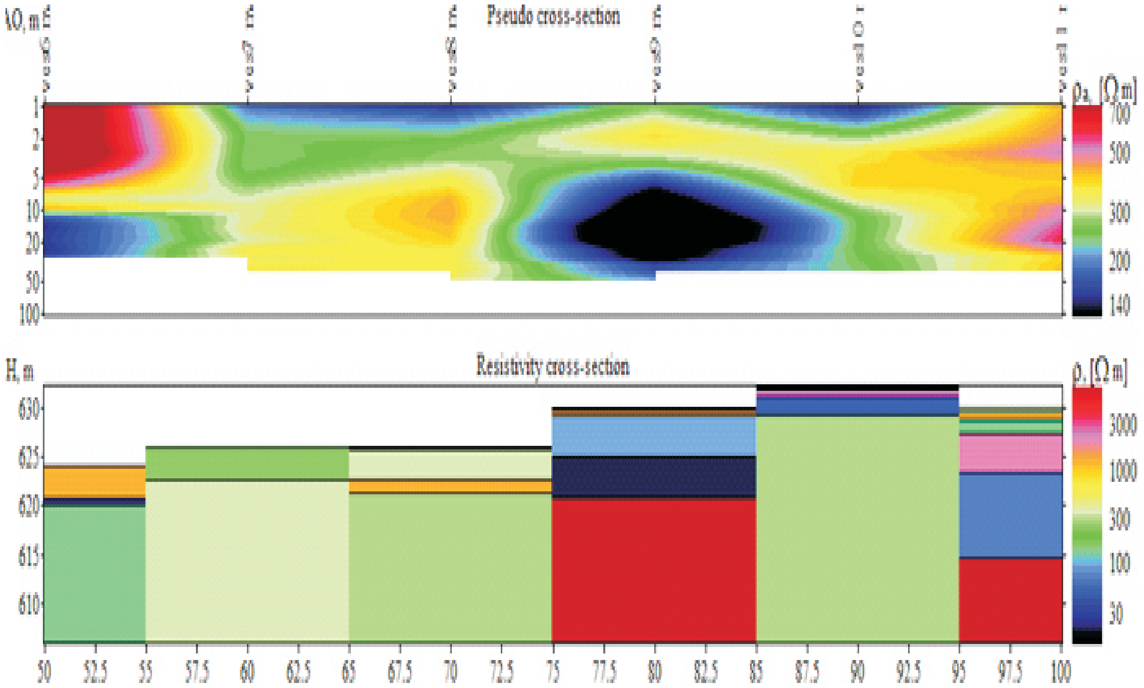


Figure15 Cross Section Across VES6-VES11

Table 2 Aquifer Parameters from Geoelectric Interpretation

VES No	Overburden thickness (m)	Weathered layer thickness (m)	Weathered layer Resistivity (fl m)	Thickness of fractured zone (m)	Number of layers	Type of curve
1	1.73	1.44	16.2	-	3	H
2	9.89	9.10	318.15	-	4	KH
3	0.848	-	-		3	K
4	2.19	-	-		3	K
5	3.82	16.3	73.8	-	5	KQH
6	3.97	0.77	27.9		3	H
7	3.48	3.35	261		3	A
8	4.75	3.0	396		4	AK
9	9.33	8.54	66.7	-	5	KQH
10	2.8	1.8	57.1		4	KH
11	15.4	8.8	75.7	-	6	KHKH

Table 3 Derivation of Hydraulic Conductivity using different aquifer thicknesses

Station /VES No	Depth to fractured freshrock (m)	Depth to fractureless freshrock (m)	Thickness of aquifer from VES Interpretation (m)	Thickness of aquifer derived from water table (m)	Thickness of screened aquifer (m)	Resistivity of aquifer (fl m)	Calculated Hydraulic conductivity Aquifer m/day
1	1.73	60	59.707	52	12	2121.2	0.6767955394
2	-	10.9	6.52	2.9	12	24.3	0.6697062728
3	0.848	60	59.152	52	12	34.7	0.660712777
4	2.19	60	57.81	52	12	154	0.5657935265
5	3.82	30.4	26.6	22.4	12	289.9	0.474166828
6	3.97	60	56.80	52	12	155	0.5650584728
7	3.48	60	59.874	52	12	315.5	0.4586462508
8	4.75	60	55.25	52	12	313	0.460139276
9	4.9	9.33	8.54	1.33	12	66.75	0.6337497862
10	2.8	60	59.004	52	12	176	0.5498410396
11	1.32	15.4	10.27	7.4	12	107.35	0.6011678725

Table 4 Comparison of pumping test Transmissivity and Transmissivity values calculated using different aquifer thicknesses

Station/ VES no	Transmissivity T calculated using thickness of aquifer from VES	Transmissivity T calculated using thickness of aquifer from depth to water	Transmissivity T calculated using thickness of screened aquifer	Transmissivity T from pumping Test of borehole (m^2/day)
1	40.4094313	34.8247262	8.12154647	10.8675
2	4.366484899	1.942148191	8.036475274	
3	39.0824822	34.3570644	7.928553324	
4	32.7085238	29.4101263	6.78952232	
5	12.61283762	10.6213369	5.69000194	6.3530
6	32.0953213	29.3830406	6.78070167	
7	27.4609856	23.8496028	5.50375501	2.7125
8	25.422695	23.9272424	5.52167131	
9	5.41222317	0.84288722	7.60499743	
10	32.4428207	28.5917341	6.59809248	
11	6.17399405	4.44864226	7.21401447	4.8450

4.2 Discussion

The interpretation of the resistivity survey revealed 3 layer curves of the type H: i.e. ρ1Ωρ2Ωρ3 for VES1 and VES6; of the type K: i.e. ρ1Ωρ2Ωρ3 for VES3 and VES4; and of the A type: i.e. ρ1Ωρ2Ωρ3 for VES7. It shows 4 layer curves of the type KH: i.e. ρ1Ωρ2Ωρ3Ωρ4 for VES2 and VES10; and of the type AK: i.e. ρ1Ωρ2Ωρ3Ωρ4 for VES10. While it is 5 layer curves of the type KQH: i.e. ρ1Ωρ2Ωρ3Ωρ4Ωρ5 for VES5 and VES9. VES 11 shows a 6 layer curve of the type KHKH: i.e. ρ1Ωρ2Ωρ3Ωρ4Ωρ5Ωρ6. The aquiferous zones were identified to be layer 2 in VES1; and layer 3 in VES2, VES3, VES4, VES6 and VES7 (the layer mostly consist of both overburden and fracture aquifers). Also, in VES5 and VES8, the aquiferous zones are layer 4. In VES9 and VES10, layer 3 constitutes the weathered aquifer while layer 4 is the fracture aquifer. In addition, layer 5 constitutes the overburden aquifer in VES11. The resistivity values of these zones have been used to compute the hydraulic conductivity (K) using equation (10). Also, the thickness of the aquifer used for calculating Transmissivity from hydraulic conductivity were determined in three different ways: (a) using the thickness, h= Depth to fresh basement rock minus Depth to water table (b) using the thickness h of aquiferous zone derived from VES interpretation and (c) using the thickness h of the screened aquiferous zone of the available boreholes. Ultimately, the Transmissivity values got from the VES interpretation were compared to the values got from pumping test of the boreholes. It should be noted that some assumptions were made in the process of calculating the thickness of aquifer by the three methods, these are: (a) Where the thickness of the aquiferous zone is not well defined by VES interpretation, the depth to fractureless freshrock is taken to be 60m. (b) Depth to water table in the area is generally taken to be 8m. (c) The thickness of screened aquiferous zone is taken to be 12m. The thickness of the aquifer used for calculating Transmissivity from

Hydraulic Conductivity were determined in three different ways: (a) using the thickness, h= Depth to fractureless fresh basement rock minus Depth to water table and (b) using the thickness h of aquiferous zone derived from VES interpretation and (c) using the thickness h of the screened aquiferous zone from the available boreholes. The Transmissivity values from the three different aquifer thicknesses were now compared to those got from pumping test. It was observed that where the thickness of the aquiferous zone is well defined by the VES interpretation, the Transmissivity values correlate fairly with the pumping test results for all the different aquifer thicknesses as seen in VES2, VES5, VES9 and VES11. On the other hand, where the thickness of the aquiferous zone is not well defined, so that the depth to fractureless freshrock is taken to be 60m, the Transmissivity values are much higher than the pumping test Transmissivity values, except where the thickness of screened aquiferous zone is used (see Table3). This goes on to say that where the thickness of the aquifer is not well defined by the VES interpretation, the thickness of screened aquiferous zone should be used (for instance, one should find the thickness of the screen used for boreholes in the area). The high Transmissivity values may be as a consequence of the fact that the calculations takes into consideration that the porosity and permeability are constant and continuous throughout the length of the aquifer. And also, only a part of the aquiferous zone is usually actually screened.

Also, based on the VES curves, the psedosections and the resistivity cross sections, the high groundwater potential zones in the area have been identified as VES3, VES4, VES5, VES6, VES7, VES8 and VES10

CONCLUSION AND RECOMMENDATION

CONCLUSION

The goal of this research primarily was to determine the hydraulic properties of an aquifer using the Singh 2005 and Singhal and Niwas 1981 formulae, and at the same time to test the validity of these formulae. As a result, the Transmissivity values were determined using the hydraulic conductivity values with the thicknesses got from different methods. However, it was discovered that where the thickness of the aquiferous zone is well defined by VES interpretation, the Transmissivity values got tend to correlate with the values from pumping test. Conversely, if the thickness is not well defined by the VES interpretation, the Transmissivity values got thereof are too high, and cannot be relied upon. Also the high groundwater potential zones in the area have been located.

RECOMMENDATION

It is recommended that where the thickness of the aquiferous zone is well defined by the VES interpretation, the Transmissivity values got will approximate true Transmissivity within the limit of experimental error. On the other hand, if the aquiferous thickness is not well defined, then thickness of screened aquiferous zone should be used.

REFERENCES

Abubarka A; Ahmed A.I and Dewu B.M, 2016. Groundwater Investigation Using Geophysical Methods- A Case study of Unguwa Sarki Community Area, Kufena Zaria Nigeria. Book of Readings: 6th National Water Conference 2016, 121-131

Ajibade A.C and Wright J.B, 1989. The Togo-Benin Nigeria Shield: Evidence of CruAggregation in the Pan African Belt, Technophys 165, p125-129

Biella G; Lojez A and Tabacco I 1983.Experimental Study of Some of Hydrogeophysical Properties of Unconsolidated Media, Ground Water, 21, 741–751,

Brace, W. F 1977.Permeability from resistivity and pore shape, J. Geophys. Res., 82, 23, 334–339,

Bussian A. E, 1983. Electrical conductance in porous medium, Geophysics, 48, 1258–1268

Chen J; Hubbard S and Rubin Y, 2001. Estimating Hydraulic Conductivity at the South Oyster Site from Geophysical Tomographic Data using Bayesian Techniques based on the Normal Linear Regression Model, Wat. Resour. Res., 37, 6, 1603–1613,

Dhakate R and Singh S.B, 2005. Estimation of Hydraulic Parameters from Surface Geophysical Methods, Kaliapani Ultramafic Complex, Orissa, India. Journal of Environmental Hydrology

Fitches W.R; Ajibade A.C; Egbuniwe I.G; Holt R.W and Wright J.B, 1985. Late Protezoic Schist Belts and Plutonism in Northwestern Nigeria. Journal of Geological Society, 142, London. P319-337

Fitts C.R, 2002. Groundwater Science, Elsevier Science Publications. The Netherlands, 167-175

Freeze R. A. and Cherry J. A 1979. Groundwater. Prentice- Hall, Inc., Englewood Clifs, N.J,

Heigol P. C; Gilkeson R. H; Cartwright K and Reid P. C, 1979. Aquifer Transmissivity from Surflcial Electrical Methods, Ground Water, 17, 330–345,

Hubbard S and Rubin Y, 2002. Hydrogeophysics: State-of-the-Discipline, EOS v. 83, 51, 602, 606,

Jupp D. L. V and Vozo K, 1975. Stable Iteration Method for Inversion of Geophysical Data, Geophys. J. Roy. Astr. Soc., 42, 957–976

Kelly W.E, 1977. Geoelectric Sounding for Estimating Aquifer Hydraulic Conductivity. Journal New England Water Works Association 15(6), 406-454

Kelly W. E, 1977a. Electrical Resistivity for Estimating Permeability, J. Geotech. Eng. Div, 103, 1165- 1168,

Kelly W. E, 1977b. Geoelectrical sounding for estimating aquifer hydraulic conductivity, Ground Water, 50, 6, 420–425,

Krasny J, 1993a. Classification of Transmissivity magnitude and Variation. Groundwater 31(2), 230-236

Kudamnya E.A and Osumeje J.O, 2015. Geoelectric Investigation of the Groundwater Potential Distribution within the Northern Basement Complex of Nigeria. International Journal of Scientific ang Engineering Research 6(2). 1152-1160

Omotayo K.E and Eduvie M.O, 2017. Investigating the Determination of Hydraulic Properties of Aquifers using Electrical Resistivity Method Solely at Jere, Kagarko Local Government Area of Kaduna State. Proceedings at the7th National Conference 2017

Osumeje J.O; Recto A.A; Raimi J; Oniku S.A and Kudanmya E.A, 2016. Using Geophysical Technique to Determine Groundwater Yield for some part of Fika Local Government Area of Yobe State. Proceedings at the 6th National Water

Conference 2016. 49-57

Roy K. K and Elliot H. M, 1981.Some observations regarding depth of exploration in DC electrical methods, Geo-exploration, 19, 1–13

Singh K. P, 2003a. A New Approach for Detection of Hidden Aquifer Using DC Resistivity Data Transforms, J. Geolog. Soc. India, 61, 540–548

Singh K. P, 2003b. Geo-electrical exploration for groundwater in a Hard Rock Region of Hyderabad, India, First Break, 21, 29–34

Singh K.P, 2005. Non Linear Estimation of Aquifer Parameters from surfacial resistivity measurements. Hydrol. Earth System Science, Discus 2, 917-938

Singhal D.C and Sri Niwas, 1981. Estimation of Aquifer Transnissivity from Dar- Zarrouk Parameters in Porous Media. Journal of Hydrology. Vol. 50, 393- 399

Sri Niwas Singhal D.C, 1985. Aquifer Transmissivity of porous media from resistivity data, J. Hydrol., 82, 143–153

Urish D. W, 1981. Electrical Resistivity: Hydraulic Conductivity relationships in glacial out wash aquifers. Water Resources 17, 1401-1408