Estimation of aquifer hydraulic parameters from surficial geophysical methods: a case study of Ota, Southwestern Nigeria

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Abstract. Geoelectrical resistivity surveys have been carried out using Schlumberger configuration within the Iyana Iyesi area of Ota, Ogun state. The aim of this research was to experimentally estimate the hydrogeophysical parameters of an aquifer (porosity, transmissivity, hydraulic conductivity and permeability) which have been completed successfully. Since drilling of boreholes specifically to compute the hydraulic parameters is relatively expensive, estimation of the parameters from vertical electrical soundings is considered a reliable alternative. The results showed that the study area has majorly low value of overburden materials serving as the protective capacity to the aquifers that are characteristically high in porosities and transmissivities. This low protective capacity denote the high vulnerability of the aquifer system to the influx of surface-based contaminants. The aquifer systems within the study area possess significantly high storativity property based on their high porosity and transmissivity.

Keywords: Electrical resistivity, Groundwater exploration, Hydraulic parameters, Sedimentary terrain, Aquifers porosity, Aquifer transmissivity

1. Introduction

Adequate availability and sufficient access to good water for domestic and industrial use is a critical issue worldwide. The groundwater is a dependable source of portable water supply for both home-use and agricultural activities (irrigation). This source is characteristically cost effective with high quality water supply in major urban centers in most developing countries. Considering the importance of groundwater, the quantitative aquifer characterization has become important in addressing some hydrogeological issues such as low yields and productivity. In order to estimate hydro-geophysical parameters of the subsurface aquifer, geophysical surveys need to be carried out. Geophysical methods provide information about the subsurface over a variety of spatial resolution and they depend on the characteristic physical properties of rocks. These techniques are relatively cheap, labour intensive and sensitive to different properties. There are many methods used in geophysical surveys for hydro-geophysical investigations but the most commonly used method is the geoelectrical resistivity method which can either be conducted in electrical profiling or vertical electrical sounding modes, a combination of which gives 2D, 3D and 4D time-lapse surveys. Several works have been carried out on the evaluation, exploration and exploitation of groundwater within the crystalline basement and sedimentary terrains of Nigeria [1-15].

This research focuses on estimating hydro-geophysical parameters such as transmissivity, hydraulic conductivity, porosity and permeability from surface electrical resistivity measurements. Surficial geoelectrical resistivity survey involves the injection of electrical current into the ground using electrodes in order to understand the lateral changes and vertical cross sections of the natural hydro-geologic setting. This method of geophysical investigation is also useful to delineate a localized buried objects and monitor the presence and mobility of contaminants in the subsoil and groundwater.

2. Methodology

2.1. *Location and the geology of the study area*

The study area is Iyana Iyesi, Ota situated within the Ado–Odo LGA of Ogun state, southwestern Nigeria. The state lies approximately between latitude 6.2°N and 7.8°N. The area is characterized by a gentle slope with a low lying area, and the two major climatic seasons are dry and season. Ota and its environs fall in the eastern portion of the Dahomey (or Benin) basin of Southwestern Nigeria extending from the continental margin of the Gulf of Guinea (Fig. 1). The stratigraphy of the Dahomey basin consists of the Abeokuta Group which is subdivided into Ise, Afowo and Araromi Formations [17]. The Abeokuta Group lies directly above the base of the basement complex; this in turn is overlain by Ewekoro Formation and others [18] [19].

2.2. *Data acquisition and processing*

Vertical electrical sounding (VES) survey was carried out using Schlumberger array at 12 different locations in the area (Fig. 2). The overburden materials are not too thick to necessitate the use of large current electrode spacing for deeper penetration, therefore the maximum AB/2 used was 320m on a logarithmic scale which began at a distance of 1.0m. ABEM Terrameter was used for the data acquisition. An initial spacing was chosen, and the current electrodes were moved outward while the potential electrodes were maintained at fixed points. At some points where the AB/2 became large enough, an increase of the potential electrode spacing was needed. The resistivity readings at every VES point were automatically displayed on the digital screen and saved. VES field curves may have subtle inflections which require the interpreter to make decisions as to how real or how significant such features are. Often a noisy field curve is smoothed to produce a graph which can then be modelled more easily. The field data smoothed and corrected as necessary, were plotted on a log-log graph and interpreted on a set of standard master curves. The estimated geoelectric parameters from the partial curve matching process were adopted as initial model parameters for computer-based iterations on an iteration software (WIN RESIST) which was used to iterate the sounding curves of (VES 1-12) to obtain the final model geoelectric layers parameters.

2.3. *Hydraulic parameters estimation*

The similar expressions for both electrical flow through a conductive medium and the fluid flow are described below based on the Ohm's law and Darcy's law.

$$J = -\sigma * dV / dr \tag{1}$$

$$Q = -K * \frac{dh}{dr}; K = k * y / \mu \tag{2}$$

where in equation (1) J, σ and V represent current density, electrical conductivity (reciprocal of electrical resistivity ρ) and the electric potential at a point with distance r. In equation (2), Q, h, k, μ and y are the flow rate, hydraulic head, permeability, viscosity and specific weight. The physical relationship between rock properties was first attempted by Archie [20] on a clay free sands.

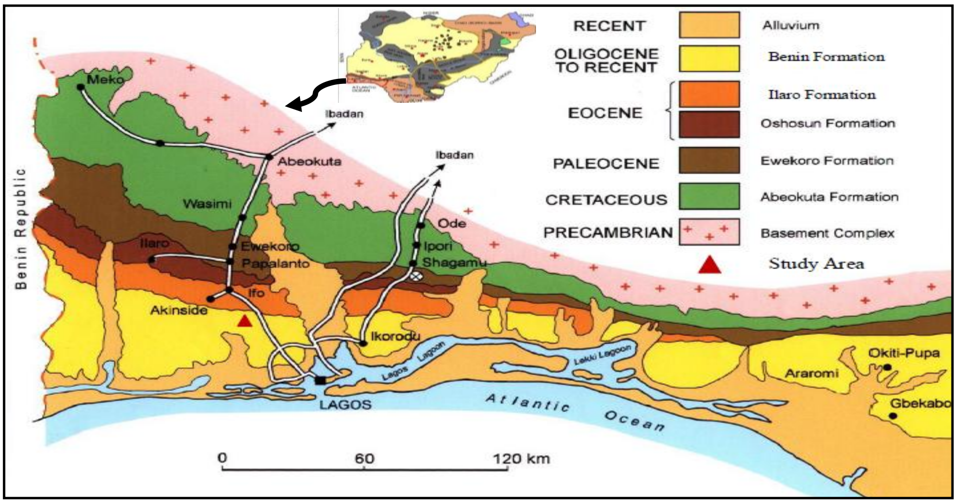

Fig.1: Geological sketch map of Nigeria showing the major geological components: basement, younger granites, and sedimentary basin (after [16])

Fig. 2: Displaying the location of the VES points within the study area using google map.

$$F_f = {\rho_r}/{\rho_w} \tag{3}$$

$$\rho_r = a * \rho_w \phi - mS_w - n \tag{4}$$

where Ff , ρr, ρw, ϕ, a and Sw are the formation factor, bulk and fluid resistivities, porosity, tortuosity (a) and water saturation, the cementation and saturation exponents are m and n respectively. In this research, the computation of hydraulic conductivity was carried out using the Kozeny – Carman-Bear equation as presented in equation (5).

$$k = \left(\frac{\delta_w g}{\mu}\right) \bullet \left(\frac{d^2}{180}\right) \bullet \left[\frac{\varphi^3}{(1-\varphi)^2}\right] \tag{5}$$

where d and δ_W are the grain size and fluid density (taken to be 1000kg/m^3). The μ is the dynamic viscosity (0.0014 kg/ms) [21]. The estimated hydraulic conductivity values are in m/sec using Eq.5. The properties of an aquifer are not governed by hydraulic conductivity (K) alone, but by the parameter, transmissivity (T). The transmissivity was estimated using Darcy's law for groundwater which was defined as:

$$T = K * h \qquad (6)$$

where K and h are the hydraulic conductivity and thickness. Water samples were gotten from the different VES locations and were tested with an apparatus called the conductivity meter which measured the electrical conductivity of the samples.

3. Results and Discussion

The results of the VES data inversion is presented in Figs (3 and 4). The number of the geoelectrical layers range from six to eight with the topsoil having depths range of 0.9 – 1.7 m, while the resistivity of this substratum ranges 49.4 – 295.8 ohm-m. Different delineated lithologies which are the Top Soil, Sandy Soil, Lateritic Clay, Confining Bed, Sand (aquifer) and Shale/Clay. The main aquifer which is fairly coarse sand unit is interpreted as the seventh geoelectrical layer (Table 1) with thickness ranging from 11.7 m to 13.1 m, and average bottom depth of about 60.0 meters. The estimated hydraulic parameters such as hydraulic conductivity, porosity, formation factor, transmissivity and permeability parameters of the rock (Table 2). Water samples were gotten at each location and tested for the hydraulic conductivity values. The thickness and resistivity were gotten from the inverse model while the formation factor and porosity were determined using Archie's law. Table 2 shows that the transmissivity of each VES is relatively high and porosity is also high. Since aquifers are characterized by its ability to store, transmit and retain water. Thus, the possible aquifer present in the study area is highly transmissible and porous.

4. Conclusion

Vertical electrical resistivity surveys have been carried out using Schlumberger configuration in Iyana-Iyesi area of Ota, Ogun state. The aim of this research was to experimentally estimate the hydrogeophysical parameters of an aquifer (porosity, transmissivity, hydraulic conductivity and permeability) which have been completed successfully. High porosity and transmissivity of the aquifer system in the area prove them to be highly viable and productive. Since drilling of wells specifically to compute the hydraulic parameters is relatively expensive, estimation of the parameters from vertical electrical soundings is considered a reliable alternative. Although this research has illustrated the power of hydrogeophysical methods for improving the resolution and understanding the subsurface properties, they are often still limited in their ability to inform about parameters that may be most relevant at the larger scales where water resources or environmental contaminants are managed. Based on our results, it has been concluded that the vertical electrical sounding surveys and analysis of water samples provide cost effective methodologies to estimate the hydraulic parameters of subsurface aquifers other than the expensive pumping test method. Therefore, with improved delineation of aquifer geometry and accurate estimation of hydraulic parameters for a viable aquifer system from surface-based geoelectrical resistivity surveys, sustainable groundwater resource exploitation and management can be planned for effectively.

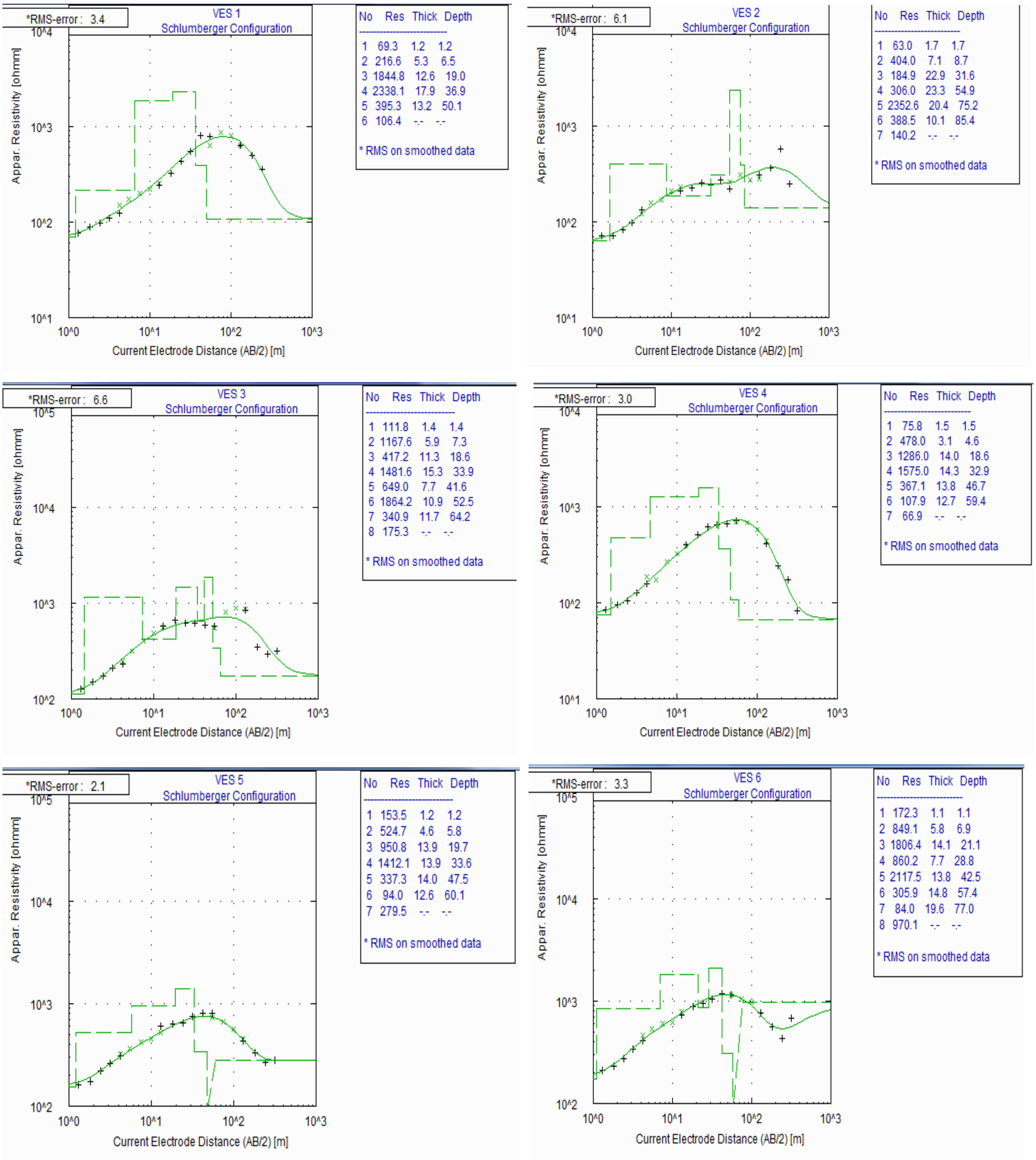

Fig. 3: Sounding curves interpretation for VES (1-6).

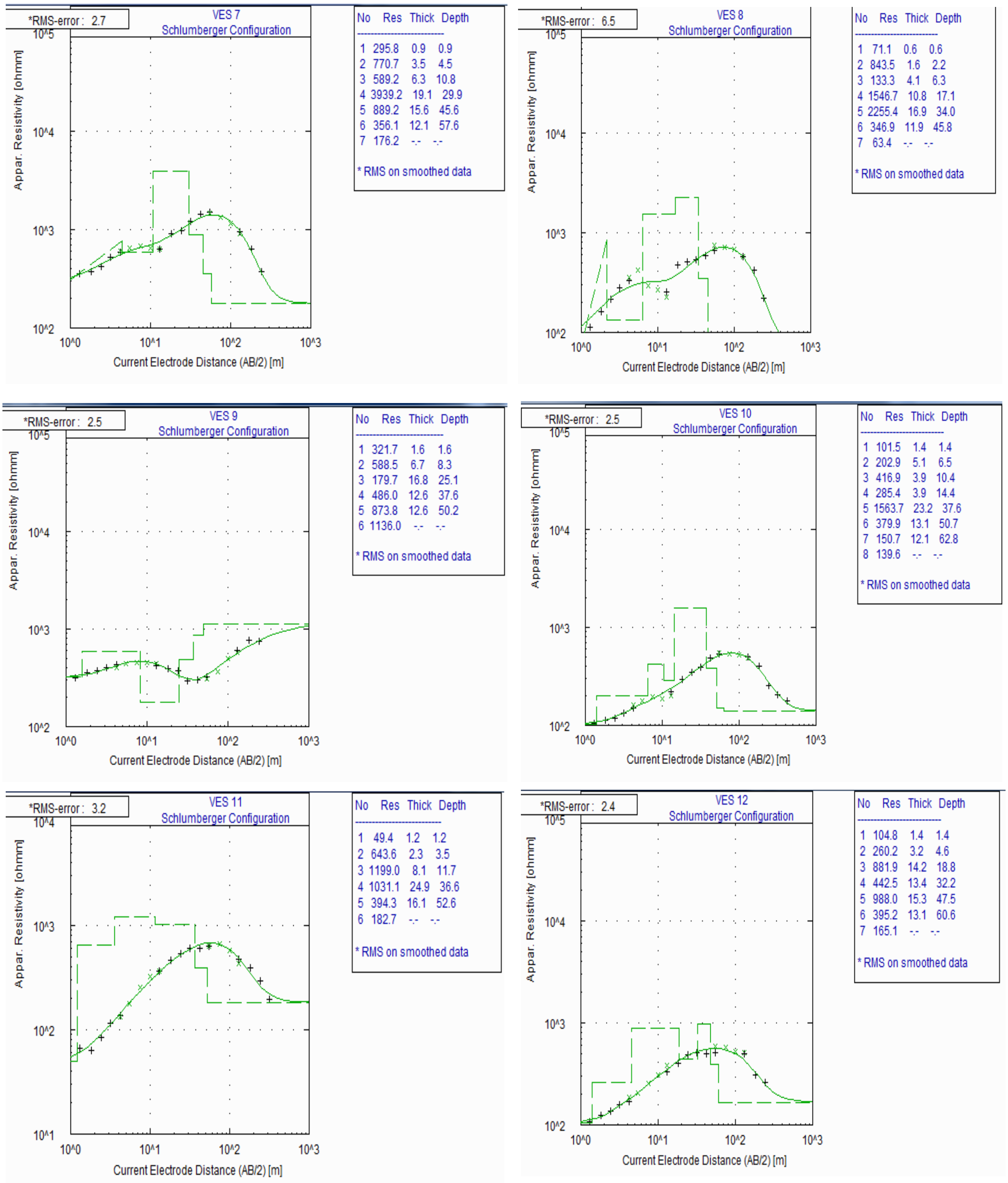

Fig. 4: Sounding curves interpretation for VES (7-12).

Table 1: Table showing geoelectrical parameters for the delineated layers from the VES data

VES		Layer 1	Layer 2		Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8
	Probable Lithology	Topsoil	Sandy Clay		Lateritic clay			Confining Clayey Sand	Sand (Main Aquifer)	Shale/Clay
1	Resistivity	69.3	216.6			1844.8	2338.1	395.3	106.4	
	Thickness	1.2	5.3			12.6	17.9	13.2		
	Depth	1.2	6.5			19.0	36.9	50.1		
2	Resistivity	69.0	404.0		184.9	306.0	2352.6	140.2		
	Thickness	1.7	7.1		22.9	23.3	20.4			
	Depth	1.7	8.7		31.6	54.9	75.2			
3	Resistivity	111.8	1167.6	417.2	1481.6	649.0		1861.2	340.9	175.3
	Thickness	1.4	5.9	11.3	15.3	7.7		10.9	11.7	
	Depth	1.4	7.3	18.6	33.9	41.6		52.5	64.2	
4	Resistivity	75.8	478.0		1286		1574	367.1	107.9	66.9
	Thickness	1.5	3.1		14		14.3	13.8	12.7	
	Depth	1.5	4.6		18.6		32.9	46.7	59.4	
5	Resistivity	153.5	524.7		950.8		1412.1	337.7	94.0	279.5
	Thickness	1.2	4.6		13.9		13.9	14.0	12.6	
	Depth	1.2	5.8		19.7		33.6	47.5	60.1	
6	Resistivity	172.3	849.1		1806.4	860.2	2117.5	305.1	84.0	970.1
	Thickness	1.1	5.8		14.1	7.7	13.8	14.8	19.6	
	Depth	1.1	6.9		21.1	28.8	42.5	57.4	77.0	
7	Resistivity	295.8	770.7		589.2	3939.2		889.2	356.1	176.2
	Thickness	0.9	3.5		6.3	19.1		15.6	12.1	
	Depth	0.9	4.5		10.8	29.9		45.6	57.6	
8	Resistivity	71.1	843.5		133.3	1546.7		2255.4	346.9	63.4
	Thickness	0.6	1.6		4.1	10.8		16.9	11.9	
	Depth	0.6	2.2		6.3	17.1		34.0	45.8	
9	Resistivity	321.7			588.5	179.7		486	873.8	1136.0
	Thickness	1.6			6.7	16.8		12.6	12.6	
	Depth	1.6			8.3	25.1		37.6	50.2	
10	Resistivity	101.5	202.9		416.9	285.4	1563.7	379.9	150.7	139.6
	Thickness	1.4	5.1		3.9	3.9	23.2	13.1	12.1	
	Depth	1.4	6.5		10.4	14.4	37.6	50.7	62.8	
11	Resistivity	49.4	643.6			1199	1031.1	394.3		182.7
	Thickness	1.2	2.3			8.1	24.9	16.1		
	Depth	1.2	3.5			11.7	36.6	52.6		
12	Resistivity	104.8	260.2		643.6	881.9	442.5	988.0	395.2	
	Thickness	1.4	3.2		2.3	14.2	13.4	15.3	13.1	
	Depth	1.4	4.6		3.5	18.8	32.2	47.5	60.6	

Table 2: Table showing aquifer geologic properties for VES data

VES NO.	THICKNESS (m)	BULK RESISTIVITY (Ωm)	AQUIFER RESISTIVITY (Ωm)	HYDRAULIC CONDUCTIVITY (m/sec)	FORMATION FACTOR	TRANSMISSIVITY (m^2/s)	POROSITY	PERMEABILTY (m^2) x 10^7
1	10.04	106.4	45.45	2.375	2.3410	23.845	0.52	3.39314
2	14.25	140.2	71.43	4.998	1.9627	71.2215	0.595	7.14029
3	9.17	175.3	76.92	2.649	2.2790	24.29133	0.531	3.78454
4	12.7	107.9	83.33	66.236	1.2949	841.197	0.8197	94.6229
5	12.6	94	83.33	381.234	1.1280	4803.548	0.912	544.62
6	19.6	84	62.5	49.82	1.344	976.425	0.80	71.168
7	9.58	176.2	100	8.459	1.7620	81.03722	0.647	12.0848
8	7.65	63.4	55.55	304.574	1.141	2329.991	0.903	435.106
9	12.6	873.8	58.82	0.009913	14.86	0.1249	0.125	0.014161
10	12.1	150.7	55.55	1.353	2.7129	16.3713	0.464	1.9333
11	10.52	182.7	55.55	0.692	3.2890	7.27984	0.4	0.988444
12	10.1	165.1	55.55	0.983	2.9721	9.9283	0.433	1.40402

Acknowledgements
The authors wish to appreciate the Covenant University Centre for Research, Innovation and Discovery for the conference support sponsorship.

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