Geoelectric estimation of aquifer parameters in the Southern part of Edo State, Nigeria

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Abstract

A geoelectric investigation was carried out in the southern part of Edo State, Nigeria. The VES points were geo-located using the Global Positioning System (GPS). The co-ordinates of the eighteen VES locations lie within latitudes (6.31^0-6.70^0) and longitudes (5.88^0-605^0). The elevations also range from 81 m-236 m.

The interpretation and analysis of the VES data show that the aquifer parameters; the Transmissivity has the range of (64.6-1064.1) m^2/day, Hydraulic conductivity (2.1-8.3) m/day, while the resistivity of the geoelectric layers range from (115.5-18111.8) ohm-m respectively.

Introduction

The purpose of this study is to investigate the groundwater flow and evaluate its characteristics using the geoelectric method. The accuracy of the geoelectric method over in the groundwater study was established by the work of [1-3]. They reported on the ability of the resistivity method to furnish information on the subsurface geology which cannot be obtained by other geophysical methods in groundwater studies. The geoelectric method techniques have been successfully utilized in: assessing water supply potential in basement aquifers [4], exploring aquifer boundaries in the plain of Yemem [5], the assessment of the groundwater resources potentials within the Obudu basement area of Nigeria [6] and assessment of the near surface groundwater resources potentials within the eastern Niger Delta [7].

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), and Transmissivity (T) are all commonly applied hydraulic parameters in groundwater flow modelling [8, 9]. Application of field hydrogeological method of assessment is a standard technique for evaluating these aquifer properties; however estimating K, T, 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 generally is proving very effective for water content estimation, water quality assessment and mapping of the depth to the water table and bedrock

[10]. 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. Use of Wenner and Schlumberger array vertical electrical sounding (VES), profiling, and also electrical tomography techniques have become very common in groundwater exploration and contamination studies, and there are standard, published direct and indirect interpretation techniques specifically for VES data [11]. Recently, attempts have been made by researchers also to obtain such hydraulic parameter estimates from resistivity measurements [12-14].

In porous media and alluvial aquifers, transmissivities, formation factors and permeability can be estimated using empirical/semi-empirical correlations, often using simple linear relations [15-19]. In the present study, Schlumberger resistivity soundings have been assessed in alluvial (porous medium) aquifers for possible relationships with hydraulic parameters.

Theoretical background

The theory of mathematical expressions used for investigation of aquifer by geoelectrical surveys are much explained [20,11,21]. The Schlumberger configuration method of Vertical Electrical Sounding (VES) has been applied for obtaining the aquifer parameters. The depth of investigation in a Schlumberger sounding array varies typically between 0.25AB to 0.5AB [22].

Mathematically, electric current flow (J) in a conducting medium is governed by Ohm's law and groundwater flow in a porous medium. Darcy law, both having similar forms of equation

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

$$q = -K \frac{dh}{dr} \tag{2}$$

where J = current density (ampere per unit area)

σ = electrical conductivity (Siemens/m)

V = electrical potential (volts)

r = distance (metres)

q = specific discharge (discharge per unit area)

K = hydraulic conductivity (or permeability, m/s)

H = hydraulic head (m)

The analogy between these two phenomenons is widely accepted [8, 9].

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

$$\frac{d^2V}{dr^2} + \frac{2}{r}\frac{dV}{dr} = 0 \tag{3}$$

and for groundwater flow,

$$\frac{d^2h}{dr^2} + \frac{1}{r}\frac{dh}{dr} = 0 \tag{4}$$

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

$$V = \frac{\rho I}{2\pi}\frac{1}{r} \tag{5}$$

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

$$h = \frac{Q}{2\pi T} Inr \tag{6}$$

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

$$T=kb \tag{7}$$

In general terms, since larger connected pores makes for better flow characteristics for both water and electric current it is expected that at the very least there should be some relationship between electrical and hydraulic parameters. Direct linear relationship between resistivity and hydraulic parameters (K and T) do not exist. The relationship between hydraulic conductivity, K and resistivity, ρ is controversial and various authors have reported both direct, [23] and inverse [24]. The character of the relationship (direct and inverse) depends mainly on the rock type and its porosity, while the form of the relationship (rectilinear or curve linear) is modified by relations between direction of groundwater flow, rock bedding and resistivity. In this study nevertheless an attempt is made to identify (site-specific) empirical relations in two particular aquifer types (alluvial, fissured) and then to identify more general aquifer relations. Moreover, hydrogeological properties of the aquifer in fractured aquifers generally vary rapidly.

Methodology

Four electrodes arrays are commonly used at the surface, one pair for introducing into the earth, the other pair for measurement of the potential associated with the current. The field procedure in the Schlumberger electrodes configuration (Figure 1) is to expand the current electrodes successively while the potential electrodes remain fixed.

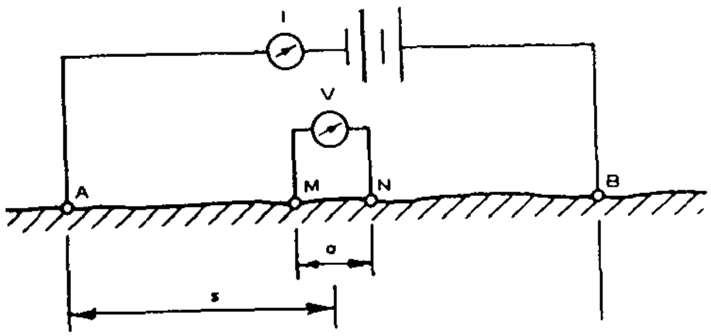

Figure 1: Schlumberger Configuration

AB = current electrodes, MN = potential electrodes: S = AB/2, a = MN

The apparent resisitivity is expressed as:

$$\rho_a = \pi \left[\frac{s^2}{a} - \frac{a}{4}\right] \frac{V}{I} \quad (8)$$

The accuracy in estimation of thickness and resistivity of the aquifer must be adequately maintained while interpreting the VES data, rms error <5%. Thickness and resistivity of the aquifer at various observation points are obtained by inversion of VES data. The root mean square (rms) error between observed and computed VES data is maintained less than 5% while computing the resistivity and thickness of the aquifer by employing inversion scheme [25]. For a fractured aquifer, the inverse relation between hydraulic conductivity, K and resistivity, ρ is expressed by [26] equation.

$$K = 33.7\ x\ \rho^{-0.268} \quad (9)$$

In the field, data were acquired using ABEM Terrameter 300C with a Booster for deeper penetration of current, the data were subjected to curve matching and computer iterations using Interpex IxDv2, Ip2win and Sufer 8 softwares. The results of the interpretation are as shown in Table 1 and Figures 2-7 respectively.

Table 1: Showing Aquifer parameters

VES	Resistivity (Ωm)	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Aquifer Depth (m)	Lat. (Deg)	Long. (Deg)	Elevation (m)
1	4570.4	3.5	261.2	179.8	6.63	5.99	236
2	9544.1	2.9	169.9	72.9	6.66	6.00	198
3	18111.8	2.4	159.9	98.6	6.54	6.03	199
4	216.3	8.0	678.2	168.9	6.52	6.04	144
5	183.6	8.3	688.0	143.7	6.50	6.05	118
6	115.5	7.7	937.3	163.4	6.49	6.05	141
7	287.4	7.4	1064.1	173.4	6.45	6.04	162
8	3734.0	3.7	156.8	100.4	6.43	6.02	158
9	786.6	5.6	271.2	118.1	6.36	5.96	138
10	4492.0	3.5	168.3	136.2	6.34	5.94	112
11	2085.9	4.3	192.6	93.3	6.33	5.91	111
12	982.6	3.7	170.9	129.7	6.32	5.90	108
13	986.5	2.1	64.6	38.9	6.31	5.88	81
14	544.1	6.2	285.3	87.7	6.70	5.90	138
15	2466.5	4.2	56.9	46.8	6.39	5.94	211
16	3803.7	3.7	91.3	112.6	6.54	5.88	137
17	2040.0	4.4	278.9	124.4	6.55	5.88	166
18	2070.3	3.5	628.9	198.6	6.55	5.88	166

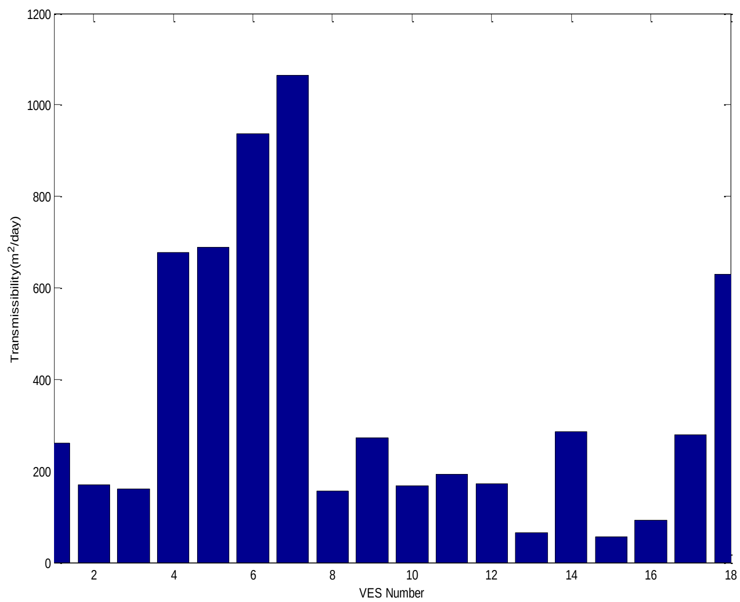

Figure 2: Aquifer Transmissivity chart

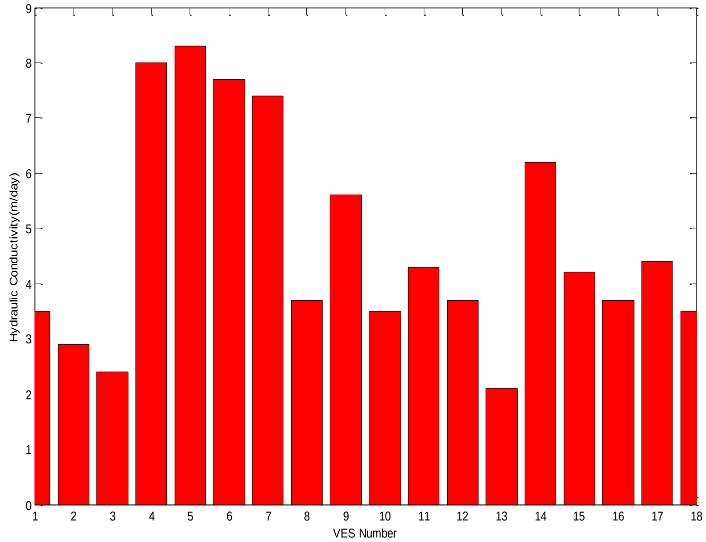

Figure 3: Aquifer Conductivity chart

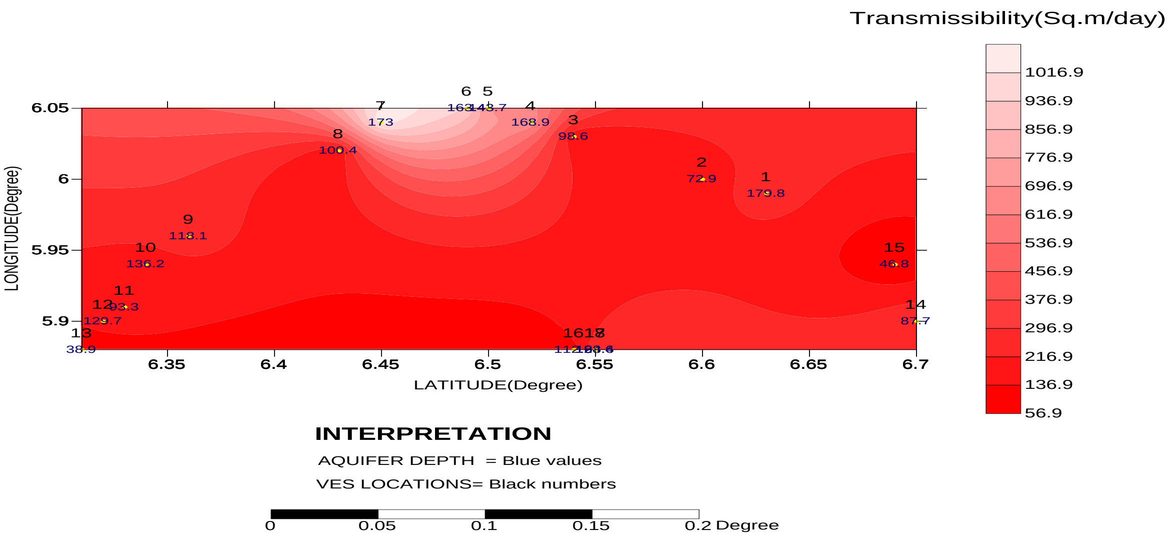

Figure 4: Aquifer transmissivity image map

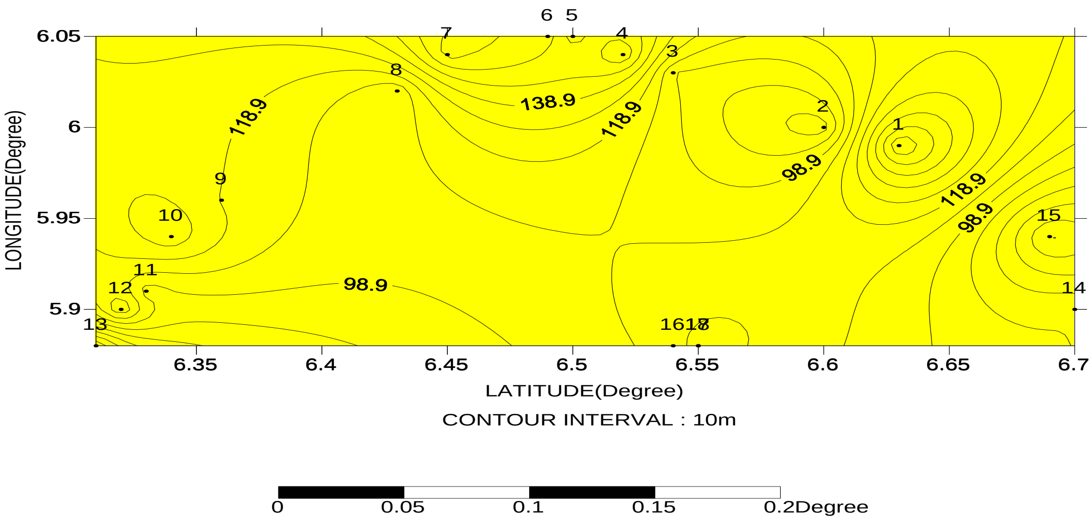

Figure 5: Aquifer depth contour map

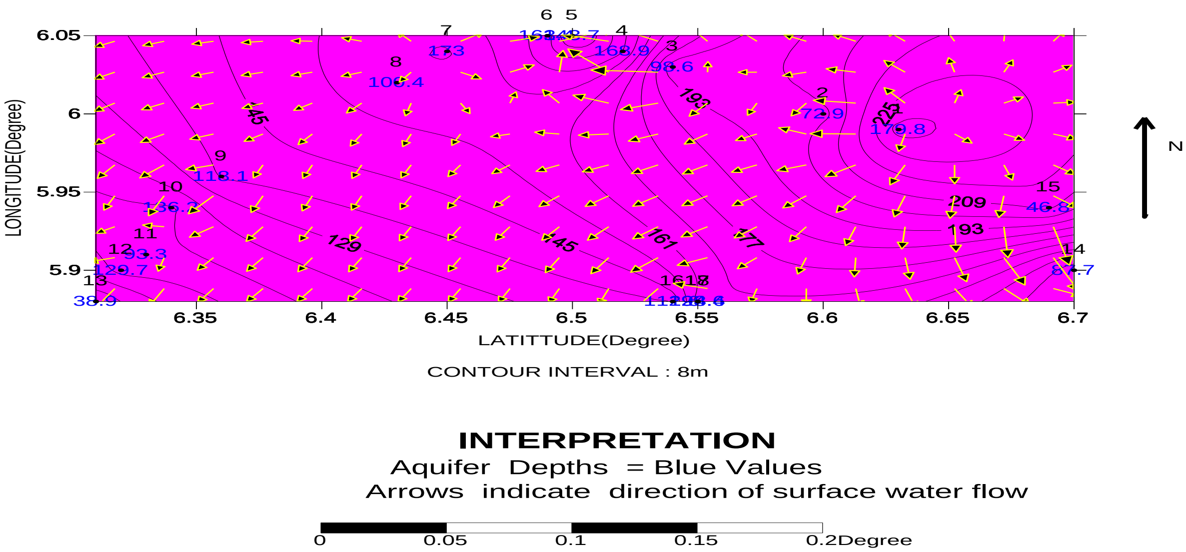

Figure 6: Topographic Map

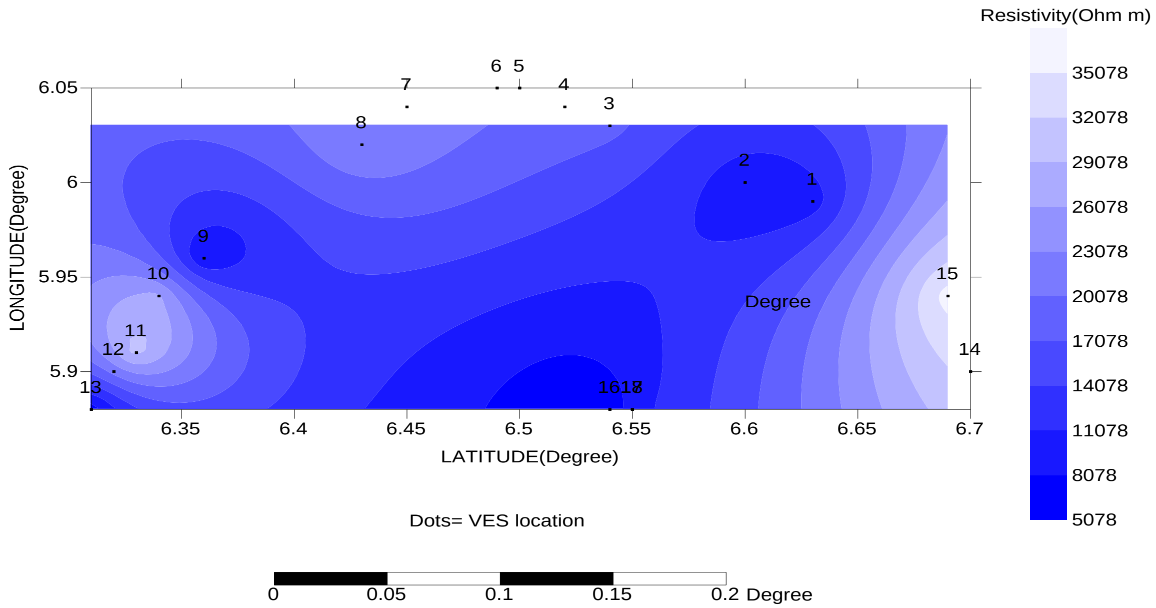

Figure 7: Bed rock resistivity image map

Discussion of results

The results of the interpretation of the various VES locations in Table 1, showed the geoelectric layers resistivities, depths, transmissivity, hydraulic conductivity and geo-electric location obtained from the computer assisted Interpex I x 1D v 2 software. The aquifer transmissivity and hydraulic conductivity chart, aquifer contour map, bedrock resistivity image map, topography map and transmissivity image map which allow us at a glance to view the information of the study area in the pictorial form are as shown in figures 2-7 respectively. From figures 2 and 3, it is clear that the transmissivity and hydraulic conductivity are high in VES 4, 5, 6 and 7 an indication that the aquifer in the area is highly prolific and has good yield.

Conclusion

After the analysis of the acquired field data, the result show that the study area is made of 5-8 earth layers with various depths, (38.9 m-198.6 m) and resistivities, (115.5 Ωm-18,111.8 Ωm). The aquifer parameters; the Transmissivity has the range of (64.6-1064.1) m^2/day, and Hydraulic conductivity (2.1-8.3) m/day respectively. As can be seen from the analysis, the area under investigation has a high prolific aquifer.

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