Geophysical Characterisation of Shallow Aquifers in a Sedimentary Area: A Case Study

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ABSTRACT

A geophysical survey involving the Schlumberger vertical electrical sounding (VES) electrical resistivity was done in Ode Aye, a sedimentary area in, southwestern Nigeria with the aim of delineating and characterizing shallow aquifers in the area. In this study twenty-four VES stations were occupied along six traverses. The study delineated three distinct geologic units-the lateritic top soil/sand layer, the loose sand/sandstone layer, and the shale/sandy shale layer. The middle layer (loose sand/sand stone layer) was delineated as the aquifer unit which range in thickness between 7.5-32.1m. The aquifer unit was however characterized as prone to contamination due to the shallow nature of the overburden top layer. It was suggested that boreholes drilled in the area should be properly cased to enable the sieving of the recharge groundwater.

Keywords: Geophysical, Resistivity, Sandstone, Clay, Shallow, Aquifers.
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INTRODUCTION

Ode Aye is underlain by the sedimentary rocks of southwestern Nigeria. Sedimentary basins generally contain large water quantities [3] Several studies have been carried out with the aim of achieving this fact using geophysical, geological, hydrogeological and a combination of the above or other methods [2, 8].

Resistivity measurements are associated with varying depths depending on the separation of the current – potential electrodes in the survey [1]. Geoelectric resistivity soundings have been employed in this study to delineate the subsurface geological units, aquifer units and characterization of the shallow aquifer units in the area. This is because contaminated surface water has killed many people than other substances in the world necessitating the use of groundwater [5]. The study is expected to enhance the knowledge of the shallow aquifers and success rate of groundwater extraction in the area.

Theory
The resistivity of a medium is governed by ohms law which states that

$$R = \frac{\Delta V}{I} \qquad (1)$$

$$\frac{\Delta V}{I} = \frac{\rho L}{A}$$

$$\rho = \frac{A\Delta V}{IL} \qquad (2a)$$

$$V = \frac{I\rho L}{A} \qquad (2b)$$

For two current electrodes at the surface of a homogenous isotropic ground (Figure 1a)
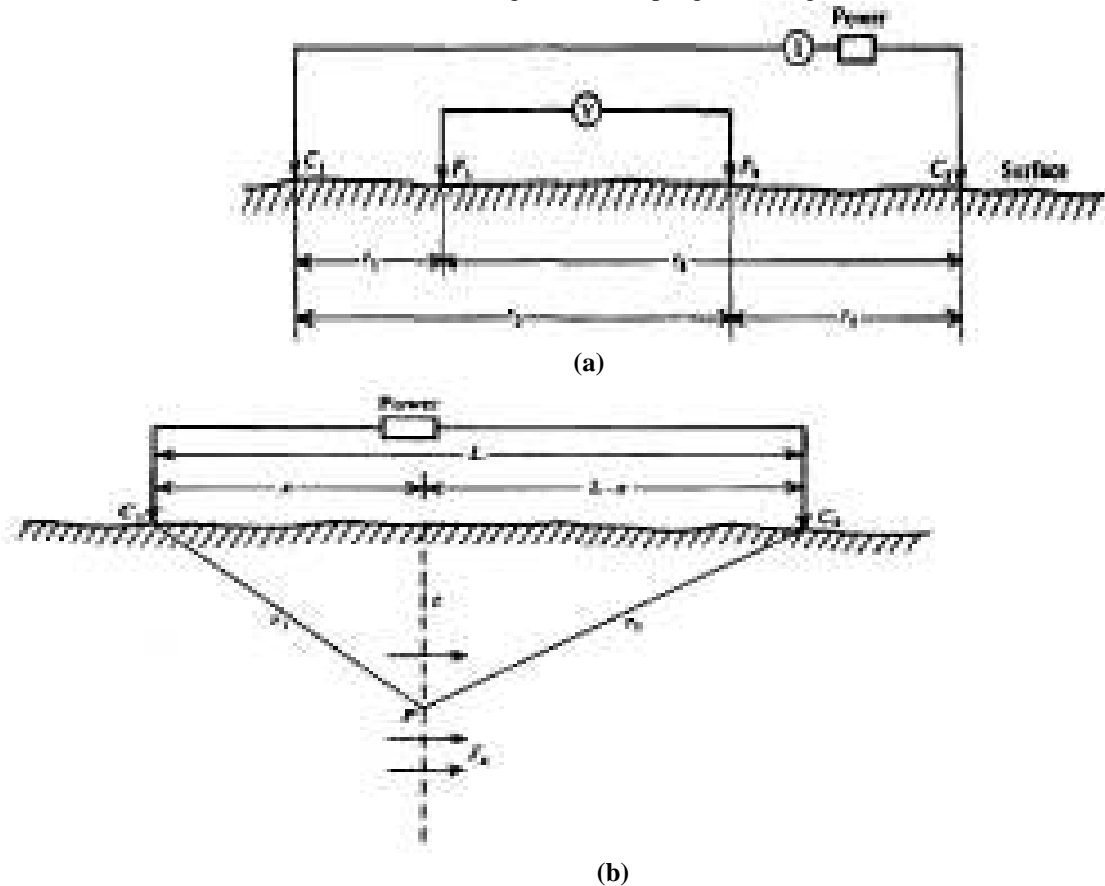

(a)

(b)

Figure 1. (a) Two current and two potential electrodes on the surface of homogenous isotropic ground. (b) Determining the current density in uniform ground below the surface.

$$V_1 = \frac{A_1}{r_1} \tag{3a}$$

Where $A_1 = \frac{I\rho}{2\pi}$

Since the currents at the two electrodes are equal and opposite, V due to C_2 at P is:

$$V_2 = \frac{A_2}{r_2}$$

Where $A_2 = \frac{I\rho}{2\pi} = -A_1$

$$\therefore \quad \Delta V = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right] \tag{4}$$

Where
ρ   is the resistivity of the medium (Ohms)
R   is the resistance of the material/median (Ohms)
V   is the potential across the material (Volts)
I   is the current input (Ampere)
L   is the length of the medium (M)
A   is the cross-sectional area of medium (M^2)
r   is the electrode separation (M)

Equation (4) corresponds to the four electrode spread normally used in resistivity field work. The current flow lines are distorted by the proximity of C_2

The horizontal current density at point p (figure 1b) is given by;

$$I_x = \frac{I}{2\pi} \frac{L}{\left(Z^2 + \frac{L^2}{4}\right)^{3/2}} \qquad (5)$$

The fraction of current flowing through a strip of the vertical plane $\partial_y \partial_z$ between depth Z_1 and Z_2:

$$\partial I_x = \partial_x \partial_y \partial_z = \frac{I}{2\pi} \frac{L}{\left(\left(l^{1/2}\right)^2 + y^2 + Z^2\right)^{3/2}}$$

The fraction of the total current through a long strip Z_2-Z_1;

$$\frac{I_x}{I} = \frac{L}{2\pi} \int_{z_1}^{z_2} dz \int_{-\infty}^{\infty} \frac{dy}{\left(\left(\frac{L}{2}\right)^2 + y^2 + z^2\right)^{3/2}} \qquad (6)$$

$$= \frac{2}{\pi}\left(\tan^{-1}\frac{2z_2}{L} - \tan^{-1}\frac{2z_1}{L}\right) \qquad (7)$$

Which ha sa broad maximum when L = 2 $\sqrt{Z_1 Z_2}$ if Z2 $\rightarrow$ (7) becomes

$$\frac{I_x}{I} = I - \frac{2}{\pi}\tan^{-1}\frac{2z}{L}$$

$I_x = 0.5I$

Where
L is separation between current electrodes C1 and C2
Z is depth of Penetration
I_x is current at depth = 0.5I
I is the input current.

When L = $2Z_1$, half the current flows in the top layer and half below it and since the potential variations measured at the surface are proportional to the subsurface current flow, much current should be passed into the ground and sufficient spacing should be employed to reach the target of interest [9].

MATERIALS AND METHODS

LOCATION AND GEOLOGY OF THE STUDY AREA
Geographically, the study area is located on long $4^0 45^1 0E$ and Lat $6^0 34^1 60N$ and falls within the tropical rainforest belt in Ondo State, Nigeria. (Figure2)[7]. It has a gentle undulating terrain to the south with a topographic elevation of approximately 75m above sea level. The annual temperature ranges from $24-27^0c$ with a mean annual rainfall of over 2500mm [4].

Geologically, the area falls within the Dahomey basin and is underlain by the coastal plain sands of the Benin formation (Figure 2). The sands are relatively sorted and non-cemented and the sediments deposited during the late Tertiary-Early Quaternary period [6]. The formation is predominantly shally with outcrops of shale along a spring [8]. The aquifers are characteristically continental sands, gravels or marine sands with the lateritic earth overlying the sands as well as the underlying impervious shale/clay member of the Akimbo formation. Adequate rainfall is however guaranteed in the study area.

METHODOLOGY
The geophysical study employed the electrical resistivity method-Schlumberger vertical electrical sounding (VES) technique- along a total of five (5) traverses in an S-N direction with inter-traverse and intra-traverse spacing of 100m. The PASI-E2 DIGIT meter was employed in the data acquisition. The computed apparent resistivity values

were partially curve-matched and iterated using the WinRESIST software to generate corresponding geoelectric parameters for interpretation.

Figure 2 Geological map of Ondo State showing the Study Area (after Les Editions 2002).

RESULTS AND DISCUSSION

The geoelectric parameters are displayed as geoelectric sections (Figure 3) and the sections display three (3) distinct geologic layers. The topmost layer has resistivity values in the range of 139.4-1290.6 ohm-m and thickness in the range of 0.4-4.2m and the composition of this layer is mainly lateritic topsoil and sand which constitute the alluvium deposit in the area. The second layer has resistivity values in the range of 918.3-717 ohm-m and thickness in the range of 7.5-32.1m; and it is composed of loose sand/sandstones. The third layer has resistivity values in the range of 111-973.6 ohm-m comprising of shale/sandy shale.

The loose sand/sandstone layer constitutes the shallow aquifer units. The surficial aquifer unit(s) were determined from the sounding curve interpretation and supported by contrasts in resistivity between the distinct geological layers. The depth to the top of the aquifer varies from 0.4- 4.2m across the area.
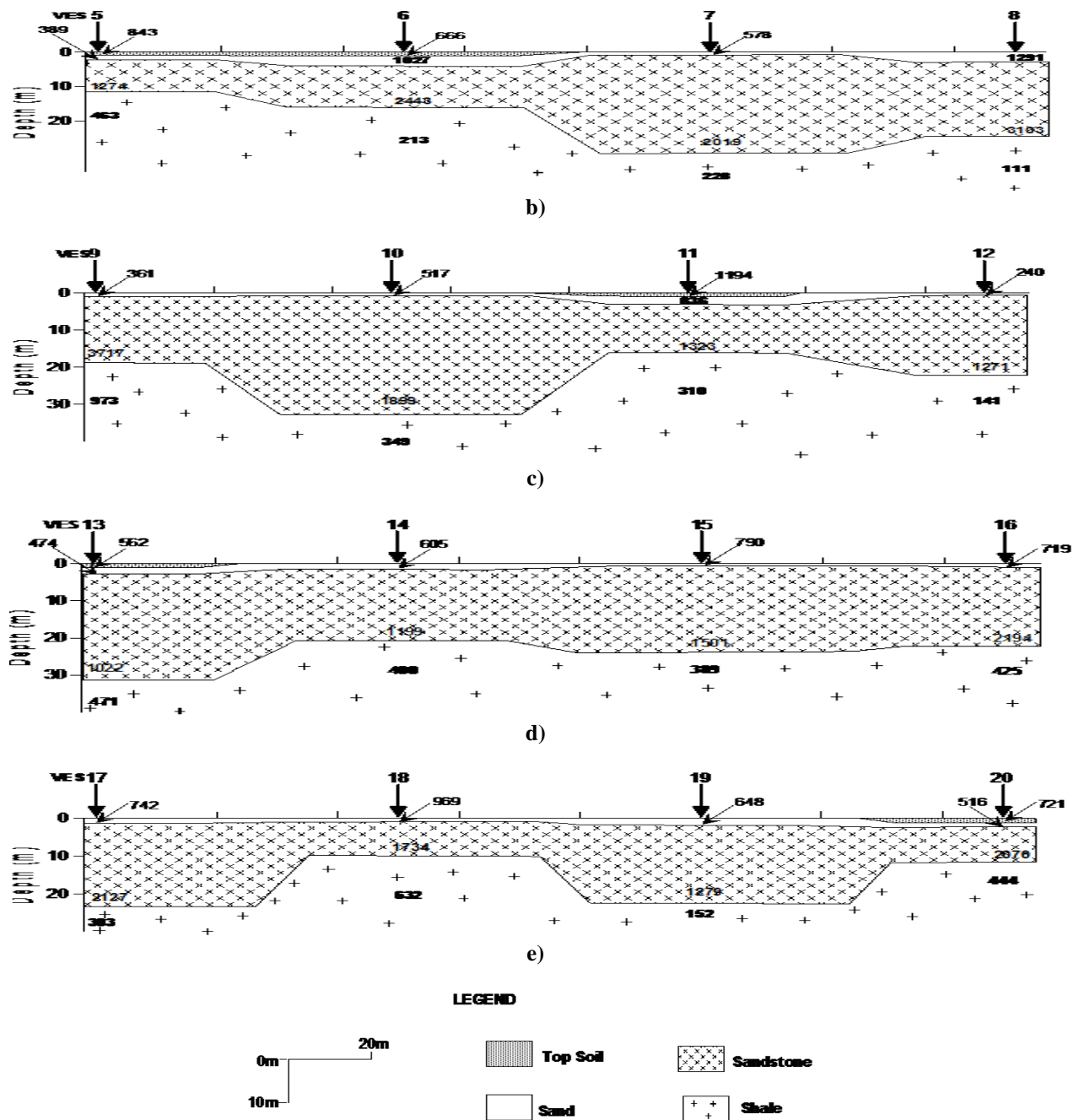

a)
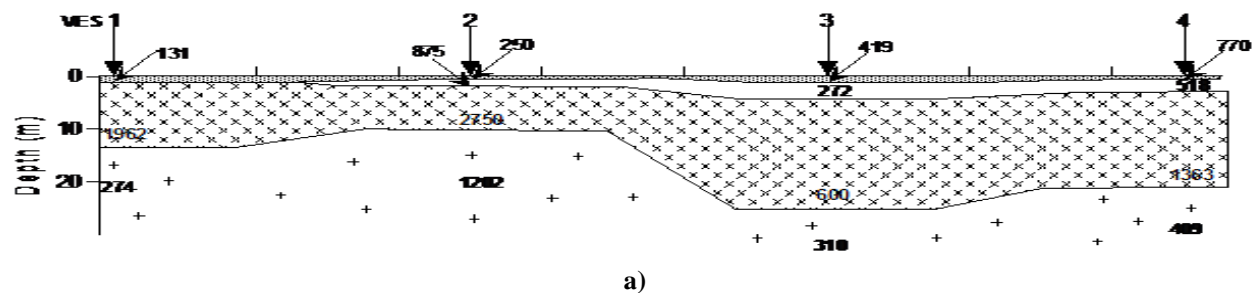
Figure 3(a –f).: Geoelectric Sections along traverses 1 – 5 in an S – N direction.

CONCLUSION

From the geoelectric sections, three geologic layers were delineated – lateritic topsoil/sand, loose sand/sandstones and shale/sandy shale layers. The two upper layers are composed of permeable materials underlain by porous materials.

The second layer is the shallow aquifer unit since it is underlain by the relatively porous shale/sandy shale layer and its thickness (7.5-32.1m).

Based on the depth to the second layer, and its permeable nature, the existing aquifer units are prone to contamination. Hence, boreholes drilled in the area should be deep – greater than 6m and less than31m – wherever possible, and properly cased to prevent infiltration and enable the sieving of the recharge ground water in the area.

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