



ON THE Dar-Zarrouk PARAMETERS AND AQUIFER HYDRAULIC CONDUCTIVITY DETERMINATION: A CASE STUDY OF ISHARA/ ODE-REMO GEOLOGICAL TRANSITION ZONE, SOUTHWESTERN NIGERIA

¹Ariyo, S.O, ²Adeyemi, G.O and ³Akintola, O.O

¹Department of Earth Sciences, Olabisi Onabanjo University, Ago-Iwoye

²Department of Geology, University of Ibadan, Ibadan

³Federal College of Forestry, Jericho, Ibadan

Corresponding author email: soariyo@gmail.com

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ABSTRACT

Fluid transmissivity and electric transverse resistance are important parameters in groundwater exploration. Determination of these parameters provides a good knowledge of the potential of porous media, because they relate fluid flow to electric-current conduction, in terms of layer thickness, permeability and resistivity. In this study, both parameters were determined in this study from the interpretation of Vertical electrical sounding data obtained. Direct relationships between both parameters were obtained and the relationship can be used to determine the transmissivity and hydraulic conductivity of the aquifer. The relationship suggests that an increase in both parameters indicate presence of zones of high water potential within the aquifers. In the absence of pumping test, these Dar-Zarrouk parameters can be used to determined the hydraulic conductivity of aquifer in an area and groundwater potential evaluation.

Keywords. *Dar-Zarrouck Parameter, Aquifer, Hydraulic, Conductivity, Nigeria*

INTRODUCTION

Recent advances in the automatic inversion of Vertical Electrical Sounding data offer opportunity to describe the relationship of the resistivity of a granular aquifer to its hydraulic conductivity. Relationships between fluid transmissivity (or simply transmissivity, also known as transmissibility), electric transverse unit resistance (or simply transverse resistance) and electric longitudinal unit conductance (or simply Longitudinal conductance) are based on the nature of relationships between hydraulic conductivity (permeability; k) and electric resistivity (Reference). Since the mechanisms of fluid flow and electric-current conduction through porous media are generally governed by the same physical parameters and lithological attributes, the hydraulic and electric conductivities are dependent on each other. The technique of transverse resistance has been applied in several studies in order to determine hydrodynamic parameters (Nafez, *et.al.*, 2010)

In the interpretation of Vertical electrical sounding (VES), the true resistivity layers must be estimated from the apparent resistivity of the curves observed in the field. The depths are also roughly estimated from the length of the configuration (distance between the current electrodes AB Schlumberger device). To achieve this, One hundred and fifty (150) VES points were occupied in the study areas

However, the parameters which may be interpreted from geoelectrical data are resistivities and locations of boundaries. Assuming that the earth is composed of n layers, the flow of current in such a geoelectric section is controlled not only by the individual resistivities of the layers, but also their thicknesses and the order of disposition of resistivities of the layers.

The geoelectrical parameters of such a section are described by the resistivities ($\rho_1, \rho_2, \rho_3, \dots, \rho_n$) and thicknesses ($h_1, h_2, h_3, \dots, h_{n-1}$), etc. In addition the resistivities ρ_l, ρ_t in the longitudinal and transverse directions as also longitudinal conductance S, and transverse resistance T are also used to describe a geoelectrical section. These quantities are interrelated in the following manner. The T and S values are also known as Dar Zarrouk parameters.

When the current flows parallel to the geoelectrical boundaries the parameter that influences current flow is longitudinal conductance S and when current flows normal to the bed boundaries, the transverse resistance T is significant. When a number of layers are involved in a geoelectric section, their total longitudinal conductance S or the total transverse resistance T may be considered.

$$S = S_1 + S_2 + S_3 + \dots \text{ where } S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \dots$$

$$T = T_1 + T_2 + T_3 + \dots \text{ where } T = h_1 \cdot \rho_1 + h_2 \cdot \rho_2 + h_3 \cdot \rho_3 + \dots$$

If the total thickness of the layers in the geoelectric section considered is H then average longitudinal resistivity $\rho_l = H/S$ and average transverse resistance $\rho_t = T/H$. The ρ_t is always greater than ρ_l .

The entire section will be thus anisotropic with regard to electrical resistivity. A coefficient of electrical anisotropy, λ can be defined as

$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}}$$

where λ is equal to or greater than 1. A mean value of the resistivity for the formation (ρ_m) can be defined as $\rho_m = \sqrt{\rho_l \cdot \rho_t}$. The λ and ρ_m have great significance in groundwater prospecting. The above parameters, i.e. ρ_t and ρ_l were calculated from the interpreted vertical electrical soundings data obtained in the studied area. The Dar-Zarrouk parameters have been used for the development of an indirect resistivity interpretation by Kosinski and Kelly, 1981. More researchers have tried to establish a direct relation between transverse resistance and aquifer transmissivity by empirical relations (Abduulah *et al.*, 2010). Niwas and Singhal (1981) estimated the aquifer transmissivity from the Dar-Zarrouk parameters in porous media by using analytical relations between the existing relations between aquifer properties and resistivity-related parameters and confirmed direct relations despite variations in hydraulic anisotropy. Niwas and Singhal (1985), proposed a modification to the previously mentioned approach to incorporate variations in the quality of groundwater, but the direct relationship between transmissivity and transverse resistance was retained.

If a prism has isotropic and homogenous aquifer material having a unit cross section area and thickness h, it is considered that hydraulic and electric parameters can be combined to give the following equations

$$T = K\delta R = KC/\delta \dots\dots\dots 3$$

$$\delta = 1/\rho, R = h \cdot \rho, C = h/\rho, C = h \cdot \delta$$

- T = aquifer transmissivity (m²/s)
- K = Hydraulic conductivity (m/s)
- δ = electrical conductivity (μ s/cm)
- ρ = resistivity of the medium (Ω -m)
- R = resistance transverse of the aquifer (Ω - m²)
- C = Longitudinal conductance (Ω ⁻¹)

In areas of similar geological conditions and water

quality, the product $K\delta$ remains fairly constant (Niwas and Singhal, 1981). Thus transmissivity can be replaced with transverse resistance in a similar geologic setting (Chukwudi *et al.*, 2010, Kenneth and Ebufibo 2012).

Site Description

The study area includes Ode-Remo, Ishara, Akaka and Ilara in Southwestern Nigeria (Fig.1). The area is located between Latitudes $6^{\circ} 55'$ and $7^{\circ} 01'$ North and Longitudes $3^{\circ} 40'$ and $3^{\circ} 44'$ East. The site is bounded to the east by Ibadan-Ijebu-Ode road, to the south by Sagamu and to the west by Abeokuta.

GEOLOGY OF THE STUDY AREA

Both crystalline and sedimentary rocks were represented in the study area. Both have been described extensively by several authors in southwestern Nigeria. The sedimentary rocks which underlie about 4,000 square miles ($6,400\text{km}^2$) were mapped and described by Jones (1964) while Jones and Hockey (1964) were responsible for the complete description of the crystalline basement rocks of the region (Fig.2). The migmatite –gneiss in the study area was formed during the older granite orogeny through the introduction of metasomatic material (quartz and feldspar) to gneiss (Jones and Hockey 1964). The next rock to be formed was the quartz-mica schist which was thought to have sedimentary origin (Jones and Hockey, 1964).

The youngest rock is sandstone whose contact with quartz-schist is defined by an unconformity about 1km from the Odemo Palace along Ishara-Fidiwo road (Fig. 3).

The basement complex rocks found in the study area are quartz –mica schist and Biotite granite gneiss. The Quartz-mica schist outcrops poorly in the study area. Road cuts along the Lagos-Ibadan highway and Ishara –Fidiwo road have exposed the weak highly foliated and folded rock. Its susceptibility to weathering is probably responsible for the scarcity of outcrops. The schist in the study area has undergone a high degree of weathering to the extent that the sample easily turns into powder when touched.

From the field observation, the mineral contents of this rock are muscovite, biotite, quartz and K-feldspar. The migmatite gneiss in the study area is highly foliated and folded with a mixture of granite (quartzo-feldspathic) and mafic highly foliated bands.

Cross-cutting relationship shows that the granitic band in the rock intruded the foliated band. From the field observation, the mineral contents of

this rock in order of abundance are quartz, biotite, muscovite and K- feldspars Ariyo, 2014).

MATERIALS AND METHODS

Although geophysical methods are being routinely used for exploration for groundwater, at times it becomes a challenge because of various factors such as geometry and depth of the aquifer and the yield of groundwater. Further, in the absence of surface manifestations of structures favourable to groundwater occurrence, instead of depending on one particular geophysical method, an integrated geophysical strategy plays an indispensable role not only in mapping and understanding the nature of aquifers but also ensures a better success rate of exploration.

In the course of this research work Electrical Resistivity Method involving Vertical Electrical Soundings (VES) technique was adopted for the geophysical survey. One Hundred and fifty (150) such VES stations were probes in the study area (Fig. 4). The VES data are presented as depth sounding curve which is a plot of apparent resistivity value along the y-axis against the electrode spacing along the x- axis on a log-log graph that is of the same modulus as the interpretation master curve.

Determination of Aquifer Transmissivity from Dar-Zarrouk Parameters.

The Dar-Zarrouk parameters have been used for the development of an indirect resistivity interpretation by Kosinski and Kelly, 1981. More researchers have tried to establish a direct relation between transverse resistance and aquifer transmissivity by empirical relations (Abduulah *et al.*, 2010). Niwas and Singhal (1981) estimated the aquifer transmissivity from the Dar-Zarrouk parameters in porous media by using analytical relations between the existing relations between aquifer properties and resistivity-related parameters and confirmed direct relations despite variations in hydraulic anisotropy. Niwas and Singhal (1985), proposed a modification to the previously mentioned approach to incorporate variations in the quality of groundwater, but the direct relationship between transmissivity and transverse resistance was retained.

If a prism has isotropic and homogenous aquifer material having a unit cross section area and thickness h , it is considered that hydraulic and electric parameters can be combined to give the following equations

$$T = K\delta R = KC/\delta \quad \dots\dots\dots 3.8$$

$$\delta = 1/\rho, R = h.\rho, C = h/\rho, C = h.\delta$$

T = aquifer transmissivity (m^2/s)
 K = Hydraulic conductivity (m/s)
 δ = electrical conductivity ($\mu s/cm$)
 ρ = resistivity of the medium ($\Omega\text{-m}$)
 R = resistance transverse of the aquifer ($\Omega\text{-m}^2$)
 C = Longitudinal conductance (Ω^{-1})

In areas of similar geological conditions and water quality, the product $K\delta$ remains fairly constant (Niwas and Singhal, 1981). Thus transmissivity can be replaced with transverse resistance in a similar geologic setting (Chukwudi, *et al.*, 2010, Kenneth and Ebufibo 2012).

RESULTS AND DISCUSSION

Transverse Resistance Map and Determination of Zones with High Groundwater Potential in the Study Area

Transmissivity as a hydraulic characteristic of aquifer is widely used for hydrogeologic investigation (Ariyo, 2014). The parameter is defined as the product of its hydraulic conductivity and the thickness of layer.

$$T = K.b \quad \dots\dots\dots(4)$$

Where, T is transmissivity, K is hydraulic conductivity and b is thickness of aquifer (Todd, 1980 & Hadi, 2009).

According to Maillet, (1974) Transverse Resistance (R_t) one of the Dar Zarrouk parameters is defined as

$$R_t = \rho b \quad \dots\dots\dots(5)$$

Where, b and ρ are thickness and resistivity respectively of the layer (Maillet, 1974).

The relationship between transmissivity and transverse resistance is meaningful, simply because hydraulic conductivity and resistivity have a linear relationship (Niwas and Singhal, 1981). Combining equation 4 and 5 gives:

$$T = KRt/\rho \quad \dots\dots\dots(6)$$

The relationship is suitable for determination of aquifer transmissivity, as the ratio

K/ρ is assumed to be constant in areas with similar geologic setting and water quality (Hadi, 2009 and

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Chukwudi, *et al*, 2010). On a purely empirical basis, it can be admitted that the transmissivity of an aquifer is directly proportional to the Transverse Resistance (Hadi, 2009).

Therefore, Transverse Resistance maps is used in the determination of zones with high groundwater potential (Toto, *et al*, 2008, Braga, *et al.*, 2006) and suitable for drilling wells. According to Fig. 5, the Transverse Resistance values is lower around Ishara and Akaka while is higher in Ode-Remo and Ilara. Based on this, areas around Ode-Remo and Ilara are groundwater potential zone while some part of Akaka and Ishara can be regarded as good to moderately groundwater potential zone.

CONCLUSION

The aquifer transmissivity values obtained via Dar-Zarrouk parameters show that the transmissivity of the aquifer materials in the area varied from one zone to another. In the Basement complex area, the aquifer transmissivity were generally low while in the sedimentary terrain it was moderately high. Within the transition zone the parameter was found to be moderate. Area around Ishara Township where compacted/ferruginised sandstone outcrop behave like typical basement complex area. This can be attributed to the hard nature of the outcrop sandstone in the area.

Drilling of wells to determine aquifer hydraulic parameters is often prohibitively expensive, thus Dar Zarrouk transmissivity technique outlined in this study in determining the aquifer transmissivity from VES is a cost effective alternative. The advantage of using Dar Zarrouk parameters to estimate transmissivity is that the non-uniqueness of interpreting resistivity data is minimized. The results give a useful first approximation of the transmissivity variation and could be used to site exploratory boreholes.

The results obtained can be applied to similar porous media which enable one to determine the hydraulic transmissivity and the electric transverse resistance of layers, from which the permeability or the electric resistivity can be obtained (in case there no possibility of pumping test), if the layers thicknesses are known.

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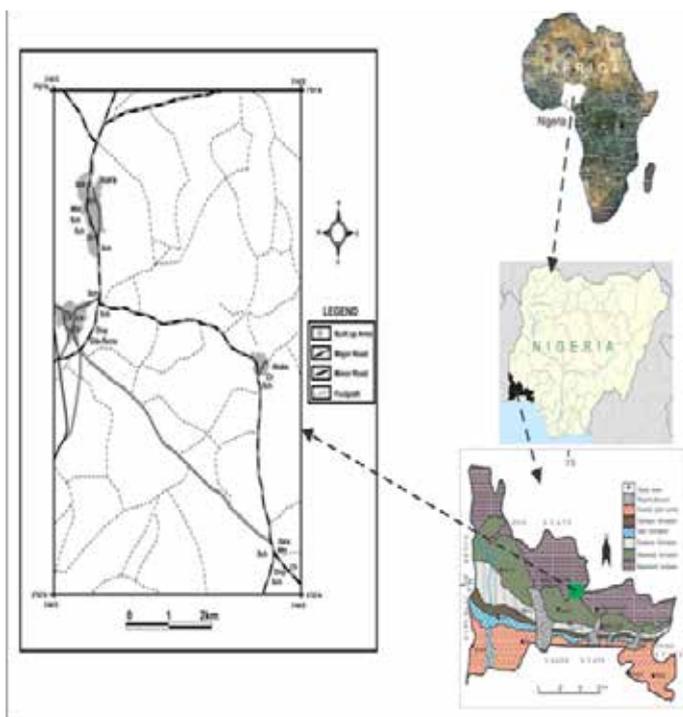


Fig. 1. Site Description and Accessibility Map of the Study Area

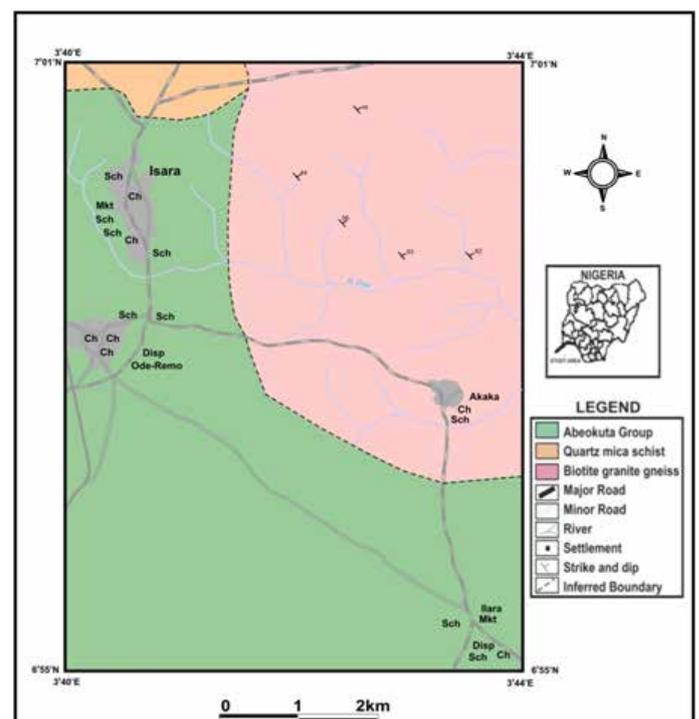


Fig. 2. Geologic Map of the Study Area (Modified after Ariyo, 2005)



Fig. 3. Basement Complex and Sedimentary Contact Zone in Northern Part of The Study Area

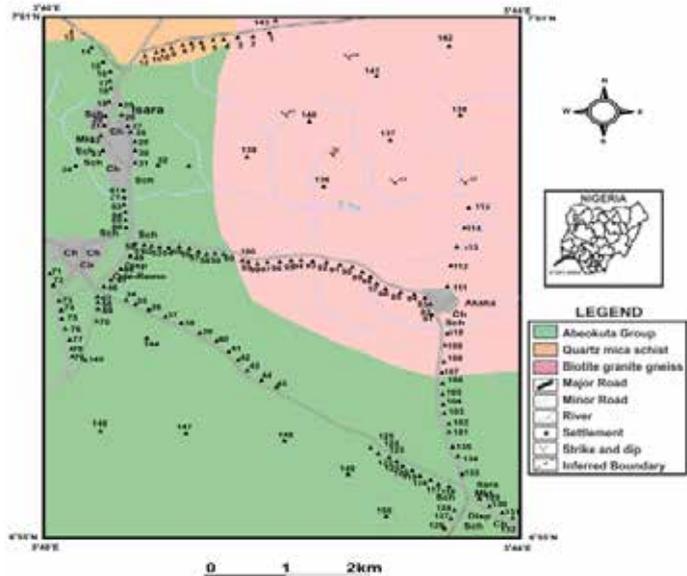


Fig.4. Geologic Map and VES Stations of the Study area

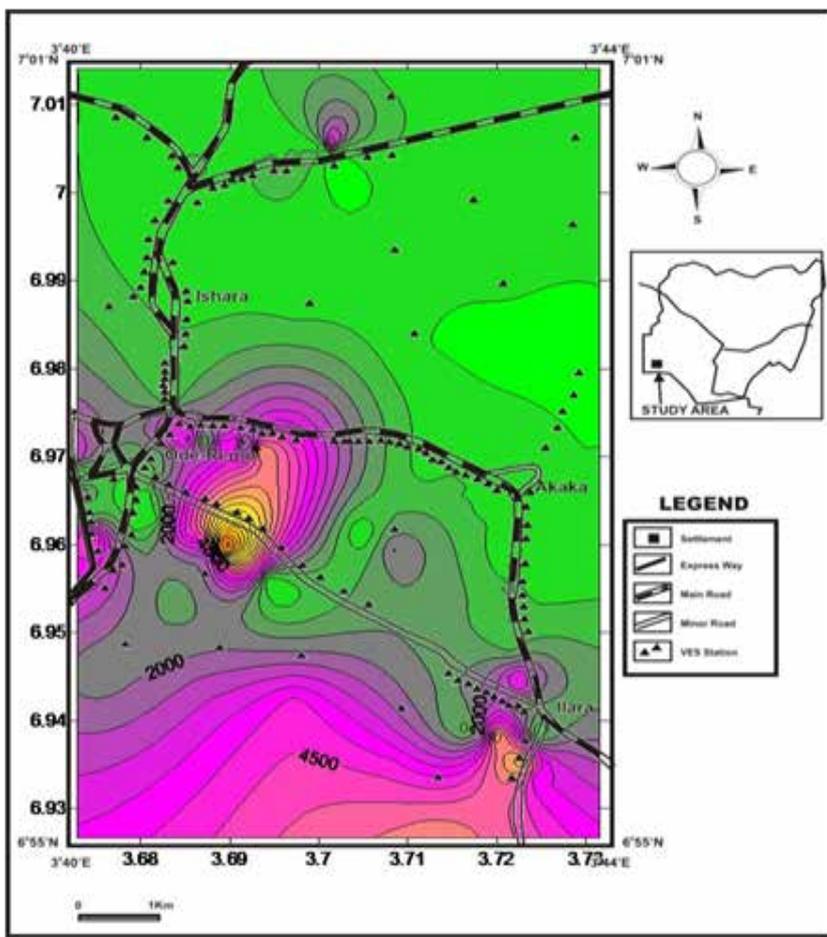


Fig. 5. Total Transverse Resistance Map