GEOELECTRIC STUDY FOR GROUND WATER IN THE CRYSTALLINE BASEMENT AREAS: A CASE HISTORY FROM EDO STATE, NIGERIA

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Abstract

Geoelectric study using the Schlumberger electrode configuration with maximum current electrode spacing of 294m was carried out in Ogugu, Ogbe-Oke and Egbigere. The ABEM SAS 300C Terrameter was used. Depth to water level in the existing hand dug wells was also measured. Interpretation of 37 Schlumberger soundings(15 in Ogugu, 10 in Ogbe-Oke and 12 in Egbigere) revealed an acquifer which is weathered or semi-weathered rock of thickness 8.25-15.50m in Ogugu, 7.00-11.90m in Ogbe-Oke and 5.75-8.25m in Egbigere with H-type curves dominating in the area. The depths to the weathered rock (which is aquifer) in Ogugu, Ogbe-Oke and Egbigere were respectively 6.50-8.42m, 3.33-8.64m and 1.80-6.57m, also the apparent resistivities of the weathered rock were respectively 640-3510Ωm, 165-1440Ωm and 120-1045Ωm. The depths to water level in the wells were 6.60-8.30m in Ogugu, 3.40-8.70m in Ogbe-Oke and 2.10-5.40m in Egbigere while the depth to basement or the thickness of the overburden in Ogugu, Ogbe-Oke and Egbigere were respectively 15.34-22.50m, 13.75-20.42m and 7.69-14.82m. The vertical electrical soundings has successfully determined the weathered rock as the acquifer.

***Keywords**: Geoelectric study, acquifers, weathered/semi-weathered rock, basement and Edo State.*

Introduction

Despite sufficient rainfall in large parts of Edo State of 2300-3500mm per year and an average of 2850mm per year , the area suffers from water scarcity for agricultural, domestic and industrial purposes. This is primarily because of large run off and limited water percolation into the ground. The groundwater in the basement terrain such as the study area (which is Ogugu,Ogbe-Oke and Egbigere) is mainly contained in the porous and permeable weathered basement zones. The ground water yield from the weathered horizon is often supplemented by the accumulated groundwater in the fractured and or jointed column of the basement rocks (Satpathy and Kanungo, 1976; Olorunniwo and Olorunfemi, 1987; Hazell *et. Al.* 1988; Owoade and Moffat; 1989).

Occasionally, the density of fractures and or joints in this latter horizon may be so high that it becomes the main aquifer unit. This is particularly so in situations where the network of fractures/joints extends to the surface at the abstraction point or at a distance away for direct surface recharge from precipitation, as it is the case with the weathered layer. Confined or concealed fractures are predominantly recharged from lateral groundwater movement.

As observed in Olorunfemi *et. al.* (1991), the sand/clayey sand horizon, described by Reboucas and Cavalcante (1989) as basement detrital overburden aquifer may contain an appreciable quantity of groundwater. The broad classification by Reboucas and Cavalcante (1989), of the basement terrain aquifers in Brazil into three; the weathered basement aquifers, the

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basement detrital overburden aquifers and the fractured rock aquifers is relevant to the Nigerian basement complex area. However, the aquifer rarely exist in isolation. The Nigerian experience shows a complex inter-relationship between the different aquiferous units particularly the weathered/fractured basement aquifers (Olorunfemi and Fasuyi, 1993).

The electrical resistivity method is one of the most relevant geophysical methods applied in groundwater investigation in the basement terrain (Ako and Olorunfemi, 1989; Limaye, 1989; Owoade and Moffat; 1989). The relevance of the method is based on the usually significant resistivity contrast between the weathered zone and or fractured column and the very resistive fresh bedrock. The nature of the weathered layer and the degree of fracturing of the basement rocks are dependent on the sub-surface geology (Reboucas and Cavalcante, 1989; Olorunfemi and Okhue, 1991).

Boreholes in the basement complex areas are drilled to different depths depending on the aquifer thickness or depth to the unfissured bedrock or the choice of the client, based on economy.It is therefore the aim of this study to determine the thickness and depth of the weathered layer which is the probable aquifer in the area.

Local Geology of the Study Area

The study area (Figure 1) is underlain by older granites and the undifferentiated gnesis-magnetite series of the basement complex. The principal out cropping rocks comprises of highly weathered granites featuring remnants of large feldspar crystals and well-defined zones of quartz-rich veins. This type of rock practically constitute the high elevations of the fairly rugged topography that characterizes the terrain. The surface sand material is highly enriched in cobble-sized boulders of quartz.

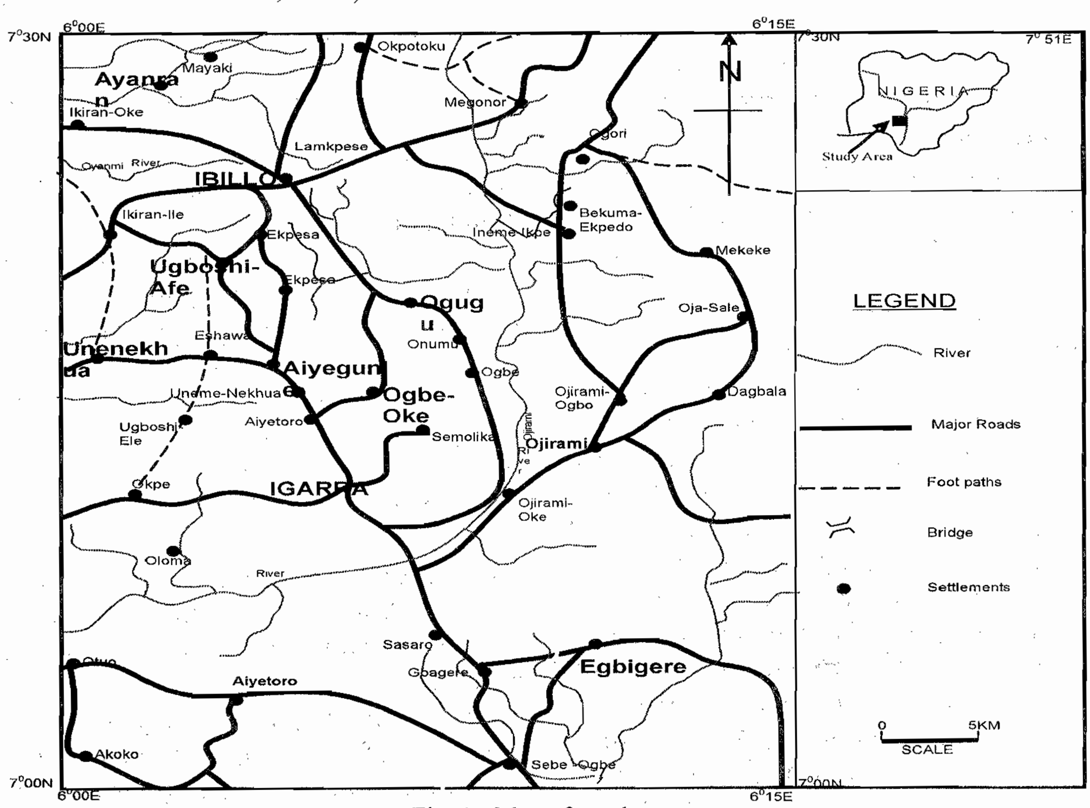

Fig. 1: Map of study area

The area is part of the Ojirami river drainage basin. The basin comprises of numerous stream channels which occupy the various depressed areas in a rather deudritic to angular pattern. These channels which are seasonally charged by rain and/or springs merge southwards in a minor tributary of the Ojirami river.

Theory

The apparent resistivity of an inhomogeneous formation is given by Habberjam(1975):

$$l_a = 2\pi\left(\frac{1}{r_1}-\frac{1}{r_2}\right)^{-1}\left[1+\left(\lambda^2-1\right)\sin^2\theta\sin^2\alpha\right]^{\frac{1}{2}}\frac{\Delta V}{I}=\frac{K\Delta V}{I} \quad (1)$$

where k = geometric factor which depends on the array in use,

α = dip of the anisotropy

θ = angle of strike

λ = coefficient of anisotropy $=(l_t/l_i)^{1/2}$

l_t = transverse resistivity normal to the bedding plane

l_l = longitudinal resistivity parallel to the bedding plane

?V = potential difference and

r_1, r_2 = distance of surface electric potential from a point source of current, I.

The Schlumberger electrodes array was used for the purpose of this research. The geometric factor for the Schlumberger array is given as;

$$k = \pi\left(\frac{a^2}{b}-\frac{b}{4}\right) \quad (2)$$

where a = distance from the center of the array to the current electrode, b = distance between the potential electrodes. The technique of data interpretation used involves seeking a solution to the inverse problem namely the determination of the subsurface resistivity distribution from surface measurements. A very good solution to the inverse problem is the kernel function. It is used in interpreting apparent resistivity measurements in terms of lithological variation with depth. The function assumes the earth to be locally stratified, inhomogeneous and isotropic layers and, unlike apparent resistivity function it is independent of electrode configuration. It cannot be measured in the field but has to be obtained from a transformation of measured apparent resistivities. The kernel function utilized in this work is derived after Ghosh(1971). If the observed apparent resistivity is given by

$$l_a(r) = r^2\int_0^\infty T(\lambda)J_1(\lambda r)dr \quad (3)$$

Then the kernel function is given by Habberjam(1975) as;

$$T(\lambda) = \int_0^\infty (1/r)\,l(r)J_1(\lambda r)dr \quad (4)$$

where J is the first-order Bessel function of the first kind and T (λ) is the transformed resistivity data. Dar-Zarrouk resistivity curve is independent of any underlying layers. The basic mathematics for graphical construction of Dar-Zarrouk curves are given by Orellana(1963) and Zohdy(1973). The curves may be used to give true layer thickness h_j and resistivity l_j by the equation:

$$h_j = l_j\left[\frac{L_{m,j}}{l_{m,j}}-\frac{L_{m,j-1}}{l_{m,j-1}}\right] j = 1, 2, 3,\ldots n \quad (5)$$

$$l_j = \left[\frac{L_{m,j}l_{mj}}{L_{mj}/l_{mj}}-\frac{L_{m,j-1}l_{m,j-1}}{L_{m,j-1}/l_{m,j-1}}\right] \quad (6)$$

$h_1 = L_{mj}$, and $l_1 = l_{m1}$ (7)

where $l_{mj} = (T_j/S_j)^{1/2}$, $L_{mj} = (T_jS_j)^{1/2}$,

$$Tj = \sum_{i=1}^{j} ti \text{ and } Sj = \sum_{i=1}^{j} Si,\quad i = 1,2,3,\ldots n$$

S = the total longitudinal conductance of a section of horizontal layers of thickness, h_j, and resistivity, l_i, T= total transverse resistivity of the same layer above. The importance of Dar-Zarrouk function is that it is uniquely related to the apparent resistivity function.

Methods

Geoelectric study using the Schlumberger electrode configuration was conducted to gain as much insight into the vertical variation and lateral extent of subsurface materials. Results of the study were tied to all available geological and hydrogeological information so as to arrive at conclusions consistent with the acquifer data.

Routine field practice was followed in the survey. The equipment used was ABEM SAS 300C Terrameter. Schlumberger array was employed in all the VES measurement. The maximum current electrode separation (AB) of 294m was achieved in some VES locations. Measurements were carried out at points such that there are six equally spaced points in a decade of a log scale.

The end result of the field measurement is the computation of the apparent resistivity (la) using equation (1).

The apparent resistivity values wre plotted against the half-current spacing (a) using log-log sheet. These plots constitute the field curves which were immediately interpreted qualitatively in the field and later subjected to computer-assisted iterative interpretation. The program used for the purpose of computing theoretical resistivity model given a set of layer parameters employ a 9-point digital linear filters (Koefoed, 1979). This relies on the transformation of a VES curve into its corresponding resistivity transform curve using forward filters such as those developed by (Ghosh, 1971; Koefoed, 1979). The resulting set of layer parameters were interpreted in terms of their lithologic equivalent. The depths to the weathered layers obtained from the VES were also compared with the depths to the water level in the hand dug wells.

Results and Discussion

The different type curves observed in the study area are shown in Table 1 and Figure 2.Based on distinctive geoelectric characteristics, the type curves have been classified as HA, QHA, QKH, QH, KH and AA with 50% of the curves being HA type curves. All the type curves are curves obtainable from the Basement complex area, such as the study area. The H-type Curve has sandy/lateritic topsoil underlain by clay/sandy clay and the weathered/fresh bedrock in its section: This sequence has been recognized in the south western part of Nigeria (Olorunfemi and Olorunniwo, 1985). The H-type curve becomes an HA-type where the weathered bedrock is significantly thick such that it is delineated as a separate layer. In such a case the sandy/clay layer and/or the weathered bedrock could be exploited for ground water. The geoelectric section for the QH type curve is composed of clayey sands topsoil underlain by sandy clay, weathered basement and the fresh bedrock.

The major aquiferous zone delineated for the study area is the weathered/fractures zones.The weathered layer has thicknesses and depths ranging from 5.75 15.50m and 1.80 8.64m respectively with resistivities ranging from 120-2510Ωm . The result is confirmed by the measured depths to water in the hand dug wells ranging from 2.10 8.70m which is within the weathered layer from the interpreted VES curves (Table 1). Table 1 also shows that the depths to basement (or thicknesses of overburden) is 7.69 22.50m indicating a relatively thick over burden. The basement has resistivities ranging from 1640-3660Ωm Therefore, the presence of producing hand dug wells in all the locations where the VES results revealed thick weathered basement and thick overburden is an evident that the geoelectric method is efficient for groundwater study in agreement with Chilton and Foster (1995), and the study area has been identified to have good

Table 1: Depths to water level in the existing hand dug wells and the results of interpretation of nearby VES curves.

Location and VES No.	Curve Type	Thickness of clay (m)	Depth to the weathered layer (m)	Thickness of weathered layer (m) with Apparent Resistivity (Ωm) value in bracket	Depth to basement or thickness of overburden (m)	Depths to the water (m) of nearby hand dug wells (m)
Ogugu – 1	QHA	5.75	8.27	8.50 (640 Ωm)	16.77	8.430m
Ogugu – 2	HA	6.13	7.08	15.50 (3510 Ωm)	22.50	7.10 m
Ogugu – 3	KQH	6.35	8.42	7.65 (787 Ωm)	16.09	8.44 m
Ogugu – 6	HA	5.55	6.50	7.22 (912 Ωm)	13.82	6.60 m
Ogugu – 9	QHA	6.00	7.07	8.25 (1080 Ωm)	15.34	7.10 m
Ogugu – 10	QH	6.60	7.88	8.21 (1710 Ωm)	16.11	7.90 m
Ogugu – 15	KH	N0 clay	7.22	8.45 (1530 Ωm)	15.85	7.40 m
Ogbe-Oke – 1	HA	7.68	8.64	11.78 (165 Ωm)	20.42	8.70 m
Ogbe-Oke – 3	AA	No clay	6.21	7.80 (1440 Ωm)	14.01	6.40 m
Ogbe-Oke – 7	AA	No clay	3.33	11.90 (907 Ωm)	15.23	3.40 m
Ogbe-Oke – 8	HA	6.00	6.75	7.00 (950 Ωm)	13.75	6.80 m
Ogbe-Oke – 10	QH	4.50	7.10	8.61 (210 Ωm)	15.81	7.20 m
Egbigere – 2	HA	5.20	5.34	9.22 (1045 Ωm)	14.56	5.40 m
Egbigere – 4	HA	2.93	3.05	6.60 (128 Ωm)	9.69	3.20
Egbigere – 5	QHA	5.35	6.57	8.25 (360 Ωm)	14.82	5.40 m
Egbigere – 7	HA	1.20	1.80	7.00 (120 Ωm)	8.80	2.10
Egbigere – 12	HA	1.35	1.90	5.75 (286 Ωm)	7.69	2.20m

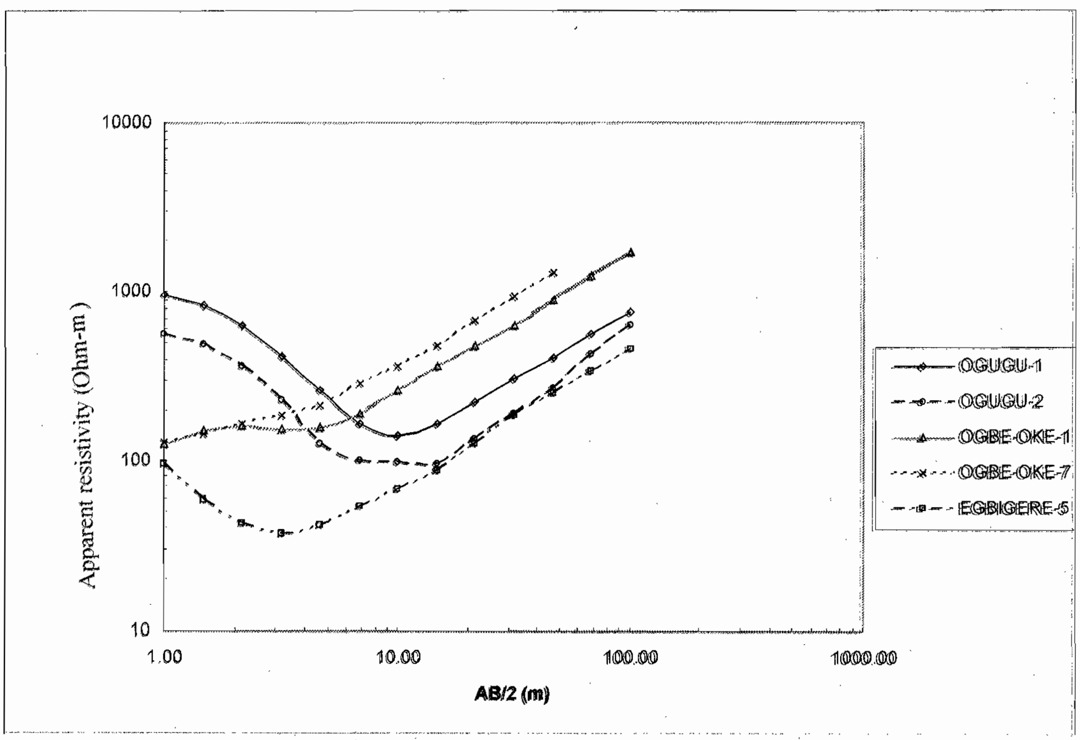

Fig. 2: VES curves in Ogugu, Ogbe-Oke and Egbigere, Edo State

groundwater potential.

As a matter of fact, the groundwater prospects of basement complex areas of Nigeria have mixed reviews in the literature. This state of affairs reflects varying degrees of ignorance as to the proper status of basement complex rocks (and their weathered derivatives) as aquifers. The study is therefore emphatic and positive on the prospects of the economic exploitation of groundwater within the basement complex areas of Edo State through geophysical approach, as long as the limitations of basement complex rocks and their associated weathered products as sources of water supply are clearly recognised.

This study has also shown that the veneer of regolith, the fresh basement rocks are highly fractured at shallow and even at great depths; thus basement complex rocks and their weathered derivatives constitute reservoirs of ground water. Some of the favourable factors responsible are; the high rate of annual rainfall in this area which result in high recharge rates; development of deep weathered profiles; presence of fracture zones in basement rocks; as well as inhomogeneities in basement rocks resulting in contact zones with attendant permeability contrasts, a condition which in fact favours the occurrence of springs.

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