HYDROGEOPHYSICAL EVALUATION OF THE GROUNDWATER POTENTIAL OF THE CENTRAL PART OF OGUN STATE, NIGERIA

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ABSTRACT

Vertical Electrical Soundings (VES) and hydrogeological data were used to delineate the subsurface sequence and map the aquifer units with a view to evaluating the groundwater prospect of the central part of Ogun State, Southwestern Nigeria. Thirty Schlumberger VES with maximum current electrode spacing (AB) of 2000 m were carried out and interpreted by partial curve matching and computer assisted 1-D forward modeling using the WIN-RESIST software. The aquifer test data were analyzed using the Cooper and Jacob method and an empirical technique. The results indicated that the subsurface up to 1000 m (1 km) depth consisted of five major layers. The first layer, which was about 25 m thick with resistivity of 69 - 2795 ohm.m, was the residual soil composed of the topsoil, laterite and saprolite. The second layer, about 30 - 380 m thick, was a highly resistive (738 - 8942 ohm-m) partially saturated coarse-grained sandstone; with a saturated portion characterized by representative hydraulic conductivity (K) of 2.44 m/day, constituted the first aquifer unit. A clayey horizon characterized by layer resistivity of 40 ohm-m to 300 ohm-m and thickness of 30 m to 70 m was the third layer. The moderately resistive (331 1812 ohm-m) fourth layer, about 10 m - 900 m thick, was a fine-grained sandstone that constituted the second aquifer unit with representative K value of 6.34 m/day. The fifth layer was the highly resistive geoelectric basement occurring at depths ranging from 30 - 1078 m. The study concluded that based on the representative K values and aquifer thickness, the sedimentary terrain could be classified as having high groundwater potential while the transition zone can be classified as having low to moderate groundwater potential.

INTRODUCTION

Ogun State, Nigeria has population of about four million people with land mass of about 16,742 km^2. It is the only State that shares land border with the highly industrialized and densely populated Lagos State (Fig.1). The acute shortage of land for development in Lagos State has led to rapid population influx into several neighbouring towns of Ogun State. Mostly affected are zones having proximity to Lagos Metropolis and which have been classified as Development Pressure Area (DPA) in the Conceptual Regional Plan of the State. It is envisaged that there would be tremendous increase in water resources demand of the State leading to extensive exploitation of groundwater resources to meet requirements for both domestic and industrial water demands.

Subsurface mapping to determine the spatial distribution of aquifer units is an important aspect of regional hydrogeological study for effective groundwater modeling. The conventional method commonly adopted for this process in areas with abundance of borehole data involves correlation of lithological logs derived from borehole completion data or borehole geophysical logging data (Oteri, 1984; Longe et al., 1987; Fatoba and Olorunfemi, 2004).

However, in areas with paucity of borehole completion data or when the quality of most of the available is poor, integration of geophysical methods, with few borehole completion data is adopted for aquifer mapping. The electrical resistivity method involving the Vertical

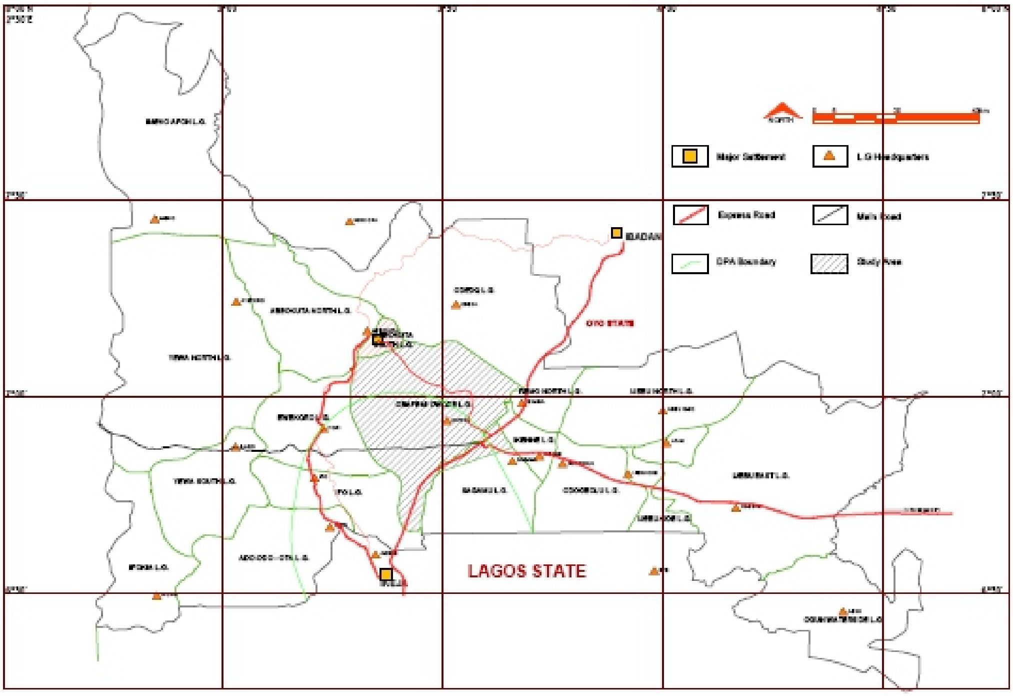


Figure 1 Map of Ogun State Showing the Study Area (Modified After Geography / Regional Planning Department, Olabisi Onabanjo University, Ago-Iwoye, 1992)

Electrical Sounding (VES) technique, had been found effective in achieving good spatial coverage for mapping of aquifer units (Ako 1989; Mbonu et al., 1991 and Ojo et al., 2007).

Ogun State is beset with paucity of proper borehole completion data. There is no record of any State sponsored hydrogeological study while few of the available industrial and domestic boreholes have proper completion records. Hence, previous hydro-geological studies of the State (Idowu, 1992 and Idowu et al.,1999) were based mainly on the few available boreholes data which were not adequate for effective delineation of the subsurface sequence of the various aquifer units.

The central part of Ogun State (study area), is plagued by numerous abortive and low groundwater yielding boreholes, while many of the productive boreholes have poor completion records; thus resulting in paucity of borehole data. This is generally attributed to difficulties encountered in drilling through some of the highly compacted lithological units. This study was undertaken to map the aquifer units in the central part of Ogun State with a view to generating appreciable geoelectric and hydrogeological data base for an effective groundwater potential evaluation.

DESCRIPTION OF STUDY AREA

Ogun State occurs within the humid tropical rain forest region of Nigeria characterized by two climatic seasons; the rainy season of about eight months (March October) and the dry season of about four months (November February). The State has an average annual rainfall of about 1300 mm and an annual potential evapo-transpiration of about 188 mm. The drainage density of the State is high and is characterized by many big perennial rivers such as Ogun, Ewekoro and Berre that mostly have dendritic drainage pattern (Akanni,1992). The study area lies within Latitudes 6° 41'N - 7°9'N and Longitudes 3° 16'E - 3°41'E covering an areal extent of about 915 km^2 (Fig. 1). The area has elevation ranging from 40 m in the South to 154 m in the North.

The geologic units of the State are composed of crystalline rocks of the Basement Complex and sedimentary rocks of the extensive Dahomey Basin. Stratigraphic units of the Nigerian sector of the Dahomey Basin which are also found in Ogun State are composed of the late Cretaceous predominantly sandy strata of the Abeokuta

Group as the oldest. The overlying Tertiary strata include limestone, of the Ewekoro Formation, shale, of the Akinbo Formation, mudstones/shale of the Oshosun Formation, sandstone of the Ilaro Formation. Other younger strata are the Oligocene to Recent continental sands of the Benin Formation as well as recent alluvial sediments (Fig.2). (Omatsola and Adegoke, 1981; Adewuyi, 1984; Adediran et al., 1991; and Nton et al., 2009).

The saturated sandstone, limestone and sandy sediments within these strata constitute the aquifer units. The high annual rainfall of the State indicates proper recharge of these aquifer units. Substantial part of the study area falls within area underlain by deposits of the Abeokuta Group, while minor part occurs within the transition zone between the crystalline basement rock and sedimentary rocks (Fig. 2).

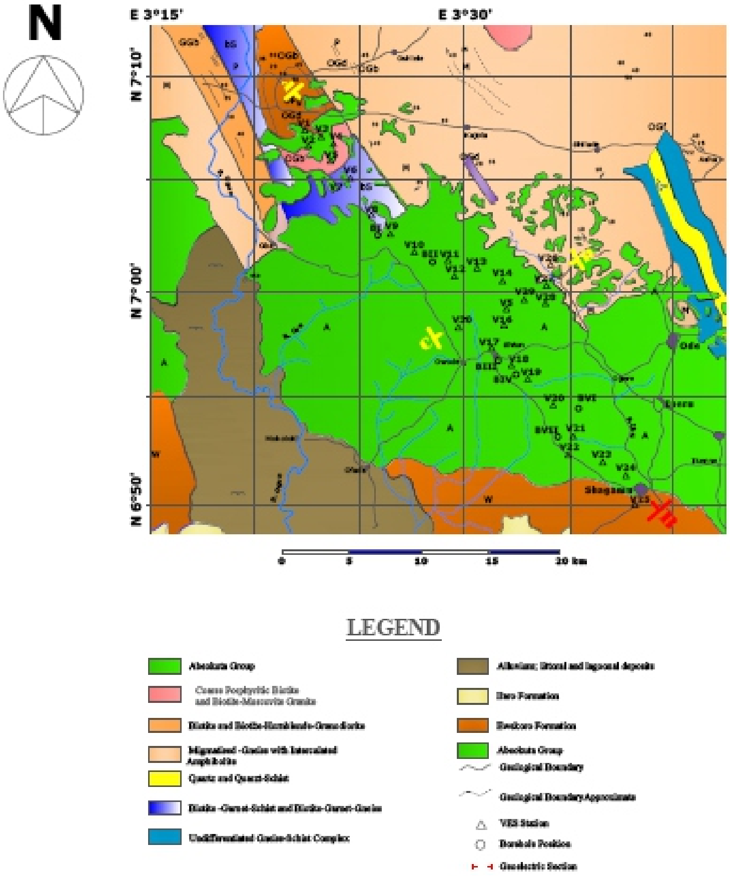


Fig. 2 Geological Map of the Study area Showing the VES and the Borehole Positions (Modified After Jones and Hockey, 1964.)

MATERIALS AND METHODS OF STUDY

Completion data of seven water wells within the study area were collected and collated. One of the wells (BH VII) has adequate hydrogeological data that included proper lithologic log, a suite of down-hole geophysical logging data and fairly long duration (2880 minutes) aquifer test. The remaining six wells (BH I VI) were drilled to depths ranging from 60 m to 90 m, four of which (BH II VI) have poor lithologic description and short duration (120 minutes) aquifer tests. The remaining two wells (BH I-II) have proper lithologic description but no aquifer test data. All the wells partially penetrated the aquifer exploited. The Cooper and Jacob method of solution and empirical technique using the Razack and Huntley (1991) relationship for specific capacity and transmissivity were used to analyze the boreholes aquifer test data.

The electrical resistivity method utilizing the VES technique was used to further delineate the subsurface lithological sequence. Thirty (30) VES stations were occupied in the study area (Fig. 2) with the Schlumberger electrode configuration with maximum total current electrode spacing

(AB) of 2000 m. The digital PASI 16 GL Resistivity Meter was used for the data acquisition. In most cases, inter-station distance of 1 km was adopted within the basement complex/transition zone, with corresponding distance of 2 km. within the sedimentary terrain except where the terrain topography and the highway tortuosity made this impracticable. Current booster was used to increase the current density for the large electrode spacing measurements. The VES data were interpreted quantitatively by the partial curve matching technique using master curves developed for horizontally multilayered earth mode

The obtained layer resistivities and thicknesses of the subsurface layers were used as starting model parameters in a 1-D forward modeling using the WIN-RESIST software. In locations with thick sedimentary sequence, depth to the Basement Complex was not achieved with the adopted maximum total current electrode spacing (AB) of 2000 m. The approximate method (Keller and Frischknecht, 1966) involving imposition of the S-line on the terminal branch of the sounding curve was used to estimate the apparent minimum depths to the Basement bedrock.

RESULTS AND DISCUSSION

Lithological Units

Based on description of the mud logging data and interpretation of borehole geophysical logging data, lithological units in the area is composed of predominantly sandy deposits with minor clay intercalations from ground surface to about 167 m. (Fig. 4).

The basal layer constituting the first lithological unit is a fine-grained sandstone that was recorded only beneath BH VII from about 100 m to 167 m depth. Overlying the fine-grained sandstone is a clayey lithological unit composed of clay/shale and sandy clay deposits that was recorded in borehole BH II and BH VII. This layer constitutes the last layer in BH II. A medium/coarse - grained sandstone characterized by intercalations of thin bands of clay and highly compacted conglomerate/ferrugenous sandstone overlies the clay/shale unit. The superficial lithologic unit, about 30 m thick, is composed of laterite, lateritic clayey sand, hard crust or mudstone that is considered as the residual soils produced by weathering of the coarse sandstone. Static water level in the area occurred at depths ranging from 20 m in the extreme south to about 70 m in the central and northern part.

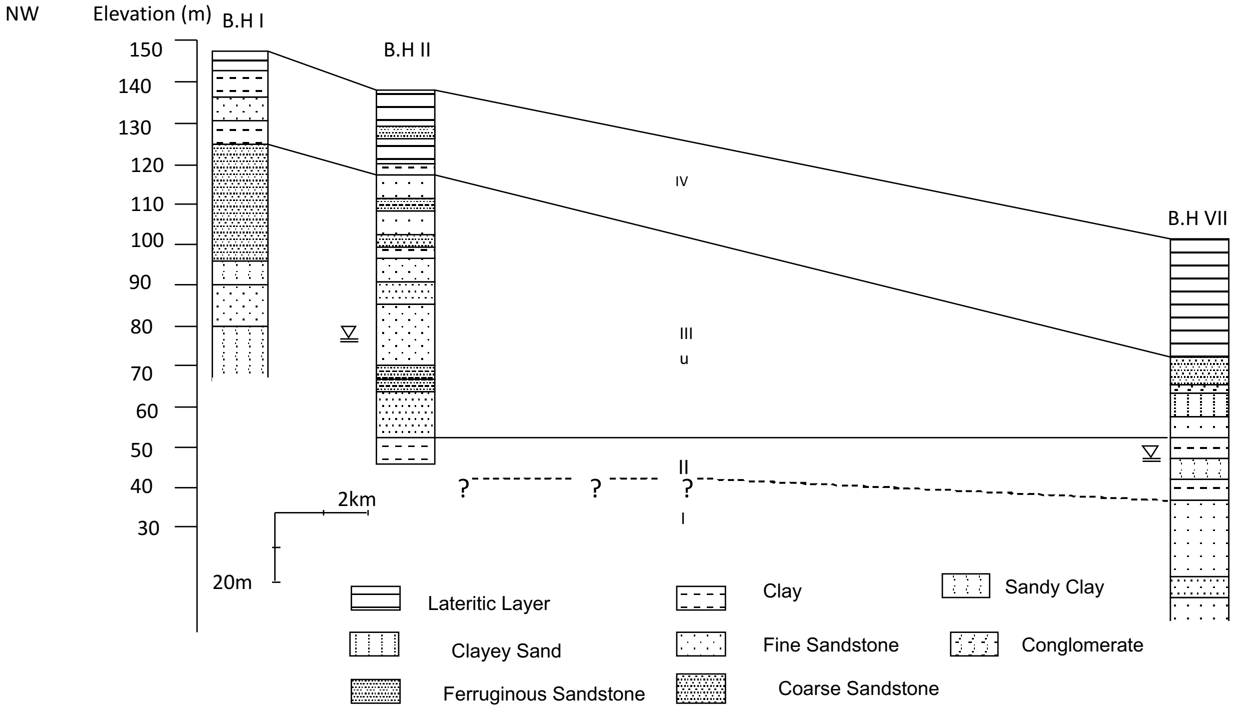


Fig. 4. Correlation of Borehole Lithologic Logs

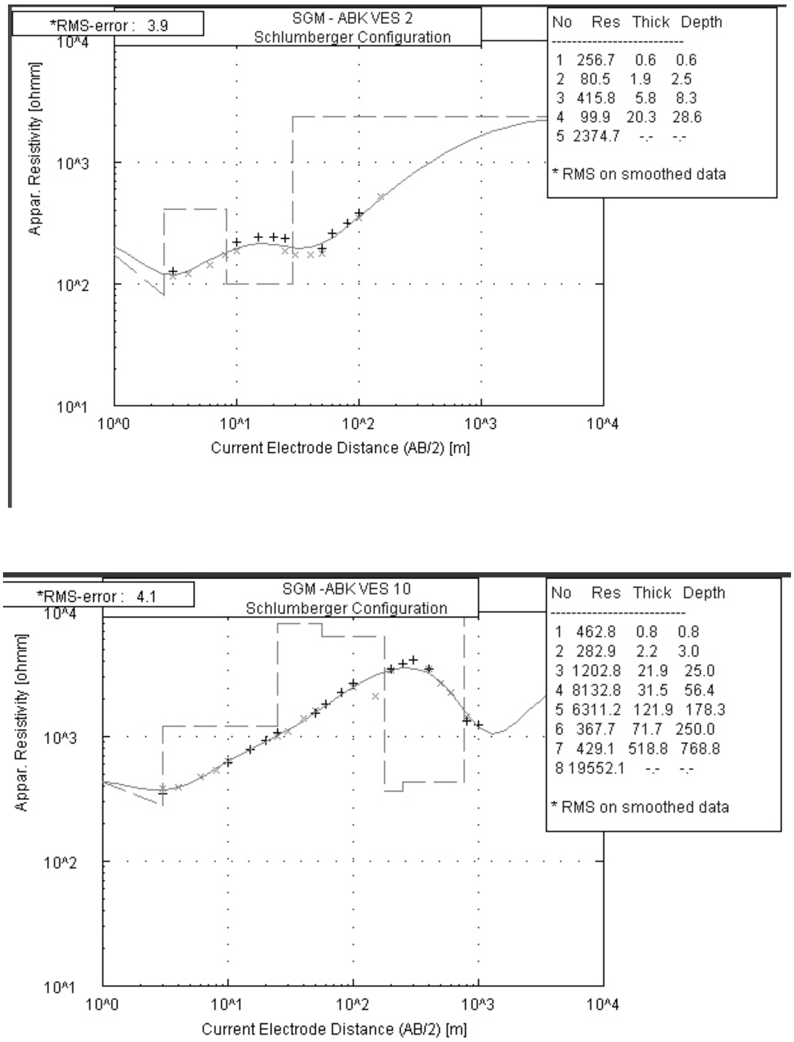
Geoelectric Characteristics

The interpretation results of the VES are summarized in Table I. The VES curves within the transition zone generally vary from simple four to seven layer type (KH, HKH , AKQH ,QHKQH). The VES curves within the sedimentary terrain are five to eight layer type (AK, AAK, HAKQ, HKHK, AKQQ, HAAK, HAKQ, HKHKQ and AKQHKHA). (See Figure 5).

Interpretation of the VES results, which was guided by the lithologic logs, indicates occurrence of five major geoelectric layers from ground surface to about 1000 m depth. The first geoelectic layer is the topsoil with resistivity values that generally range from 69 ohm-m to 2795 ohm-m indicating clay, clayey sand, sand and lateritic topsoil. The layer thickness ranges from 0.6 m to 1.5 m. The second geoelectric layer is composed of laterite and saprolite with resistivity values that range from 311 ohm-m to 2795 ohm-m and thickness that varies from 1.7 m to 30 m. These two layers are residual soils developed by in-situ weathering of the Basement Complex rocks and the sandstone of the Abeokuta Group. The third geoelectric layer is the partially saturated medium to coarse-grained sandstone characterized by resistivity values that generally range from 738 ohm-m to 8942 ohm-m. The layer has thickness of less than 50 m in the transition zone (VES 1, VES 7 and VES 26) and in the extreme southern part (VES 19 to VES 25), but attains appreciable thickness of 90 m to 380 m in the central part, along both the A-B Section (VES 8 -VES19), and C-D Section (VES 27 VES 30). The fourth geoelectric layer, characterized by resistivity values that vary from 331 ohm-m to 1812 ohm-m, is a saturated fine-grained sandstone with intercalations of sandy clay (100 ohm-m to 216 ohm-m) and clay deposits (29 ohm-m and 87 ohm-m.). The layer is also highly variable in thickness beneath the two sections, varying from less than 10 m to about 300 m in the transition zone, and from 110 m to 930 m in the sedimentary terrain.

Table 1. Summary of VES Results and Interpretation

VES Station	DEPTH (m) $d_1/d_2/d_3/\&.d\ n\ -1$	RESISTIVITY *(Ohm-m)* $//\rho_1/\rho_2/\ \rho_3\ /\&\ \ \rho_n$	TYPE CURVE
1	0.6/1.7/5.9	338/411/116/1089	KH
2	0.6/2.5/8.3/28.6	257/81/416/100/2375	HKH
3	0.9/4.9/8.2/22.0/28.1/222.2	2795/2290/1351/10683/5491/752/4087	QHKQH
4	0.9/2.8/6.4/53.5/77.6	556/341/957/2045/364/7107	HAKH
5	1.5/4.4/17.3/46.0/386.9	388/608/7563/8942/135/5637	AAKH
6	0.9/3.3/9.5/13.4/48.9	177/611/955/137/37/591	AKQH
7	1.0/1.6/15.2/80.3	166/484/862/29/966	AKH
8	0.9/9.4/99.1/731.8	147/362/4472/175/9122	AKH
9	1.0/18.3/157.9/467/669	202/964/6660/1678/111/16924	AKQH
10	0.8/3.0/25.0/56.4/178.3/250.0/768.8	463/283/1203/8133/6311/368/429/19552	HAKQHA
11	0.8/20.9/55.0/143.5/1073	804/1464/3729/11387/564/47755	AAKH
12	1.1/8.6/22.9/42.9/143.3/823.3	1926/531/2575/13807/7978/588/21993	HAKQH
13	0.8/11.6/181.5/282.6/965.6	384/517/6821/492/212/11816	AKQH
14	0.6/2.4/6.0/24.3/217.3/738.2	193/889/309/694/6154/437/20217	KHAKH
15	0.9/4.1/26.3/117/179	566/792/922/3351/858	AAK
16	0.8/3.9/19.1/57.9/219.1/367.6/747.5	417/317/1403/840/4036/1649/363/19783	HKHKKQH
17	0.8/3.0/17.7/115.3/413.3/763.1	147/53/2735/576/11104/1529/	HKHKH
18	0.9/6.7/30/165/277/527	302/342/4835/941/278/249/737	AKQQH
19	0.9/6.9/49.4/798.6	320/171/4261/300/10973	HKH
20	0.9/4.2/7.0/13.0/37.0/50.0/324	104/293/550/235/8636/108/180/2509	AKHKH
21	0.9/4.5/12.3/56.9/176.9/282.9	69/126/374/4382/422/76/1564	AAKQH
22	0.8/1.8/5.2/29.2/74.2	400/500/300/720/2100/600	KHAK
23	0.8/5.0/10.1/21.4/92.3/246.4	549/127/539/153/4809/1613/	HKHKH
24	0.7/1.7/3.2/16.5/25.6/221.9	140/172/698/471/1168/250/1114	AKHKH
25	1.0/4.1/7.3/21.0/91.4/135.6/183.9/ 570.2	82/259/2211/810/244/672/112/926/5935	AKQHKHA
26	0.8/2.8/5.0/42.0	401/2065/418/133/632	KQH
27	1.0/12.0/43.0/122.0/153.0	320/991/17718/710/113/6436	AKQH
28	1.0/3.0/8.0/30.0/147.0/641.0	1266/343/1130/10304/11501/575/21791	HAAKH
29	0.6/2.3/13.1/42.8/394.9/596	486/187/1006/4226/3208/216/12993	HAKQH
30	0.9/1.1/2.4/20.4/73.2/149.1/784	98/184/51/255/3813/759/331/7725	KHAKQH



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No   Res  Thick  Depth
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 1  256.7   0.6   0.6
 2   80.5   1.9   2.5
 3  415.8   5.8   8.3
 4   99.9  20.3  28.6
 5 2374.7   -.-   -.-

* RMS on smoothed data
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No   Res  Thick  Depth
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 1   462.8   0.8    0.8
 2   282.9   2.2    3.0
 3  1202.8  21.9   25.0
 4  8132.8  31.5   56.4
 5  6311.2 121.9  178.3
 6   367.7  71.7  250.0
 7   429.1 518.8  768.8
 8 19552.1   -.-    -.-

* RMS on smoothed data
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Fig. 5. Typical Schlumberger Depth Sounding Curves

The geoelectric basement, which is the last layer, was difficult to classify in terms of lithology due to the fact that the basal sandstone/conglomerate of the Abeokuta Group that unconformably overlies the Basement Complex rocks is also highly resistive giving rise to obscured geoelectric boundaries between the two units. Depths to this basement vary from 10 m to about 1000 m.

Delineation of Aquifer Units

In view of paucity of borehole completion data within the area, the obtained geoelectric parameters were used to define the major hydro-lithologic units. The first aquifer unit is the highly resistive, partially saturated, medium/coarse-grained, unconfined sandstone constituting the third geoelectric layer. Six of the boreholes (BH I-VI) were terminated within this aquifer. The second aquifer unit is the fine-grained sandstone that constitutes the fourth geoelectric layer. The aquifer is generally confined//semi-confined by the thin clay/shale/sandy clay layer observed within the borehole logs. Borehole VII was terminated within this aquifer. Based on analysis of the pumping test the first aquifer unit has an estimated transmissivity (T) that ranges from 56.55 m^2/day to 99.22 m^2/day with an average of 78.50 m^2/day while the corresponding average hydraulic conductivity (K) is 2.44 m/day. The second aquifer has estimated T of 368 m^2/day with corresponding K of 6.34 m/day. These values fall within the range of K classified as moderate (Hamil and Bell, 1980). In view of the paucity of hydrogeological data in the area, the average K values were taken as representative of the aquifers and used along with the aquifer thickness for an initial evaluation of the groundwater prospect of the area.

Basement Topography and Groundwater Prospect

The geoelectric basement, which occurs at highly variable depths within the area of study, depicts series of down-faulting and up-faulting that resulted into fault created basement depressions and ridges filled with predominantly sandy deposits of the Abeokuta Group. Hence, the geoelectric basement topography influences thicknesses of the aquifer units and groundwater prospect of the area (Figs. 5 and 6).

Within the transition zone, the static water level is generally deep, (40 m to 75 m) and the basement generally occurs at shallow depths ranging from less than 30 m to 80 m except in the down-faulted portion characterized by depth range of 222 m to 387 m. The coarse sandstone constituting the first aquifer unit is completely dry in this zone, while the second aquifer unit has thickness ranging from 10 m 300 m. Hence, the zone is classified as having low to moderate groundwater potential. Locations within the zone characterized by less than 50 m thick aquifer is classified as having low groundwater potential while the minor down-faulted basement portions filled with over 100 m to 300 m aquifer is classified as having moderate groundwater potential.

On the other hand, within the sedimentary terrain, the basement occurs at depth ranging from 300 m to 1078 m along both NW- SE and NE SW Sections. Thickness of the first aquifer unit beneath the A B Section varies from 10 m in the Southern part to 360 m in middle part. Corresponding thickness beneath the C D Section ranges from 30 m to 300 m. The second aquifer thickness in the terrain ranges from 110 m to 930 m with an average of 427 m. Therefore, based on the combined thickness of 140 - 1000 m, recorded for the two aquifer units (with an average of 531 m), the sedimentary terrain is classified as having very high groundwater potential. It is pertinent to note that aquifer units in locations with deep water table of above 50 m are bounded at the top by dry sandstones to maximum depth of about 75 m; boreholes in such locations must be terminated at a minimum depth of 100 m to avoid exploitation of perched aquifer.

Fig 6 Geoelectric Section along Section A-B

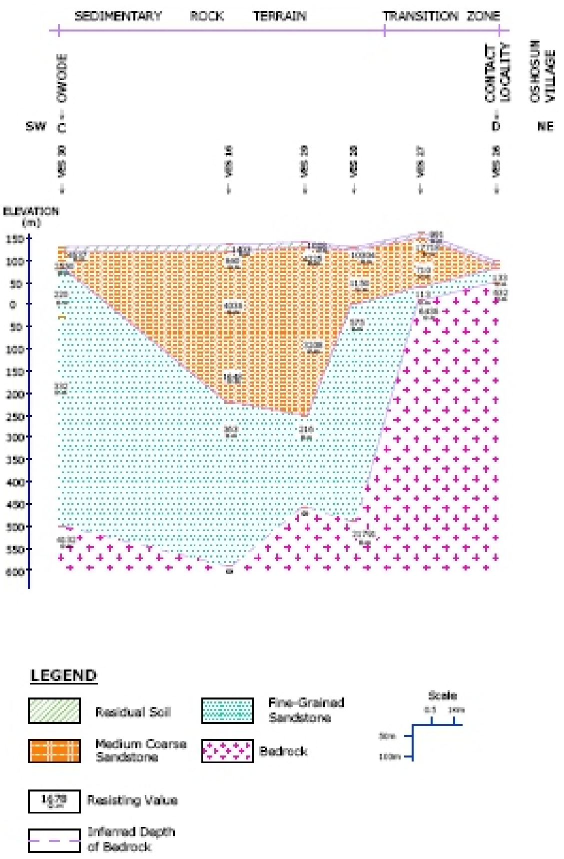

Fig 7 Geoelectric Section along SW-NE Section.

CONCLUSIONS

The Vertical Electrical Sounding (VES) technique was used along with few borehole completion data to delineate the subsurface sequence and map the aquifer units in central part of Ogun State. The study was carried out to generate data to assist in the initial planning for the anticipated high increase in demand for the groundwater resource of the area.

The geoelectric sounding involved 30 VES using the Schlumberger array. Results of the geoelectric sounding interpretation indicate occurrence of five major geoelectric layers from ground surface to depth of about 1000 m composed of: the topsoil, laterite ; the residual soil (laterite and saprolite), the partially saturated medium to coarse-grained sandstone; the fine-grained sandstone and the geoelectric basement (basal sandstone and the crystalline Basement Complex rocks).

Two aquifer units were delineated from this subsurface sequence. The first aquifer is the saturated portion of the unconfined medium/coarse-grained sandstone with average thickness of 114 m and K of 2.16 m/day. The second aquifer unit is the fine-grained confined/semi-confined sandstone that has an average thickness of 427 m within the sedimentary terrain The aquifer occurs as unconfined unit within the transition zone and has irregular thickness. Based on the moderately high hydraulic parameters of the aquifers, the transitional zone that is characterized by thin to moderately thick aquifer is classified as having low to moderate groundwater potential. The sedimentary rock terrain that is characterized by average combined aquifer thickness of 531 m is classified as having very high groundwater potential.

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