

DETERMINATION OF AQUIFER UNITS USING VERTICAL ELECTRICAL SOUNDING TECHNIQUE: A CASE STUDY OF FEDERAL LOW COST HOUSING ESTATE, OKEHO, SW NIGERIA.

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Abstract: The groundwater development of Federal Low Cost Housing Estate Okeho involved the use of schlumberger vertical electrical sounding technique. The result of the survey showed that qualitatively three major curve types H, QH and KH were observed. The geoelectric layers range from 3 to 4 while the quantitative interpretation resulted in deducing layer parameters of 190-1103Ωm and 0.70-1.10m for the topsoil. The intermediate layer has layer resistivity of 93 -1590Ωm and thickness of 0.9-4.70m while the weathered basement has resistivity and thickness of 18-50Ωm and 6.0-10.4m. The bedrock resistivity range from 426-6284Ωm with an infinite thickness; the bedrock resistivity of less than 1000Ωm in this area and the weathered layer constitute the aquifer.

Keywords: Aquifer occurrences, Geoelectric Parameters, Sounding Curves

1. INTRODUCTION

The use of surface geophysical techniques for groundwater study is necessary in reducing its rate of wildcat search. [1], started with a systematic geophysical investigation for groundwater in parts of southwestern Nigeria, used seismic refraction and electrical resistivity methods in the basement terrain and resistivity method only in sedimentary area. The result from the basement area revealed that subsurface fractures are good targets for groundwater. In the basement terrain, irrespective of thin or thick overburden the existence of faults and fractures improved substantially the yield of boreholes [2]. The present study is in the use of vertical electrical sounding in understanding the hydrogeological condition of the study area; this will involve determination of the thickness and resistivity of the subsurface layers, delineating the fracture zones, establishing depth to bedrock, which will be used to decide potential areas for tapping the groundwater.

2. GEOLOGICAL SETTING

In the basement complex of Nigeria, six major groups of rocks have been recognized [3]; which include:

- (a) The migmatite-gneiss complex, which is the most widespread rock type

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- (b) The migmatite-gneiss complex, which is the most widespread rock type
- (c) Slightly migmatized to non-migmatized meta sedimentary and meta igneous rocks
- (d) Charnockitic, gabbroic and Dioritic rocks
- (e) The older granite
- (f) Metamorphosed to unmetamorphosed calc-alkaline volcanics and hypabyssal rocks
- (g) Unmetamorphosed dolerite dykes, basic dykes and syenite dykes etc.

The Nigeria basement complex (Fig.1) is widely believed to be mainly Proterozoic in age. Four orogenic events, affected the basement complex of Nigeria, which are:

- | | |
|-----------------|----------------------|
| (a) Pan-African | c.600 million years |
| (b) Kibarian | c. 1.1 billion years |
| (c) Eburnean | c.2 billion years |
| (d) Liberian | c.2.8 billion years |

However, radiometric data gotten from rocks of the basement complex indicate Eburnean orogeny and Pan –African being the most significant in Nigeria. The Eburnean orogeny is accompanied by widespread migmatization and granitisation of sediments and volcanics. The Pan-African orogeny product is found in every part of the country and is characterised by intrusion of granites, local migmatization and mobilization. The granite rocks associated with this most important orogeny are called older granites. The older granites are large masses of igneous rocks.

Folds, thrust, tectonic fabric, shearing and migmatism reflect the effect of the Pan-African orogeny. The older granites, which are the most manifestation of the Pan-African orogeny, cover the wide areas in Nigeria and part of West Africa; in south western Nigeria: Okeho, Iseyin, Shaki

among others. The older granites make up about 20 percent of the basement outcrop in eastward and 40-60 percent in the northeast ward [4].

The basement complex consist of several types of older granites namely: Migmatite granite, granite gneiss, pegmatite dyke and fine-grained granites,

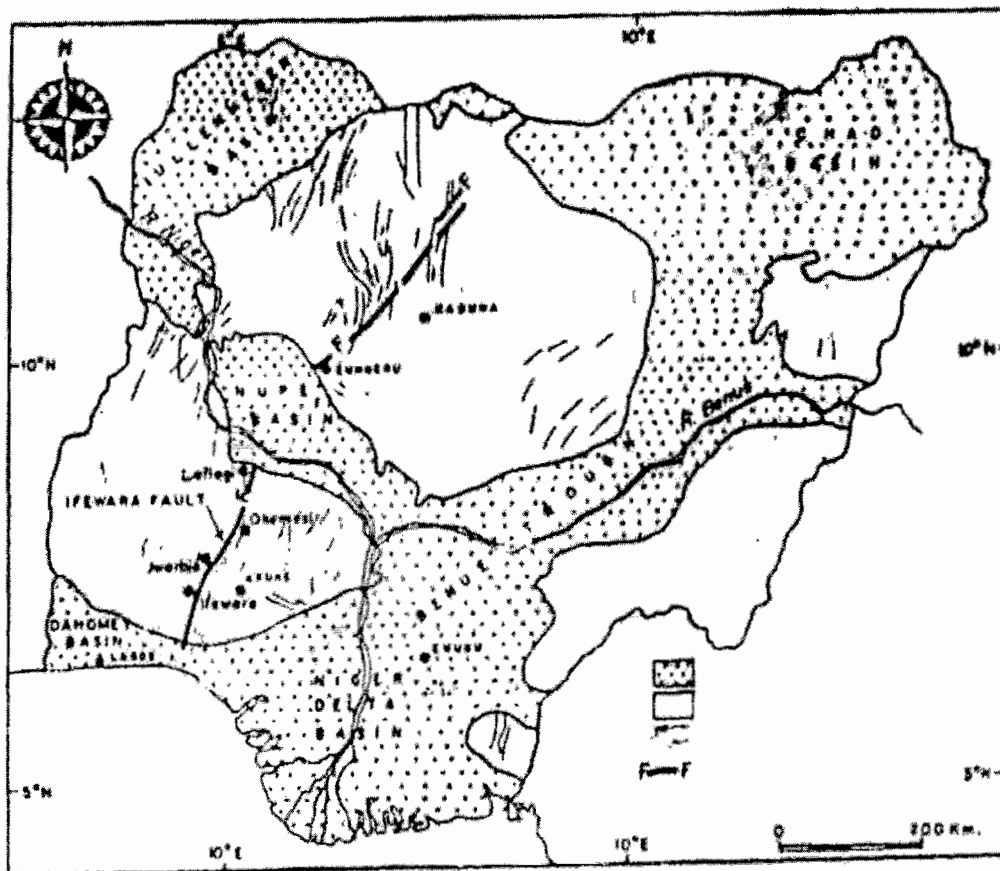


Fig. 1 Geological map of Nigeria (after [18])

medium to coarse porphyritic biotite and biotite hornblende granite; slightly deformed pegmatite

PHYSIOGRAPHY AND GEOLOGY OF THE STUDY AREA

Okeho is situated between longitudes $3^{\circ} 20^1E$ to $3^{\circ} 25^1E$ and latitudes $8^{\circ} 1^1N$ to $8^{\circ} 4^1N$ (Fig.2). Most of the surface sources of water are seasonal. The mean annual rainfall is about 1270mm [5] with July being the wettest. The area lies within the southwestern Nigeria crystalline basement block. Gneisses and schist form the country rock on which granitoid plutons (potassic syenite and porphyritic granite) intruded during the Pan African thermo-tectonic events (ca 600 ± 150 Ma). The plutonic rocks form prominent hills, around Okeho town where the VES measurements were determined. However, the dominant rock type in the study area is syenite (Fig.3a). The syenite is

characterised by the development and alignment of feldspar crystals [3,6,7]. The contact between the syenite and the porphyritic granite, which fringes varies from sharp to gradational. Minor joints and fractures could be seen on the outcrops. Other rock types of the study area include amphibolite, schist and gneisses.

HYDROGEOLOGY OF THE STUDY AREA

The hydrogeology of an area is controlled by such factors as geology, structures and climate of the area. This is because the geological formations underlying the area and the structures determine the type of aquifer to be encountered and the means of recharging them while the climate determines the amount and rate of recharge of the aquifer [8,9].

The major surface waters in the area are rivers Oyan and Ofiki (Fig.3b) and the tributaries of river Ogun forming the main drainage system. The main

rivers flow southwards with their tributaries flowing into them from east and west directions. Most of the main streams trends approximately north to south thus they are structurally controlled. The tributaries follow the dip directions and join the main streams at approximately 90° producing a pattern of trellised drainage.

Groundwater occurrence in the basement complex is mostly unpredictable because the complex has limited potential for groundwater accumulation. The crystalline nature of the rock make it impervious but fracturing, fissuring jointing and weathering may impose secondary porosity on

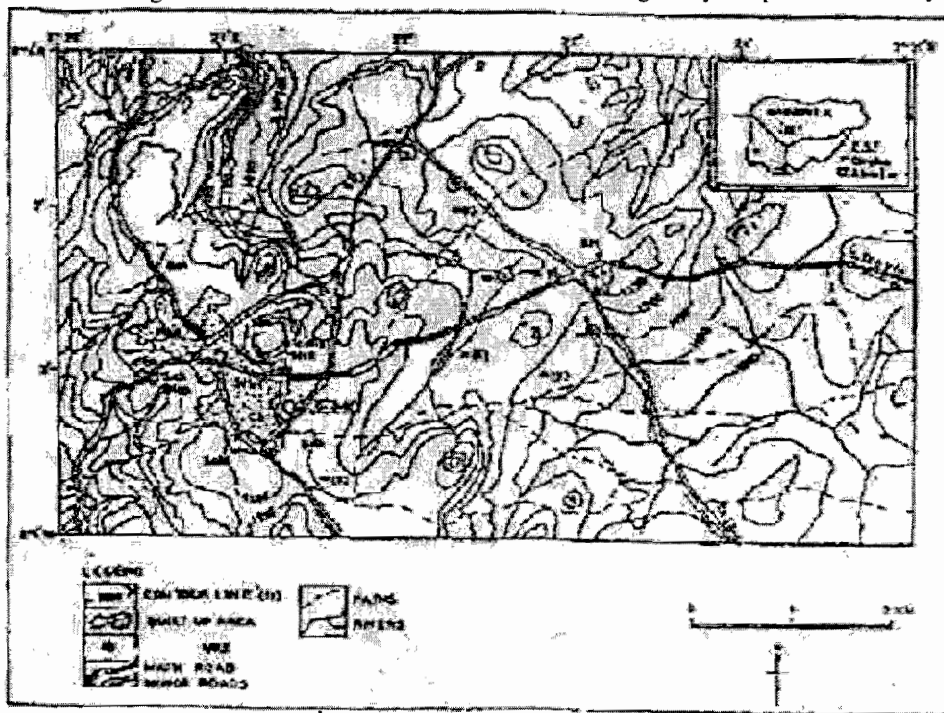


Fig. 2: Topographic Map of Okocho area

these rocks making them favorable for groundwater storage.

The granites and the gneisses weathered to form residual clay, which often reduce the permeability and potential of the weathered materials however partial weathering could result in the formation of laterite/sands as the weathered profile. This can be locally important as a source of groundwater particularly for shallow wells. The highest groundwater yields in the basement terrain are areas where thick overburden overlies the fractured zones [10]. The presence of moderately to high coefficient of anisotropy at relatively appreciable depth is indicative of linear geologic structures of good subsurface impression, which is a good groundwater index [11].

3. FIELD PROCEDURE

The geophysical investigation involved the use of electrical resistivity method [11,12,13] in which vertical electrical sounding (VES) technique was used. A schlumberger geoelectric sounding array, which is one of the most widely used configurations, was employed [14,15]. In this case, the potential electrodes (MN) are closely spaced

while the current electrodes (AB) is increasingly spaced such that $MN \leq AB/5$.

An ABEM Terrameter SAS 300B and its accessories were used for data collection. This is used to measure the resistance of the subsurface layers. The SAS (Signals Averaging System) allows for averaging the result obtained from the subsurface where readings were taken at specific current electrode spacing. The current electrode spacing (AB/2) range from 1m to 133m while the potential electrode spacing (MN/2) range from 0.2m – 15m. A total of about twenty (20) vertical electrical sounding data were obtained over the entire area (Fig.4).

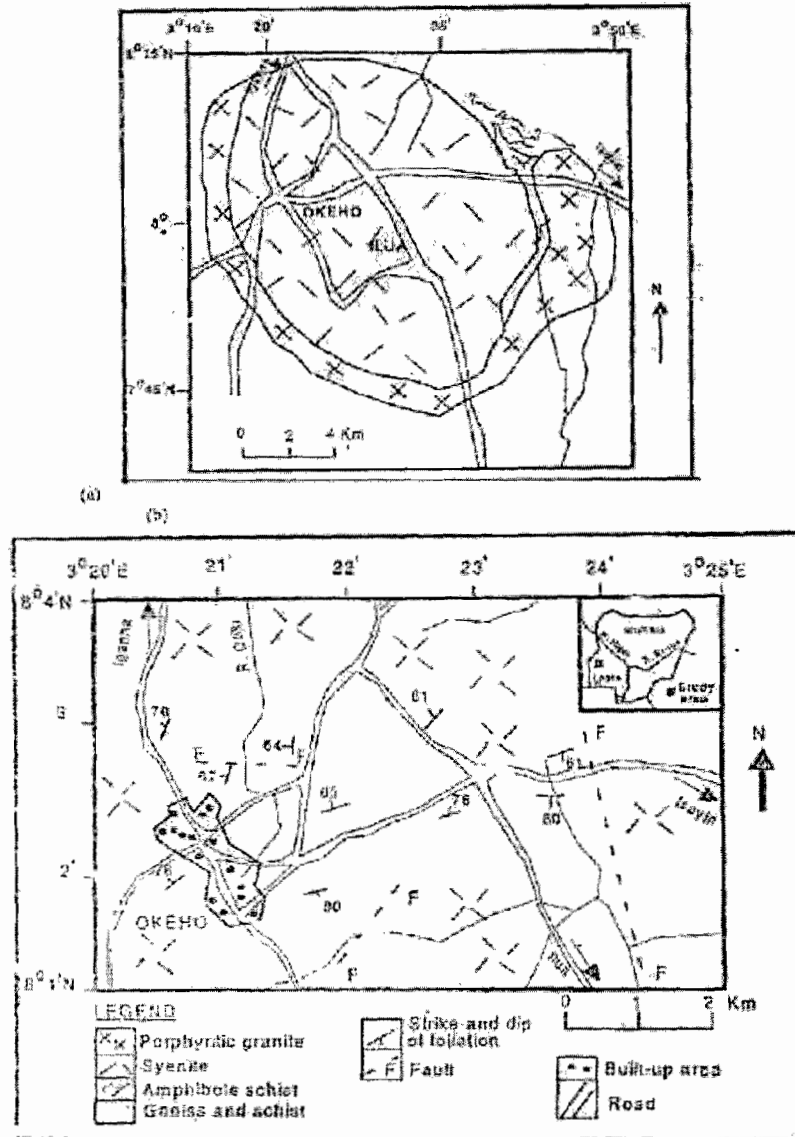
4. DATA INTERPRETATION

The sounding curves were interpreted qualitatively and quantitatively. The quantitative interpretation involved visual inspection of field curves for number of layers and its layer characteristics. The quantitative interpretation of the VES curves involved partial curve matching using 2-layer model curves and its corresponding auxiliary curves. Multi-layered field curves were matched segment-by-segment starting from small electrode spacing. Theoretical VES curves were generated

from partial curve matching interpretation result (layer thickness and layer resistivity).

Computer generated curves were then compared with observed field curves such that where a good fit of above 90% was obtained on the two curves [16]; the interpretation result was considered satisfactory; otherwise the geoelectric parameters

were modified as appropriate and the procedure repeated until a satisfactory fit was obtained. The geological interpretation of the geoelectric models resulting from the quantitative interpretation of VES curves was based on lithological information obtained from wells in the vicinity of the area.



**Fig. 3: (a) Regional geologic setting of the study area (adapted from [7])
(b) Geologic map of the study area**

5. RESULTS AND DISCUSSION

(a) Curve Types and Aquifer Occurrences

Qualitatively, three (3) curve types namely H, KH and QH were identified in the area. The relationship between the curve types and the subsurface is revealed from the number of its geoelectric layers, which is controlled by the degree of weathering of the lithologic units. These

distinct geoelectric units have varying layer parameters (layer resistivity and thickness) from which the curve characteristics and aquifer system can be delineated. The mode of aquifer occurrences in the basement study can be classified into four types:

Type 1: Occurrences in the saprolite (in-situ weathered materials) overlying the fresh basement.

Type 2: Occurrences in the decomposed veins within the fresh basement

Type 3: Occurrences in the fractured bedrock.

Type 4: Occurrences in quartzites [17]

Depending on the range of layer resistivity and thickness the first three-aquifer types (Type I, II,

and III) could be established in the study area. From Table 1 the type 1 aquifer was delineated for H curve type while in KH and QH curve types Type I, II, III aquifer types were established. The type II and III aquifer types seem more promising for groundwater development because it is underlain mostly by fractured bedrock.

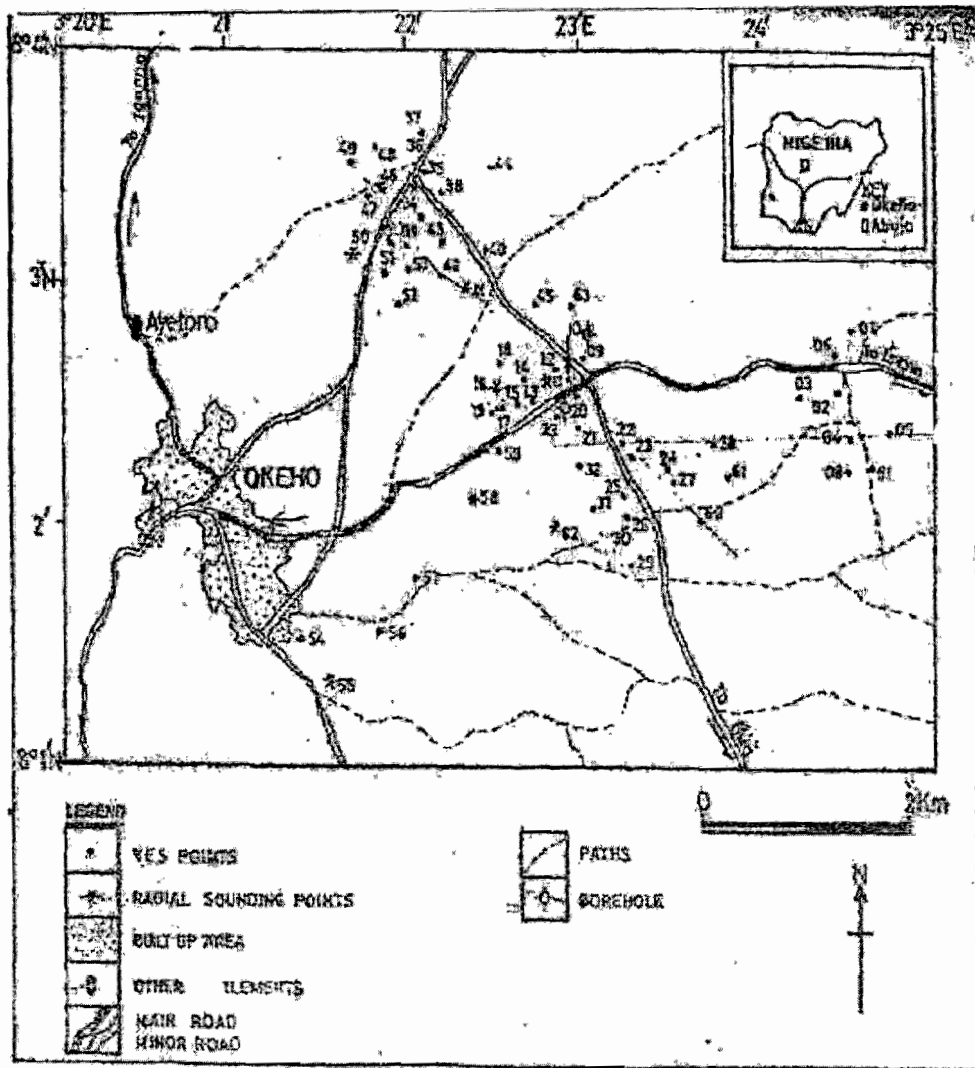


Fig. 4: Location map of the study area showing the Vertical Electrical Sounding positions

(b) Curve Types and Layer Characteristics

The quantitative interpretation of the sounding curves yields information on their layer parameters (Table 1). From this table 1, the H curve type is characterised by varying resistivity of 260 – 380 ohm-metres for the topsoil and thickness 0.70 – 1.50m. Also, the thickness layer has resistivity of 50 – 95 ohm-metres and thickness 2.5 – 5.5m while the third layer is the bedrock of resistivity 4000 –

5189 ohm-metres. The intermediate layer, which is the weathered part above the bedrock, consists of probable materials of clay/clayey/sands. This layer serves as the aquifer and relevant to siting of shallow hand-dug wells, which could be affected by seasonal variation particularly when, it is not underlain by fractured bedrock.

The KH curve type showed a four-layer case having layer resistivity of 680 – 1365 ohm-metres,

880 – 1600 ohm-metres, 40 – 56 ohm –metres, and 1180 – 6285 ohm-metres which correspond to the top soil, intermediate layer, the weathered basement and the bedrock respectively (Table 2). The low resistivity value of the weathered basement showed that this layer is saturated having moderate thickness of 7 – 12m relevant to development of hand pump wells.

The QH curve type showed a decreasing resistivity value except the last layer ($\ell_1 > \ell_2 > \ell_3 < \ell_4$). This decreasing resistivity value showed that the intermediate layer of resistivity 110 – 480 ohm-

metres could be tapped for groundwater development in conjunction with the weathered basement and the bedrock particularly when fractured. The bedrock resistivity of 420 - 1445Ωm is diagnostic of fractured bedrock in the study area. The intermediate layer thickness is 1.0 – 1.5m while the weathered basement thickness is 6.0 – 12.0m (Table 1c). The intermediate layer, the weathered basement and the fractured bedrock when combined together could form excellent aquifers in this study area.

Table 1: Curve types/ Aquifer Types of Federal Government Low Cost Housing Estate Okeho Oyo State.

(a) H Curve Type

	Range of Resistivity	Range of Thickness (m)	Probable Geologic units	Aquifer Type	Remark
Topsoil	2.60 – 380Ωm	0.70 – 0.85	Sands clay/ sands/ clayey sands/ laterite	Type I	Fair except when underlain by fractured bedrock
Intermediate Layer	50 – 95Ωm	2.5 – 5.5	Clayey sands/ sands/ clay		
Bedrock	4000 – 5189Ωm	-	Crystalline Bedrock		

(b) KH Curve Type

	Range of Resistivity	Range of Thickness	Probable Geologic materials	Aquifer type	Remark
Topsoil	680 – 1365Ωm	0.70 – 0.85	Sands/gravels/ laterite	Type I, II, III	Promising when underlain by fractured Bedrock
Intermediate Layer	880 – 1600Ωm	0.50 – 2.50m	Sands/gravels/ Hard pan		
Weathered Basement	40 – 56Ωm	7.0 – 12.0m	Clayey sands/ clay / sands (Decomposed zone)		
Bedrock	1180 – 6285	-	Fractured to crystalline bedrock		

(c) QH Curve Type

	Range of Resistivity	Range of Thickness	Probable lithology materials	Aquifer type	Remark
Topsoil	180 – 1102Ωm	0.70 – 1.50m	Sands/gravels/ laterite	Type I, II, III	Promising
Intermediate Layer	110 – 480Ωm	1.00-1.50m	Sands/sandy clay laterite		
Weathered Basement	18 – 50Ωm	60 – 12.0m	Decomposed zone sands/clay/clayey sands		
Bedrock	420 – 1445	-	Fractured Bedrock		

(b) Geoelectric Layer Analysis of the study area

Table 2, is the geoelectric layer analysis of the study area that provided information on the layer resistivity and thickness of the subsurface layers. The resistivity of the topsoil range from 190 - 1105Ωm with thickness of 0.70 – 1.50m; while the intermediate layer has resistivity of 59 -

1600Ωm with thickness 0.90 – 5.50m such that the lower limit of the resistivity range could be saturated with water for citing of, hand-dug wells. The weathered basement layer resistivity range from 19 - 50Ωm and thickness of 6.0 – 12.0m. This layer is relevant for groundwater development of the area, which allowed the use of hand-pump wells. The bedrock resistivity is 420 - 6285Ωm

hence the lower limit resistivity value is diagnostic of fractured bedrock, which is a reliable, and promising basement aquifer.

This aquifer favours the use of **surface pump**.

(d) Basement Aquifers and Geophysical Characteristics

The basement aquifers that have been identified in this study area are the type I, II, and III aquifers, which are the weathered basement, fractured bedrock and decomposed veins within the bedrock aquifers. The regolith materials above the basement aquifer range in thickness from 0.70 – 3.50m (Table 3). Thus generally these regolith materials characterised the study area. The weathered basement aquifer has resistivity of 18.95Ωm and thickness of 2.5 – 12.0m (Table 3). The yields of basement aquifers tend to be recontrolled by the extent and depth of weathering and fracturing. The moderate weathered basement aquifer thickness will tend to give better yield than thinner ones when subjected to similar conditions; whereas

comparable high yields from thin weathered basement aquifer occur when groundwater is stored in the fractured basement.

Therefore, in this study area excellent aquifer occur where a thick weathered basement aquifer of coarse-grained materials overlie the fractured basement. The range of depth to bedrock in this area is 8.6 – 16.0m, which is generally shallow. Thus it is expected that wells in this area will be relatively shallow. The yield of a well does not essentially depend on the thickness of the overburden materials rather the existence of fractures/faults improve to a greater extent the yield of boreholes. The occurrences and interplay of the lithologic layers in this area suggest weathered basement/ fractured bedrock unconfined aquifer.

Table 2: Layer Parameter Analysis of Federal Low cost Housing Estate Okeho Oyo State.

Resistivity of Top soil	190 – 1105Ωm
Thickness of Top soil	0.70 – 1.50m
Resistivity of Intermediate Layer	50 – 1600Ωm
Thickness of Intermediate Layer	0.90 – 5.50m
Weathered Layer Resistivity	18 – 56Ωm
Thickness weathered basement	6.0 – 12m
Bedrock Resistivity	420 – 6285Ωm

Table 3: Basement Aquifer and Geoelectric Parameters of Okeho area in Oyo state.

	H	KH	QH	General
Thickness of Regolith	0.70 – 1.5m	1.63 – 3.50m	1.70 – 3.00	0.7 – 3.50m
Resistivity of Regolith	260 – 380Ωm	680 – 1600Ωm	180 – 1102	180 – 1600Ωm
Weathered Basement Aquifer Thickness	2.5 – 5.5m	7.0 – 12.0m	6.0 – 12.0m	2.5 – 12.0m
Weathered basement Aquifer Resistivity	50 – 95Ωm	40 – 56Ωm	18 - 50Ωm	18 - 95Ωm
Fractured Basement Aquifer	-	Yes	Yes	H (No) KH (Yes atimes) QH (Yes)
Range of Depth to Bedrock	3.2 – 7.0m	8.6 – 16.0m	7.7 – 15.0m	3.2 – 16.0m

6. CONCLUSION

The use of surface pump for the wells is suggested because of the relative thin overburden materials that characterised the study area. The groundwater development is promising towards the central and the southern portions of the study area. The basement aquifer delineated is relevant to giving adequate water supply to the people living in the estate if properly harnessed.

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