

# HYDROGEOLOGICAL STUDY OF PARTS OF CHARNOKITE TERRAIN OF AKURE SOUTHWESTERN NIGERIA

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## ABSTRACT

Hydrogeophysical study of parts of Charnockite terrain of Akure, southwestern Nigeria was carried out using the electrical resistivity method. The study involved one hundred and fifty two (152) Schlumberger geoelectric soundings (with seven (7) of them parametric) alongside static water level measurements in 102 hand-dug wells. The Precambrian Crystalline Basement Complex rocks underlying the area consist largely of Charnockite with some granite and migmatite-gneiss bodies. The interpreted results enabled the determination of overburden thickness, longitudinal unit conductance (S) and coefficient of anisotropy ( $\lambda$ ). The static water level measurements were used to determine the vadose zone thickness and groundwater flow direction. The overburden thickness in the study area ranges between 2.0 and 66.9 m; bedrock resistivity range between 748 and  $\infty$ -m while the vadose zone thickness ranges between 0.5 and 11.3 m. The groundwater potential of the area was classified based on the overburden thickness (h) and resistivity values ( $\rho$ ). Thus, areas characterized by 100  $\rho$  800 -m with h  $\leq$  45 m are classified as high, while areas presenting 15  $\rho$  h  $\leq$  45 m are classified as medium and areas of h  $\leq$  15 m are classified as low. A modified geologic classification of the study area using  $\lambda$  values was undertaken with  $\lambda > 1.2$  areas classified as Charnockite while areas with  $\lambda < 1.2$  classified as granite and migmatite-gneiss complex. A correlation of the field geological map with the  $\rho$  map presents a good correlation especially within areas underlain by Charnockite.

**KEYWORDS:** Charnockite, resistivity, groundwater, overburden thickness, longitudinal unit conductance and coefficient of anisotropy.

## INTRODUCTION

The northwestern flank of Akure metropolis is underlain principally by Charnockite rocks (Owoyemi, 1996). In Akure, rocky outcrops are barely visible in the areas underlain by the Charnockite rocks as they are presumably easily weathered and consequently constitute the gently undulating terrains of the town. By careful inspection of the settlement and growth pattern within Akure town, it is observed that the gently undulating terrains are attracting rapid urbanization as it is easier and cheaper for settlers to undertake constructions. Thus, the areas play host to the city square, many educational institutions, commercial centers/offices, industrial layouts and residential estates.

Charnockite is a series of foliated igneous rocks of wide distribution in Africa and thus constitutes one of the important petrological units within the Precambrian Basement Complex rocks of Nigeria. According to Dada et al., (1989), it was at Toro that Charnockite was first described within the Nigerian Basement by Falconer (1911) where it was then referred to as a "quartz diorite porphyrite". Wright (1970) described it as undeformed acid and basic dykes. They are generally characterized by their dark greenish to greenish grey appearance which makes them easily recognizable in hand specimen. They usually contain quartz + plagioclase + alkali feldspar + orthopyroxene + clinopyroxene + hornblende  $\pm$  biotite  $\pm$  fayalite. Accessory minerals are usually zircon, apatite, and iron ores (Olawajun, 2006).

The Charnockite series include rocks of pyroxene and olivine (Obaje, 2009). Very often the different rock types occur in close association as one set forms bands alternating with another set, or vein traversing it, and where one facies appears the other also usually are found. The Charnockite series include rocks of many different types, some being felsic and rich in quartz and microcline, others mafic and full of pyroxene and olivine, while there are also intermediate varieties corresponding mineralogically to norites, quartz-norites and diorites (Obaje, 2009).

The term 'Charnockite' consequently is not the name of rock, but of an assemblage of rock types, connected in their origin arising by differentiation of the same parent magma. Olawajun (1981) described three modes of occurrence. The first occurrence is within what seems to be "core" of the granite rock. The second is their occurrence along the "margins" of the granite bodies. These two modes of occurrences are of the coarse grained origin variety. The third form of occurrence is represented by the discrete bodies of gneissic fine-grained charnockitic rock within the country gneisses. Of these three modes of occurrence, only the second mode of occurrence is found within the Akure area. Charnockites are usually of Proterozoic age (late Precambrian). Tubosun et al., (1984) use the U-Pb method on zircons, attributed precise Pan-Africa age of 634 $\pm$ 21 Ma to the Charnockite of Akure.

As Akure town expands most especially across the Charnockite terrain, access to good quality water

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supply is becoming increasingly difficult due to inadequate pipe borne water supply. The insufficient pipe borne water supply is thus augmented by groundwater abstracted through hand-dug wells and some boreholes in the metropolis. Unlike other natural resources, groundwater is dynamic in nature and its occurrence and movement varies with time and space. The movement, accumulation and yielding capacity of groundwater depend upon the geological environment. Charnockite terrain has unsure groundwater yielding potential because of the abundance of clay materials and iron oxides associated with its area of occurrence. However, for a successful groundwater development programme in such unsure terrain, it is essential that painstaking exploration project be conducted in a manner consisting of near accurate delineation of the water bearing units and the probable depths to resistive basement rocks.

This research was therefore borne out of the need to evaluate the groundwater potential of parts of Charnockite terrain of Akure as the area is the fastest developing part of the town. The result will enhance the description of underlying hydrogeological features in the lowland Charnockite terrain of the town and evolve spatial groundwater distribution pattern within the area.

The electrical resistivity method which is a fairly rapid cost effective means of determining the gross configuration of an aquifer has been adopted for this study. The method is useful in locating areas of maximum aquifer thickness and has been used extensively both in the basement and sedimentary environments.

Basement Complex rocks are known for their characteristic low porosity and negligible permeability except in cases of heavy weathering (Mogaji et al., 2011). As such, good permeability development in the form of interconnected network of joints and fractures usually presents a favourable hydrogeological setting. These fractures/joint zones are usually delineated with their characteristic resistivity lows within host resistivity highs as usually observed on geophysical field data and hence the relevance of the survey method in this study.

**LOCATION DESCRIPTION, CLIMATE AND GEOMORPHOLOGY**

The study area which constitutes the northwestern flank of Akure metropolis occupies land area of about 42.74 square kilometres and lies between latitude N07° 14' 50" and N07° 18' 30" and longitudes E05° 08' 40" and E05° 12' 05" (Figure 1).

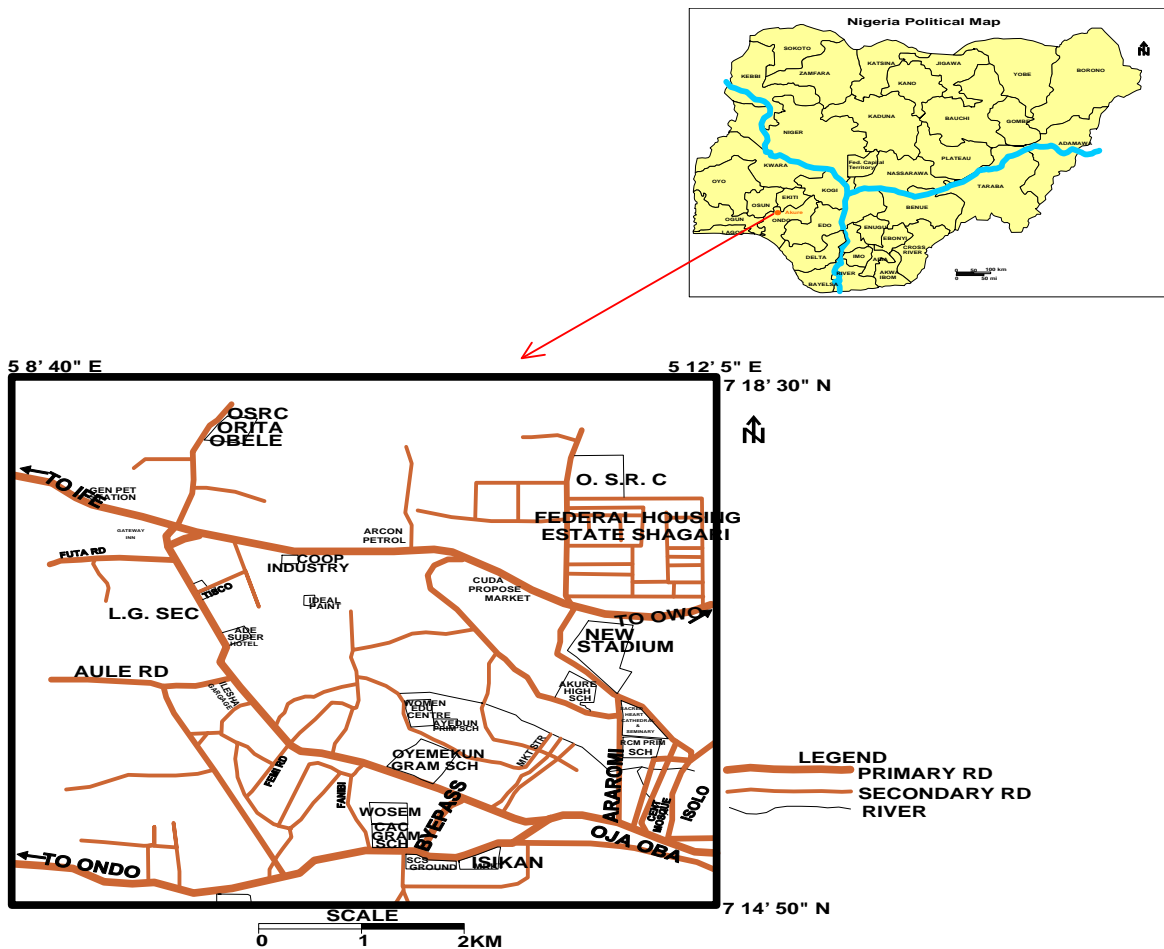


Figure 1: Layout map of northwestern flank of Akure (Adapted from Google Earth (2015) while inset is the political map of Nigeria)

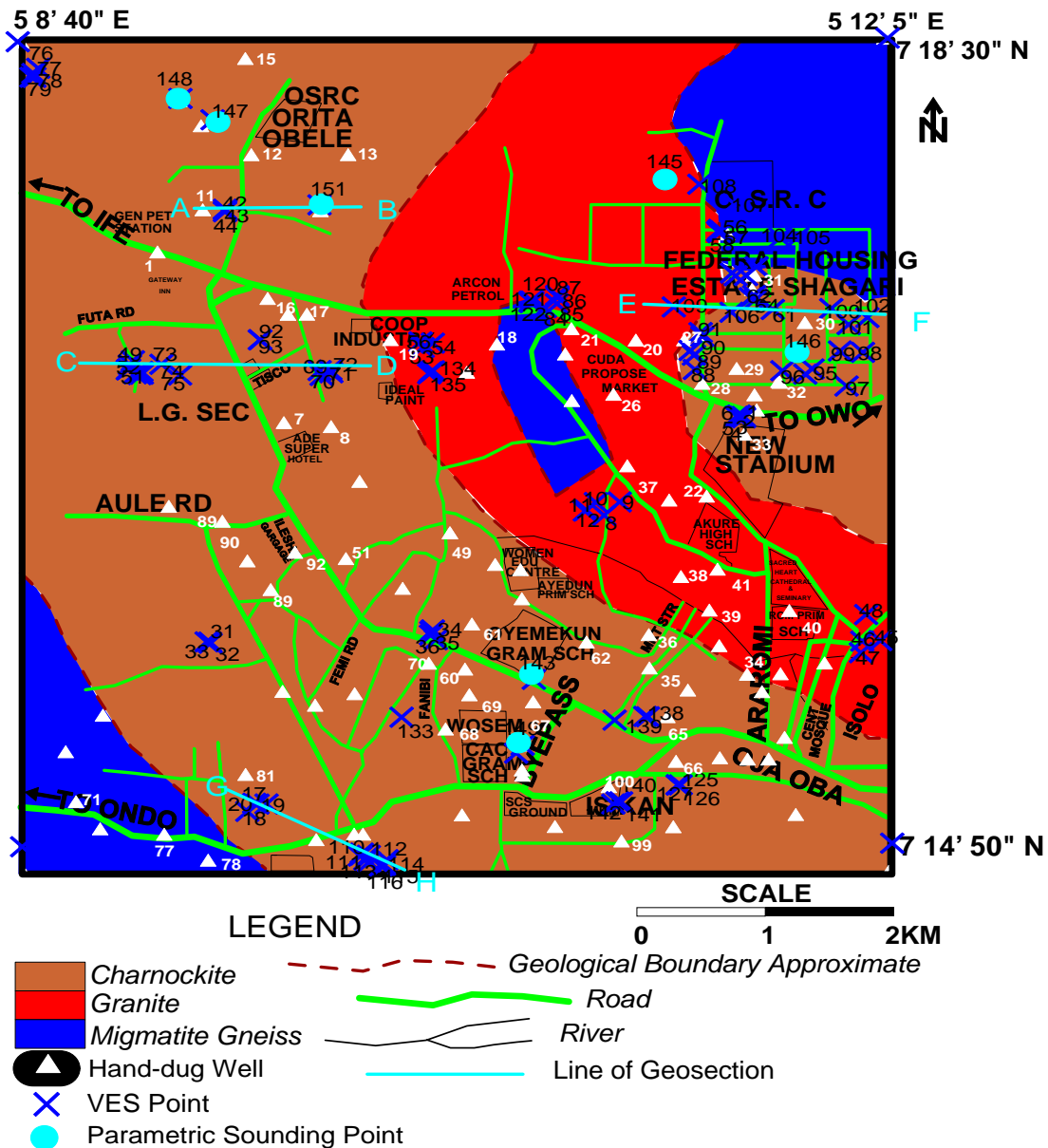
Akure is situated within the rain forest belt of Nigeria with a climate of wet season spanning from April to October and dry season between November and March. The town experiences the hottest weather from February to March and also experiences the dry wind (harmattan) from December to early February. The area lies within the zone of moderate annual rainfall of about 1,300 to 1,700 mm while humidity is relatively high during the wet season and low during the dry season with temperature varying between 22°C and 31°C throughout the year (Iloje, 1981).

The topography of the Basement Complex terrain of Akure is generally undulating with a virtually rugged terrain consisting of hills and valleys with field recorded elevation varying between 330 m above mean sea level in the southwestern flank (Nigeria Army

barracks) and 399 m in the northeastern flank (Shagari Estate).

**GEOLOGY OF THE STUDY AREA**

The rocks encountered in the area of study are mainly Charnockite and some bodies of granite and migmatite gneiss complex (Figure 2). Even though the Charnockite rocks outcrops were not encountered, evidences of their occurrences were observed from charnockitic boulders encountered in some places. It is thus presumed that areas in which Charnockite were encountered cover a large extent of about 60% of the area from northwest to southeast and east. The Charnockite rocks occur as smooth rounded boulders in some areas in form of oval to sub-circular and elongated bodies.



**Figure 2:** Geological Map of the Study Area (adapted from Geological Survey of Nigeria Sheet 61) showing locations of VES points, Hand-dug wells and geoelectric section profile lines.

The emplaced fine-grained granites were encountered in the northeast and southwest flanks while the migmatite-gneiss rocks with limited occurrence were encountered in the northeastern flank around Federal Housing Estate (Shagari Village), southwestern and central parts around Ondo State Industrial Park. The rocks occur as variant banded gneiss and granite gneiss. They are fine-to-medium grained strongly foliated biotite gneisses with varying dips. The migmatite shows a diffuse contact with the Charnockite around the Federal Housing Estate (Shagari Village).

The geology and boundaries of the lithologic units in Figure 2 were inferred in places where they are concealed by superficial residual soils.

## MATERIALS AND METHODS OF STUDY

ABEM SAS 1000 digital resistivity meter was used for field data acquisition. The electrical resistivity method was adopted using the vertical electrical sounding (VES) technique. The Schlumberger array was utilized for field data acquisition. One hundred and fifty two (152) VES locations were occupied including seven (7) parametric soundings.

Hydrologic field study involving static water level measurements in one hundred and two (102) hand-dug wells was also undertaken. Static water level estimations were made using Buddermeier and Schloss (2000) method. A total of seven (7) parametric soundings were carried out near existing hand dug wells to constrain the data utilized for the study. The parametric soundings were conducted with the rms-errors ranging between 2.4 and 5.5%.

The interpretation of VES curves involved curve matching (Keller and Frischknecht, 1966) and computer iteration using WinResist Version 1.0 (Vander Velpen, 2004) to refine the initial geoelectric parameters obtained from curve matching.

## RESULTS AND DISCUSSION

The VES data interpretation (Figure 3) delineated three to four major geoelectric units comprising the topsoil, lateritic/weathered layer, fractured basement and the resistive bedrock. The topsoil resistivity values present 13 - 960  $\Omega$ -m range with thickness varying from zero (bare outcrop) around Isikan in the south to 2.0 m in the central area around Oyemekun Grammar School. The lateritic/weathered layer has resistivity in the range of 10 – 3671  $\Omega$ -m with most of the values less than 200  $\Omega$ -m. The resistivity values indicate lithology in the suite of sandy clay and clayey sand. Thickness values of the weathered layer range from 0.4 m in Ondo Road area in the southwest to 66.9 m at Stateline Road in the west. Fractured bedrock columns delineated are defined by resistivity values in the range of 13 to 1189  $\Omega$ -m while the thickness values range from 0.8 to 33.0 m. High resistivity in the area of study suggests possibility of dry fractured column that may lack interconnectivity while low resistivity values in this zone indicate high fracturing and saturation conditions thus constituting areas of some favourable hydrogeologic setting. The geoelectric basement is assumed to be infinitely resistive in the entire area.

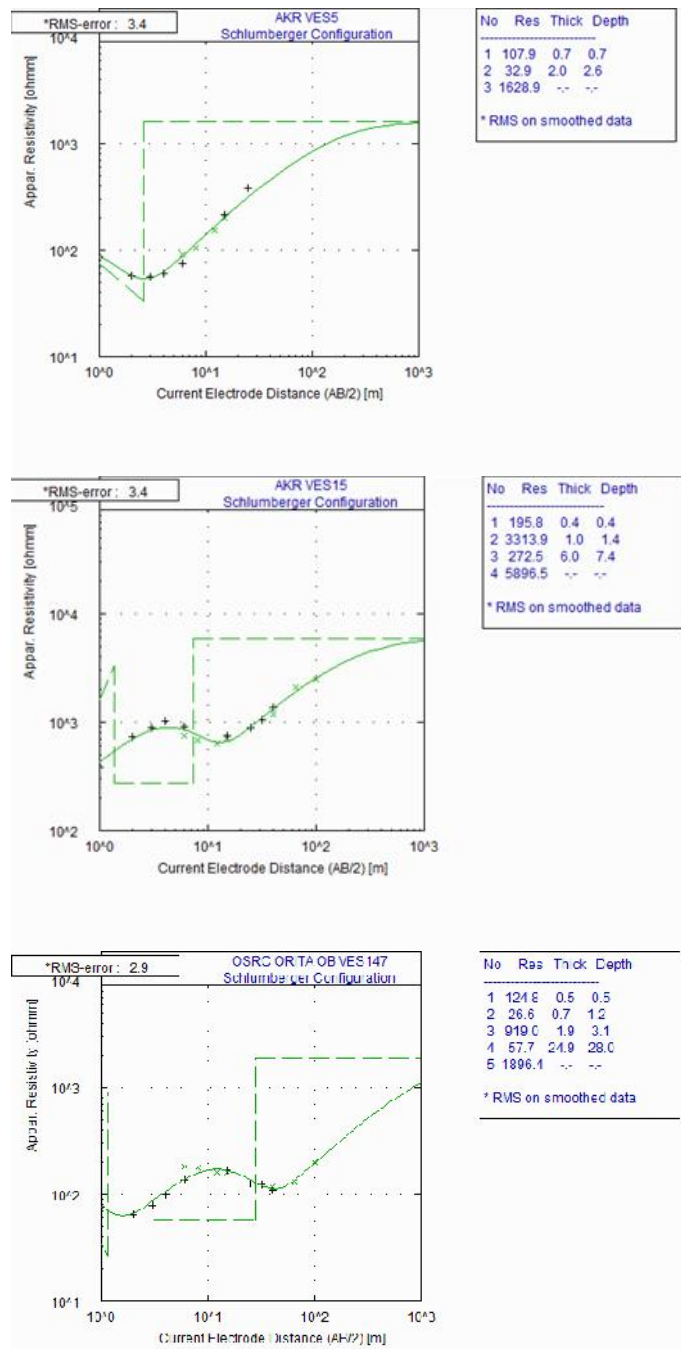
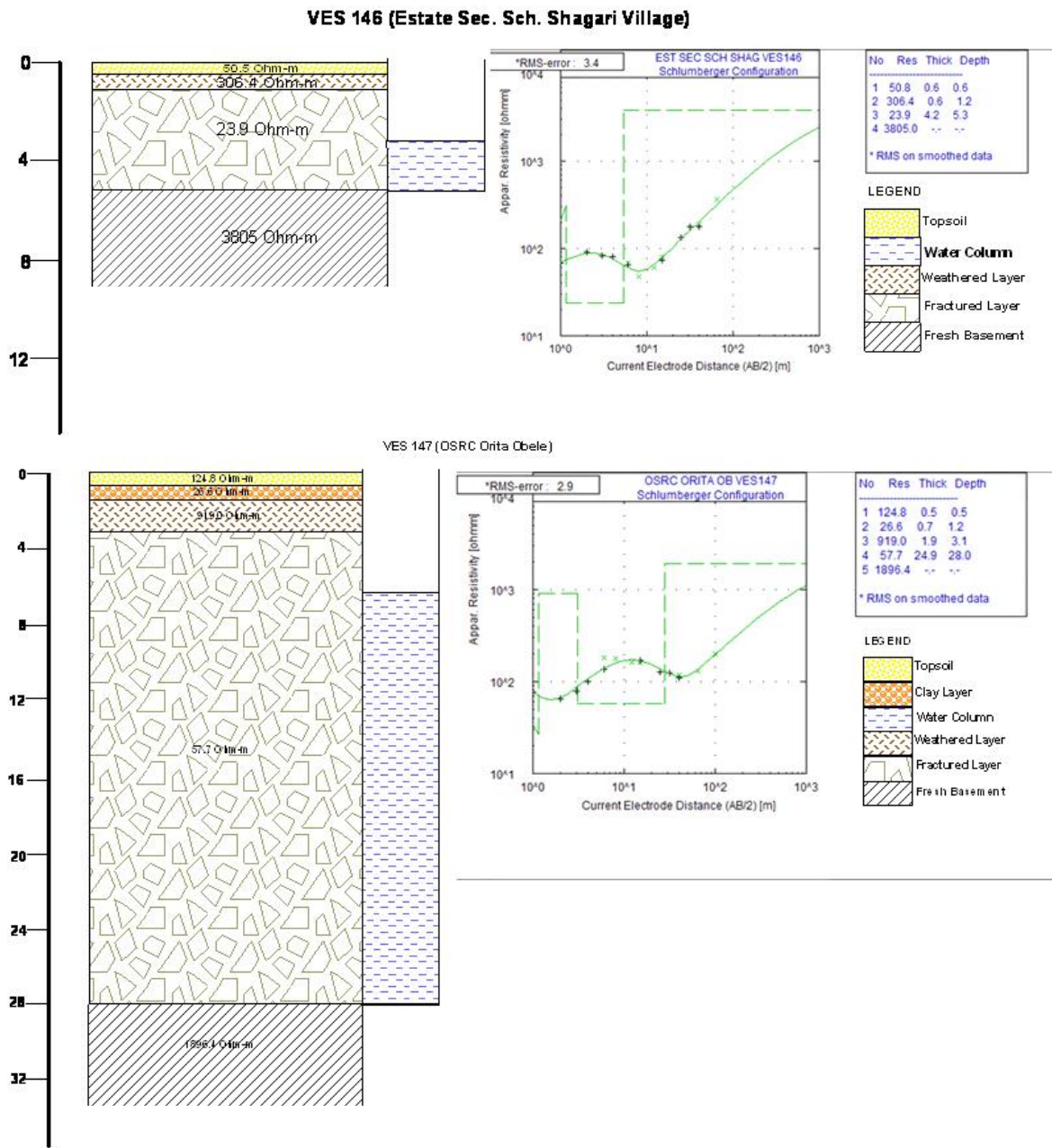


Figure 3: Typical sounding curves obtained from the Study Area

**Parametric Sounding**

The lithology log of each hand-dug well was correlated with the geoelectric sounding data (Figure 4). The lithology exposures recorded comprise the topsoil, laterite/clay unit and the static water surface. However, the VES interpretations present up to four geoelectric

layers above the static water level. A fair correlation exists between the static water level in the hand-dug wells and the presumed water saturation points in the VES. The results obtained for this study are presumed to be of high quality and consequently reliable.



**Figure 4:** Typical parametric sounding obtained from the study area.

**Goelectric Sections**

The electrical resistivity contrasts existing between lithological sequences in the subsurface are often adequate to enable the delineation of goelectric layers and identification of aquiferous or non-aquiferous layers (Lashkaripour et al., 2005; Dodds and Ivic, 1998). Four interpretive goelectric sections were generated along AB, CD, EF and GH for Orita-Obele, Akure South LGA Secretariat, Federal Housing Estate (Shagari Estate) and Ondo Road respectively for the correlation of goelectric sequences obtained from interpreted VES curves (Figures 5 – 8).

The Orita-Obele goelectric sequence (line AB) N-W generated from results of VES 42, VES 43 and VES 44 and comprising four goelectric layers (Figure 5) consists of the overburden materials with resistivity values of 30 - 355  $\Omega$ -m and thickness ranging from 21.0 to 35.6 m. The characteristic low resistivity (< 200  $\Omega$ -m) and fairly thick overburden thickness within this vicinity makes the zone a fairly satisfactory hydrogeological setting environment. The fresh basement is characterized by high resistivity values.

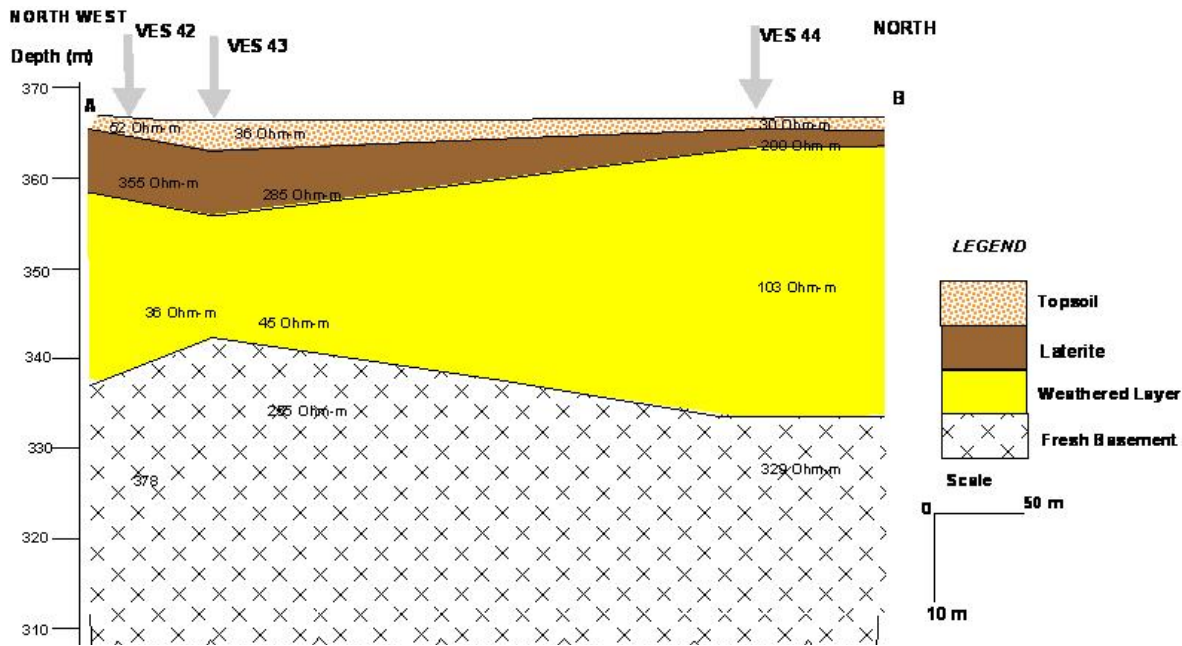


Figure 5: Geoelectric Section along Line AB (Orita-Obele Area).

Four geoelectric layers were delineated on the West-East geoelectric section of line CD around Akure South L.G.A. Secretariat (Figure 6). The overburden is characterized by resistivity values varying from 52  $\Omega$ -m in the saturated zone to 2909  $\Omega$ -m in the upper lateritic column and thickness values ranging from 7.7 to 28.7 m. A bedrock ridge was delineated beneath VES 54, VES 73 and VES 69 while bedrock depression underlies the western and eastern flanks beneath VES 51, VES 52 and VES 70. Bedrock depressions in a typical Basement Complex area are groundwater collection centers (Ayolabi et al., 2003). The characteristic low resistivity (

< 200  $\Omega$ -m) and thick column (> 26 m) within the vicinity of the bedrock depressions make these zones to be of favourable hydrogeological setting.

The N-E trending line EF geoelectric section of Figure 7 was obtained around the Federal Housing Estate. The overburden is typified by resistivity values ranging from 32 to 1324  $\Omega$ -m with thickness ranging from 4.1 to 58.7 m. The section shows existence of bedrock depressions beneath the eastern and northern flanks with bedrock ridge underlying the center of the traverse. The bedrock depressions are areas of groundwater accumulation.

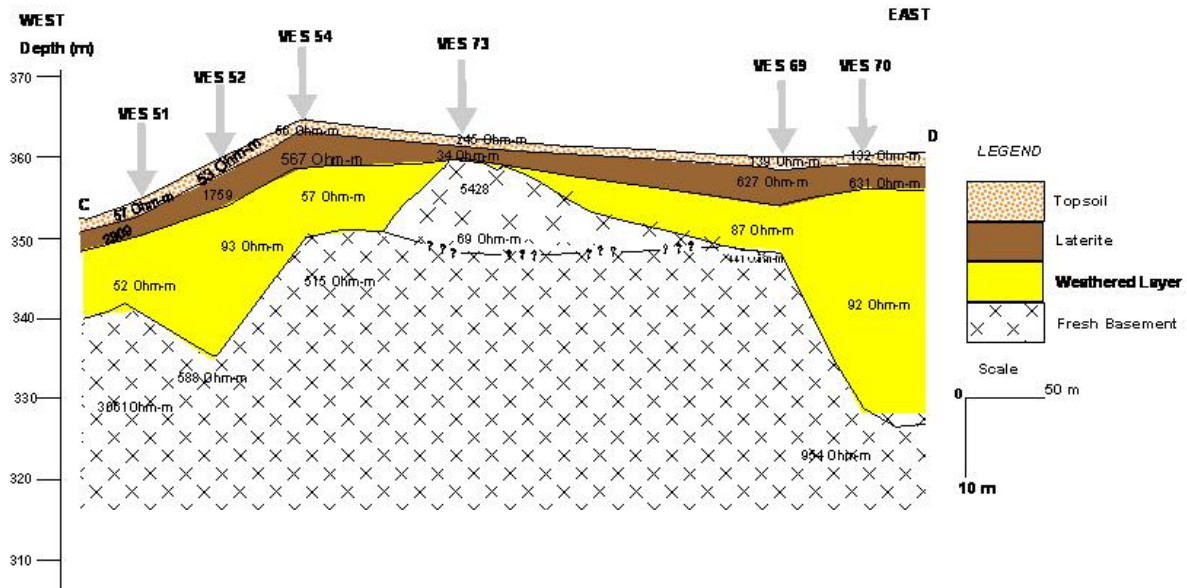


Figure 6: Goelectric Section along Line CD (Akure South LGA Secretariat Area)

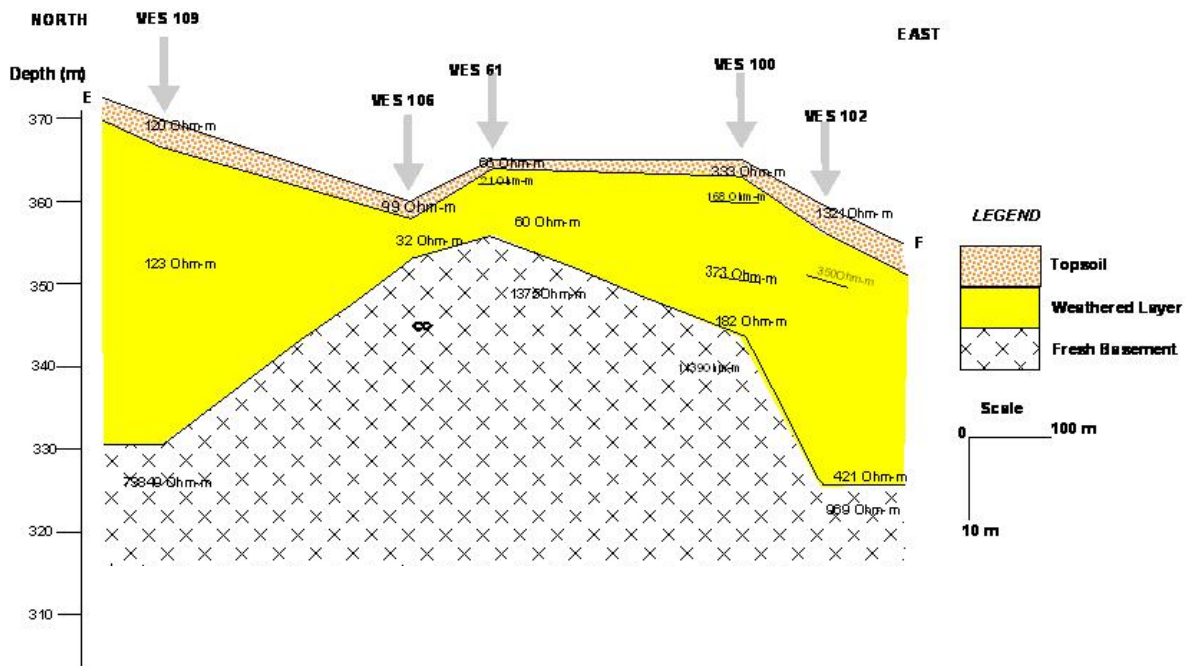


Figure 7: Goelectric Section along Line EF (Federal Housing Estate Area)

Three geoelectric layers were delineated on the geoelectric section of line GH around Ondo road (Figure 8). The topsoil is defined by resistivity in the range of 20 to 403 Ωm and thickness ranging from 0.5 to 1.3 m.

The weathered layer is defined by resistivity within the range of 22 and 70 Ωm with thickness values ranging from 1.8 to 12.9 m. The third layer is the fresh basement and is resistive.



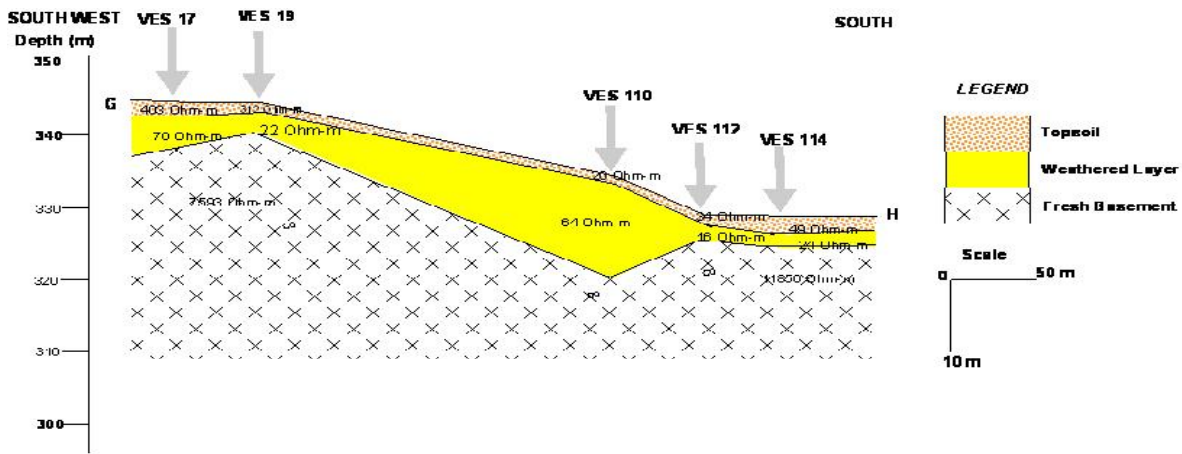


Figure 8: Geoelectric Section along Line GH (Ondo Road Area)

**Overburden Thickness**

The overburden is considered in this study to be the materials above the fresh bedrock at each VES location. The interpreted depths to the bedrock beneath all the VES stations were plotted and contoured as overburden thickness map with classifications (Figure

9). Maximum overburden thickness of 66.9 m was obtained in the area thus constituting about 84.47% of 79.2 m maximum depth to bedrock obtained by Olorunfemi and Okhue (1992) in the basement complex terrain at Ile-Ife southwestern Nigeria.

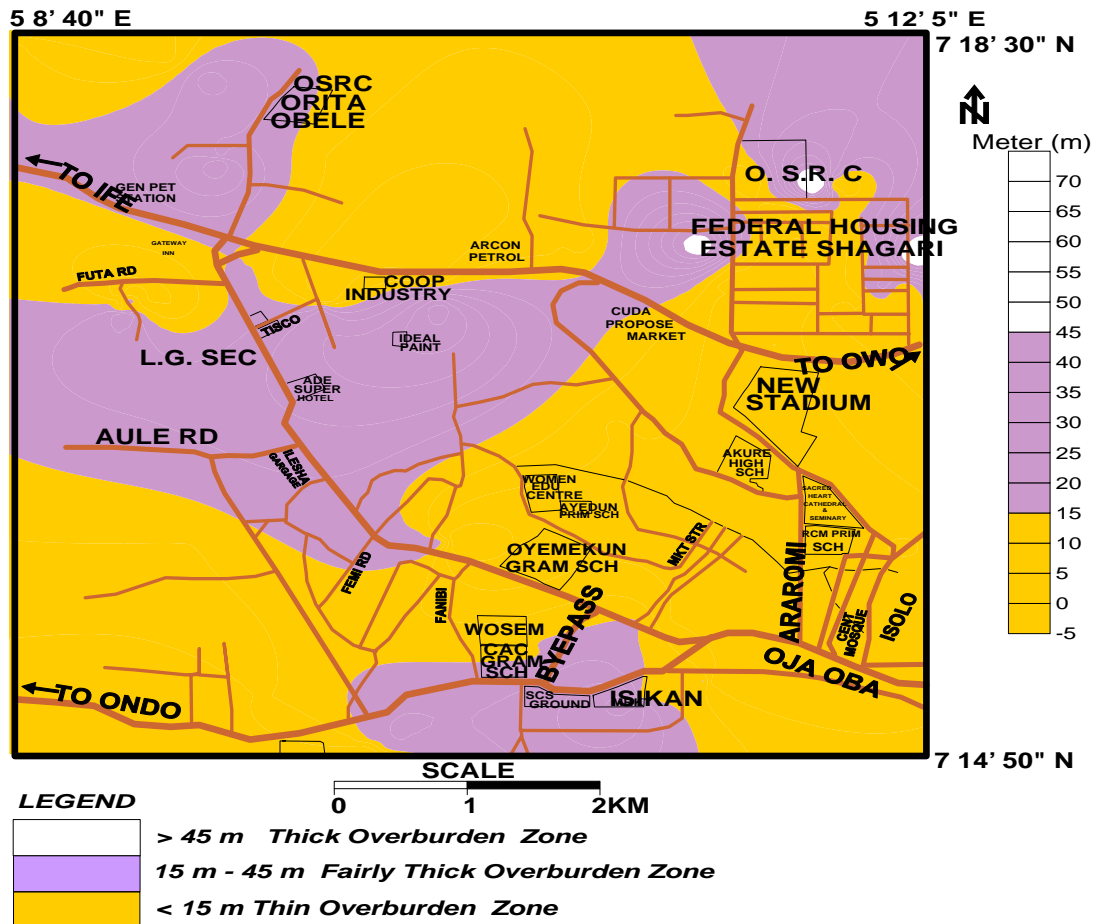


Figure 9: Overburden Thickness Map of the Charnockite Terrain of Akure

The classifications on the Figure 9 map are thin ranking (h 15 m), medium ranking (15 h 45 m) and thick ranking (h 45 m). Studies in similar Basement terrain (Omosuyi et. al., 2003; Bala and Ike, 2001) have identified areas with thick overburden cover as high groundwater potential zones. Areas underlain by medium ranking overburden thickness (15 h 45 m) are the western flank (Akure South LGA Secretariat and Aule Road); central part (Ideal Paint Warehouse); northwest (Orita-Obele, AKAD); southern flank (CAC Grammar School and Isikan market); northeastern flank (Federal Housing Estate (Shagari Village)). Areas of thin ranking (h 15 m) are in the central (Araromi, Central Market) and eastern (new Stadium) flanks of the area.

**Groundwater Potential Evaluation of the Study Area**

The groundwater potential map of the study area (Figure 10) was generated from the synthesis of the overburden thickness map and the water-level elevation contours. Studies in similar Basement terrain (Omosuyi et al, 2003; Bala and Ike, 2001) have identified areas with thick overburden cover and resistivity values between 100 and 800 ohm-m as high groundwater potential zones. Correspondingly, areas with thin (h 15 m), moderately thick (15 h 45 m) and thick ( 45 m) overburden covers are classified as low, moderate and high groundwater potential zones respectively.

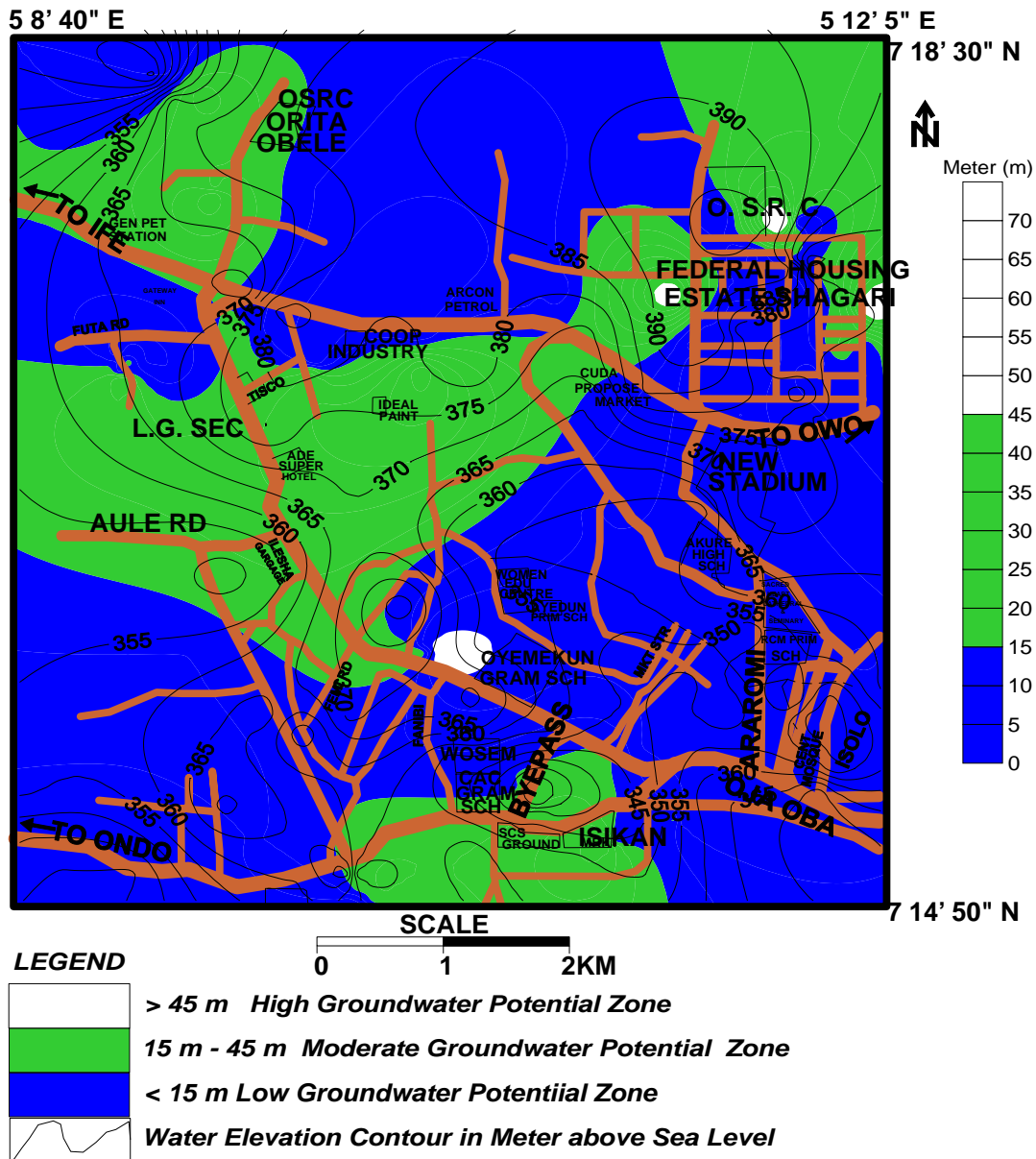


Figure 10: Groundwater Potential Map of the Charnockite Area of Akure

Areas around Akure South Local Government Secretariat, Aule Road; Ideal Paint Warehouse; Orita-Obele; AKAD in the northwest; CAC Grammar School ground; Isikan market in the southern flank; the Federal Housing Estate (Shagari Village) in the northeastern flank are classified as moderate groundwater potential zones. Apart from the fairly thick overburden cover of this zone, the water-level contour depicts this area as groundwater collection zone (low hydraulic heads). The zone also shows aquifer connectivity from the northeast (Orita-Obele) to the west and central part (Akure Local Government Secretariat and Ideal Paint Warehouse). The parametric soundings in this zone (Orita-Obele) indicate water column of 22 m and 9 m at VES 147 and 151 respectively. This zone presents some favourable hydrogeologic settings for groundwater development.

Araromi, Central Market and New Stadium, in the eastern and southeastern part of the study areas are classified as areas with low groundwater potential. The water-level contour in this zone describes discontinuous aquifers (cyclic contours) in the east (New Stadium) and in the southeast (Oyemekun Grammar School and Isolo). The parametric sounding within Oyemekun Grammar School indicates water column of 2 m at VES 143.

**Susceptibility of Aquifer to Contamination**

Geoelectric parameters derived from resistivity and thickness (Dar Zarouk parameters) include longitudinal unit conductance, ( $S_l = h/\rho_l$ ) and Coefficient of Anisotropy, ( $\rho_l = \rho \sqrt{\lambda}$ ). These secondary geoelectric parameters are particularly important when they are used to describe a geoelectric section consisting of several layers (Zhody et al 1974).

The total longitudinal unit conductance values have been utilized severally in the evaluation of overburden protective capacities over hydrogeologic structures (Oladapo and Omotola 2015; Okiongbo et al., 2011; Atakpo and Ayolabi, 2008; Braga et al., 2006). Longitudinal unit conductance values within the study area range from 0.01 to 2.7 mhos. The longitudinal unit conductance map of Figure 11 shows that the hydrogeologic structures underneath Orita-Obele, Oyemekun, Isikan, Araromi (northwest through to southeastern parts) have overlying materials consisting of moderate to good protective capacity rating (0.1 - 2.7 mhos). The northeastern and southwestern flanks of the area are weakly protected (0.01-0.1 mhos) from contaminant infiltration.

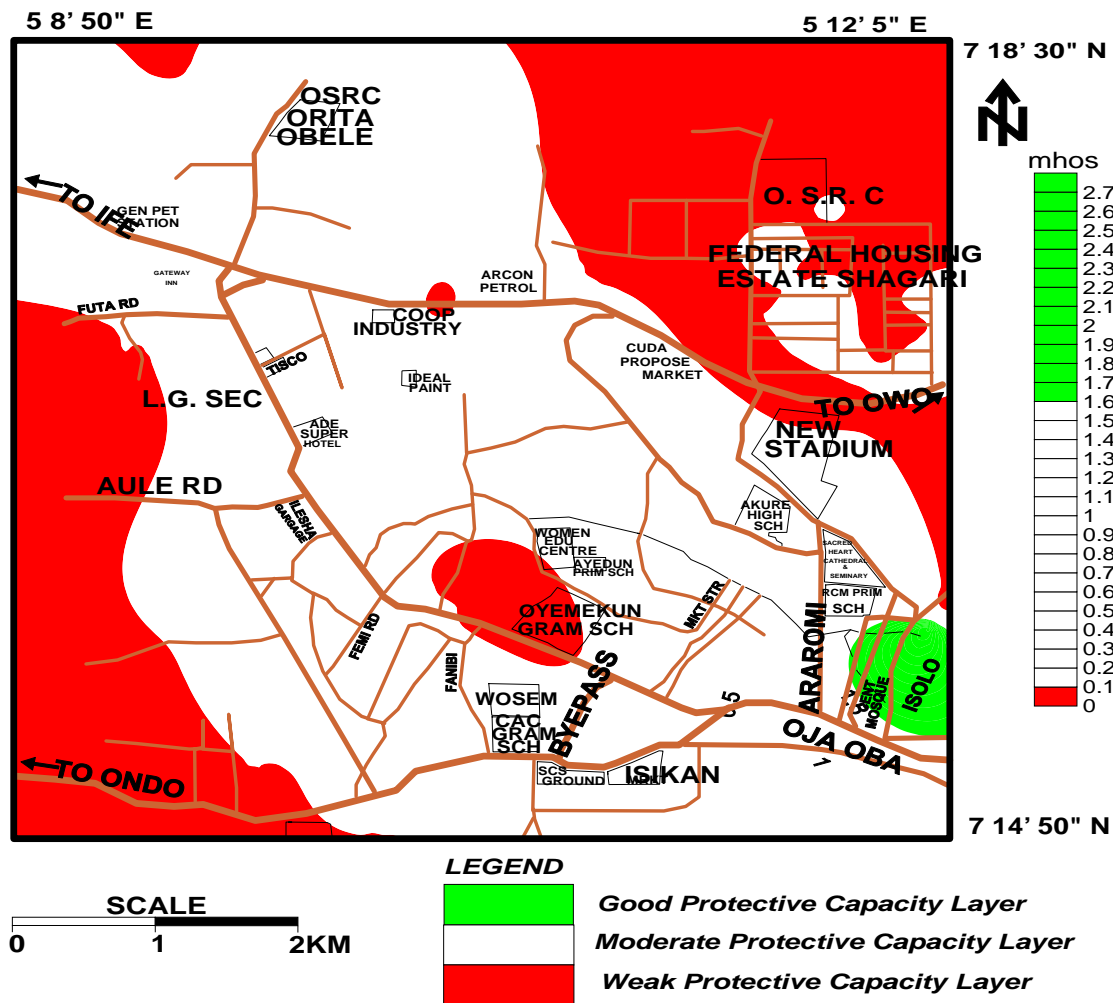


Figure 11: Longitudinal Unit Conductance Map of the Charnockite Area of Akure

**Anisotropy ( ) and Geologic Boundary Modification**

Anisotropy ( ) is related to preferential permeability directions channelling groundwater flow within the aquifer (Steinich and Marin, 1996). The coefficient of anisotropy has been shown to have the same functional form as permeability anisotropy to a first order (Bespalov et al., 2002). Thus a higher coefficient of anisotropy implies higher permeability anisotropy. Higher-permeability anisotropy implies higher groundwater flow. Thus areas of high anisotropy may be target areas for possible groundwater abstraction. The coefficients of anisotropy ( ) values in the area vary between 1.0 and 1.98. Fractures at localities with relatively high values of coefficient of anisotropy possess relatively high fracture porosity and relatively

low specific surface area and are thus more likely to be intensely fractured and permeable.

Coefficient of anisotropy has also been used to delineate lithology contacts in typical Basement terrain (Oladapo et al., 2004; Olorunfemi and Okhue, 1992). A modified geologic classification of the study area using coefficient of anisotropy was undertaken (Figure 12). The results of the geologic modification reveals that rocks of low anisotropy (1.0 – 1.2) and presumably charnockitic underlie the Federal Housing Estate (Shagari Village) in the northeast, New Stadium in the east, Isikan in the south, Ilesha Motor Park and Femi Road in the central areas while the other parts of the area with higher anisotropy (1.2 – 1.97) are underlain by granites and migmatites.

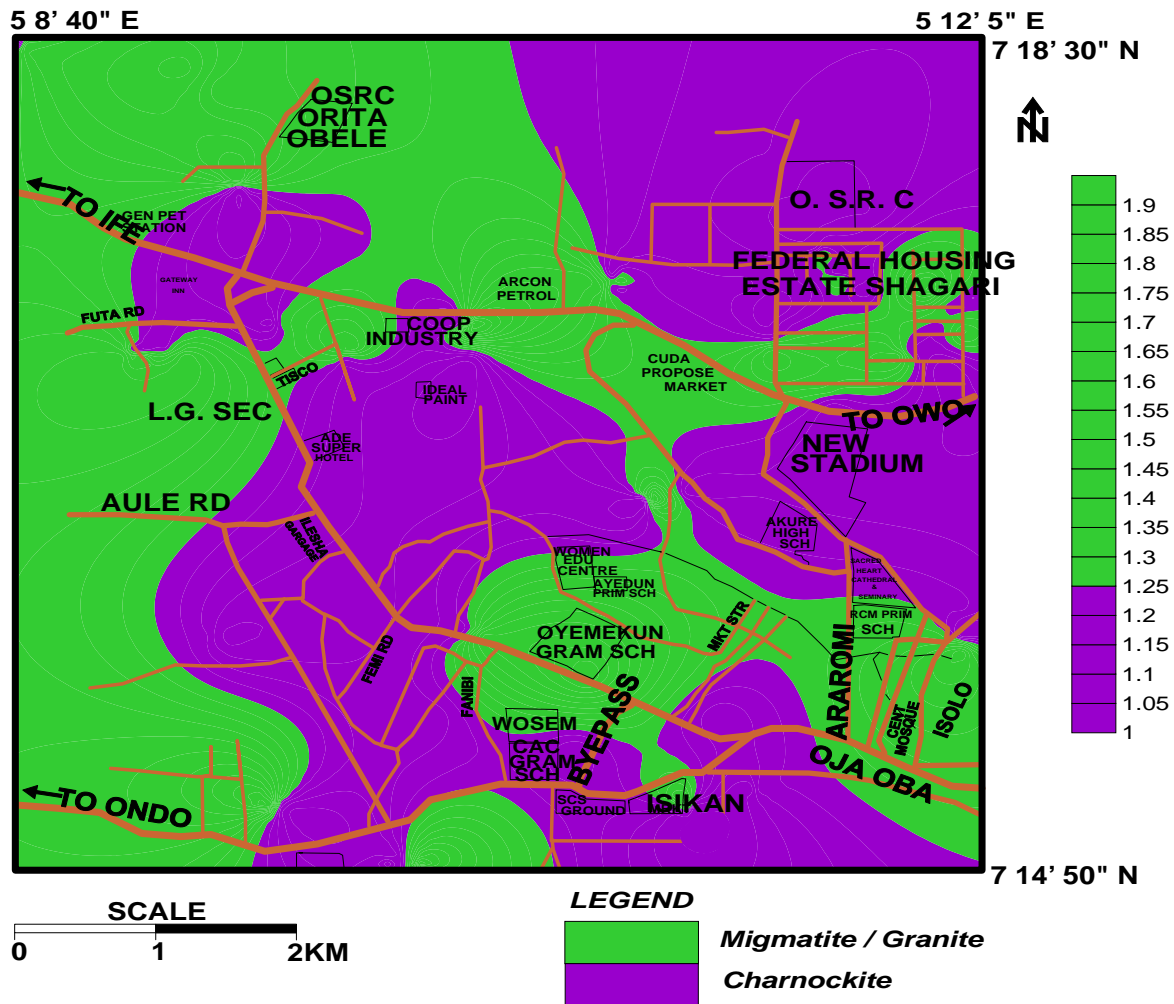


Figure 12: Modified Geological Map of Study Area using Coefficient of Anisotropy ( )

**Correlation of Results**

A correlation of the field geological map with the coefficient of anisotropy map shows a good correlation especially within areas underlain by Charnockite ( 1.2). Charnockite underlay is confirmed in areas around Orita-Obele, in the northeast; Akure South LGA Secretariat, in the west; C.A.C Grammar School in the

South. However, there is a slight departure around north of Federal Housing Estate in the northeast flank (Figure 13). The low level of correlation observed in this area is possibly due to inferred geological contact determination during the geological fieldwork.

From the overburden thickness map, zones of thick to fairly thick overburden cover show good

correlation with areas presumably underlain with Charnockite. This suggests that zones underlain by Charnockite are more weathered. These areas are:

Orita-Obele, Akure South LGA Secretariat, Isikan and the Federal Housing Estate (Shagari Village).

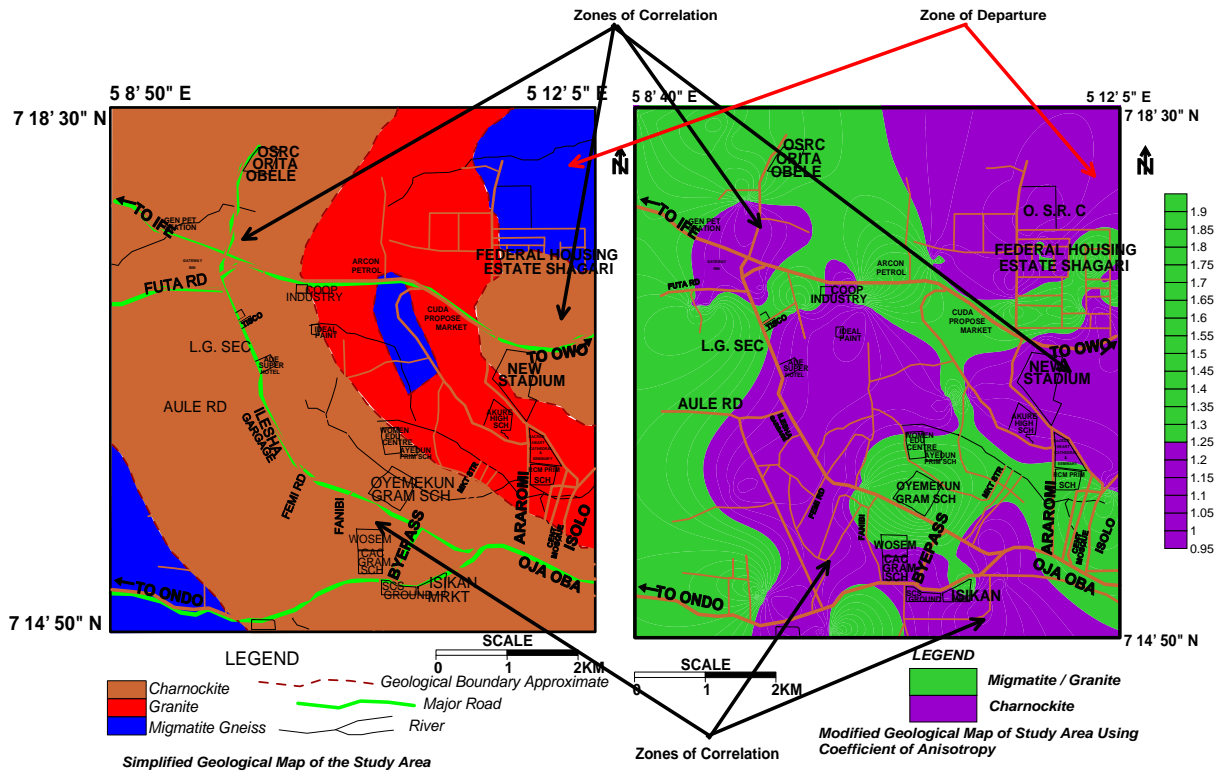


Figure 13: Correlation of the Field Geological Map with the Modified Geological Map Using Coefficient of Anisotropy ( ).

CONCLUSIONS

Hydrogeophysical study of parts of Charnockite terrain of Akure, southwestern Nigeria has been carried out using vertical electrical sounding involving the Schlumberger array, and static water level measurements in hand-dug wells. The interpreted VES data enabled the determination of the depth and subsurface configuration of the crystalline bedrock. Three geoelectric units were delineated viz: the topsoil, the weathered/fractured layer and the highly resistive bedrock. The static water level data enabled the determination of the unsaturated zone thickness with values ranging from 1.5 in the flood plains to 11 m in the elevated areas. The study has also shown the overburden thickness values to range from 2.0 to 66.9 m with bedrock resistivity values varying between 248 and -m. The study enabled the classification of the area into groundwater potential zones based on the delineated overburden thickness, second order geoelectric parameters and water-level elevation.

Low groundwater potential zones are areas situated on the northern flank of the city (Arcon Petrol station, Ondo State Industrial Park and Federal Housing Estate (Shagari village)), some areas on the southwestern flank (Ondo Road) and central area of the town (Araromi, Oja-Oba (Central Market) and Oyemekun Grammar School).

Areas identified as moderate groundwater potential zones are: Orita Obele in the northeast, Akure South LGA Secretariat and Aule Road in the west, Femi Road and Isikan market in the south, and Gbeleaje Estate west of Shagari village in the north. These areas are underlain by Charnockite, granite and migmatite gneiss. This shows groundwater occurrence in all the lithology units.

High groundwater potential areas are quite limited in size and comparatively insignificant. The isolated areas are situated west of Oyemekun Grammar School in the city center area and northern fringes of Federal Housing Estate on the northern flank of the town.

The longitudinal unit conductance map reveals that the areas of medium and high groundwater potential ratings are overlain by moderate protective capacity layering units. Hence, aquifers in these areas are less vulnerable to contamination.

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