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Electrical Resistivity Sounding for Subsurface Delineation and Evaluation of Groundwater Potential of Araromi Akungba-Akoko Ondo State Southwestern Nigeria

Muraina Z. Mohammed[1*] Thompson H. T. Ogunribido[2] & Adedamola T. Funmilayo[3]
[1, 2, 3] Department of Geology & Applied Geophysics, Adekunle Ajasin University, Akungba Akoko
PMB 001, Akungba-Akoko, Ondo state. Nigeria.
[*]E-mail of the correspondence author: drmmohammed@yahoo.com

Abstract
Electrical resistivity sounding of Araromi area of Akungba Akoko was conducted with a view to delineating the subsurface units and evaluating the groundwater potential of the area. Forty (40) Schlumberger vertical electrical resistivity soundings were acquired with ABEM SAS 1000 Resistivity Meter. The electrode spacing (AB/2) was varied from 1 – 65 m with maximum spread length of 130 m. The interpretation of the data was quantitative, and involved partial curve matching and computer iteration technique using WinResist software.
Three to four distinct subsurface geologic layers were identified from the geoelectric layers, aided by borehole lithological logs. These included a lateritic clay/sandy clay/clayey sand/sandy topsoil, clayey weathered layer, partially weathered/fractured basement and the fresh basement with resistivity and thickness values of 3-174 ohm-m and 0.7-1.5 m; 196-472 ohm-m and 3.9-20.1 m; 533-742 ohm-m and 1.8-4.2 m; and infinity ohm-m respectively**.**. The depth to bedrock varied from 0 to 20.1 m. The bedrock relief was generally uneven, with bedrock elevations that varied between 312 and 346 m above sea level. The bedrock relief map delineated two major parallel basement depressions striking approximately NW-SE as the major groundwater collecting centers. The isopach map of the overburden showed generally thin overburden (< 15 m). The weathered/fractured layer constituted the dominant aquifer units with tendency for low groundwater potential rating arising from the clayey and thin nature of the overburden. Future groundwater resource development in the study area is considered feasible in few places characterized by relatively thick and sandy column of the overburden units.
Keywords: Schlumberger, Sounding, Electrode, Resistivity, Thickness, Groundwater, Rating

1. Introduction

The availability of safe and potable water in an environment is a veritable index of a tremendous role to the development and growth of a community. Araromi area of Akungba Akoko is a new settlement notably for staff and students of Adekunle Ajasin University in Akungba town. It is bounded in the east and south by neighboring towns of Iwaro- Oka and Etioro - Supare Akoko respectively, and it is situated southeast of Akungba town between Ikare and Owo towns in the northern part of Ondo state southwestern Nigeria.

Araromi-Akungba community has witnessed an exponential increase in population of various groups of people in recent times. The inhabitants range from students to civil workers and artisans/local traders that migrated to earn livings with the relocation of a state university to Akungba Akoko few years ago. This development heralded an increased local economy of the community as well as impacted heavy demands on potable water for domestic uses. Inhabitants depend primarily on shallow water wells/hand-dug wells and surface water resources which usually run dry during the dry season. During this period, limited amount of potable water for consumption is usually sourced from water vendors and few boreholes sunk by the state government and few individuals. These provisions are grossly inadequate as further efforts by group of individuals and governmental agencies are not meeting expectations as two out of three boreholes sunk for water supplies usually fail as soon as works are completed on them.

At present, groundwater via shallow hand dug wells and few borehole constructions constitutes a major source of drinking water supply in this area. The yields are somewhat variable and less than expected average considered enough for the overall populace. In order to ease the problem of water scarcity and improve the living standard of the community this study was initiated to delineate the subsurface geological sequences and their hydrogeological characteristics/groundwater potentials in the light of the notably sustainable groundwater yield of typical basement terrains. Generally, surface water accumulates after precipitation under the influence of gravity in rock cavities as a vast groundwater reservoir supplying wells, boreholes, springs and flowing streams (Harr 1962). In a typical Precambrian Basement Complex area, this groundwater reservoir is usually contained within the weathered and the tectonically induced geological features; fractured/fissured, sheared or jointed/faulted basement columns of the rock unit(s). These geological processes alter the rock units to reduce resistivity at depth of burial and hence increase the porosity and permeability of such units for groundwater accumulation, discharge and exploitation. This, therefore, constitutes the basis of the choice of geoelectrical resistivity sounding survey in this present study.

The method has been successfully employed in the delineation of subsurface geological sequence, geological structures/features of interest, aquifer units, types and depth extent in almost all geological terrains. This is because of the significant resistivity contrasts that exist between different earth materials (Olorunfemi & Fasuyi 1993). The resistivity method can therefore map interface along which a resistivity contrast exists. This interface may or may not coincide with geological boundary (Telford *et al.* 1990). The electrical resistivity survey / method works on the basis of energizing the subsurface via the use of two current electrodes with the resulting potential difference measured by another two electrodes termed the potential electrodes.

2. Site Description

2.1 Site Location and Physiography

The study area is located in Araromi- Akungba-Akoko, Ondo State, Southwestern, Nigeria (Figure 1). It is confined within latitudes 7^0 27' 5.82" and 7^0 27' 41.63" and longitudes 5^0 43' 41.43" and 5^0 44' 29.43" which approximate

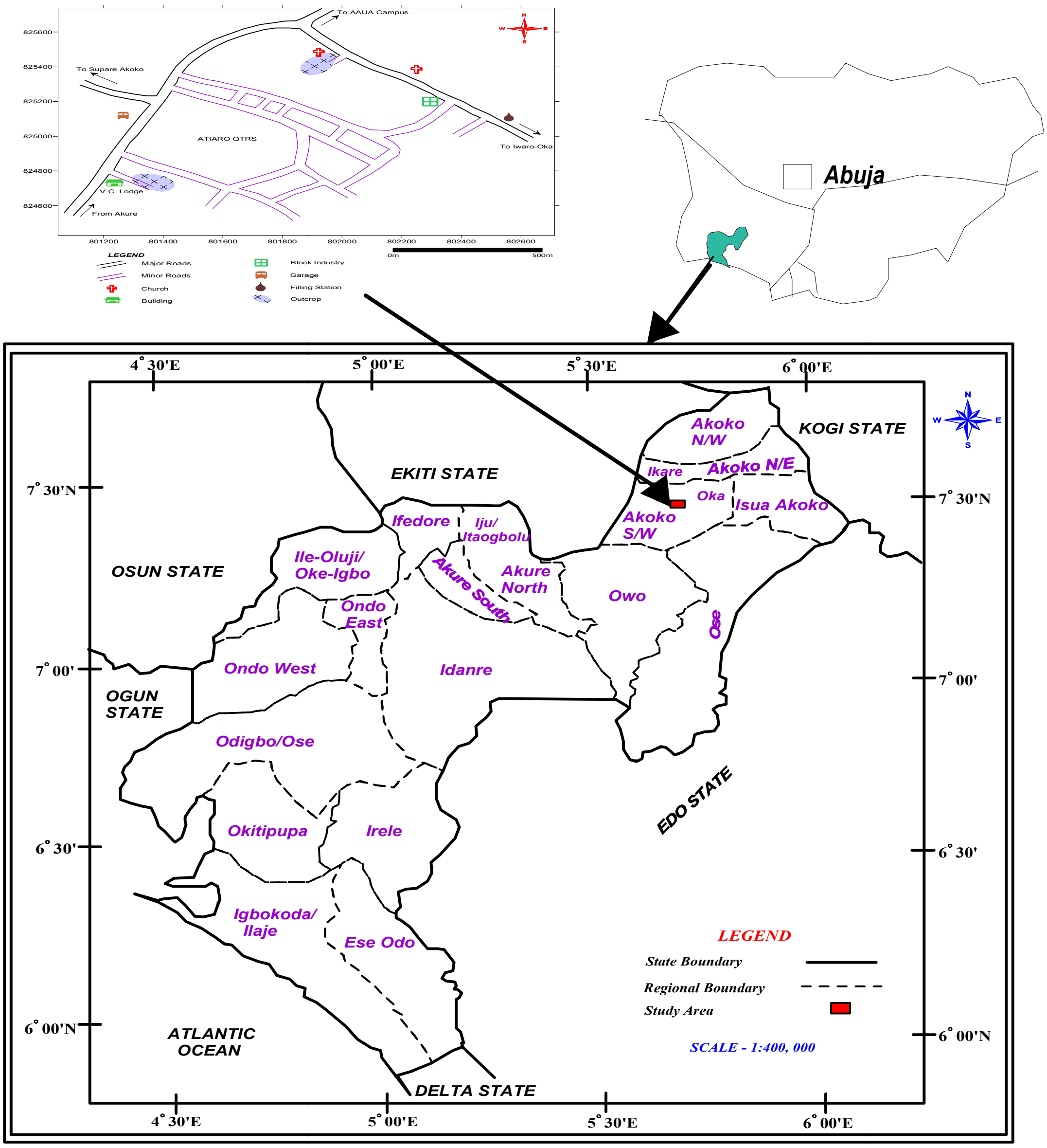

Figure 1. Map of Ondo State showing the Study Area and the Layout

northings and eastings of 825739 mN and 802713 mN and 801047 mE and 824429 mE of the Universal Traverse Mercator (UTM) Minna Zone 31 coordinates respectively. It covers an areal extent of about 1.5 km sq. The study area is characterized by relatively gentle undulating terrain with elevations of between 326 and 350 m. Bordering the site in the far north and south ends are hills and inselbergs. The features create a broad valley for the infrastructural development on the land expanse of the area. The hills trend between 090^0 and 125^0. The mean annual rainfall is about 1300 mm and mean temperature of 27^0C (Duze & Ojo 1982). The vegetation is characterized by wooden shrubs, palms, moist deciduous trees and herbaceous plants. The site is usually with dense vegetation in the rainy season and sparse in the dry season. However, human interference has reduced the vegetation. The area is generally drained by river Alatan.

2.2 Geology and Hydrogeology

The survey area is underlain by the Precambrian Basement Complex rock of southwestern Nigeria. The basement rock exposures are however found as lowland outcrop in few places within the survey area particularly where basement is shallow and erosional activities are active. However, according to Rahaman (1976 & 1988 a), the area is underlain by Migmatite - gneiss-quartzite Complex with the granite gneiss and grey gneiss being the major units while the minor units include Mafic, granodiorite, pegmatite, garnet-sillimanite gneiss and quartzite (Figure 2). The area is sandwiched between two parallel prominent E-W ridges/inselbergs of granite gneiss composition found at the north and south ends. The features create a broad valley for groundwater resource development. Generally, in a typical basement complex area, groundwater is usually contained in the weathered column and fractured/fissured, sheared or jointed/faulted basement columns. These geological processes alter rock units to reduce resistivity and hence increase the porosity and permeability of such units for groundwater accumulation. The study area is covered with variety of lateritic soil

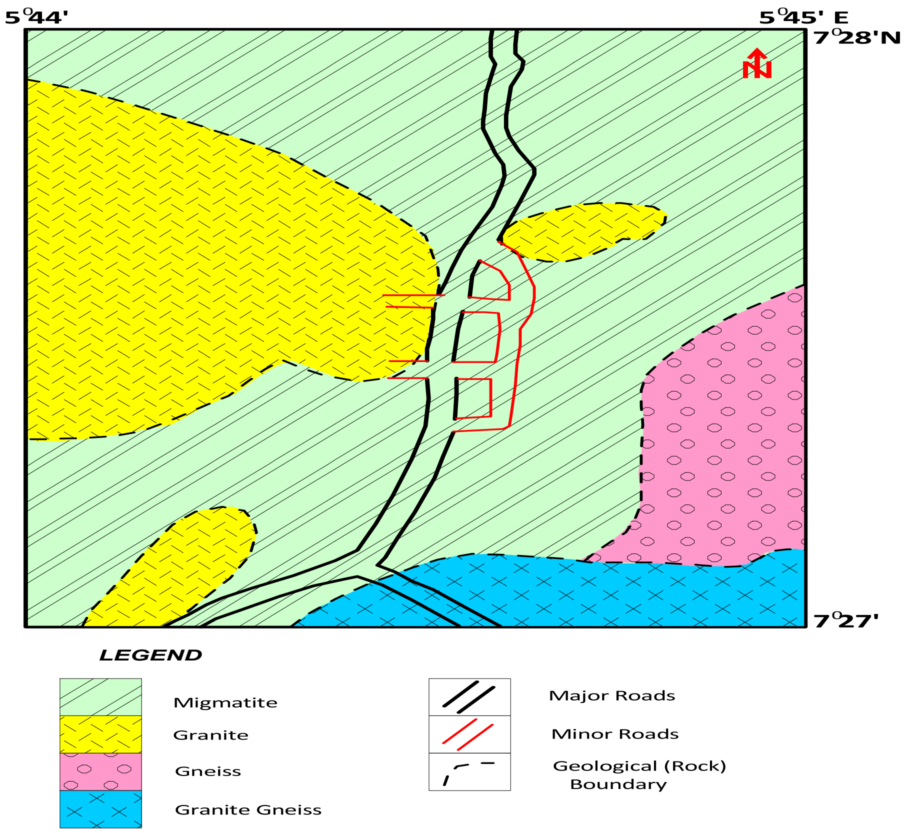

Figure 2. Geological Map of Akungba-Akoko (modified after Farotimi, 2002).

being a product of in situ weathered of the parent rocks. These weathered zones typically have been the source of groundwater in hand dug wells. The static water level of wells and few boreholes in the area range between 1.5 to 8.0 m.

3. Methods of Study

3.1 Field Survey/Data Acquisition Technique

Forty (40) Schlumberger vertical electrical resistivity soundings were acquired at selected stations not more than 75 m station – station interval particularly along and/ or few meters away from major / minor roads / footpaths and built – ups (Figure 3). The electrode spacing (AB/2) was varied from 1 – 65 m with maximum spread length of 130 m. The ABEM SAS 1000 Resistivity Meter was used for the measurement of the ground resistance. The ground apparent resistivity measured is a function of electrode spacing, geometry of electrode array, subsurface layer thickness, angle of dip and anisotropic properties (Ako, 1979). The product of the measured ground resistance (R) value and the geometric factor (G) of the electrode array for each set up gave the ground apparent resistivity values.

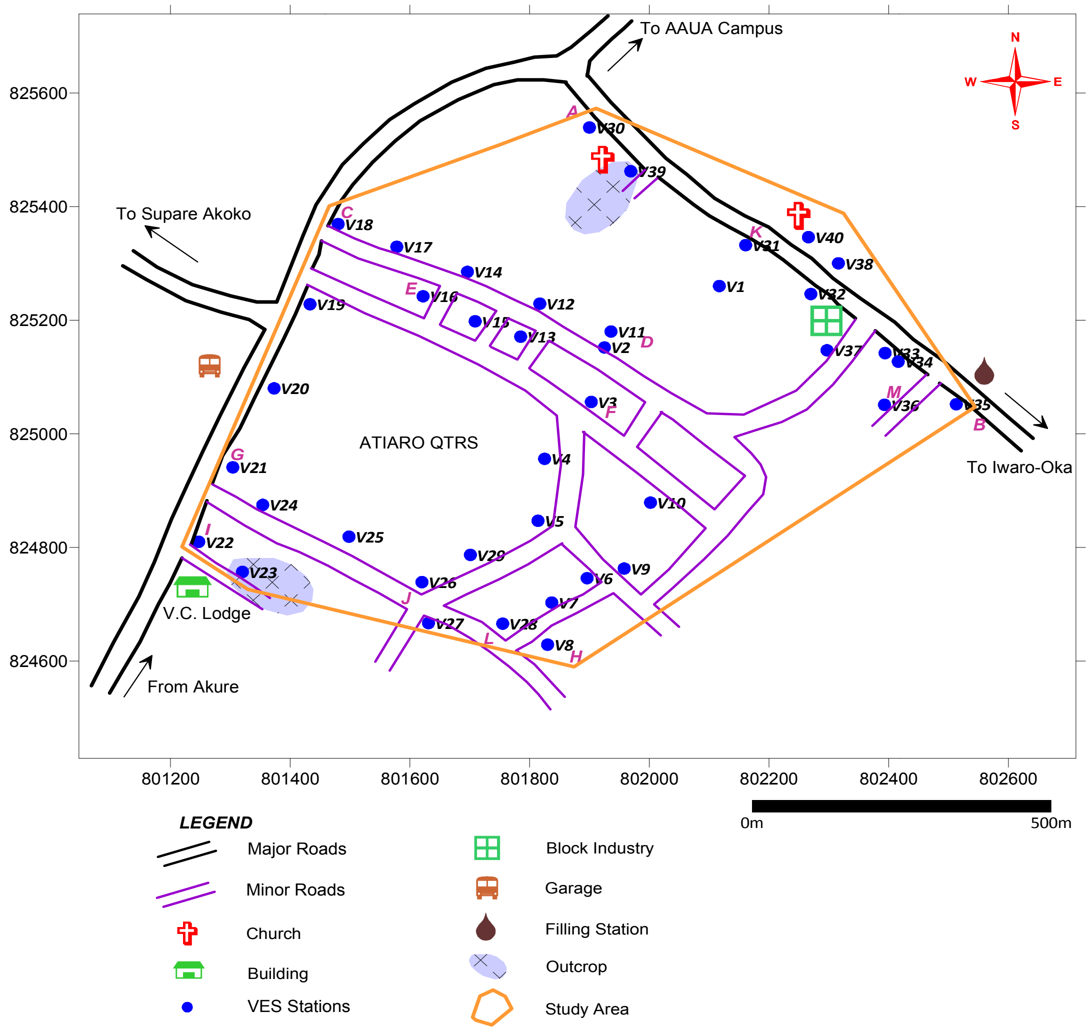

Figure 3. Data Acquisition Map of the Study Area.

3.2 Data Processing/Analysis

The data obtained from each station were plotted on transparent bi-logarithms graph paper to obtain a smooth curve for subsequent interpretation by manual partial curve matching. The partial curve matching technique involved the matching of successive segments of the field curve by a set of two-layer theoretical Schlumberger curves (Orellana and Mooney, 1966) and the corresponding auxiliary curves. The geoelectric parameters obtained from the partial curve matching were refined by computer iteration technique using WinRESIST software (Vander Velpen, 1988). The interpretation by forward and inverse modeling techniques was an interactive computer-graphic display system (Ghosh, 1974; Sharma, 2000). The system made use of a fast computer to calculate an apparent resistivity curve for a given layer sequence. From the above, the refinement of the results of the partial curve matching interpretation was obtained and found satisfactory with the root square mean (rsm) of less than 10 % .

4. Results and Discussion

4.1 Results Presentation

The results of the data obtained from the field are presented as tables, depth sounding curves, geo-electric sections and maps. However, the qualitative interpretation applied to the quantitative interpretation results of the depth sounding curves enabled the classification of the VES data into curve types. The classification ranged from simple two electrical layers to four layered curves arising from the layer resistivity combinations.

4.2 Field Curves and Geoelectric Sections

The field curves obtained within the study area are the H (6), A (16), HA (8), AA (1) and KH (7) types with the A-type being the dominant. The typical VES curve types are shown in Figures 4 (a & b).

Seven geoelectric sections were drawn in the NW-SE and approximately SW-NE directions within the study area. The sections generally delineate three to four major geoelectric/subsurface geologic layers which include; the topsoil, the weathered layer, fractured basement and the fresh bedrock (Figures 5 a – g). The resistivity of the first layer ranges from 38 - 3533 Ωm with thickness of 0 - 3.7 m. The topsoil is composed of clay, sandy clay and laterites. The resistivity of the underlying weathered layer ranges from 32 - 632 Ωm with thickness values that vary between 0 and 8.5 m. It is composed of clay, sandy clay and sand. The weathered layer is underlain by the fractured basement in few places. The resistivity of the fractured zones varies between 432 and 907 Ωm and the thickness ranges from 4.2-10.7 m. The basal unit is the fresh bedrock with resistivity that varies from 1050 to infinity ohm-m and the depth to the bedrock ranges from 0 to 14.1 m. The geoelectric sections show that the overburden is generally thin. The overburden/weathered basement is absent in places particularly beneath VES station 39 and beneath VES stations 16, 25, 26 and 28 where basement rock outcropped/thin overburden respectively. The generally thin nature of the overburden of less than 10 m in most places make the area less hydrogeologically appeal except where exist a significantly saturated thickness column of greater than 10 m in the area.

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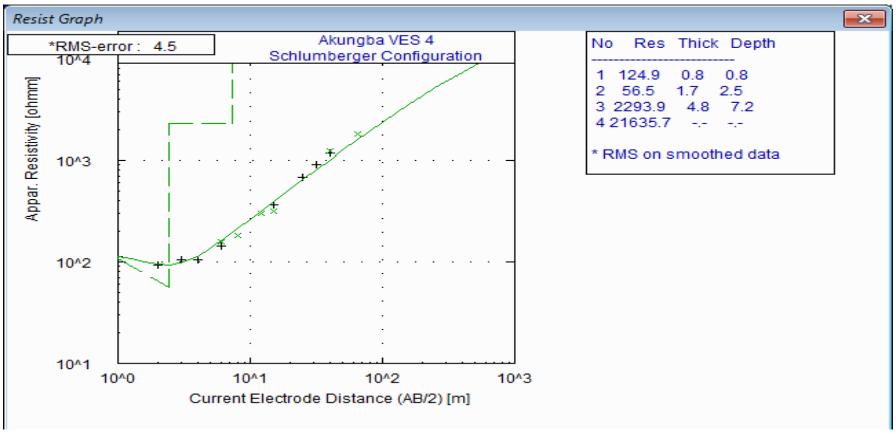


Figure 4 a: Typical HA Curve Type.

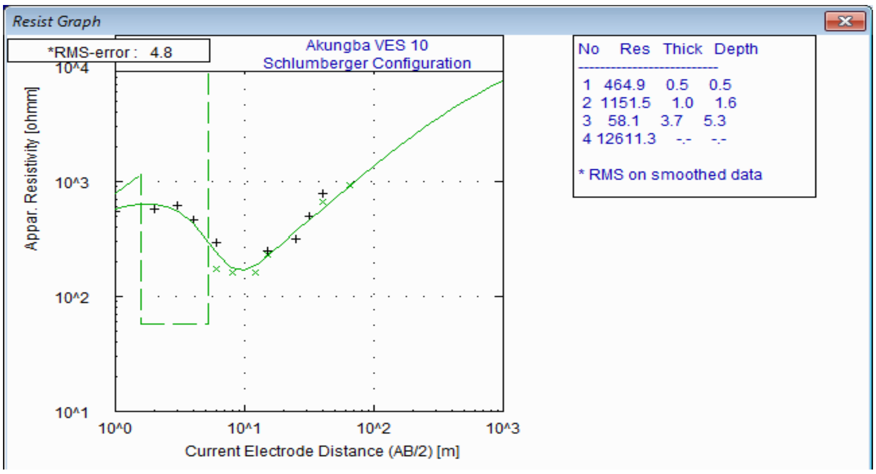


Figure 4 b: Typical KH Curve Type.

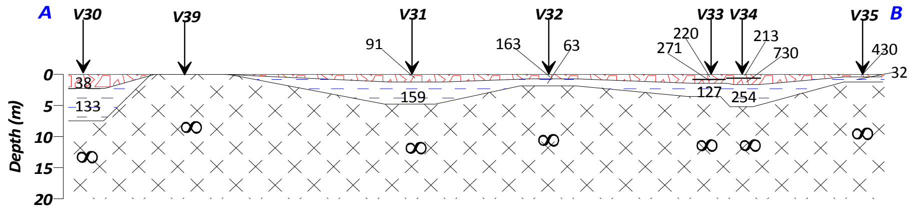


Figure 5 a: A NW-SE Geoelectric Section obtained along Line A-B (Resistivity values in Ωm).

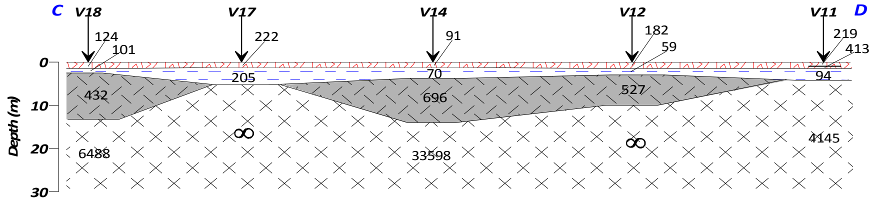


Figure 5 b: A NW-SE Geoelectric Section obtained along Line C-D (Resistivity values in Ωm).

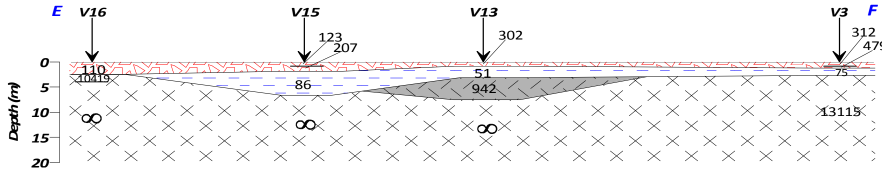


Figure 5 c: A NW-SE Geoelectric Section obtained along Line E-F (Resistivity values in Ωm)

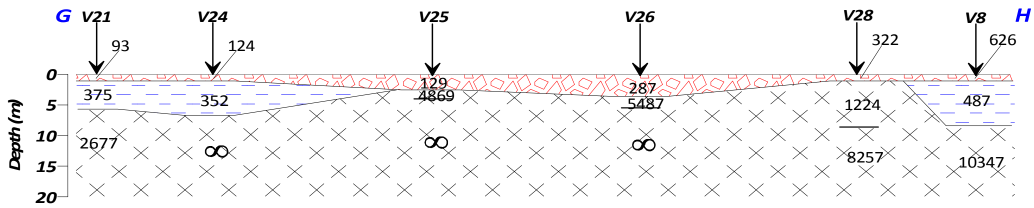


Figure 5 d: A NW-SE Geoelectric Section obtained along Line G-H (Resistivity values in Ωm)

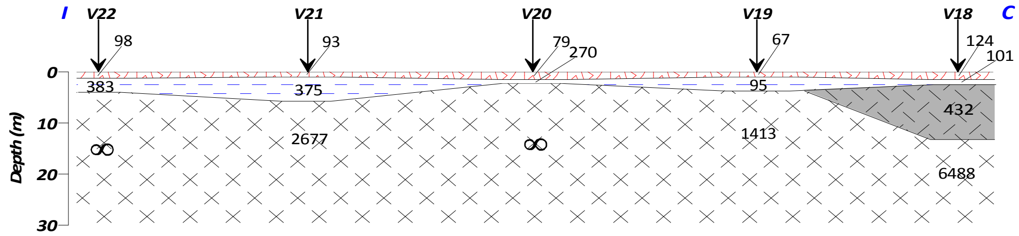


Figure 5 e: A SW-NE Geoelectric Section obtained along Line I-C (Resistivity values in Ωm).

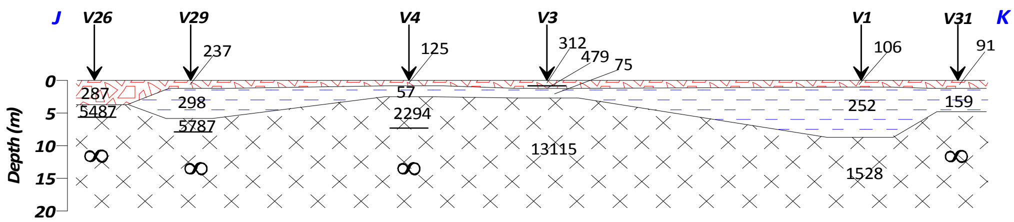


Figure 5 f: A SW-NE Geoelectric Section obtained along Line J-K (Resistivity values in Ωm)

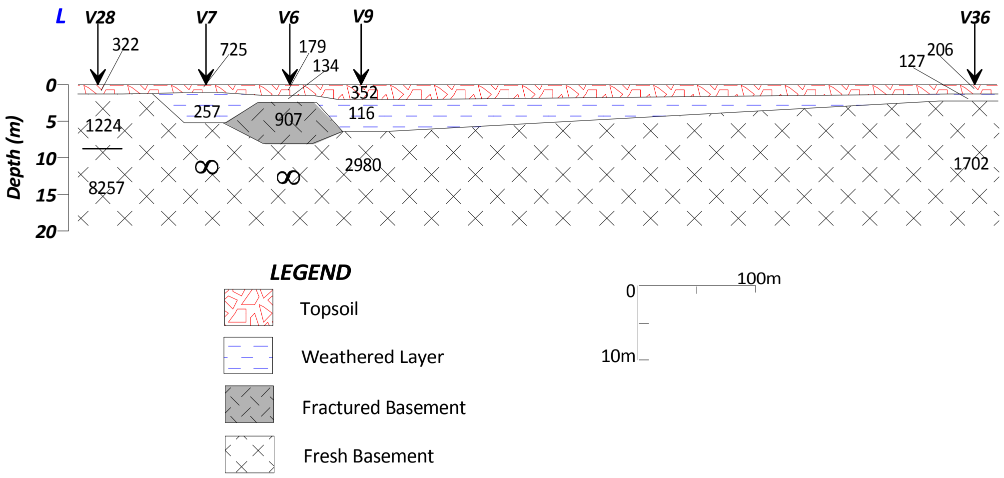


Figure 5 g: A SW-NE Geoelectric Section obtained along Line L-M (Resistivity values in Ωm).

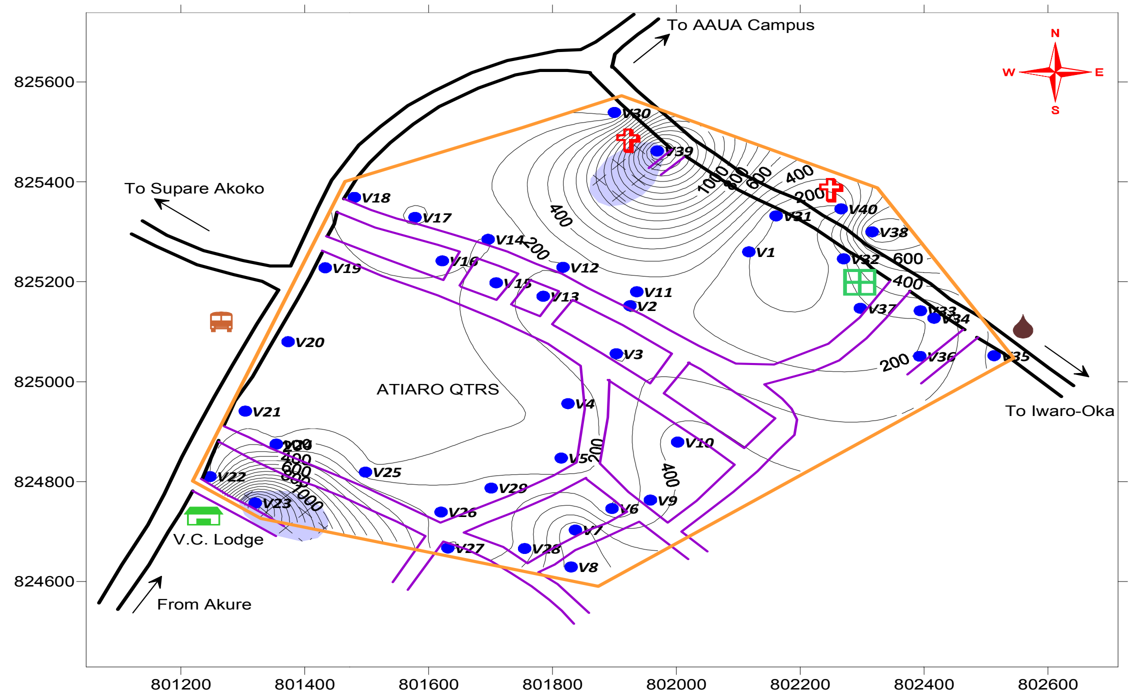
4.3 Geo-electrical Maps

The isoresistivity map of the topsoil in Araromi area of Akungba-Akoko is shown in (Figure 6 a). The map shows the variation in the resistivity of the topsoil within the study area. The topsoil resistivity varies from 38 to greater than 1000 ohm-m typical of hard-pan laterite and/or bedrock. The resistivity is generally high (>1000 ohm-m) at VES 23 stations and 39 nearest to an outcrop. The resistivity is moderately high (between 300 and 1000 ohm-m) in the eastern part of the area particularly at the extreme north-east and south-east. The resistivity of the topsoil is generally low with resistivity that is less than 300 ohm-m in the western, central and northeastern portions of the area. The map in Figure (6 b) shows the variation in the thickness of the topsoil within the study area. It shows that the thickness of the topsoil varies from 0 to 3.8 m. This generally indicates that the topsoil in the area rarely goes beyond 1 m thickness except in the western portion and in the extreme north (beneath VES station 30), including VES stations 2 and 9 where the thickness values go beyond 1.6 m. This thin nature of the topsoil is a reflection of basement highs in most places thus hinders hand-dug wells and hydrogeologically unappealed.

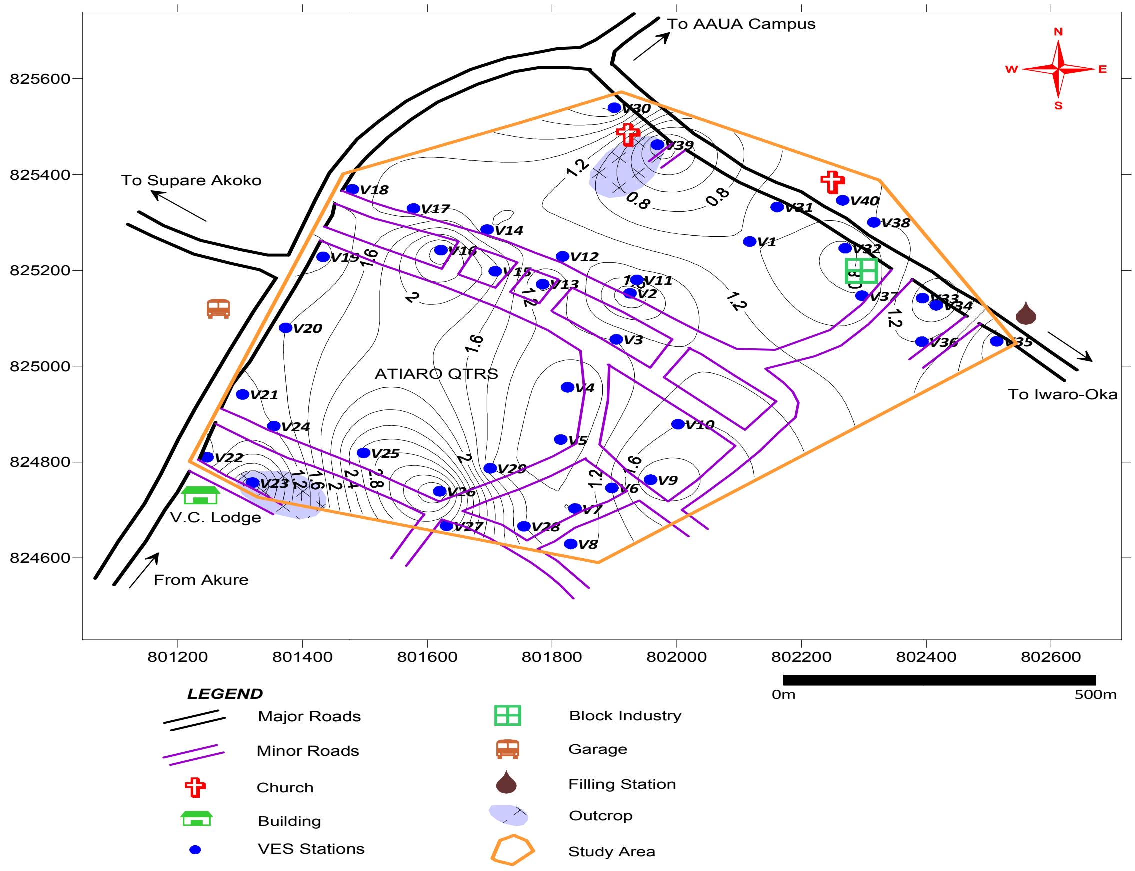
The isoresistivity map of the weathered layer is shown in Figure 6 c. The map shows the distribution in the resistivity of the weathered layer within the study area. The resistivity varies from 32 to greater than 1000 ohm-m. The region which shows resistivity values greater than 700 ohm-m is observed in the north (beneath VES station 39) and southwest (beneath VES station 23). No weathered layer was encountered in these areas but the fresh basement. The resistivity of the weathered layer is generally less than 200 ohm-m and it is observed in the central portion of the study area while the resistivity is moderately high (200-700 ohm-m) in the north and southern portions of the area. The low resistivity may be indicative of a clayey matrix while the moderately high resistivity may be indicative of a sandy nature of the column. Figure 6 d shows the distribution in the thickness of the weathered layer within the study area. The thickness varies from 0 to 8.5 m. The isopach map shows that the weathered layer is generally thin and averagely (< 4 m) and absent in some places especially beneath VES stations 23 and 39. Nevertheless, it shows pockets of fairly thick weathered layer (> 7 m) especially beneath VES stations 3, 8, 38, etc.

The distribution of the overburden thickness within the study area is generally shown in (Figure 6 e). Appreciable overburden thickness zones are possible groundwater collecting zones. Hence, unconsolidated materials could contain reliable aquifer if thick and sandy. (Satpathy and Kanungo, 1976; Olorunfemi and Olorunniwo, 1985; Dan Hassan and Olorunfemi, 1999; Bala and Ike, 2001; Mohammed and Olorunfemi, 2007; Ojo *et al.,* 2007). Also related geophysical studies in a typical basement terrain identified thick overburden as zone of high groundwater potential (Olorunfemi and Okhue, 1992; Bala and Ike, 2001; Mohammed *et al.,* 2012). The map shows overburden thickness with values that vary from 0 - 14.1 m. A relatively uniform thickness is observed throughout the study area with overburden that is very thin and rarely greater than 10 m in most places. The overburden is relatively fair in thickness (10-14 m) in the northwestern and southeastern portions in the vicinity of VES stations 14, 18 and 37. These zones are suggestive of possible groundwater potential zones in the area.

Figure 6 f shows the variation in the bedrock topography of the study area. Previous geoelectrical studies have identified hydrogeological significance of bedrock depressions (Satpathy & Kanungo, 1976,.Olorunfemi and Okhue, 1992; Dan Hassan and Olorunfemi, 1999; Bala and Ike, 2001; Mohammed, 2007; Oladapo and Akintorinwa, 2007; Omosuyi., 2010) as groundwater collecting centers and are usually characterized by thick overburden. Conversely,

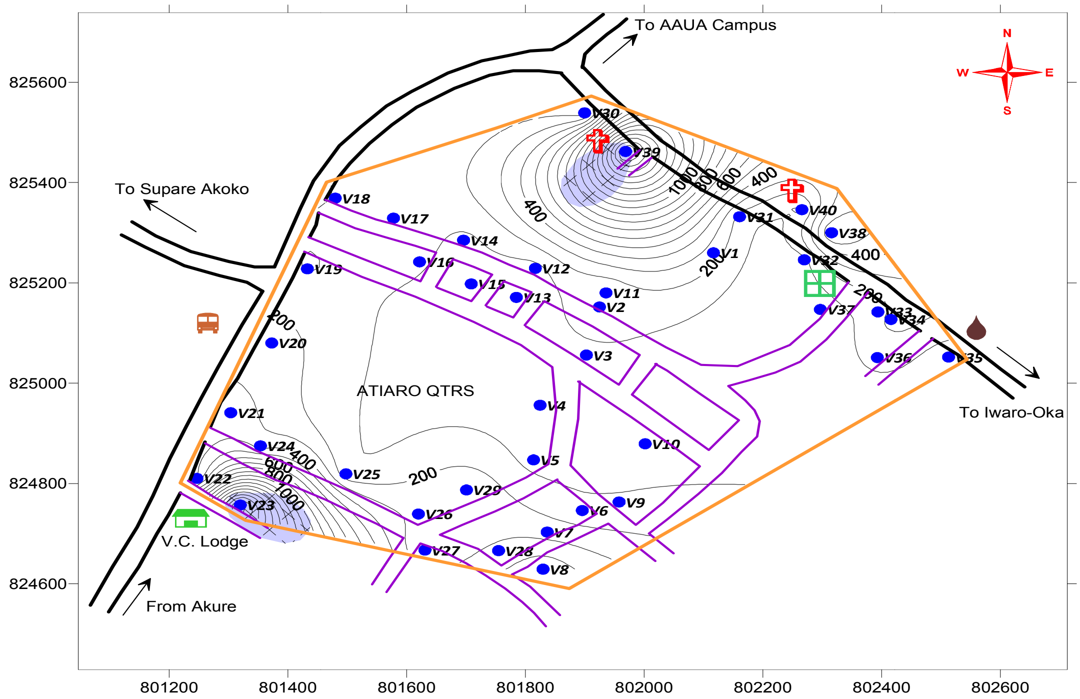


(a)

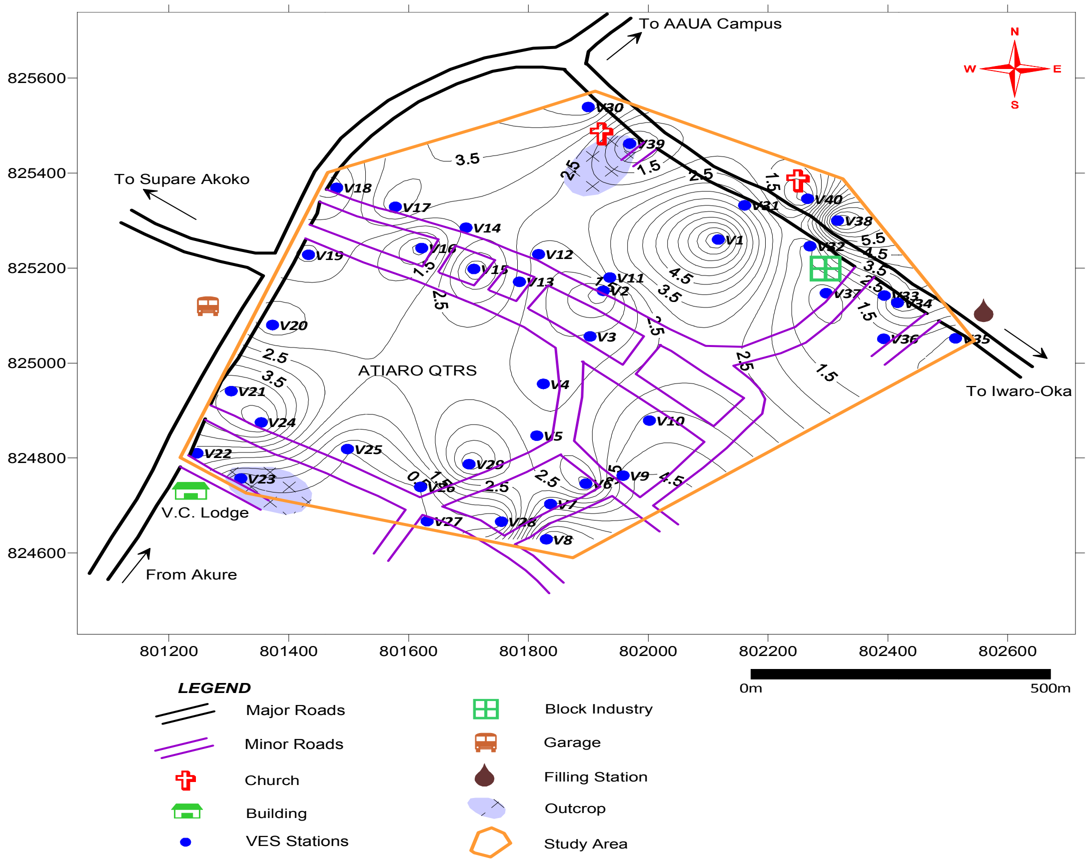


(b)

Figure 6. (a) Isoresistivity Map, **(b)** Isopach Map of the Topsoil of the Study Area

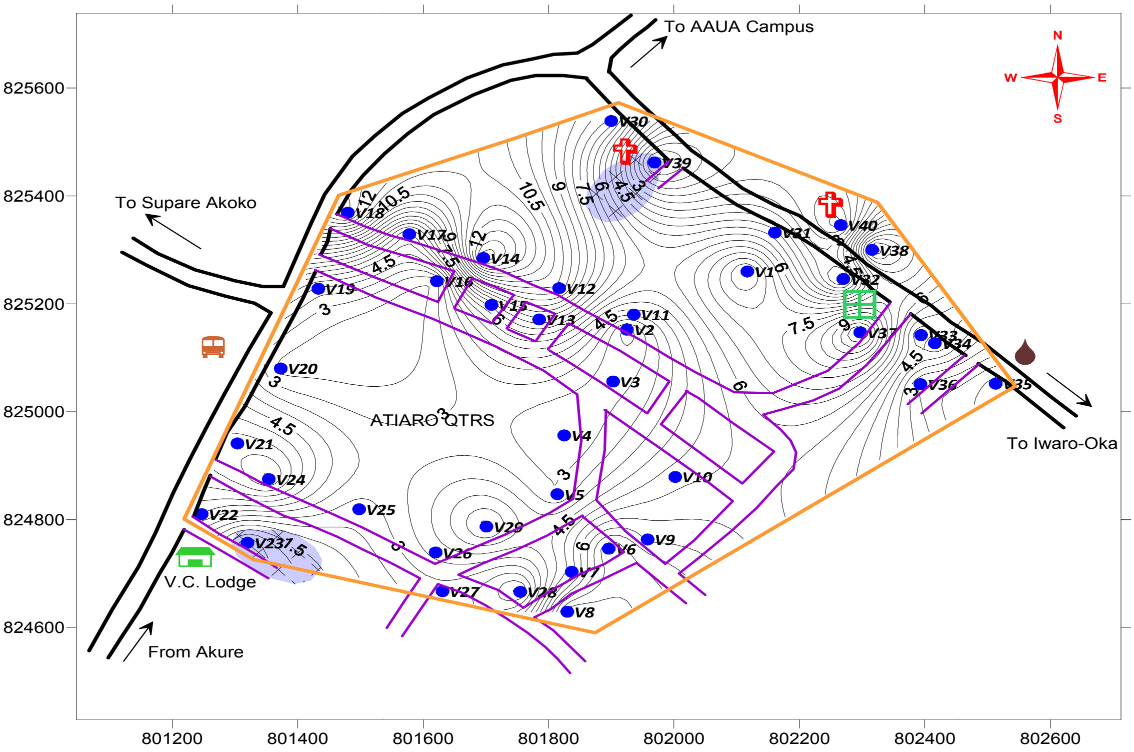


(c)

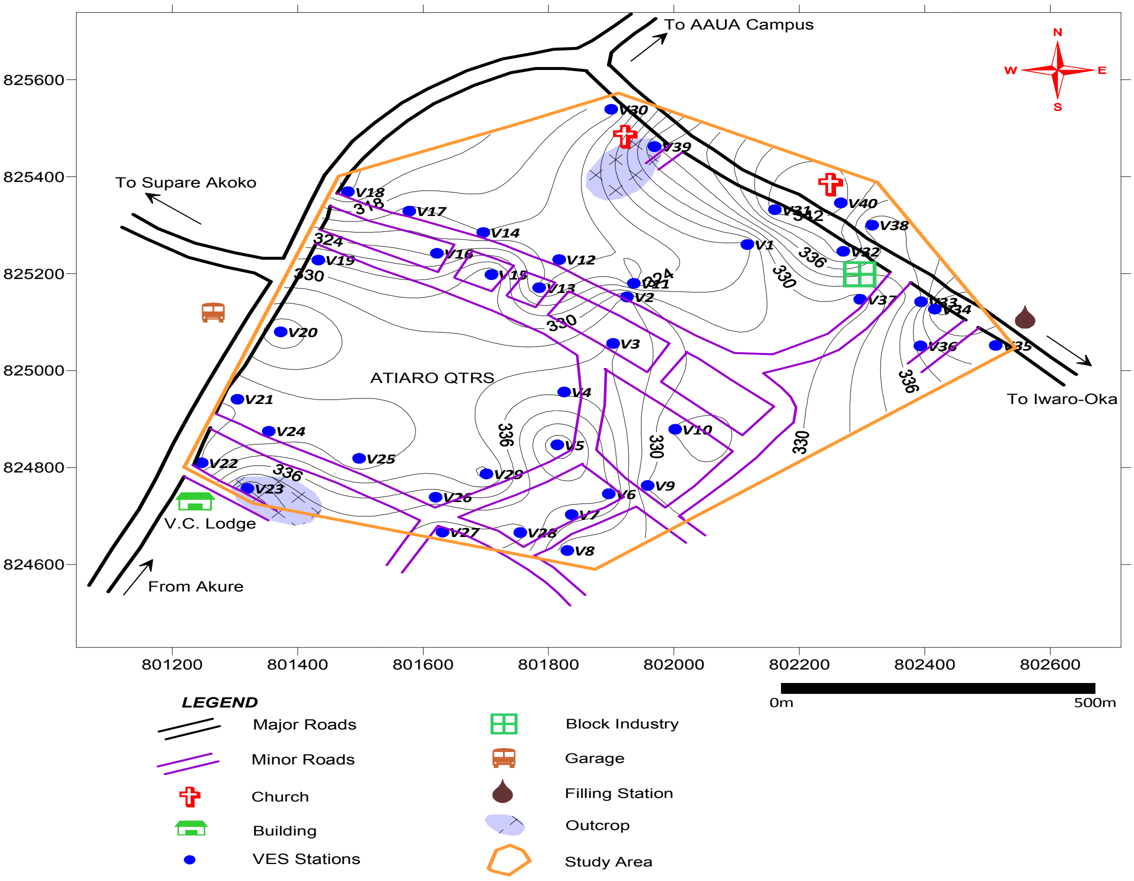


(d)

Figure 6. (c) Isoresistivity Map, (d) Isopach Map of the Weathered Layer of the Study Area



(e)



(f)

Figure 6. (e) Overburden Thickness Map, (f) Bedrock Relief Map of the Study Area

ridges are usually associated with thin overburden cover and are groundwater diverting centers. These two characteristic features are observed in (Figure 6 f). The zone with a relatively low relief is indicative of a depression. The depression found sandwiched between two highs/bedrock ridges runs parallel and trends approximately NW-SE direction of the study area where contours are closed. Hence, the lone major depression serves as groundwater collecting centre in this area and is suggestive of a major NW-SE suspected regional fault in-filled with weathering products. This result correlates with that obtained from the overburden thickness map.

5. Conclusions

Three to four geoelectric layers were delineated within the study area. These include; the topsoil, the weathered layer, partially weathered/fractured basement and the fresh basement rock. The resistivity of the topsoil reveals that its composition varies from clay to laterite. Maps generated using the obtained geoelectrical parameters revealed the variation of the different layer resistivity and thicknesses within the area. The study revealed that there exists a variable potential for groundwater development in the area. This is because of the variable thickness of saprolite/weathered/fractured columns within a short distance. The weathered/ partially weathered/fractured column is generally thin across the area except for the fairly thick columns as pockets of sandy materials found scattered the study area particularly towards the northwestern part. The weathered/fractured layer constituted the dominant aquifer units with tendency for low groundwater potential rating arising from the clayey and thin nature of the overburden. Future groundwater resource development in the study area is considered feasible in few places characterized by relatively thick and sandy column of the overburden units. Hence, the groundwater potential of the study area is generally of a low level rating, at the very best.

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Muraina Z. Mohammed born in Ogbagi Akoko Ondo state, southwestern Nigeria.

He received a B. Tech. (1992) and an M. Tech. (1997) Degrees in Applied/Exploration Geophysics from the Federal University of Technology, Akure and a Ph.D (2007) Degree in Applied Geophysics from Obafemi Awolowo Univesity, Ile – Ife, Nigeria. His major field of study is Exploration and Environmental Geophysics. His other interests are in Applied /Exploration Geophysics**;** Control Source Electromagnetic (**CSEM**) for Hydrocarbon Exploration and GPR studies of active faults.