Integrated Geophysical Groundwater Prospecting Using Electrical and Aeromagnetic Methods in Ogbondoroko, Asa Local Government Area of Kwara State

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ABSTRACT

This study presents one of the series of geophysical techniques, electrical resistivity to correlate the aeromagnetic anomaly in basement Complex rock terrain, around Ilorin, West Central Nigeria. An area of about 2km2 which is a suburb of Ilorin, part of Ogbondoroko, has been used as a case study for the application of electrical resistivity sounding, radial geoelectric sounding and sounding-cum-profiling techniques in structural mapping of basement structure identified from the aeromagnetic maps of Ilorin Sheet. In this report, a demonstration of the use electrical resistivity soundings in evaluation of aeromagnetic anomalies of a part of Ilorin is presented. A total of twenty (20) Vertical Electric Soundings (VES) using the Schlumberger array of the geophysical electrical method were carried out. The results were presented in the form of sounding curves, tables, geo-electric sections, anisotropy polygons and pseudo-sections. A low resistivity E-W trend of fractures were observed at depths >35m, which is not sympathetic with the aeromagnetic lineament picked from the aeromagnetic anomaly map of the area. However, N-S fracture trend were also delineated at shallower depths. The result will serve as a guide for the application of combined geophysical exploration technique for groundwater development options.

Keywords: Evaluation of Aeromagnetic anomaly, electrical resistivity techniques, radial geoelectric sounding

1. INTRODUCTION

Globally, the volume of groundwater contained in hard rock aquifers is not well constrained and has often been considered negligible from a water resource perspective (Comte et al. 2012). This could be attributed to the fact that hard rock possesses little or no primary inter-granular porosity and permeability and thus the occurrence of groundwater is due largely to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks (Acworth

1987; Olorunfemi and Fasuyi 1993; Olayinka et al. 1997). Groundwater accumulation in this region is controlled by a number of factors which include the parent rock type, the depth, extent and pattern of weathering, thickness of weathered materials, and the degree, frequency and connectivity of fracturing, fissuring and jointing, as well as the type and nature of the fillings in the joint apertures, Adeleke ,et al.2011.

Plate I. High yield bore hole

Plate II. High yield bore hole serving at the front of Central Mosque

There are series of geophysical methods such as electrical, gravity, electromagnetic, magnetic, seismic and radiometry, that responds to physical properties of the subsurface media which could be used singly or in combinations for subsurface sequence and structure disposition site investigation. The magnetic method is used to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks (Nicolas, 2007). The magnetic method is used to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks (Nicolas, 2007). The lineaments obtained from this and other remote sensing techniques such as aeromagnetic anomalies could be due to lithologic contact, ductile shear zones, faults and fractures. The accurate interpretation of the lithology and fractures from such lineaments would be enhanced by the use of integrated techniques (Satellite Imagery and RVES) Olasehinde, 1999. An aeromagnetic survey is a geophysical tool for mapping subsurface bedrock geology (lithology)) and structures due to variation in magnetic susceptibility of rock (Gumel et al., 1987. Olasehinde, 1990).

Different professionals have carried out and are still carrying out investigations and studies on the evaluation and interpretation of the Aeromagnetic anomaly map of Nigeria;. Prominent among the reports include detection of tectonic features from aeromagnetic anomaly map of Okigwe-Oguta axis, South of Benue Trough, Nigeria Selemo and Akaolisa (2010). The study revealed existence of charcot fault zone within this region.

Olorunfemi and Olorunniwo (1985) also carried out a study on the geoelectric parameters and aquifer characteristics of some parts of southwestern Nigeria in which they reported that the clayey sand layer and the fractured basement constitute the aquifer zones. In their own work, Ofoegbu and Mohan (1998) carried out interpretation of aeromagnetic anomalies over part of Southern Nigeria using three-dimensional Hilbert Transformation in which the structural patterns of the area were delineated. Also, the hydrocarbon potentials of parts of the Nigerian sector of the Chad basin have been re-evaluated from the interpretation of aeromagnetic anomalies by Anakwuba and Augustine (2012). From the analysis of the aeromagnetic anomaly map, they were able to determine the structural pattern, the sedimentary thickness variations within the basin and intense fractures and major fault trending. Onuba, et al. (2010) worked on the evaluation of the Total field aeromagnetic anomalies over Okigwe area, Southeastern Nigeria in order to map lineaments and estimate the depths to basement (sedimentary thickness). Nwankwo, *et al.* (2000) also carried out a spectral analysis of aeromagnetic anomalies of the Northern Nupe Basin of West Central Nigeria. Olasehinde and Annor (1996) in their work presented a regional fracture map based on the spectral evaluation of aeromagnetic maps of a poorly exposed basement terrain in Central Nigeria. Adeleke et. al., (2009) also carried out an evaluation and harnessing Basement Aquifers in Lautech, Ogbomoso, Southwestern Nigeria in which the transmissivity of the aquifers in the area were evaluated. Direen et al (2011) on a regional scale, uses airborne geophysical data to identify several features, such as limits of geological provinces, fold belts, sedimentary basins and tectonic/structural detail of shear zones over printed structural trends. Delor et al (2009) used aeromagnetic dataset to map structures, such as fault, lineament, folds and shear zones in the Nkwanta area of Ghana. El-awady *et, al* (1984) carried out quantitative as well as qualitative interpretation of the aeromagnetic data for Faryum area, Western Desert, Egypt in order to obtain more information about the crystalline basement structure and the local structures in the sedimentary section.

The present study was carried with the objective to evaluate ground water occurrence using multiple geophysical methods to evaluate ground water prospects from magnetic and electrical resistivity methods in crystalline basement rock terrain. A combination of geophysical technique will improve water well productivity for sundry groundwater development purposes. Non of previous work have used resistivity and aeromagnetic methods to evaluate water occurrence in the study area.. As the town becomes expanded in social and economic activities, the need for motorized mini water supply scheme is inevitable in semi urban communities.

Figure 1: Landsat Image map of Ilorin Area

2. STUDY AREA

2.1 Location Description.

The location falls between Latitude 80 221 57.381N to Latitude 80 231 14.941N and Longitude 4 361 06.911E to Longitude 40 361 24.631E at Ilorin, southwestern Nigeria. However, the locatio situated in the Southwestern part of Nigeria at Ilorin, Kwara State, corresponds to contact betwee two rocks. It is assumed that the lineaments observed in both the Total Magnetic Intensity (TM map and the 1st Vertical Derivative map correspond to a contact between two rocks that was forme by fractures (fig. 2). From the Total Magnetic Intensity map, the location of lineaments was pick The area was identified in the vicinity of Community Junior Secondary School, Laa Ogbondoroko, Asa Local Government, Southwestern part of Ilorin, Kwara state, Southwester Nigeria.

Ilorin is part of the known transition zone between the semi arid part of Nigeria and the humid coastal belt to the south. Ilorin falls within the tropical climate region and has two distinct seasons "dry and wet seasons". They receive a moderate amount of rainfall from the months of March October and decreases hence in frequency and intensity from the southern to the north of Nigeria The average temperature is 27oC with a mean maximum of 21.8oC. The hottest period falls within the dry season and the coldest period of harmattan comes before the rainy season. The mean monthly sunshine hours from Ilorin ranges between 2.5 and 9.5 hours within an average of 5.9 hours Rainfall condition in Ilorin exhibits greater variability both temporarily and spatial. Relative humidity varies seasonally with an average of 79.7% (Kolawole, et al 2013). The vegetation is mainly in-between the deciduous woodlands of southern Nigeria and the dry savannah of Nigeria.

These are essentially made up of grass cover, shrubs and medium sized trees of the guinea savannah type (Olaniran, 1982 and Ileoje, 1985). The vegetation in Ilorin falls within the derived Savannah. The vegetation is characterized by scattered tall trees such as Baobab, locust beans, shear butter, Acacia etc.

The annual rainfall ranges from 1,000-1,500mm, while maximum average temperature ranges between 30oC and 35oC. With this climatic pattern and size-able expanse arable and rich fertile soils, the vegetation, which is mainly the wooded Savannah is well suited for the cultivation of a wide variety of food crops like yams, cassava, maize, beans, rice, sugarcane, fruits, vegetables, etc. The mainstay of the economy is agriculture. Kolawole, et al (2013).

The area covers about 2km2 in area. Nigeria. The climate of the study area is typically tropical characterized by dry and wet seasons. The dry season is short and usually lasts 3 – 10 weeks while the wet season starts at about March and extends till October during which the rivers are at their peak. The mean annual rainfall is generally between 1200mm and 1500mm while temperature ranges from 250C to about 350C. Thus, the study area in Ilorin covers a transition between the tropical savannah in the North and Rainforest in the South. River Asa is the main river flowing across the area with many tributaries. It flows in southwestern direction. It is inferred that the zigzag course of the river is due to the interference of fractures portraying a clear trellis drainage pattern (Olasehinde *et. Al.,* 1989).

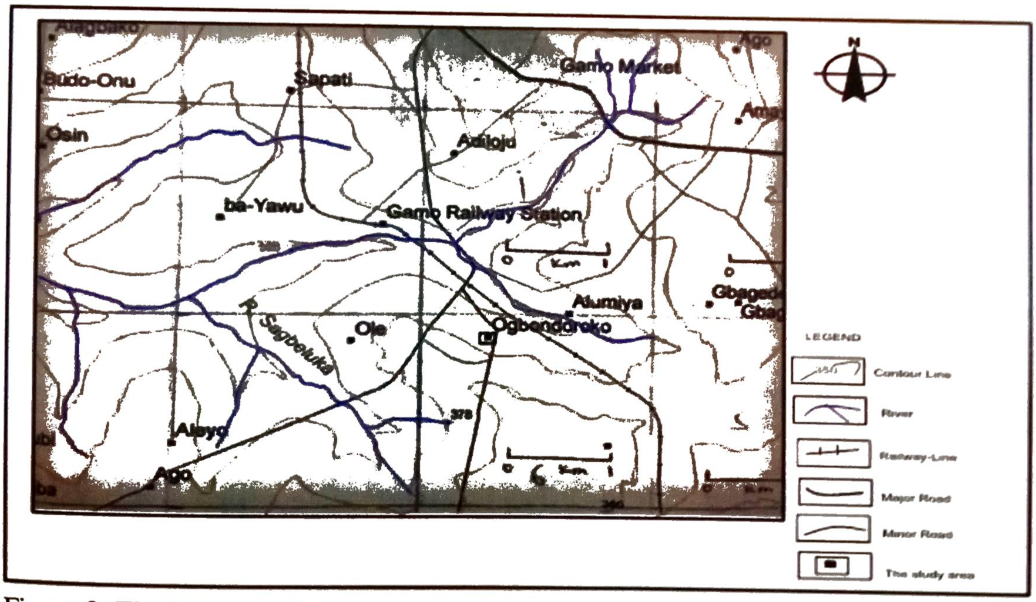

Figure 2: The Location Map

2.2 Geology Setting

The area of study forms part of the Precambrian Basement complex of Nigeria which covers nearly half the area of the country (Oyawoye, 1964), composed of three main basement complex units: Migmatite-gneisses, granite gneisses and metasediments such as quartzites, younger materials derived from weathering of those rocks constitute the major superficial deposits (Fig.3) (Rahman, 1978, 1988 & 1989; Kogbe 1989; Mc Curry, 1978. The rocks consist of granite, foliated microgranite and granodiorite, augen gneiss, sheared gneiss and banded gneiss. Several joints have been found but in the pattern which may be said to be irregular trend generally NW-SE. The crystalline basement rocks in the area are known to have been affected by both the Eburnean and Pan-African Orogenies (Annor, 1986; Rahman 1989). The Eburnean orogeny caused the migmatization and metamorphism of the ancient metasediments while the Pan-African orogeny has produced intrusions of older materials. These events have produced chains of metamorphic rocks with a NNE-SSW strike direction. The Pan-African must have been responsible for most of the fractures observed here. The tectonics of the post-paleozoic time is dominated by fractures with NW-SE direction.

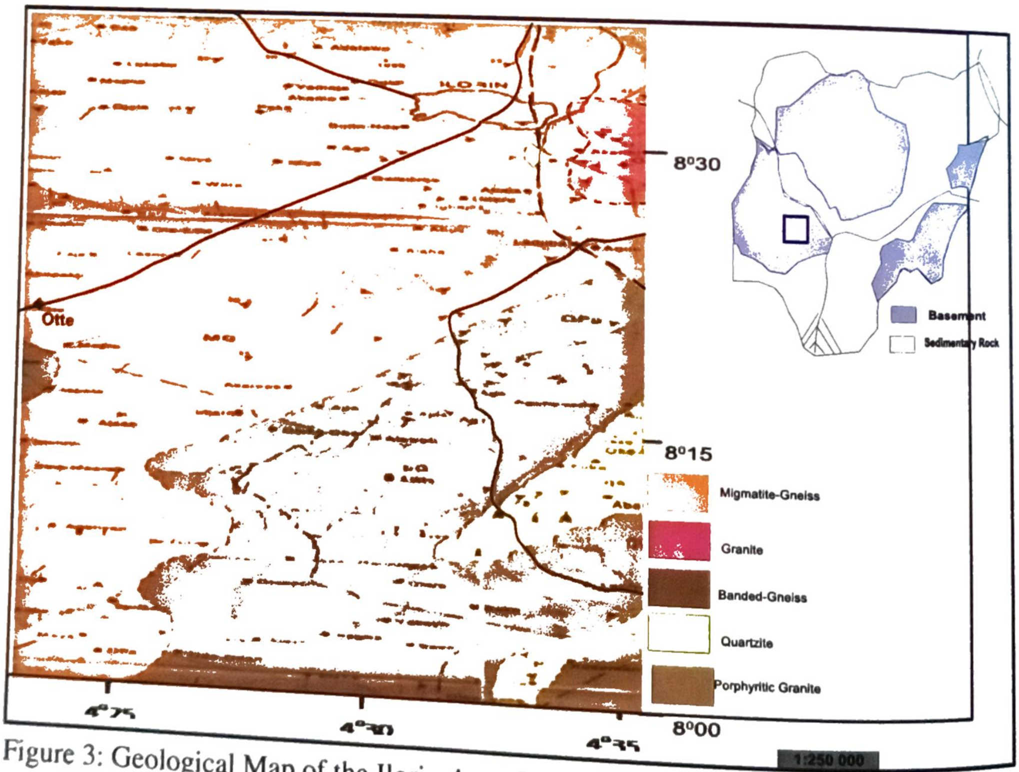

Figure 3: Geological Map of the Ilorin Area (Modified from Oluyide *et al.*, 1988). Insert: Geology map of Nigeria

2.3 Hydrogeology

Southwestern Nigeria groundwater occurrence is essentially semi-confined to confined occurring under water table condition and highly influenced by infiltration and percolation or by precipitation. Owing to the crystalline nature of the rock types in this region, the porosity and permeability necessary for groundwater occurrence are generally lacking. However appreciable porosity and permeability may have been developed during fracturing and weathering process. The highly permeable weathered fractured zone varies locally and is sometimes composed of quartzo-feldspathic and amphibolitic materials. (Plate I and II)

Plate I

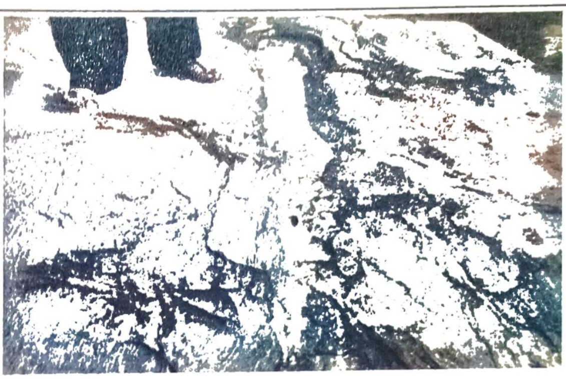

Plate II

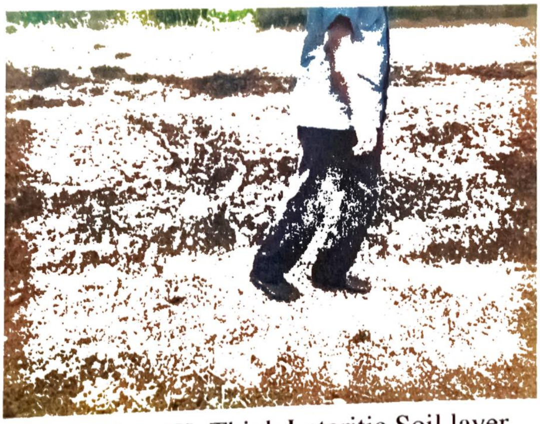

Plate III. Thick Lateritic Soil layer

Further information from available borehole lithological logs in the region revealed that weathering is fairly deep and that the rocks have been jointed and fractured severely occurring between 30 – 68m below the surface (Adelana and Olasehinde 2004).

These joints and fractures have to a large extent; control the flow direction of most rivers in this region. The weathered zone immediately overlying the fresh basement rocks are made of similar lithology but slightly brittle as a result of intense chemical weathering of the rock forming materials such as feldspar and ferromagnesian into clay and iron oxides (laterite) P{late III).

The crystalline basement represents the deeper, fractured aquifer and is noted as a poor source of groundwater. This is partly overlain by a shallow, porous aquifer within the lateritic soil cover as described by Annor and Olasehinde (1996). However, locally high concentrations of feldspars can lead to clayey layers within this cover. The area is part of the regional southwestern Highlands of

Nigeria running NW-SE, hence sub-parallel to the River Niger. The study area is situated on the northern border of the larger-scale morphological feature, being drained to the north. From direct observations, it is known that the draining creeks and rivers swell fast during and after precipitation events, thus indicating a rather low storage capacity of the soil and underlying rocks.

3. MATERIAL AND METHODS

3.1 Data Analysis and Field Investigation

3.1.1 Data Acquisitions

The data set were total field aeromagnetic data (sheet number 223) acquired during high resolution airborne geophysical surveys of Nigeria between 2003 and 2009 by Fugro Airborne Survey Limited for Nigerian Geological Survey Agency (NGSA, 2009). The survey was flown in drape mode using real time differential GPS at a sensor mean terrain clearance of 75m. Traverse and tie line spacing were 500 m and 2000 m respectively while flight and tie line directions were NW-SE and NE-SW respectively (NGSA, 2008). The data were de-cultured, leveled, corrected for International Geomagnetic Reference Field (IGRF), gridded at an appropriate cell size that enhances anomaly details and reduces possible noise and latitude effects (Patterson and Reeves, 1985).

3.2 Processing and Interpretation methodology

The Total Magnetic Field Intensity (TMI) data is a combination of so many responses, majorly from the Basement. Magnetic responses from intrusive bodies both buried and exposed as well as from mineral ores within structures could be insignificant. However, this insignificant contribution is the major target of magnetic prospection in mineral exploration. The need to separate local magnetic anomaly from regional bodies necessitates the computation of various derivatives from the TMI. These derivatives include the First and second vertical derivatives (1VD) and (2VD) of the TMI. The amplitude of the Analytic signal (ANSIG) of the TMI, the Horizontal Gradient (HGrad) of the TMI, and the Tilt Derivative of the TMI. The combination of Derivatives helps to isolate anomaly position, size, shape and orientation.

The original TMI grid is processed, filtered and transformed to produce the Derivatives using Oasis Montaj software with associated extensions of the package such as MAGMAP, SPI, CET and other modules that assisted in performing the different tasks in filtering, georeferencing, dynamic linking and various map enhancements. The First Vertical Derivative identifies bodies containing high percentage of magnetic materials (e.g Basalt, and mafic rocks) with a high frequency signature. The data also emphasised near surface structures. The Second Vertical Derivative enhances structures nearest to the ground surface and therefore has the highest frequency and usually very short wavelength. The Analytical signal helps to define the intrusive bodies and their edges. The data is a combination of derivatives; hence it is independent of anomaly shape. The Horizontal Gradient locates more accurately the exact location of faults and geologic boundaries.

The interpretation methodology involves the study and careful inspection of the TMI, 1VD, 2VD, analytical signal, the Horizontal gradient, the geologic map, the SRTM, and other relevant data integrated in a GIS platform to define:

- Boundaries of magnetic units;
- Structures dislocating or affecting the morphology of magnetic units;
- Depth and attitude of magnetic units;
- Any superposition of magnetic units;
- Lithological units;

Structures were recognized by:

- Offsets of apparently similar magnetic units,
- Sudden discontinuities of magnetic units,
- An abrupt change in depth to magnetic sources.
- A linear narrow magnetic low caused by weathering along a fault plane oxidizing magnetic minerals to non-magnetic minerals (joints can have a similar magnetic expression),
- A linear magnetic high, which may be discontinuous in nature due to magnetic minerals precipitated in the fault plane.

A ground magnetic anomaly map of the area was then prepared on a scale 1:100,000 (Fig. 2).

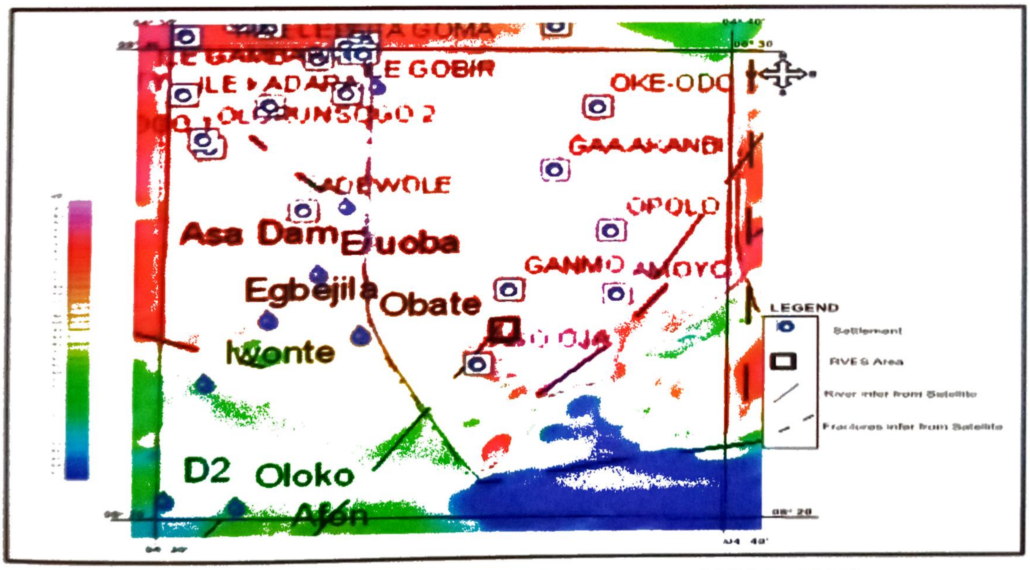

Figure 4: Total Magnetic Intensity Analysis (Data Source: NGSA, 2005).

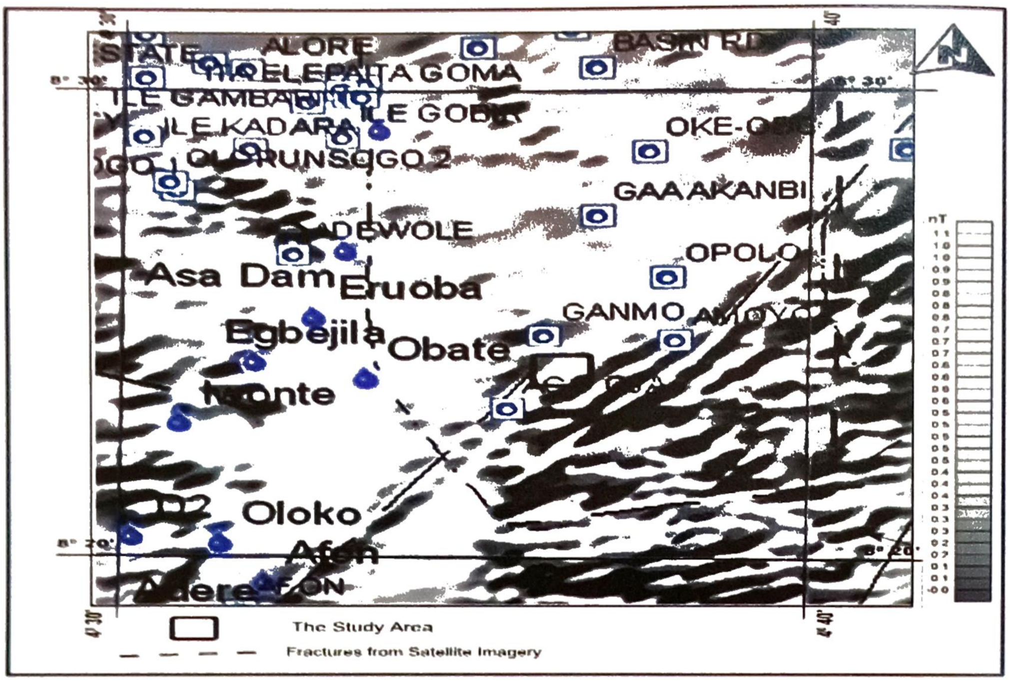

Figure 5: First Vertical Derivative Analysis of the area (Data Source: NGSA, 2005).

3.2.1 Radial Vertical Electrical Sounding

The basement structures and pattern of the area were delineated by the interpretation of the vertical electrical soundings, sounding-cum-profiling and radial geoelectric soundings in two locations and twenty (20) VES were carried out in all. Vertical electrical resistivity soundings were carried out along two profiles; Profile F (E-W) and Profile C (NE-SW) respectively (Fig. 6). The PZ-02 Resistivity meter was used for the survey. The Schlumberger electrode configuration was employed and electrode separations were expanded up to AB/2 = 60 metres. The station interval was 60m. The results were processed and sounding-cum-profiling (pseudosections) were made. Radial Geoelectric soundings were carried out at two locations with two other VES across the area suspected to be fractured from topographical considerations, satellite imagery and from the aeromagnetic anomaly maps of Nigeria (NGSA, 2005). These make up Profile F. In the radial geoelectric soundings, soundings were made along four mutual axes separated by 45o each. Profile C was chosen about 200 m NE of the area suspected to be fractured to serve as a control traverse. In this present study, the electrical resistivity sounding using Schlumberger array was employed. This array is preferred to Wenner because the small spacing between potential electrodes renders it less sensitive to shallow inhomogeneities and the expanding electrodes of the Wenner array create false anomalous zones that complicate interpretation.

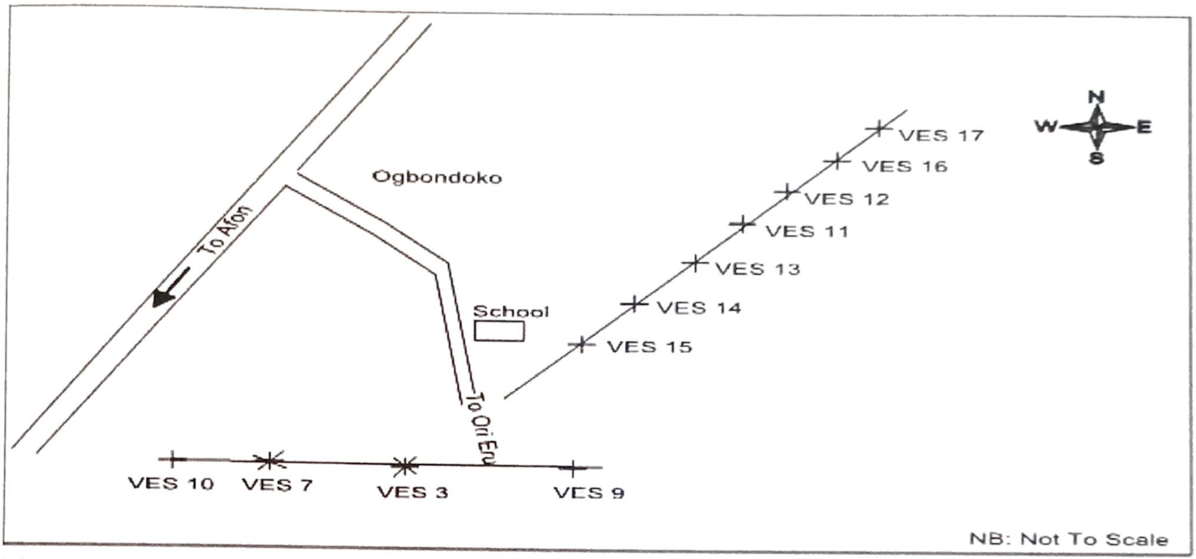

Figure 6: Sketch map for the VES and Radial Sounding

4. RESULTS AND DISCUSSION

4.1 Interpretation of Aeromagnetic Anomaly.

From the ground magnetic anomaly map NE-SW fractures were inferred in the region of the study area (Figure 4). These fractures however correspond to the direction of flow of River Asa which is the major river flowing across the study area. Hence, River Asa is seen to be fracture controlled as depicted by the fracture in the area. The low magnetic distribution is observable at the South-eastern part (deeper fracture or faulted zone) of the study area (Figure 4), trending East-North with prominence at the center (deepest fracture or fault zone). These locations are not competent for high rise structures to avoid subsidence of the structures in future which may lead to loss of valuable lives and properties but are better sites for hydrogeological purposes.

4.2 Geophysical Interpretations

4.2.1 Radial Sounding Interpretation.

The Computer iterated sounding curves computed as well. Table 1 is a summary of the typical latest results of the geoelectric sequence obtained in the study area. Generally, the area is characterized by thin top soil layer, followed below by the lateritic soil, weathered in-situ layer and the unweathered basement rock (Malik, 1978; Olasehinde and Awojobi, 2004).

Table 1: Different type curves derived from the survey data

TYPE CURVE	VES WITH THE TYPE CURVE	NO. OF VES WITH TYPE CURVE	% NO. OF VES W TYPE CURVE
KQH	VES 1, VES 2, VES 6 and VES 8	4	20%
QH	VES 3, VES 4, VES 5, VES 9, VES 12, VES 13 and VES 15	7	35%
HA	VES 10, VES 16 and VES 17	3	15%
H	VES 18, VES 19 and VES 20	3	15%
QHA	VES 14	1	5%
QHKH	VES 7	1	5%
QQH	VES 11	1	5%

The distribution of the curve type across the study area is summarized in Table 1. The predominant field curve in the area is the QH type ($\rho 1 > \rho 2 > \rho 3 < \rho 4$) of 35% (table 1 and fig 7), a four-layer subsurface setup.

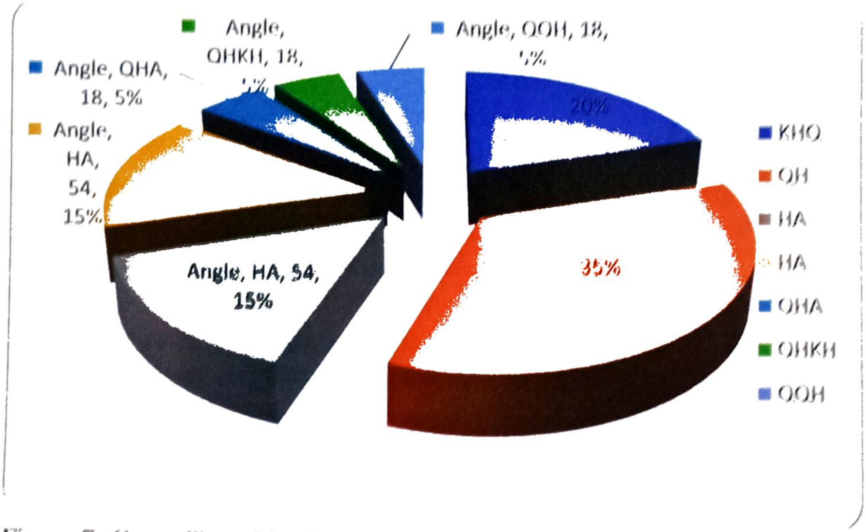

Figure 7: Curve Type Pie chart

The radial soundings reveal that the major axis of one of the anisotropy polygons R2 carried out at Location 7 trends emphatically in the E-W direction at depth >30m but trends in N-S direction at shallower depths. Meanwhile, the major axis of the other anisotropy polygon R1 carried out at Location 3 trends emphatically in the N-S direction. These results mean that the E-W fracture dominates the orientation of the fracture in the area at depths >35m and are superimposed on the weakly developed N-S fracture trend. Only at shallower depths, N-S fractures are exhibited as shown on the anisotropy polygons (Figure 4.1a and Figure 4.2a).

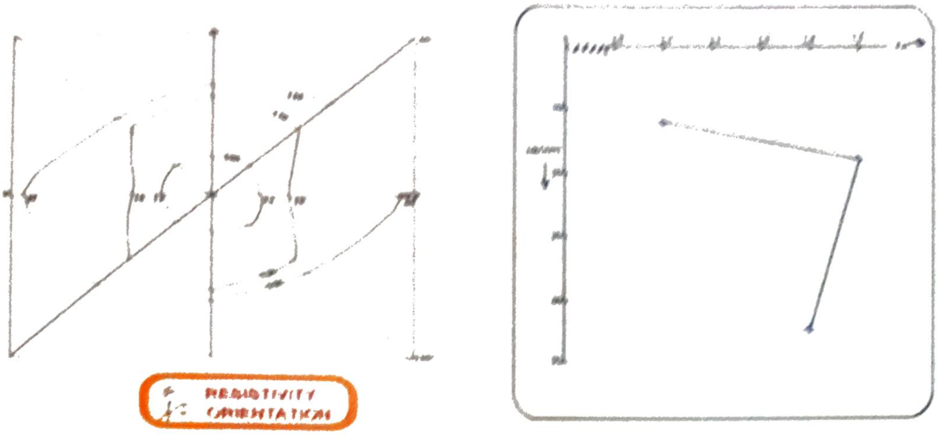

Figure 7: Anisotropy Polygon for R2 (Location 7)

The coefficient of apparent anisotropy, λa was calculated from the anisotropy polygons by dividing the length of the major axis by that of the minor axis and the values plotted against corresponding AB/2, representing the approximate depth (Fig. 7 and Fig. 8). This coefficient is a good measure of the degree of fracturing at depth. A decrease of λa with depth is expected for a diminution of fractures with depth and vice versa for the increase (Olasehinde, 1999;2011). The λa was found to decrease as the depth increases at R1 (Location 3). Meanwhile, at R2 (Location 7), λa was found to increase gradually with depth and then decrease dramatically with depth. There is an indication of greater fracture at shallower depths in the area due to higher coefficient of anisotropy at these depths.

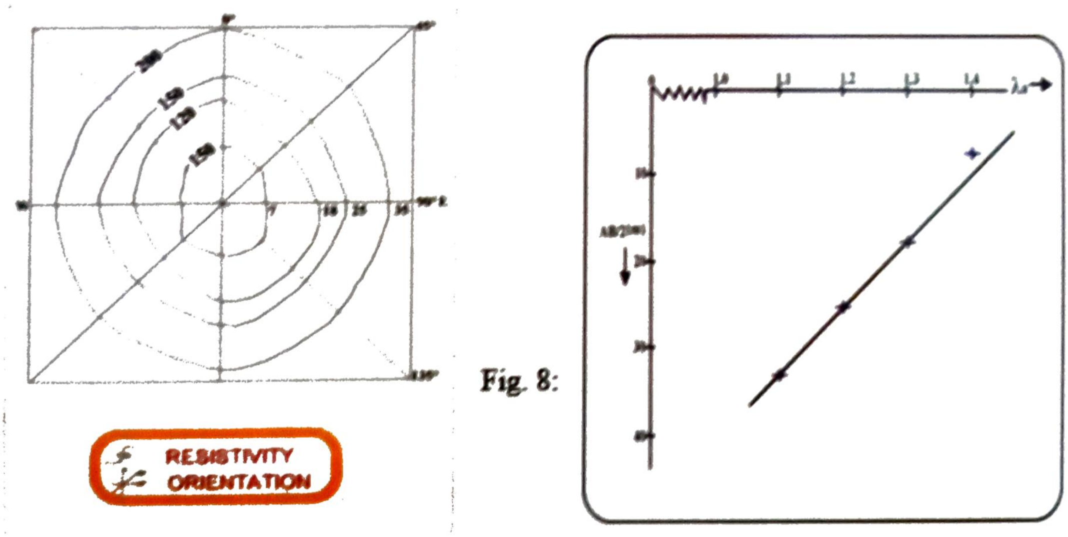

Fig. 8:

Figure 8: Anisotropy Polygon for R1 (Location 3)

4.3 Geo-electrical Sections and Logs

The results of the interpreted VES curves were used to draw 2D geoelectric sections along Pr F and C (Fig. 9 and Fig.10b) to show the Vertical distribution of resistivities within the volu the earth in the investigated area. The geoelectric sections show both vertical and lateral varia in layer resistivity, which is a revelation of the lateral and vertical facies changes inferred fro apparent resistivity pseudosection. A maximum of four geoelectric units were delineated be these sections. These include the topsoil, the lateritic soil layer, the clay/weathered rock an fractured/fresh bedrock.

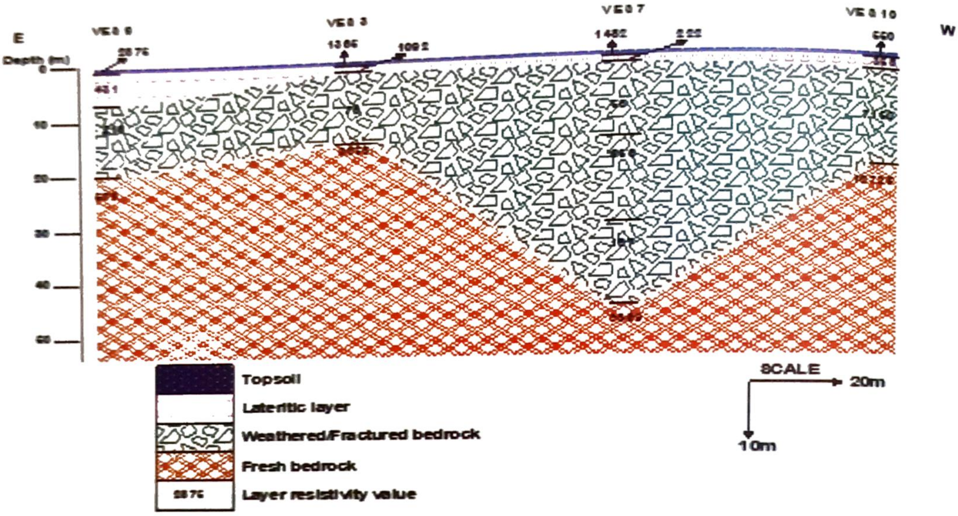

Figure 9: Geoelectric Section along Profile F.

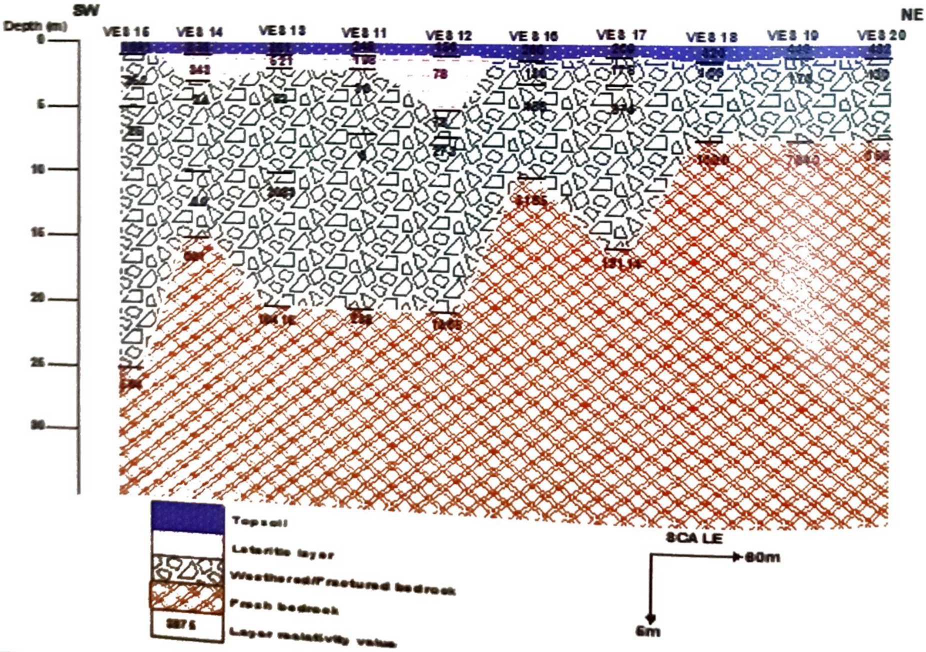

Figure 10: Geoelectric Section along Profile C

The topsoil is made up of unsaturated clay, sandy clay, clayey sand, or gravel above the water table, hence its widely varying resistivity. Layer resistivity and thickness values range respectively from 550 Ωm to 2875 Ωm and 1m along Profile F and 156 Ωm to 1681 Ωm and 1m to 1.4m along Profile C. The topsoil is underlain by a second layer of laterite in of the sounding stations in the investigated area. This layer has resistivity values ranging from 130 Ωm to 1092 Ωm with an average of 611 Ωm and thickness values from 1m to 6m with an average of 3.5m. It consists mainly of clay with welded gravels and sands. The (regolith) clay/ clayey sand/ sand saprolite layer has layer resistivity and thickness varying respectively from 30 Ωm to 7140 Ωm and 2m to 25m (Plate III). The geoelectric property of this layer depends on the sand/clay ratio and the degree of saturation (Odusanya and Amadi, 1999). The clayey sand (weathered rock) formation has a high sand content which would tend to increase the resistivity value and perhaps the hydraulic conductivity and transmissivity. The last layer which forms the bedrock is fractured in some places and highly resistive in most places. The bedrock resistivity values vary from 130 Ωm to 13114 Ωm. Studies show that the resistivity value of fresh bedrock often exceeds 1000 Ωm, beside, where it is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000 Ωm (Olayinka and Olorunfemi, 1992). The depth to the bottom varies across the profiles from 7m to 45m. The recognizable structural features in the geolelectric sections are the basement depressions and ridges. The thick weathering shown at VES 7 along Profile F in fig. 4.3a is suspected to have been aided by fracturing. Similar thick weathered zones are shown on the other Profile but with less degree of intensity than along Profile F. From Fig. 4.3a, it can be seen that the areas around VES 7 is the best for groundwater prospect. The weathering here is very thick and it is expected that this was caused by the relatively deep seated fracture as shown in the pseudosection (Fig. 4.4). From Fig 4.3b, it can be seen that sections beneath VES 15, VES 14, VES 13, VES 11 and VES 12 are highly prospective for groundwater. This is due to thick weathering. Sections beneath VES 15, 14, 13, 11 and 12 can be inferred to be an extension of the fracture observed VES 7 along Profile F (Fig. 4.3a) due to the presence of thick layer of weathered bedrock observed within these sections. It is observed that weathering does not exceed 15m beneath VES 17. This at best is useful for shallow hand-dug wells which may not be useful for water supply in the dry season. Sections beneath VES 18, VES 19, and VES 20 show fresh bedrock occurring at above 30m depth. This typifies a very poor terrain for groundwater development as the thickness of weathering is not much and no fracture was observed.

Figure 11 shows the apparent resistivity pseudosection prepared along an E-W Profile which relates VES 9, VES 3, VES 7 and VES 10. The section shows apparent resistivity values ranging from 111 Ωm at VES 3 to 2875 Ωm at VES 9. This area is characterized by high resistivity values. Resistivity decreases with depth beneath VES 9, VES 3, and VES 7 while it increases with depth beneath VES 10 along Profile F. At relatively shallow depths (≤7m), sections beneath VES 10 have relatively low resistivity values compared to other VES along the Profile F. Sections beneath other VES stations along this Profile (VES 9, VES 3 and VES 7) have relatively high resistivity values at these depths. This may be due to an increased sand/clay ratio. At greater depths (>7m), sections beneath VES 9, VES 3 and VES 7 have relatively low apparent resistivity values typifying a high clay content. At these depths, it is likely that there is a quartzitic material beneath VES 10 as observed from the close contour having high resistivity values of >1000 Ωm. Sections beneath VES 9, VES 3 and VES 7 are highly fractured due to sharp gradient of the apparent resistivity contours. There exists a thick weathering between the sections beneath VES 3 and VES 7. However, the interval between VES 9 and VES 7 are highly prospective for groundwater. This is because of a combination of fractures below VES 9, VES 3 and VES 7 and thick weathering in these parts of the section. Fig. 4.4b shows apparent resistivity pseudosection prepared along NE-SW i.e. Profile C relating VES 11 to VES 20 which serves as the Control Profile. Low resistivity contours of ≤150 Ωm are seen beneath VES 15, VES 14, VES 13, VES 11 and VES 12. These low resistivity values may be probably owing to high clay content. Sections beneath other VES stations along this Profile have relatively high resistivity values. This may be due to an increased sand/clay ratio. It can be inferred that the sections beneath VES 15, VES 14 and VES 13 are extensions of the fractured sections observed beneath Profile F. This is due to sharp gradient of the apparent resistivity contours observed in the sections. However, the interval between VES 14 and VES 16 are highly prospective for groundwater because of thick weathering in the area.

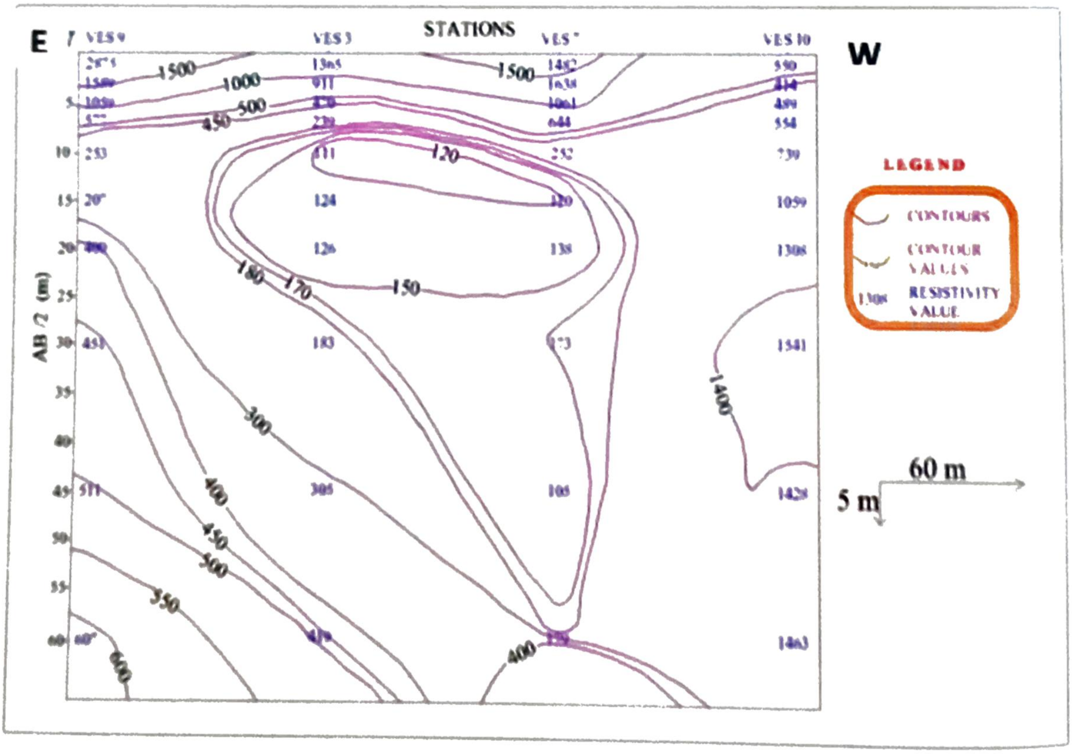

Figure 11: Apparent resistivity along Profile F

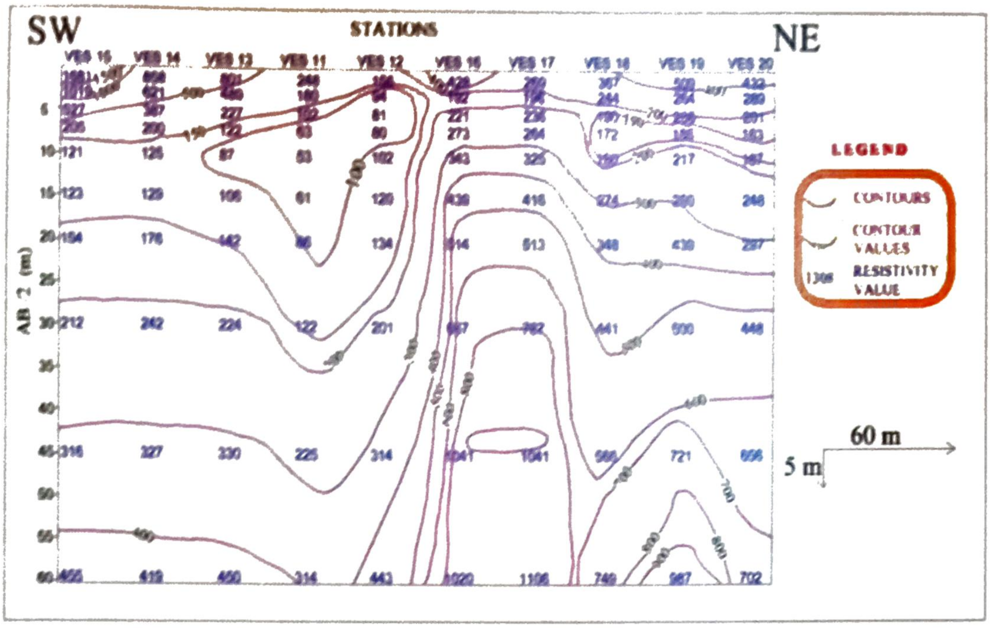

Figure 12: Apparent resistivity along Profile C

3.4 Integration of aeromagnetic anomaly with Geophysical Results

The present study on evaluation aeromagnetic anomaly in Ogbondoroko, Ilorin has been able to delineate an E-W trend of fractures superimposed on weakly developed N-S trend of fractures which only occur at shallower depths as interpreted from the apparent resistivity pseudosections and the geoelectric sections with the orientation and the degree of fracturing deduced from the anisotropy polygons and the coefficients of anisotropy. Previous study by Olasehinde (1989) on elucidation of fracture patterns of the Nigerian Basement Complex (a part of Unilorin Main Campus, North Central Nigeria) using Electrical resistivity methods revealed the existence of NE-SW and NW-SE trend of fractures are superimposed on the weakly developed N-S fracture trend. The weakly developed N-S trend of fractures delineated by this study at Ogbondoroko, Ilorin, North Central Nigeria is sympathetic with N-S fractures elucidated by Olasehinde (1989) in parts of Unilorin Main Campus, Ilorin North Central Nigeria. The N-S trend of fractures however occurs only at shallower depths in these areas. The four geoelectric layers reported in LAUTECH, Ogbomoso, Southwestern Nigeria by Adeleke (2010) agree with the geoelectric layers observed in Ogbondoroko, Ilorin North Central Nigeria with the exception of the sections with intense fractures and with Adekunle (2012) on evaluation of aeromagnetic anomaly of a part of Ogbomoso where NE-SW and NW-SE trends of fractures were established along the direction of flow of River Oba. The NE-SW and NW-SE trends of fractures reported in Ibapon, Ogbomoso, South western Nigeria by Adekunle (2012) are however not sympathetic with E-W trend of fractures delineated in Ogbondoroko, Ilorin, North Central Nigeria.

5.0 CONCLUSIONS

A multidimensional approach to the studies (i.e. Pseudosections, Geoelectric sections and Anisotropy polygons from radial soundings) has made the study both [illegible] quantitative as information missed by any of the methods is revealed by the other methodologies, necessitating justifiable conclusions. The N-S fracture pattern observed at depths is [illegible] in the area sympathetic with the weakly developed N-S fracture reported by Olasehinde (1999) in

part of University of Ilorin Main Campus, Ilorin, North Central Nigeria.

It can be concluded that the low resistivity and significantly thick weathered rock, the fractured basement and the E-W trend of fractures observed at depths >35m which though not [illegible], with the aeromagnetic lineaments picked from the aeromagnetic map of Nigeria (NGSA, 2011), may has well play a significant role in groundwater accumulation in the area. This calls for more detailed analysis.

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Prediction of Hydraulic Characteristics of Aquifer and Availability of Water Supply for Irrigation Farming in Basement Complex Terrain, in Part of Ilorin Sheet North-Central Nigeria.

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ABSTRACT

An investigation to predict ground water supply for irrigation farming around Amodu-Irapa was carried out based on data from pre-drilling, aquifer testing for six (6) exploratory wells. Cooper_Jacob non-equilibrium graphical methods were used to interprete the constant rate and recovery data to determine the hydraulic properties. The discharge values range from 1.9 l/sec to 2.5 l/s, while hydraulic conductivities and transmissivities range from 0.2m/day to 2 m/day and 12 m2/day to 36 12 m2/day respectively, with average specific capacity of 2 m3/sec/m. the average yield per hour is 100l/hr and drawdown of 15 m. The six (6) wells will provide a total daily abstraction of 1,600.8m3 based on 16 hour daily pumping schedule. The hydraulic characterization indicated an average of 16 hrs of pumping per day with mean drawdown of 31.8 m, indicating 63.6% of the mean aquifer thickness But, the quarzo-pegmatite exhibited highest transmissivity and aquifer thickness values with 316.8 m3 daily pumping at maximium drawdown of 31.6% of the aquifer thickness and can supply water for 5 ha paddy field, should be targeted during geophysical survey. Pumping in excess of 16 hours a day should be avoided without monitoring of pumping water levels to assess the groundwater resources more fully.

Keywords: Water supply, groundwater supply, aquifer testing and Amodu-Asungbolu.

1. INTRODUCTION

Many factors have to be considered if water wells are going to be used to supply a city, town, industry, hamlet or farm. It is of importance to know, for instance, whether more than one well will be required; at what rate the well can be safely pumped; whether the well will be taking more water out of the ground than is being replaced; how long the well will last and what is the quality of the groundwater. In order to answer these questions, well contractors, and other people concerned with the development of groundwater supplies will know what type of basic information is required in order to evaluate groundwater resources and plan soundly for their use. To supply commercial farmland water all year round, most mechanized agricultural practice are resulting to groundwater exploration and exploitation, the Lafiaji Sugar company Lafiaji had embarked on drilling of numbers of bore holes to replace dried water supply from river Agwan, few meter from river Niger (Owolabi and Kolawole, 2016). A 50, 000 ha farmland for rice farm at North of Aderan, Kiama Local government of Kwara State will depend mostly on groundwater (Owolabi and Okunlola, 2015). The concerns of the promoter of the project is the role of groundwater to support rice farming, during dry season and late rainy season. Rice-crop water requirement is estimated to be 6 mm/day in North-West Cambodia (Jean et al., 2016. Thus, 60 m3/day of water will be required to supply paddy field of 1 ha (Jean et al., 2016).

Pumping test results is often used to predict aquifer conditions, such as the presence of barrier boundaries, recharge and leakage effects and aquifer dewatering. Pumping test is controlled pumping of well so that the response of the production well and the growth of the drawdown and recovery can be measured. Clark (1988) suggested that the analysis of the pumping test can then be used to evaluate the aquifer characteristics. The study area comprises mainly of Crystalline basement rock and development of aquifers from crystalline rocks as a reliable source of water supply is notoriously complex, and groundwater occurrence is spatially highly variable in crystalline rock area (Wright, 1992; Chilton and Foster, 1995; Banks and Robins, 2002). Some of the greatest groundwater needs occur in the region and groundwater is the only dependable source of water for many users. Groundwater is available and widely used throughout the study area, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. Due to the low intrinsic primary permeability and porosity of the bedrock, crystalline aquifers differ in important ways from other aquifer types, and demand specific knowledge and techniques if groundwater is to be extracted and managed efficiently. A preliminary compilation and review of groundwater in the area had been documented by government, donor development agency and researchers; these include bi-water, Kwara State Water Cooperation, Olasehinde, Adelana and Olasehinde. Elsewhere JICA (2004) and NHISA reported that Ilorin and environ are water stressed and will face serious groundwater shortage.

Omada, et al., (2012) did a work on the assessment of groundwater resources in basement complex terrain of Gwarinpa-Kafe area of Abuja Metropolis, Central Nigeria for 28 boreholes. Among the 28boreholes developed, 14 (or 50%) had yield ranging from 3.33 m3/hr to 5.0 m3/hr. Wells located on weathered overburden had intermediate yield of 5.0 m3/hr to 5.2 m3/hr while the high yield are from wells located on northerly trending fractures. The groundwater resource is large enough for domestic consumption and supplements the limited surface water supply to the area.

Amah and Anam (2016) determines aquifer hydraulic parameters from Pumping Test Data Analysis: A Case Study of Akpabuyo Coastal Plain Sand Aquifers, Cross River State, South-East Nigeria. Five boreholes were subjected to a number of pumping tests: step drawdown, constant discharge and recovery tests to provide some preliminary estimation of hydraulic parameters for the study area. The results indicate that transmissivity T, hydraulic conductivity k, and specific capacity SC, ranged from 485.0m2/d to 1346.0m2/d, 9.7m/d to 27.9m/d, 0.02m3/d/m to 346.m3/d/m respectively. The litho-logs of the boreholes confirm that the estimated hydraulic parameters were obtained from unconfined gravelly sandy aquifers underlain by mostly sandy clay (aquitard)

Akaha and Pronmise (2008) investigate on Hydraulic properties from pumping tests data of aquifers in Azare area, North Eastern. Nigeria. Pumping test data from twelve boreholes were analysed to determine the hydraulic properties of the aquifers, and the availability of water to meet the conjugate demands of the increasing population. The values of the aquifer constants obtained from the Cooper-Jacob's non-equilibrium graphical method were generally low. Yield, Q, values range from 2.24 to 17.46m3/hr (6.22 x 10-4 to 4.85 x 10-3 m/sec), while Transmissivity, (T), fell between 7.39 x 10-6 and 3.55 x 10-4m2/sec and hydraulic conductivity, K, from 5.62 x 10-7 to 42.54 x 10-5 m/sec. The average specific capacity, Cs, value is 2.10 x 10-4m3/sec/m. The total yield is 98.67m3/hr or 2368.08m3/day, and drawdowns in excess of 20m were recorded. These values indicate that the hydraulic characteristics of the aquifers are poor. The implication is that the available boreholes cannot provide sufficient water for domestic and agricultural needs of the area. Hamidu et al., 2014 evaluated causes of low groundwater yield of boreholes in crystalline basement around Gwandu Town and its environ. Hydraulic properties of thirty-seven boreholes were asses.

This report aims at evaluating hydraulic charactesristics and the basement aquifer and availability of groundwater supply for irrigation in part of Ilorin sheet through the determination of aquifer characteristics of the borehole through monitored constant pumping and drawdown recovery measurements, for irrigation farmland.

2.0 MATERIALS AND METHODOLOGY

2.1 The Study Area

The study area is located north and south of link road between Irapa and Amodu-Asungbolu villages in Ifelodun Local Government Area of Kwara State, Nigeria (Fig. 1). The southern boundary runs along west – east slightly above latitude 8016' while a substantial part of the source of River Odunrun flows on northeast – northwest direction at the northern border a little above latitude 8018'. The area covers about 1,000ha (Table 1). The natural vegetation of the area belongs to the subtropical type represented by a mixture of grass, shrubs and woodland.

Boundary co-ordinates provided by the Kwara State Ministry of Lands are as follows: (In DD MM SS.S Minna).

Table 1: Study area boundary

Position	Latitude	Longitude
A	080 16.060'	040 42.835'
B	080 17.490'	040 42.800'
G	080 18.400'	040 43.410'
H	080 18.00'	040 44.560'
J	080 17.350'	040 44.500'
K	080 17.280'	040 44.020'
L	080 17.200'	040 44.010'
M	080 16.100'	040 44.210'

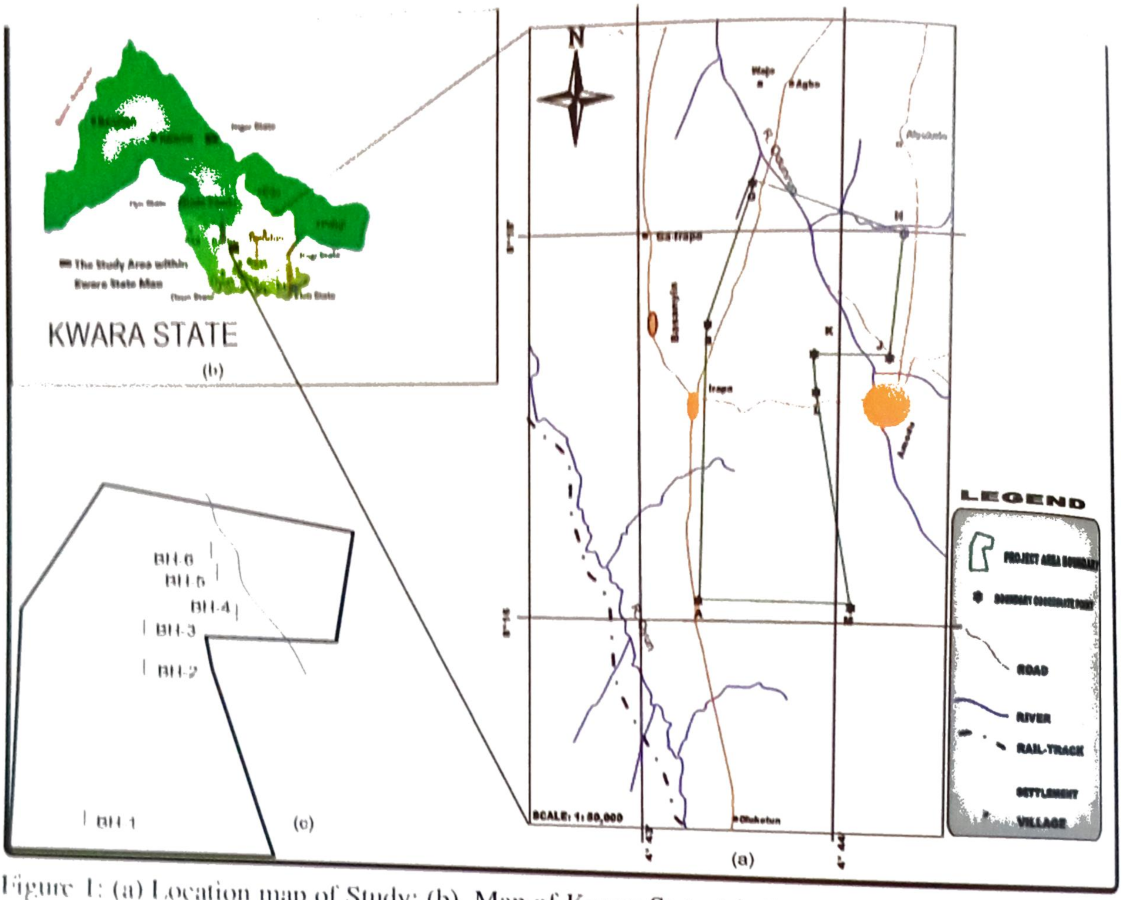


Figure 1: (a) Location map of Study; (b). Map of Kwara State (c). Borehole points (Adapted from Owolabi and Okunlola, 2015)

2.2 Regional Geology

The study area is part of basement complex, affected by the 600Ma Pan-Africa orogeny and made-up of granite, gneiss and migmatite group, (Mc Curry, 1976; OyawoyeBurke &Dewy 1972; Dada 2006). The migmatite group known as Migmatite-Gneiss Complex is the widespread of the Basement complex petro-lithological units (Rahman, 1988; Dada 2006). Asa River lies within the Migmatite-Gneiss-Quartzite Complex (Rahaman,1988). The general rock type includes; Granites, Porphyroblastic Gneiss, Biotite and Biotite Hornblende Gneiss, Older granite, Amphibolite Schist, Quartzites, quartz schists, and other minor occurrences such as pegmatites and quartz veins. However, the rocks are extremely weathered and highly fractured in most locations. The highly permeable weathered fractured zone varies locally and is sometimes composed of quartzo-feldspathic and amphibolitic materials. The class of basement rocks identified as migmatites underline about one/third of the study area (Fig. 2).

2.2.1 Geology of the Ilorin

The area is underlain by rocks of the Nigerian Basement Complex (Rahman, 1989; Mc Curry (1976).). In the area, three major rock units have been recognized namely gneisses, porphyritic granite gneiss and augen gneiss. The gneissic rocks occupy about 80% of the area. Migmatitic-gneiss is the dominant of these rock types (Oluyide, 1988). The gneiss is generally dark-grey in colour. It is medium grained and shows a dominantly north-south foliation trend. It outcrops as low-lying rock bodies. The outcrop in the area is a sequence of variably migmatitic- gneisses with concordant quartzo-feldspathic segregations and bands (Fig. 2a & d). Most of the outcrops are restricted to the northwestern edge of the study area.

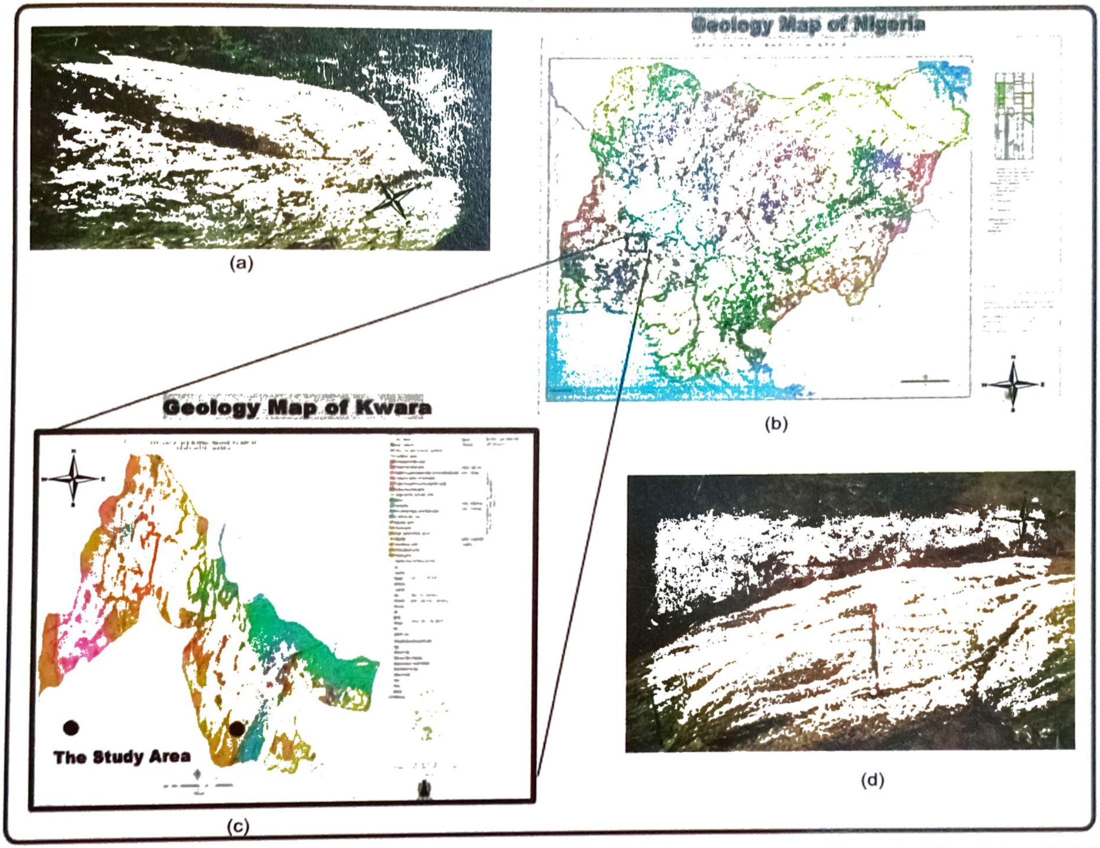


Figure 2: Geological map of the Study area (Modified from Owolabi and Okunlola, 2015). (a)Porphyritic granite gneiss with quartz veins {Red pen points to the North}. (b) Geology map of Nigeria (c) Geology map of Kwara (d): Migmatitic gneiss (N 08° 18.148'; E 004° 43.354', Elevation 381m) {Red pen points to the North}.

2.2.2 Hydrogeology

Ilorin is situated on the undifferentiated Precambrian Basement Complex rocks of granitic and metamorphic origin. These rocks represent the deeper, fractured aquifer which is partly overlain by a shallow, porous aquifer within the lateritic soil cover (Annor and Olasehinde, 1996). The rock units form part of the regional South Western highlands of Nigeria running NW-SE parallel to the River Niger (Offodile, 1987; Olasehinde *et al.,* 1998). The subsurface comprises the weathered, slightly weathered and fresh (fractured or unfractured) crystalline basement rocks. The oldest rocks in the area comprise gneiss complex whose principal member is biotite-hornblende gneiss with intercalated amphibolites. This underlies, over half of the city. Other rock types are the older granite mainly porphiritic granite, gneiss and granite-gneiss and quartz schist. The two main types of aquifer in this area are the weathered basement and jointed/fractured basement aquifers with the latter usually occurring below the former. The aquifers are localized and disconnected but occur essentially as unconfined to semi-confined under water table conditions. Although the crystalline nature of the basement rocks preclude development of the porosity and permeability necessary for good groundwater occurrence, Davis and De Wiest (1966) asserted that appreciable porosity and permeability may have been developed within these rocks through fracturing and weathering processes. Further information from available borehole lithological logs in the region revealed that weathering is fairly deep and that the rocks have been jointed and fractured severely occurring between 30 – 68m below the surface (Annor and Olasehinde, 1990).

2.3 Field Techniques

The pumping test methods used for the study are the constant rate test and recovery rate test for six (6) exploratory boreholes. Constant-rate test maintain pumping at the test well at a constant rate, i.e pumping at a specific rate over a long period of time while monitoring the drawdown, while water-level response (drawdown) is measured at specified intervals of time. The goal of this constant-rate pumping test is to estimate hydraulic properties of an aquifer system such as transmissivity, hydraulic conductivity and storativity (storage coefficient). A recovery test is also another efficient method used in controlled field experiment performed at the end of a pumping test (constant-rate) after pumping in the pumped (control) well has ended. Water-level response (residual drawdown) is measured after pumping has stopped in the control well itself. The above methods were used in the field to collect all the pumping test data around the study area. Lithological logs of the holes collected during drilling and VES data enable us to establish subsurface geological succession, as well as construct accurate well design.

2.4 Hydraulic Test analysis

2.4.1 Constant-Rate Test

Constant-rate pumping-test data can be utilized to determine aquifer transmissivity and storag coefficient. Observation wells were not available for the majority of the wells tested and hence, onl values of aquifer transmissivity were determined. Time-drawdown data were analyzed using th Cooper-Jacob (1946) modification of the Theis formula equation. This modification is generall referred to as Jacob's method.

$$T=\frac{264Q}{\Delta S} \qquad (1)$$

Where:

T= aquifer transmissivity in m2/day.

Q= pumping rate in l/sec.

ΔS= the slope of the time-drawdown graph expressed as the change in drawdown betwee any two values of time on the log scale whose ratio is 10.

One advantage of Jacob's method is that time-drawdown data can be plotted on semi-logarithmic paper, with time on the log scale and drawdown on the arithmetic scale. If aquifer characteristics are in accordance with the basic assumptions, then the data will fall on a straight line. Deviations from a straight-line plot can often be used to delineate boundary conditions or aquifer dewatering.

2.4.2 Recovery Test

Water level recovery data are often more accurate than time-drawdown data, since the recovery period is not affected by pump vibrations and fluctuations in the pumping rate. There are two common methods that are used to analyze water level recovery data. In the first method, calculated recovery versus time after pumping stopped is plotted on semi-logarithmic paper. In the second method, residual drawdown versus t/t' is plotted on semi-logarithmic paper, where t is the time since pumping started and t' is the time since when pumping stopped. The second method for analyzing water recovery data is preferred, as it provides a more independent check of the results that were calculated from the time-drawdown data. This is because the first method requires an extension of the time-drawdown plot for pumping and if there have been any deviations from a straight-line plot due to boundary effects or irregularities in the pumping rate, then the first method would provide erroneous results. Water-level measurements made during the recovery period provide a distinct set of information for aquifer or pumping test, thus providing a means of checking results that were determined from the time-drawdown period.

$$T' = 0.183 \times Q \text{ over } \Delta S' \text{ (m2/d)} \qquad (2)$$

Q is discharge in l/s and is recorded in the field

Where,
0.183 is a constant
$\Delta s'$ value is obtained from semi-log diagram

The Cooper-Jacob excel spread sheet is used to carry-out the constant rate interpretation for Hydraulic conductivity and transmissivity for both constant rate and recovery.

2.4.3 Estimating Aquifer Productivity and Storage

2.4.3.1 Specific capacitance

The specific capacity Sc is the ratio of discharging (Q) to steady drawdown (Sw).

$$Sc = Q/Sw \qquad \textbf{(3)}$$

Where,
Q = Discharge
Sw = Maximum drawdown

2.4.3.2 Groundwater Storativity

A relationship between transmissivity and specific capacity was carried out, while the groundwa storage GW was calculated as:

$$GW = Sy*Az \qquad (4)$$

Where,

Sy – the specific yield

Az – Thickness of saturated aquifer

4. RESULTS AND DISCUSSION

4.1 Hydraulic and Aquifer Charaterisation

Table 4.1 contains a summary of the results of the constant-rate pumping tests. Values of aquife transmissivity range from 9.4 m2/day to 41 m2/day and 12 hour specific capacities range from 0.0 to 41.47. Data indicated that transmissivity (recovery) was less than transmissivity (pumping) fo most tests. This might not be attributed to less turbulence and non-Darcian flow during the recovery period than during pumping.

Table 2: Constant Rate and recovery Test Results

Well no	Pumping Duration	Average Discharge	SWL	Pumping Water Level	Specific capacity (Q/s)	T(m2/day)	T'(m2/day)	K (m/day
BH1	170	2.2	0.66	5.12	0.43	19	4.5	0.22
BH 2	150	2.2	1.55	18.85	0.12	36	8.3	0.51
BH 3	72	2.2	3.1	33.25	0.07	36	8.3	0.59
BH 4	300	2.14	4.85	15.1	0.14	35	26	0.39
BH 5	50	2.5	2.5	46.30	0.05	41	9.4	0.53
BH 6	40	2.5	3.7	63.80	0.04	41	9.4	0.49

4.1.1 Borehole (BH-1).

Borehole one (BH-1) was drilled to a total depth 0f 140m and depth to basement is 3 m. During drilling, water bearing fractures were noted at 51-60 m, and 72-102m, with total fracture zone of 30 m. Constant rate method of pumping test was conducted at pump in-take level of 128m for 110 minutes. Total drawdown was 5.12m i.e. from initial static water level of 0.66m. Dynamic water level was not attained, while discharging at constant rate of 2.2 litres per second. The first change in slope occurred at about 8 mins, this is as a result of barrier boundary or limit aquifer (Vincent and Sharma 1978). The second change in slope occurred at 100 mins when dewatering of the first fractured zone began. Based on the total drawdown of 5.12m over a period of 2 hours pumping time, a pumping period of 16 hours per day at 5litres per second is initially recommended at pumping period of 8 hours interval. The pumping period can be modified to suit demand once other wellfield has been established and monitored over a full season. The transmissivity was calculated as 36m2/day.

4.1.2 Borehole (BH-2).

This borehole was drilled to a depth of150m and fractures were encountered at 39-42 m, 60-63 m, and 68- 81 m. Total fracture zones is 18 m Constant rate method of pumping test was conducted at pump in-take level of 128.4m for 120 minutes. Total drawdown was 18.85m i.e from initial static water level of 1.55m. Dynamic water level was not attained, while discharging at constant rate of 2.2 litres per second. The first change in slope occurred at 15 mins without any dewatering.

4.1.3 Borehole (BH-3).

Total borehole depth is 140m and fractures were encountered at 15 m and throughout the drilled depth. Constant rate method of pumping test was conducted at pump in-take level of 111.30m for 180 minutes. Total drawdown was 33.25m i.e from initial static water level of 3.10m. Dynamic water level was not attained, while discharging at constant rate of 2.2 litres per second. Recovery of over 73.5% was attained within 60minutes. The first change occurred at about 15 mins as a result of boundary barriers or limited aquifer, the second slope change occurred at 100 mins when dewatering of the first fracture zone began.

4.1.4 Borehole No.4 (BH-4).

Borehole one (BH-4) was drilled to a total depth 0f 170m and depth to basement is 3 m. Fractures was encountered throughout the drilled hole. Constant rate method of pumping test was conducted at pump in-take level of 120m for 300 minutes. Fractures were encountered at 3-30 m and 60-72 m Total drawdown was 15.10m i.e from initial static water level of 4.85m. Dynamic water level was not attained, while discharging at constant rate of 2.14 litres per second. Recovery of over 77.4% was attained within 60minutes. The first change in slope occurred at about 10 mins, this is as a result of barrier boundary or limit aquifer (Vincent and Sharma 1978). The second change in slope occurred at 80 mins when dewatering of the first fractured zone began.

4.1.5 Borehole (BH-5).

Borehole BH-5 was drilled to a total depth is 156m and fractures were encountered at 60-71 m and 95-110 m, with a depth to basement of 5 m. Constant rate method of pumping test was conducted at pump in-take level of 114m for 60 minutes. Total drawdown was 46.3m i.e from initial static water level of 2.50m. Dynamic water level was not attained, while discharging at constant rate of 2.5 litres per second. Recovery of over 25.7% was attained within 60minutes. The first change in slope occurred at about 8 mins, this is as a result of barrier boundary or limit aquifer (Vincent and Sharma 1978). The second change in slope occurred at 40 mins when dewatering of the first fractured zone began.

4.1.6 Borehole (BH-6).

This borehole was drilled to a total borehole depth is 163.5m and rfactures were encountered at 40 -50 m and 75-90 m, with a total fracture zone of 25 m. Constant rate method of pumping test was conducted at pump in-take level of 125.3m for 180 minutes. Total drawdown was 71.92m i.e from initial static water level of 3.70m. Dynamic water level was not attained, while discharging at constant rate of 2.5 litres per second. Recovery of over 25.7% was attained within 60minutes. The first change in slope occurred at about 8 mins, this is as aresult of barrier boundary or limit aquifer (Vincent and Sharma 1978). The second change in slope occurred at about 25 mins when dewatering of the first fractured zone began.

Table 3: Operational Policy for all the boreholes

	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6
Daily Pumping Period (Hr)	16	16	16	16	16	16
Pumping Rate (l/s)	5	4.8	4.5	5.5	4	4
Pumping Interval (Hr)	8	8	4	8	4	4
Total Abstraction (m3/day)	288	276.5	259.2	316.8	230.4	230.4
Pump Intake Level	160	140	130	160	145	150

4.2 Aquifer Characterisation and Water availability

The groundwater storage calculated with equation (4) is higher at BH-3 and BH-4 because of high transmissivity and aquifer thickness (Table 4). The mean groundwater storage calculated is 111.2 m and 83% values range between 60 and 220. The variation of the properties of the aquifer is perhaps due to variation of aquifer thickness. The estimated groundwater storage is closed to the storage estimated in other weathered hard rock aquifers (E.g Vouillamoz *et al.*, 2015).

To estimate, if the aquifer can provide 60 m3 daily for 1000 ha, The daily safe discharge of the boreholes varied considerably because of the local hydrogeology but a total discharge of 1,600,800 litres/day = 1,600.8m3/day has been calculated for the six wells tested. So for about 1000 ha of farmland, about 225 bore holes will be needed to meet the 60 m3/day of water required to supply paddy field of 1000 ha. The hydraulic characterization indicated an average of 16 hrs of pumping per day with mean drawdown of 31.8 m, this indicated 63.6% of the mean aquifer thickness (Table 4). But, the quarzo-pegmatite exhibited highest transmissivity and aquifer thickness values (Table 4), with 316.8 m3 daily pumping at maximium drawdown of 31.6% of the aquifer thickness and can supply water for 5 ha paddy field.

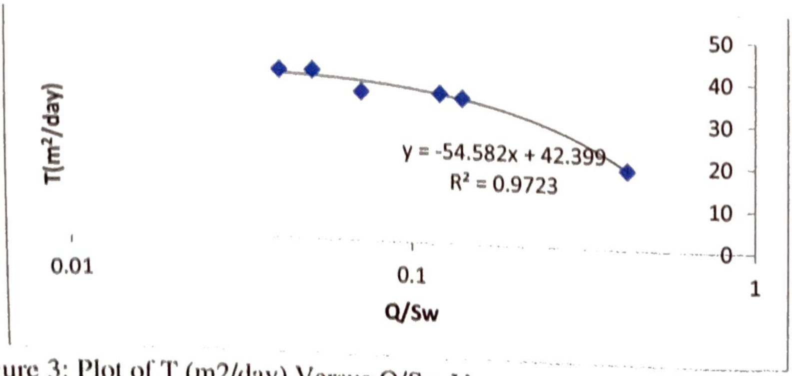


Figure 3: Plot of T (m2/day) Versus Q/Sw Versus

Table 4: Aquifer Test and Bore completion data

S/N	Total Depth	Pump-Intake	SWL	Discharge	Total Fracture Zone	Storagivity	Final Draw Down	Final Residual Draw down
1	140	111.3	3.1	2.2	30	66	33.25	24.45
2	150	128.4	1.55	2.2	18	39.6	18.85	9.5
3	102	128	0.66	2.2	100	220	5.12	3.11
4	102	120	4.85	2.14	100	214	15.1	11.69
5	156	114	2.5	2.5	26	65	46.3	11.9
6	163.5	125.3	3.7	2.5	25	62.5	71.9	00
Mean					50	111.2	31.8	

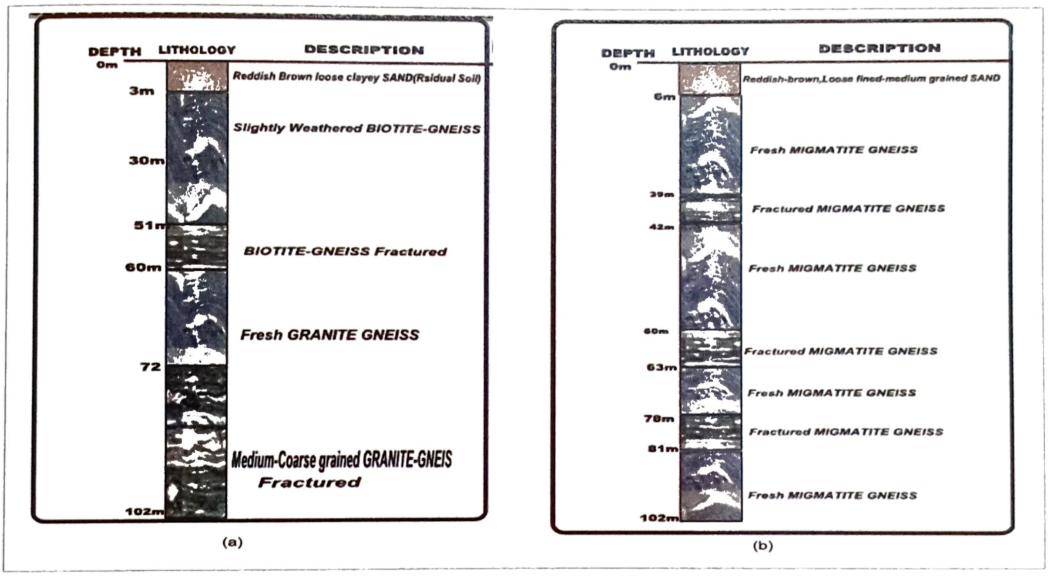
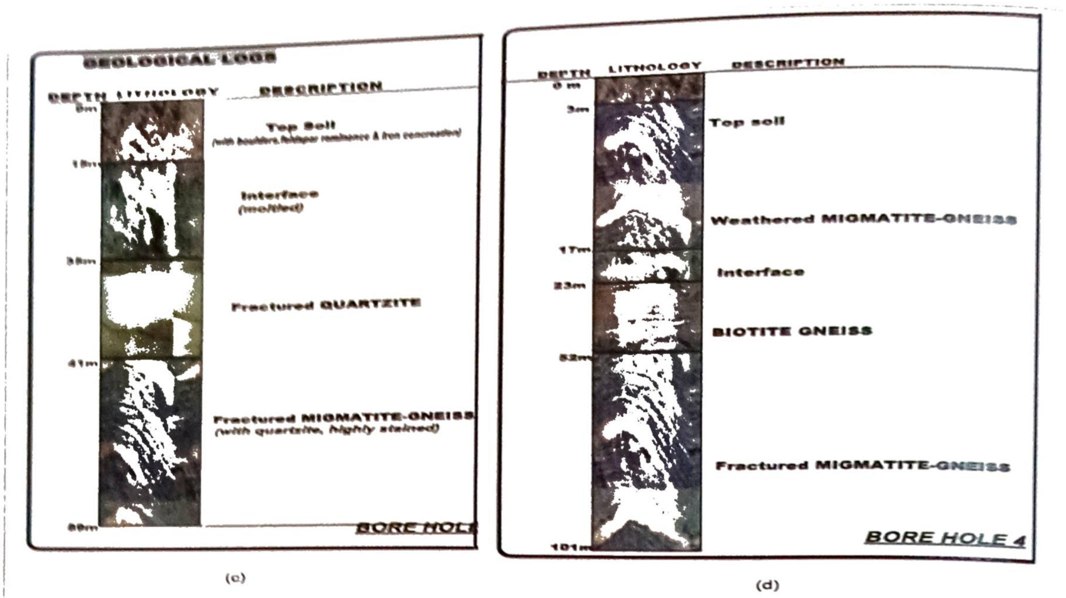


Figure 4: (a) Geological Logs for BH-1, (b) Geological Logs for BH-2 (Adapted from Owolabi & Okunlola, 2015).



(c)

(d)

Figure 3: (c) Geological Log for BH-3, (d) Geological Logs for BH-4 (Adapted from Owolabi & Okunlola, 2015)

5.0 CONCLUSION AND RECOMMENDATION

Data on Table 4 indicates that transmissivity (recovery) is less than transmissivity (pumping) for most tests. This may not be attributed to less turbulence and non-Darcian flow during the recovery period than during pumping. The boreholes revealed variable hydraulic characteristics and hence all other designated production wells should be pump tested to ascertain their safe yield. Values of aquifer transmissivity range from 9.4 m2/day to 41 m2/day and 12 hour specific capacities range from 0.04 to 41.47. This is mainly due to more pronounced fracturing in groundwater discharge areas. The transmissivity (recovery) is less than transmissivity (pumping) for most tests. This may not be attributed to less turbulence and non-Darcian flow during the recovery period than during pumping.

5.2 RECOMMENDATIONS

I. Monitoring chart for a full operational season (wet and dry) should be established and maintained especially at the initial stage.
II. Increase in discharge from the boreholes should be backed up with scientific data.
III. To meet global requirement for water supply, a total of about 225 boreholes will be needed, perhaps River Odunrun could be dammed for conjunctive use with the groundwater.

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