Geology and Hydrogeophysical Appraisal of Angwan-Doruwa, Parts of Jama'a Sheet 188 NE, Central Nigeria

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Abstract

Fresh water is essential for living but not readily available for use everywhere especially in most rural communities. Inhabitants of Angwan Doruwa and its environs, within latitude N8°56'37" to N8°59'45" and longitude E8°10'00 " to E8°13'23" parts of Jama'a Sheet 188 NE, in North Central Nigeria depend largely on surface water from streams which is prone to contamination and could lead to a rise in ill health already being experienced by the people. This prompted the need to conduct geological and hydrogeophysical studies to locate suitable underground aquifers where potable groundwater can be exploited in the area. Three methods employed in this study include; geological mapping, thin section analysis and electrical resistivity geophysical survey. Schlumberger configuration was used to investigate 15 stations within the area. Geological mapping revealed that the area comprises of migmatitic gneiss, biotite gneiss and leucocratic granite with joints trending in the NNE – SSW principal direction. Result of petrographic analysis showed presence of biotite, quartz, orthoclase, plagioclase, muscovites, perthite, microcline and amphibole as the common rock forming minerals in the area. Interpreted geophysical data revealed maximum of five and minimum of three geo-electrical layers: topsoils (TS), lateritic soils (LT, LS), weathered basement (WB) layer consisting of weathered rock fragments or regolith (R), fractured layer (FRB) and fresh basement layer (FB). The weathered and fractured basement layers have sufficient thicknesses (10 m to 30 m) to retain and transmit groundwater and therefore constitute the aquifers in the study area. The fractured basement layer at a depth of 40 m to 50 m constitutes the main aquifer in Angwan Doruwa with a very good groundwater potential while the weathered basement layer at a depth of 25 m to 35 m constitutes a good aquifer in adjoining villages. Drilling can best be achieved through the use of down-hole hammering method.

Keyword: electrical resistivity, groundwater, aquifer and geological mapping

Introduction

There is no gain saying that water is life and keeping pace with the rising demand for water is more easily achieved for groundwater than surface water (Novotny and Olem, 1994). Angwan Doruwa is an agricultural settlement from where large quantities of grains such as maize, groundnuts, and guinea corn are produced and sold out to urban areas. On a careful survey around the village, it was discovered that there is no single existing borehole as at the time of the study and the inhabitants rely mainly on surface water which is highly prone to contamination. Without doubt, there is a water problem in the area and hence, a need to investigate suitable locations and depths where potable groundwater can be exploited. Thus, the research will significantly improve knowledge on the geology, petrography, and suitable locations (depths) of groundwater aquifers within the study area hence proffering a solution to the existing water problem in the area.

The application of geophysical methods has been used successfully used in earth studies owing to the fact that it uses some physical properties such as the earth's magnetism, conductivity, density and velocity to give information on likely subsurface features or conditions (Capenter *et. al,* 2012). The electrical resistivity method being employed in this study depends on the conductivity responses of the earth materials. It is largely dependent on the porosity, permeability, fluid contents and mineral composition (type) of rocks.

The study area is Angwan Doruwa and its environs in Akwanga, North Central region of Nigeria. It is geographically sited within latitude N8°56'37" to N8°59'45" and longitude E8°10'00 " to E8°13'23 "parts of Jama'a sheet 188 NE, published by the Office of the Surveyor General of the Federal Republic of Nigeria (2008). A total area of about 30 km^2 was covered (Figure 1). The area is accessible through the Akwanga - Keffi – Abuja highway and other minor roads linking it to other adjoining villages such as Moroa. Some parts of the area are not accessible due to thick vegetation cover. Two contrasting climatic conditions characterises the study area, namely; the dry season and raining season. The dry season, with little or no rainfall is usually experienced from November to early/mid-April. The Harmattan (dry and dusty wind) experienced from November-January also characterises the dry season. April marks the beginning of the rainy season with a progressive increase and attains its peak in July (NIMET, 2018).

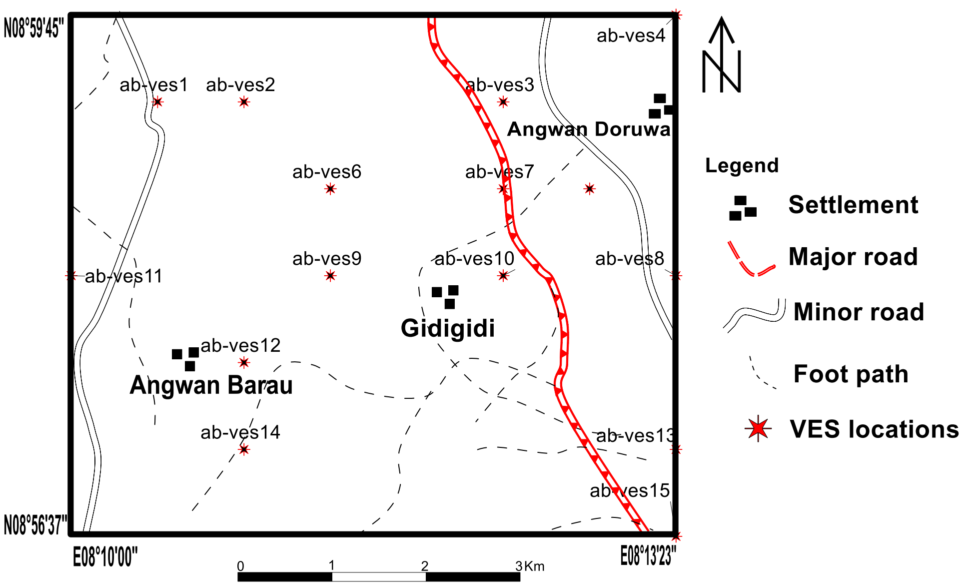

Figure 1: Location map of the Study area (digitized from Jama'a sheet 188 NE, published by the Office of the Surveyor General of the Federal Republic of Nigeria, 2008).

Methodology

Methods employed for this study include; geological mapping, thin section analysis and electrical resistivity geophysical survey.

Geological mapping

A detailed geological mapping of the study area was carried out to delineate the nature of rocks as this is crucial to the research problem. This was done after a desk study of previous works that have been carried out covering the area of study.

The mapping exercise was achieved by taking ground traverses through township roads and foot paths to rock exposures where observations were made. At each exposure, keen attention was paid to physical characteristics of rocks such as colour, texture, mineral contents and structures present. Where possible, all field measurements were taken on the rocks and structures.

Information obtained from the field mapping was used to produce a geological map of the study area (Figure 2) which shows the different rock types with their inferred boundaries. Also, the geological history of the area was deduced from this information. Orientations of joints were measured and recorded in the field. It was used to produce a rose diagram, which shows the principle direction of joints in the area.

Thin Section Analysis

Three rock samples obtained during the geological mapping exercise were analysed in the laboratory, using the thin section analytical technique. A thin section is a slice of rock 30 micrometres thick affixed to glass plate or slide with a resin called Canada Balsam. Most minerals are transparent in slices and can be viewed in transmitted light at various magnifications. Many minerals have properties that vary with the direction in which the light passes through them.

Rocks are viewed in a petrographic microscope in polarized light (plane and cross polarized light) on a rotating stage so that the various colour and refractive indices become apparent as the stage is rotated. The Balsam upon which the rock is mounted on has a refractive index of 1.538 Minerals whose refractive index is higher than 1.538 appear to stand out from the surface slide like hills and are said to have positive relief appeared as pits in the slide.

Electrical Resistivity Survey

Geophysical methods have been widely employed in earth studies over time. It involves the use of the principles of physics as it relates with the physical properties of the earth such as density, velocity, gravity, conductivity and magnetism. There are various geophysical methods which measures these different properties of the earth. Measurements are being taken at or near the surface of the earth which is influenced by the distribution of these physical properties beneath the earth.

For this study, the electrical resistivity method which explores both vertical and horizontal discontinuities in the earth based on its electrical properties was used. The earth possesses a good electrical property which is being exploited using the resistivity survey method. For instance, rocks are made up of various mineral constituents with varying electrical responses. Groundwater is also a very good conductor of electricity and could therefore be explored using the electrical resistivity method.

15 VES stations were investigated using the Schlumberger configuration. This array makes use of a pair of current electrodes and another pair of potential electrode arranged in a linear pattern with the currents electrodes spread at distance AB apart and the potential electrodes spread apart at distances MN. Using this configuration, the distance between the current electrodes AB is usually made to be equal to or greater than five times that of the potential electrodes MN. A typical field arrangement for Schlumberger array is presented in figure 3.2 below;

Results and Discussions

Petrography

Three different rock samples (S1, S2 and S3) obtained within the study area were subjected to microscopic studies using thin section analysis.

Table 1: Description of Minerals under Plane Polarized Light (PPL)

Mineral	Description
Biotite	appeared as lath-like, brown to dark brown in colour, shows strong pleochroism, high relief and one cleavage parallel to the alignment of the mineral grains
Muscovite	Appeared as lath-like, colourless, non-pleochroic, it has low relief and some grains appeared to have one distinctive cleavage
Quartz	Appeared as colourless, non pleochroic, showed very low relief relative.
Plagioclase	Appeared to be colourless, non pleochroic with low relief and no distinctive cleavage but showed a systematic fracture.
Perthite	Appeared as colourless, non-pleochroic has low relief, showed two cleavages not at right angle to one another and forms large subhedral crystals
Amphibole	Showed greyish-brown colour, non-pleochroic, has moderate relief, with no distinctive cleavage.
Orthoclase	It appeared as colourless, non-pleochroic, showed low relief; show no distinctive cleavage and have a subhedral crystal form.
Microcline	It showed first order white and grey interference colour, showed strong cross-hatch twinning which is a distinctive optical property of microcline, showed no alteration and does not undergo extinction on 360^0 rotation of the microscope stage.

Table 2: Description of Minerals under Cross Polarized Light (XPL)

Mineral	**Description**
Biotite	Biotite showed brown, no sign of alteration, has no twinning, and goes extinct at about 900 on 3600 rotation of the microscope stage.
Muscovite	Muscovite showed yellowish-brown and purple third order interference colour, showed no sign of alteration, no twinning and goes extinct at about 900 on rotation of the microscope stage.
Quartz	Quartz showed white to yellow first order interference colour, showed no sign of alteration, no twinning and goes extinct at about 900 on rotation of the microscope stage.
Plagioclase	Showed first order grey interference colour, with albite twinning which is a distinctive optical property of plagioclase, and also does not show sign of alteration.
Perthite	It showed dark-grey interference colour with slight light lamellae which are probably sodium-rich feldspar, and does not show any distinct extinction angle.
Amphibole	It showed dark brown interference colour, showed no twinning, no sign of alteration and does not show any distinctive extinction angle.

Microscopic Description of Sample S1

In thin section, the rock is seen to compose of Biotite, Plagioclase, Quartz, Amphibole, Perthite and Muscovites. Table 3 shows the estimated modal composition of each mineral in the rock sample.

Table 3: Estimated Modal Composition of S1

S/N	Mineral	Percentage Composition (%)
01.	Biotite	48
02.	Quartz	22
03.	Amphibole	15
04.	Plagioclase	8
05.	Perthite	4
06.	Muscovite	1
07.	Others	1
	Total	**99**

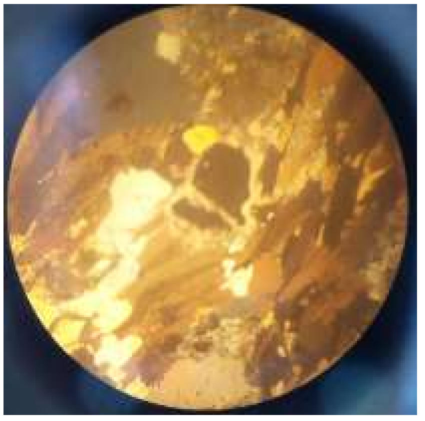

Plate I: Photomicrograph of S1 under Plane Polarized Light (using X4 Objective Lens)

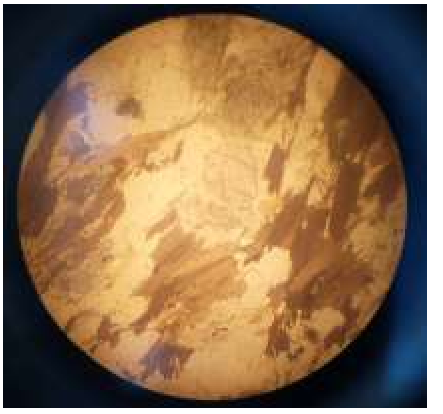

Plate II: Photomicrograph of S1 under Crossed Polarized Light (using X4 Objective Lens)

On the basis that this rock sample has strong alignment (foliation) of mineral grains and biotite minerals occurring in enormous quantity, and the presence of amphibole, suggest that this rock has been influenced strongly by metamorphism and has reached the grade of medium amphibolite facies. This information suggests that the rock is a Migmatitic Gniess.

Microscopic Description of Sample S2

Table 4: Estimated Modal Composition of S2

Mineral	Percentage Composition (%)
Biotite	32
Orthoclase	25
Quartz	21
Muscovite	12
Plagioclase Others	6 4
Total	100

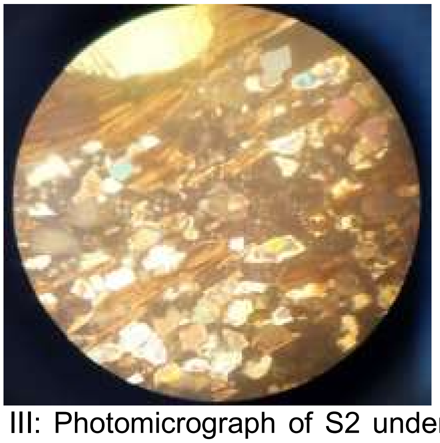

Plate III: Photomicrograph of S2 under Crossed Polarized Light (using X4 Objective Lens)

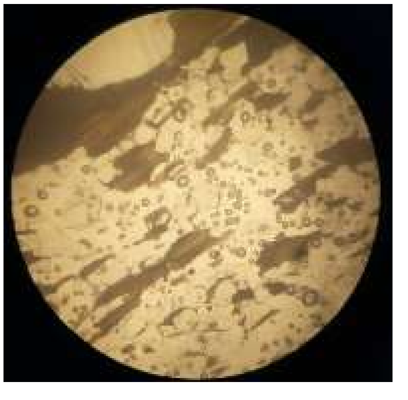

Plate IV: Photomicrograph of S2 under Cross Polarized Light (using X4 Objective Lens)

This rock sample has strong alignment (foliation) of mineral grains and biotite minerals occurring in enormous quantity, suggesting that this rock has been influenced by metamorphism. The rock is most probably a Biotite Gneiss.

Microscopic Description of Sample S3

The rock sample is seen to be made up of Biotite, Plagioclase, Quartz, and Microcline in thin section. Table 5 shows the estimated modal composition of each mineral in the rock sample.

Table 5: Estimated Modal Composition of S3

S/N	Mineral	Percentage Composition (%)
01.	Microcline	48
02.	Quartz	42
03.	Biotite	6
04.	Plagioclase	4
	Total	100

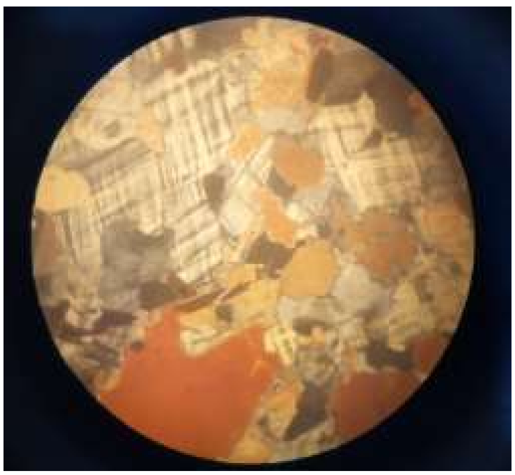
Plate V: Photomicrograph of S3 under Plane Polarized Light (using X4 objective lens)


Plate VI: Photomicrograph of S3 under Cross Polarized Light (using X4 objective lens)

No foliation was observed in thin section and the minerals does not show strong elongation of mineral grains, it can be suggest that this rock has probably not undergone partial melting and thus granitic in nature. Leucocratic Granite is suggested to be the name of the rock due to the preponderance of light coloured minerals.

Thin section analysis carried out on three rock samples obtained reveals that the area covered in this study composes of three rock types namely: Migmatite Gneiss, Biotite Gniess and Leucocratic Granites, all of which are typical Basement rocks (Figure 4.1). The ability of these rocks to retain appreciable amounts groundwater will be dependent on the amount of structures present on them.

Geology of the Study Area

The three different rock types were mapped in the study area. They include; Migmatitic Gneiss, Biotite Gneiss and Leucocratic Granites. Other minor rock units include Quartzo – Feldspartic veins and Pegmatite dykes (Figure 2).

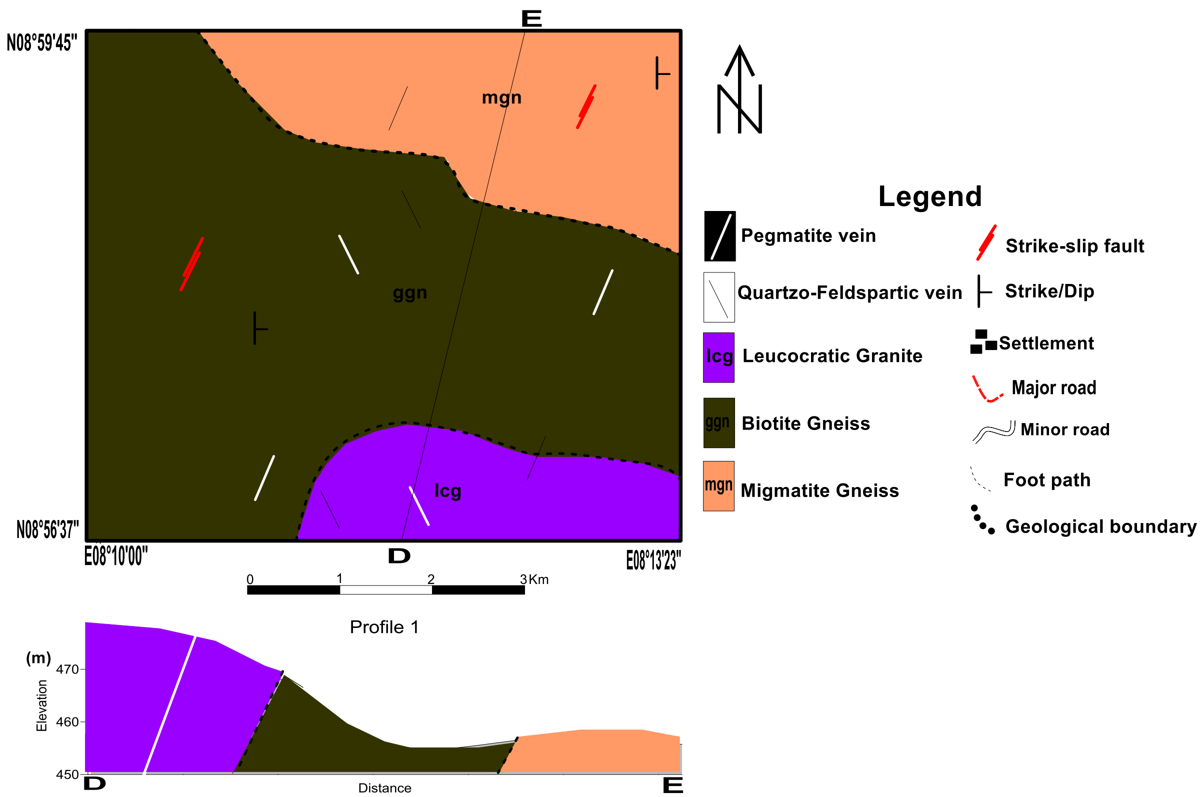

Figure 2 Geological Map of the Study Area

Migmatitic Gneiss

Migmatite Gneiss in the area mostly occurs as low lying outcrops and as boulders in few other places. They are notable in Angwan Doruwa and Angwan Dahariya and are generally medium grained with minerals such as feldspars, biotites and quartz, clearly visible on them. They appear with joint structures with pronounced alternating light and dark mineral bands (Plate VII). They are being intruded concordantly in some places by quartz – feldspartic veins and pegmatite dykes.

Plate VII: Migmatitic Gneiss exposed at Angwan Doruwa (N8°58'57'' E8°13'23'')

Plate VIII: Biotite Gneiss exposed at Angwan Maigini (N8°58'02'' E8°11'29'')

Biotite Gneiss

Outcrops of Biotite Gneiss were observed in Angwan Maigini and Angwan Barau. They are low lying and well foliated (Plate VIII) with presence of quartz veins and joints. Visible mineral grains include quartz, feldspars and biotite of medium grained sizes which are all aligned in a defined pattern.

Leucocratic Granites

They occur as intrusions, cutting across their surrounding country rocks. A prominent granitic exposure in the area is exposed in Angwan Television, bordering the study area. It is a quite massive exposure composed of minerals of medium to coarse grained sizes, bounded by gneiss in inferred areas. Mineral compositions of the rock include quartz, feldspars, biotites, muscovites with preponderance of feldspars and quartz (Plate IX). The rocks are jointed, faulted quite appreciably on the surface.

Pegmatite Veins

Pegmatite occurs as coarse grain light coloured materials. They are of great significance because they may host some economic minerals such as tourmaline, aquamarine or topaz. Here, they occur as infillings in a gneiss exposure, a little about 6cm in width in Angwan Jatau.

Prominent structures encountered in the area during the mapping exercise include; faults, joints, and veins. The presence of structures on rocks of the study area plays a very important role on its hydrogeology. In crystalline rocks, porosity of the rocks is solely dependent on the structures such as joints and faults. A dip slip fault showing a downward displacement at an angle of 14ºE (Plate XII) was noted in the area.

Veins are recognised on the field as infillings of fractured rocks by later hydrothermal fluids which then crystallize along the fracture paths. The veins observed in this study contain mostly quartz, feldspars and pegmatite. They may be short or continuous veins mostly depending on the fracture (Plate XIII) and may range in size from just a few streaks to thousands of feet. It is important to note that veins may contain diverse types of valuable minerals other than the ones here mentioned.

Joints are recognised on the field as fractured rocks showing no displacement. They are the most common structural features observed in the area on virtually all exposures and are mostly closed joints (Plate XIV). The joint orientation readings (Table 4.4) were obtained from various exposures and were used to produce a rosette diagram (Figure 4.2) showing the principle strike directions of the joints to be NE – SW.

Plate IX: Leucocratic Granite exposed at N8°58'57" E8°10'20"

Plate XI: Pegmatite Vein at Angwan Doruwa (N8°58'35" E8°10'48")

Plate XII: A Dip Slip fault at Angwan Dahariya (N8°59'04" E8°13'55")

Plate XIV: Joints at N8°55'45" E8°13'22"

Table 6 Strike reading for Joints in the Study Area

S/N	Strike Values (°)	S/N	Strike Values (°)	S/N	Strike Values (°)
1	16	2	172	23	18
2	60	3	24	24	36
3	32	4	50	25	32
4	64	5	108	26	28
5	70	6	28	27	310
6	12	7	22	28	28
7	16	8	24	29	32
8	20	9	122	30	36
9	30	0	18	31	26
10	18	1	28	32	40
11	38	2	42	33	63

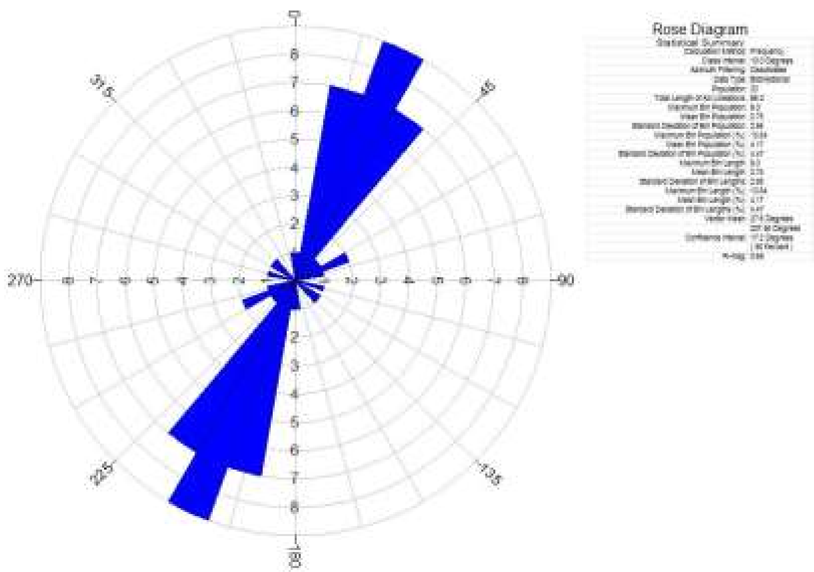

Figure 3: Rosette Diagram of Joints in the Study Area

Angwan Doruwa area falls under the North-Central Nigerian Basement Complex believed to be Precambrian in age. As observed from field studies, it comprises of Migmatite-Gneisses, Biotite Gneisses and Granites. The granite rocks can be said to be the youngest units in the area which intruded the pre-existing Gneisses. The Biotite Gneisses after undergoing the process of metamorphism and migmatization as a result of the injection of magma, graded into Migmatite-Gneisses.

Granites are said to be formed during the Pan African orogeny (Grant, 1878) which did not only change the mineralogy of the parent rocks but also led to the formation of different structures. Therefore, the structures present on the rocks in the study area may be attributed to the Pan African event which may have had a great effect on the topography of the area through formation of new hills in some parts and tilting some of the rocks. The most predominant structural trend in the area is towards the NE-SW direction which conforms to the N-S and NE-SW direction given by Grant, (1878) as the structural trend of the Pan African deformation.

Geo – electrical Survey Interpretations

Fifteen Vertical Electrical Sounding (VES) stations were surveyed in the study area. Strategic points were selected in the village for the survey. Field resistivity data was processed using IPI 2WIN computer program which produced sounding curves. The field apparent resistivity data and log – log graphs of apparent resistivity versus depth for all the VES stations are presented in appendix 1 and 2 respectively.

Results of the interpreted VES curves are shown in table 4.5 and table 4.6 from where it can be observed that the most predominant curve type obtained in the study area is the H curve ($\rho 1 > \rho 2 < \rho 3$). A maximum of five and minimum of three geo-electrical layers were delineated for VES stations in the study area namely: the topsoils (TS), which consists of sand materials with varying resistivity range of 337 Ωm to 706 Ωm and thickness range of 0.2 m to 2.5 m. The layer of lateritic soils (LT, LS) has resistivity range of 776 Ωm to 2141 Ωm and thickness range of 0.2 m to 2 m. The weathered basement (WB) layer constitutes of weathered rock fragments or regolith (R) which could serve as an aquifer in the area with a promising resistivity range of 16.6 Ωm to 466 Ωm with thickness ranging from 2 m to 14 m.

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The fractured layer (FRB) has resistivity range of 50 Ωm to 471 Ωm and thickness of 8.2 m to 35.2 m. The fractured rocks layer is the main aquiferous layer in the study area, and should be the target main during drilling. The fresh basement layer (FB) has a high resistivity value of greater than 20, 000 at depths of about 60 m in the study area implying that the layer is an undisturbed one, lying in its fresh state as its name implies.

Studies have shown that the resistivity value of fresh bedrock often exceeds 1000 Ωm. However, where it is fractured/sheared and saturated with fresh water, the resistivity often reduces below 1000Ωm (Olayinka and Olorunfemi, 1992). This might probably be the case for the study area. Based on the above interpretations, the area is hydrogeologically promising, although the quantity of groundwater obtainable will vary from one location to another.

Figure 4 and 5 shows the isoresistivity maps for the aquiferous weathered and fractured rock layers in the study area respectively. The area can be classified into two in terms of groundwater potentiality: good and very good. The isoresistivity map of the weathered basement layer shows that Angwan Barau has very good groundwater potential compared areas around Gidigidi and Angwan Doruwa with good groundwater potential. Figure 6 further indicates that areas around Angwan Barau have appreciably thick weathered rock layer (above 15 m) which constitutes the main aquifer. The weathered layer should be the main target when drilling particularly in Angwan Barau.

Table 7: Interpreted Resistivity Result for Vertical Electrical Sounding (VES 1-9)

VES No.	No. of Layers	Resistivity (Ωm)	Layer Thickness	Curve Type	Remark
	1	418	0.76		TS
1	2	1743	0.59	H	LT
	3	I6.6	1.56		WB
	4	138	11.6		FRB
	5	14225	-		FB
	1	337	1.02		TS
2	2	823	1.08	HA	LT
	3	54.4	2.59		WB
	4	315	31.6		FRB
	5	21737	-		FB
	1	377	0.91		TS
3	2	752	0.86	H	LT
	3	66.1	13.3		WB
	4	26026	-		FB
	1	514	3.36		TS
4	2	74.5	4.45	H	WB
	3	676.9	-		FB
	1	780.9	0.6		TS
6	2	466.8	2.5	H	WB
	3	235	35.3		FRB
	4	56177	-		FB
	1	5746	0.2		LT
7	2	692	4.9	H	WB
	3	76.3	9.4		FRB
	4	44395	-		FB
	1	6207	0.2		TS
8	2	737	4.7	H	R
	3	111	14		FRB
	4	23101	-		FB
	1	1766	2.1	H	LS
9	2	51.9	13.8		WB
	3	16011	-		FB

TS – Top Soil LS – Lateritic Soils L – Laterite WB – Weathered Basement FRB – Fractured Rock FB – Fresh Basement R - Regolith

Table 8: Interpreted Resistivity Result for Vertical Electrical Sounding (VES 10-15)

VES NO.	NO. OF LAYERS	RESISTIVITY (Ωm)	LAYER THICKNESSS	CURVE TYPE	REMARK
	1	771	2.5		LS
10	2	348	22.6	H	FRB
	3	I170	-		FB
	1	771	2.5		LS
11	2	348	22.6	HA	FRB
	3	1165	-		FB
	1	3214	0.3		TS
12	2	1042	1.7	H	LT
	3	199	20.2		WB
	4	3121	-		FB
	1	706	0.3		TS
13	2	2141	0.9	H	LS
	3	76	17.3		WB
	4	34575	-		FB
	1	192.2	0.4		TS
14	2	568.9	17.9	H	LS
	3	144.4	18.7		WB
	4	15389	-		FB
15	1	328	0.8		TS
	2	673	09		LT
	3	143	5.9	K	WB
	4	55.7	8.2		FRB
	5	21779	-		FB

TS – Top Soil LS – Lateritic Soils L – Laterite WB – Weathered Basement FRB – Fractured Rock FB – Fresh Basement R – Regolith

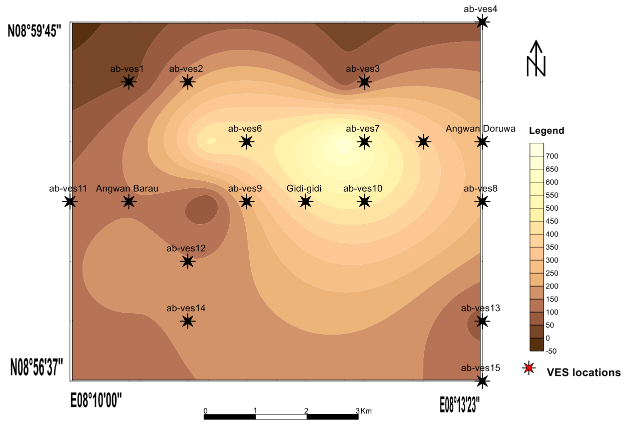

Figure 4: Isoresistivity map of weathered layer in the study area

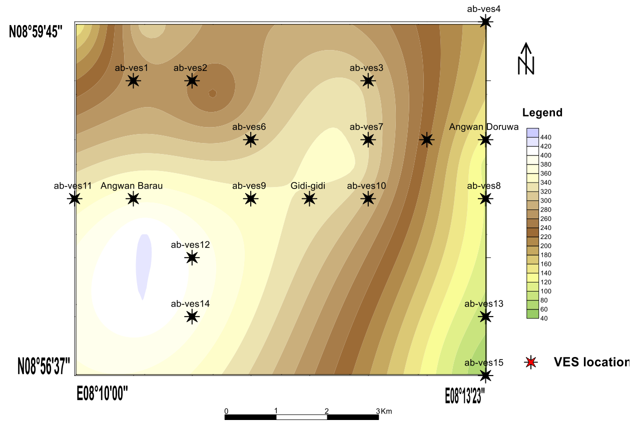

Figure 5: Isoresistivity Map of fractured basement in the study

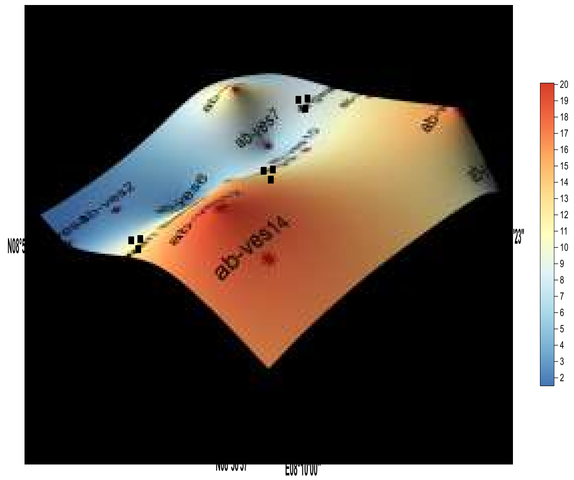

Figure 6: 3D Thickness Surface of the Weathered Basement rocks in the study area

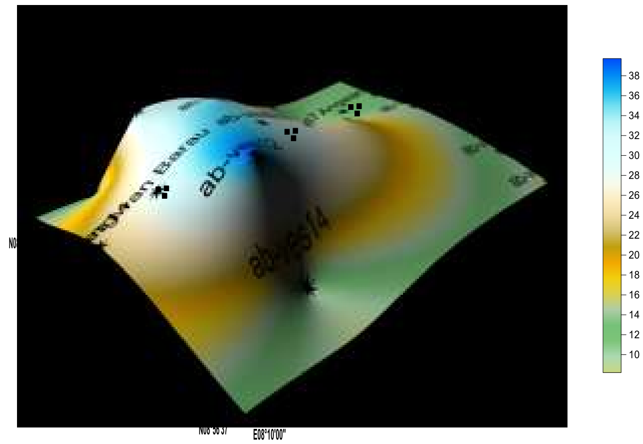

Figure 7: 3D Thickness Surface of Fractured Basement Rocks in the study area

Gidigidi and Angwan Doruwa tend to have a very good groundwater potential with aquifer thickness of 20 m to 30 m therefore the fractured rock layer constitutes the main aquifer to be targeted during drilling at a depth of 45 m to 50 m.

Conclusion

The main Rock types in the area consist of Migmatitic Gneiss with minerals such as biotite, quartz, amphibole, plagioclase, perthite and muscovite; Biotite Gneiss with minerals such as biotite, orthoclase, quarts, muscovites and plagioclase; Leucocratic Granites with minerals such as plagioclase, microcline, biotite and quartz. Structures present in the rocks include faults, veins and joints trending in the NNE – SSW principal direction. Secondary porosity in structures in the area favours the accumulation of and transmission of groundwater.

A maximum of five and minimum of three geo-electrical layers were delineated for

VES stations in the study area namely: the topsoils (TS), which consists of sand materials with varying resistivity range of 337 Ωm to 706 Ωm and thickness range of 0.2 m to 2.5 m. The layer of lateritic soils (LT, LS) has resistivity range of 776 Ωm to 2141 Ωm and thickness range of 0.2 m to 2 m. The weathered basement (WB) layer constitutes weathered rock fragments or regolith (R) with resistivity range of 16.6 Ωm to 466 Ωm and thickness ranging from 2 m to 14 m. The fractured layer (FRB) has resistivity range of 50 Ωm to 471 Ωm and thickness of 8.2 m to 35.2 m. The fresh basement layer (FB) has a high resistivity value of greater than 20, 000 at depths of about 60 m in the study area implying that the layer is an undisturbed one, lying in its fresh state as its name implies. Weathered and fractured basement layers have sufficient thickness (greater than 30 m) to retain and transmit groundwater. They therefore constitute the aquifers in the study area. The weathered basement layer constitutes the main aquifer in Angwan Barau with very good groundwater potential. The aquifer is appreciably thick (above 15 m) to hold and transmit groundwater while the fractured basement layer constitutes the main aquifer in Gidigidi and Angwan Doruwa with a very good groundwater potential. Aquifer thickness ranges from 20 m to 30 m. The application of geological mapping and geo-electrical resistivity survey is therefore a useful tool in delineating suitable aquifers.

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