Geology and Geophysical Investigation using Electrical Resistivity Method in Parts of Minna, Sheet 164 SW, North Central Nigeria

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Abstract

Geology and geophysical investigation using electrical resistivity method was carried out in parts of Minna, Sheet 164 SW, North-Central Nigeria to establish groundwater potential of the area. Geological mapping was done by both traverse and exposure mapping techniques and five representative samples were subjected to petrographic studies. Horizontal Electrical Profiling (HEP) employing Wenner array to probe 20 m, 40 m and 60 m depths were done on five stations along each of three profile lines oriented west to the east. This is in order to determine the lateral variations in apparent resistivity at various depths. Eighty Vertical Electrical Soundings (VES) were done using the Schlumberger array to a total depth (AB/2) separation of 110 m so as to study the variation of resistivity of the ground at variable depths. Geologic mapping and Petrographic studies results revealed granite as the major lithology with schist occurring in the east. Principal joint directions trend in the NE - SW direction indicating weathering and probable high groundwater potentials along this direction. The HEP result showed lower resistivity to the middle portion of the study area indicating favourable areas for detailed VES. VES results revealed three geoelectric layers: the soil/lateritic (upper), the weathered and the fresh/fractured layers. Six different geo-electric curves were generated from the analysis namely: HA, AA, HK, AK, KH and QH portraying various aquifers within the region. The area is slightly weathered and the fractures were convergent to the middle portion of the study area indicating more groundwater accumulation towards that direction.

Keywords: Groundwater, Basement Complex, Investigation, Electrical Resistivity, Fractures

1. Introduction

Water is a precious and exceptionally important natural resource, without which life is not possible. Water is utilized daily for domestic, commercial, agricultural, industrial and recreational purposes. Civilizations have flourished with the development of reliable water supplies and have collapsed as water supplies failed (Fetter, 2012; Troften, 1973). The need for potable water has increased astronomically in response to increasing demand attributable to civilization, technological breakthroughs and population increase. The inadequate or near absence of public water supplies has led to almost complete dependence of groundwater to meet potable water demands. In the past decade, assessing this precious resource posed no much problem. In recent times however, the number of failed and abandoned boreholes are on the increase. This is not unrelated to complexity of the hydrogeology attributable to the discontinuous nature of fractured aquifers, inappropriate exploration strategies and inadequate understanding and misinterpretation of acquired hydrogeologic data. Much emphasis has been placed on geophysical surveys alone, chiefly the electrical resistivity method (Idris, 2000). This research therefore is aimed at resolving this unacceptable development by establishing groundwater potential of the study area through integrated geological and electrical geophysical methods in order to delineate groundwater potential zones in the study area.

1.1 Study Area

Minna, the capital city of Niger state is located within the north central part of Nigeria. The study area is located within Minna town between latitudes N9°35′24″ to N9°38′24″; and longitudes E6°31′12″ to E6°34′12″ on a topographic map 1:50,000 comprising parts of Bosso and Chanchaga local government areas of Niger state. The total area coverage is 30.69 km^2 (5.54 km by 5.54 km). The study area is characterized by two distinct seasons; the rainy and dry seasons.

2. Materials and Methods

Geological mapping of the area was done by both traverse and exposure mapping techniques on an enlarged scale of 1: 25,000. The mapping involved observation, description and collection of data and rock samples from exposures using conventional geologic mapping tools. Five rock samples from the study area were petrographically analysed at the Nigerian Geological Survey laboratory in Kaduna. Horizontal Electrical Profiling (HEP) was done on points along three profile lines from the western to the eastern part, using the Wenner array to probe 20 m, 40 m and 60 m depths at each point in order to determine the lateral variations in apparent resistivity at these various depths within the study area. Vertical Electrical Sounding (VES) was then conducted on points along the three profile lines using the Schlumberger array to a total depth (AB/2) separation of 110 m and MN/2 separation of 15 m using McOhm – EL2, Model – 2111 resistivity meter. At each point, current was passed into the ground from a Direct Current (DC) power source through two current (outer) electrodes and the earth's response measured through two potential (inner) electrodes. The apparent resistivity is calculated automatically by the measuring device and displayed on the screen. This was repeated at variable depths throughout the sounding. HEP and VES points are shown on fig. 1. The apparent resistivities obtained from geophysical studies involving Horizontal Electrical Profiling (HEP) and Vertical Electrical Sounding (VES) carried out in the study a rea were used to plot resistivity graphs using MS Excel and the win-resist software from which the geoelectric profiles/sections; contour plots of depth/thickness and isoresistivities of the geoelectric layers were generated

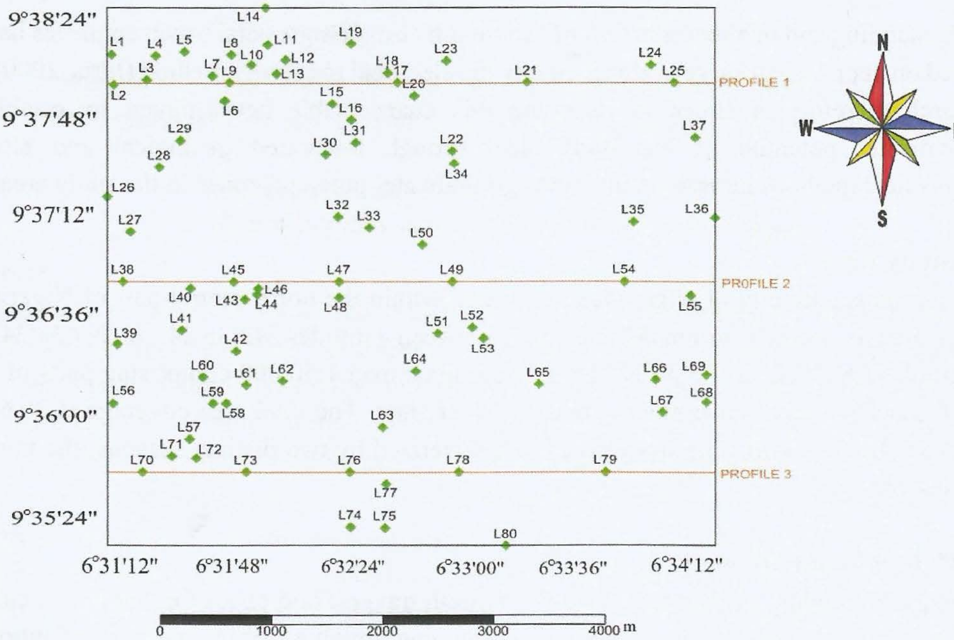

Figure 1: Horizontal Electrical Profiling and Vertical Electrical Sounding points

3. Results and Discussion

The geological map of the area and its cross section derived from field and petrographic results of rock studies within the area is shown in Fig. 2. It reveals that the study area falls within the basement complex of Nigeria and is underlain predominantly by granites (over 90 %) while the eastern area is underlain by rocks belonging to the metasedimentary rocks – schist made up of Amphibolite covering less than ten percent of the study area. The cross section from point A – B shows the two rock types and also shows that the granites are the youngest of the two rock types by the slight tilt of granitic boundary on the schist.

The common structures found in the study area were mostly fractures (fissures, cracks or joints), the rosette diagram (Figure 3) obtained from joint readings on rocks of the area reveals that the principal joints trends in the NNE - SSW direction while the adjoining minor joints trends in the W – E direction.

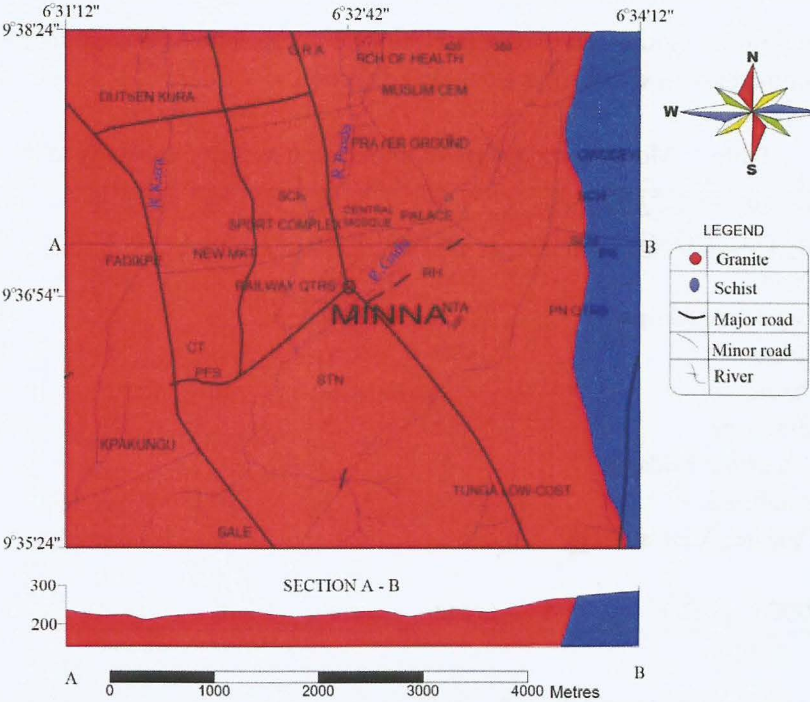

Figure 2: Geological map of the study area

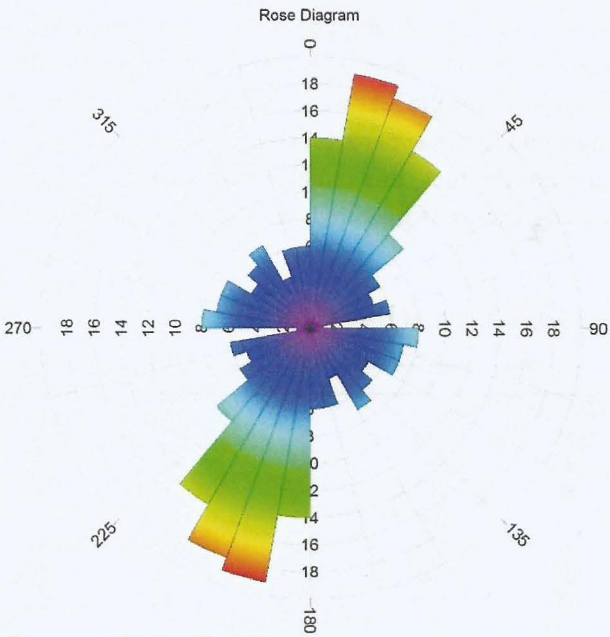

Figure 3: Rosette diagram of joint directions

A summary of the result of the petrographic analysis (magnification X10) of the rock types from the study area gives the modal composition of minerals as shown in Table 1. The pecrcentage modal composition of minerals displayed an increasing trend in the pecrcentage modal composition of quartz and muscovite from the southwestern to the northeastern part and a decreasing trend in the biotite and plagioclase feldspar composition through the same direction which imply an increase in weathering along that direction.

Table 1: Modal composition of minerals in rocks of the study area

SAMPLE LOCATIONS	L 19	L 22	L 25	L 26	L 45
MODAL COMPOSITION	%	%	%	%	%
Quartz	45	50		50	45
Plagioclase feldspar	30	25		25	30
Biotite	10	5		5	15
Olivine			15		
Muscovite	10	15		20	2
Orthoclase Feldspar	5				
Hornblende			80		
Opacque Mineral			5		
ROCK NAME	Granite	Granite	Schist	Granite	Granite

The apparent resistivity values obtained from HEP is shown in Table 2, while Figures 4, 5 and 6 illustrate apparent resistivity curves of profile points at AB/2 = 30 m, 60 m and 90 m respectively. The results in general, showed higher apparent resistivity values at Points 1 (western part) throughout profile lines 1 and 2 with decreasing trends to Points 4 where they rise at points 5 (eastern part), profile 3 however has its lowest points at Points 2, 4 and 5. Also there is an increasing trend in the apparent resistivity from the northern to the southern parts when we compare the profile lines, this indicates that, within the basement, points that have lower apparent resistivity values, if fractured, will have higher groundwater potential

Table 2: Apparent Resistivity (Ohm-m) of HEP points

POINTS	AB/2 (m)	1	2	3	4	5
PROFILE 1	30	138	62	30	45	58
	60	334	85	49	127	200
	90	562	649	233	186	278
PROFILE 2	30	371	240	83	39	601
	60	711	550	230	198	790
	90	985	472	416	310	937
PROFILE 3	30	422	144	356	128	110
	60	918	222	431	250	198
	90	1740	362	624	377	414

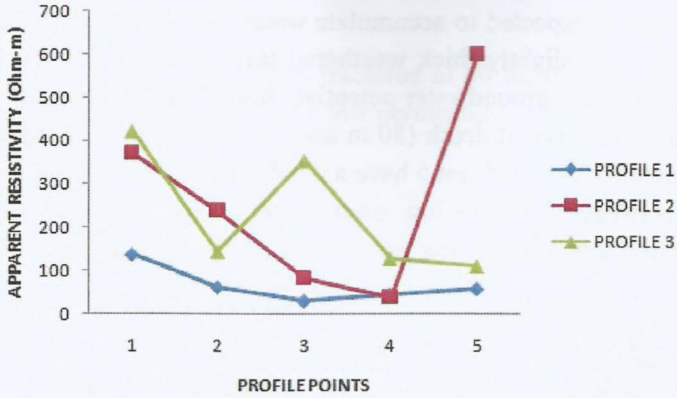

Figure 4: HEP Curves at AB/2= 30 m

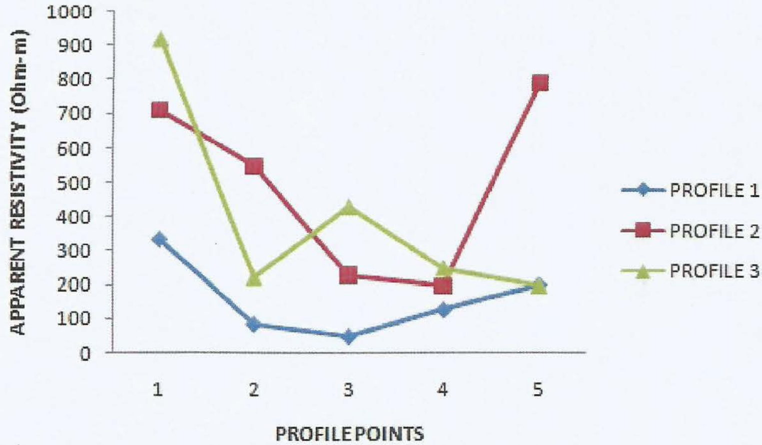

Figure 5: HEP Curves at AB/2= 60 m

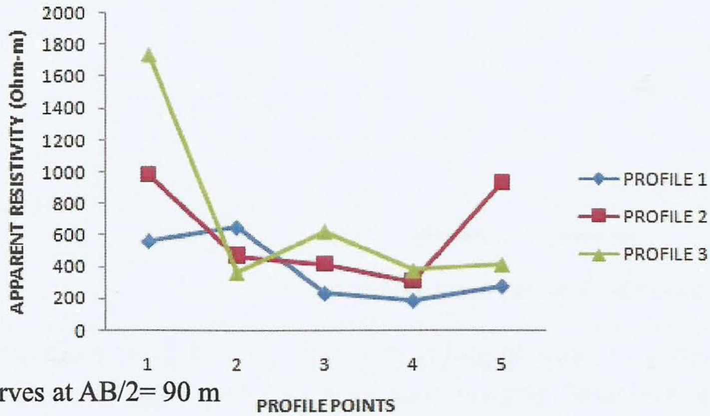

Figure 6: HEP Curves at AB/2= 90 m

Figure 7 shows geoelectric logs (derived from layers obtained from resistivity curves) of points along profile 1. Point 1 of Profile 1 shows thin soil and weathered layers with no fracturing, this imply that areas around this point will have low groundwater potential; Point 2 have undergone appreciable weathering but not well fractured this will only imply that here, only the weathered layer is expected to accumulate water most especially as the soil layer is also thick; Point 3 shows a slightly thick weathered layer and fracturing at 60 m, this point is expected to have medium groundwater potential; Point 4 also have a slightly thick weathered layer but fractures converge at depth (80 m and 90 m), this point is expected to have a high groundwater potential; though Point 5 have a thick weathered layer and is also fractured at 30 m and 80 m, it is expected to have low groundwater potential because the point is located on schist and schist is a low groundwater permeability rock (Idris, 2010).

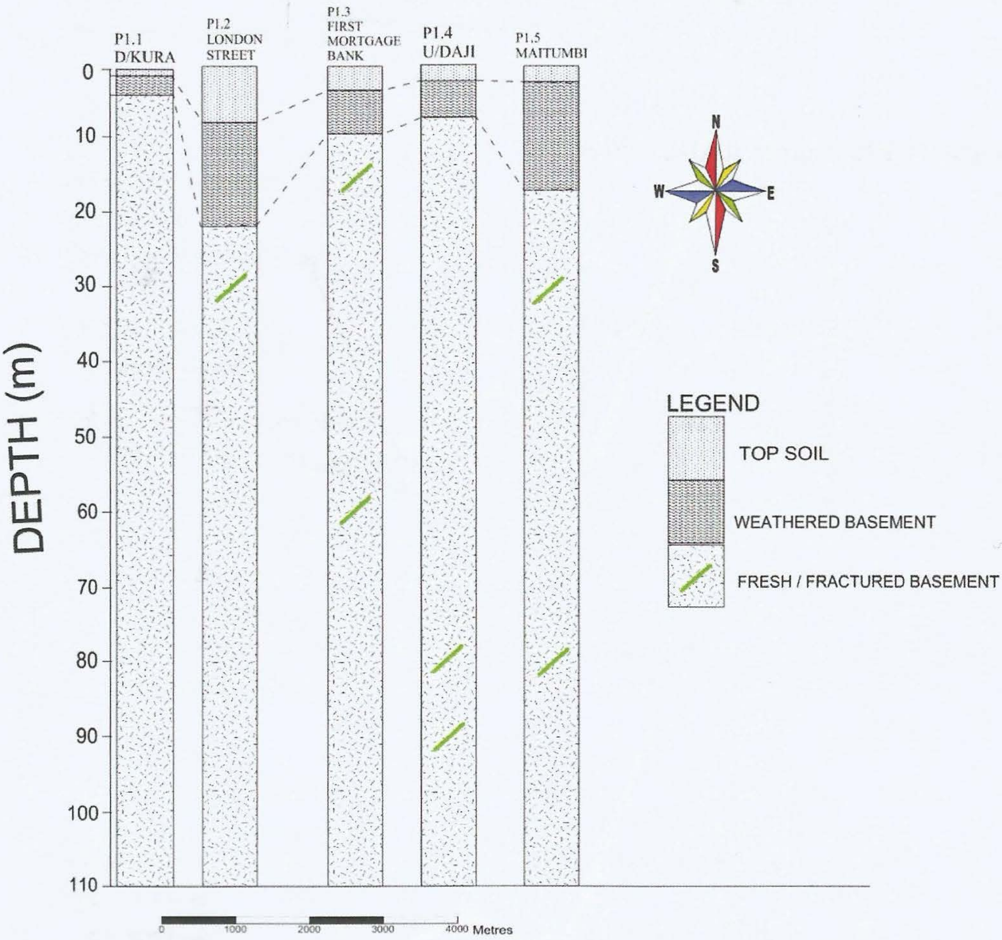

Figure 7: Geoelectric logs of points along profile 1

Figure 8 shows geoelectric logs of points along profile 2. Point 1 of Profile 2 shows thin soil and moderate weathered layer and fractured at 40 m and 110 m, this imply an area with medium groundwater potential; Point 2 also have thin soil and moderate weathered layer but fractures converge at depth (80 m and 90 m), this will imply a high groundwater potential; Point 3 shows a slightly thick weathered layer and fracturing at depths of 50 m and 80 m, this point is expected to have a high groundwater potential; Point 4 also have a slightly thick weathered layer and fractured at 40 m and 80 m, this point is expected to have a high groundwater potential; Point

5 have a slight weathered layer and is also fractured at 90 m, but is expected to have low groundwater potential because it is within the low permeability rock (schist).

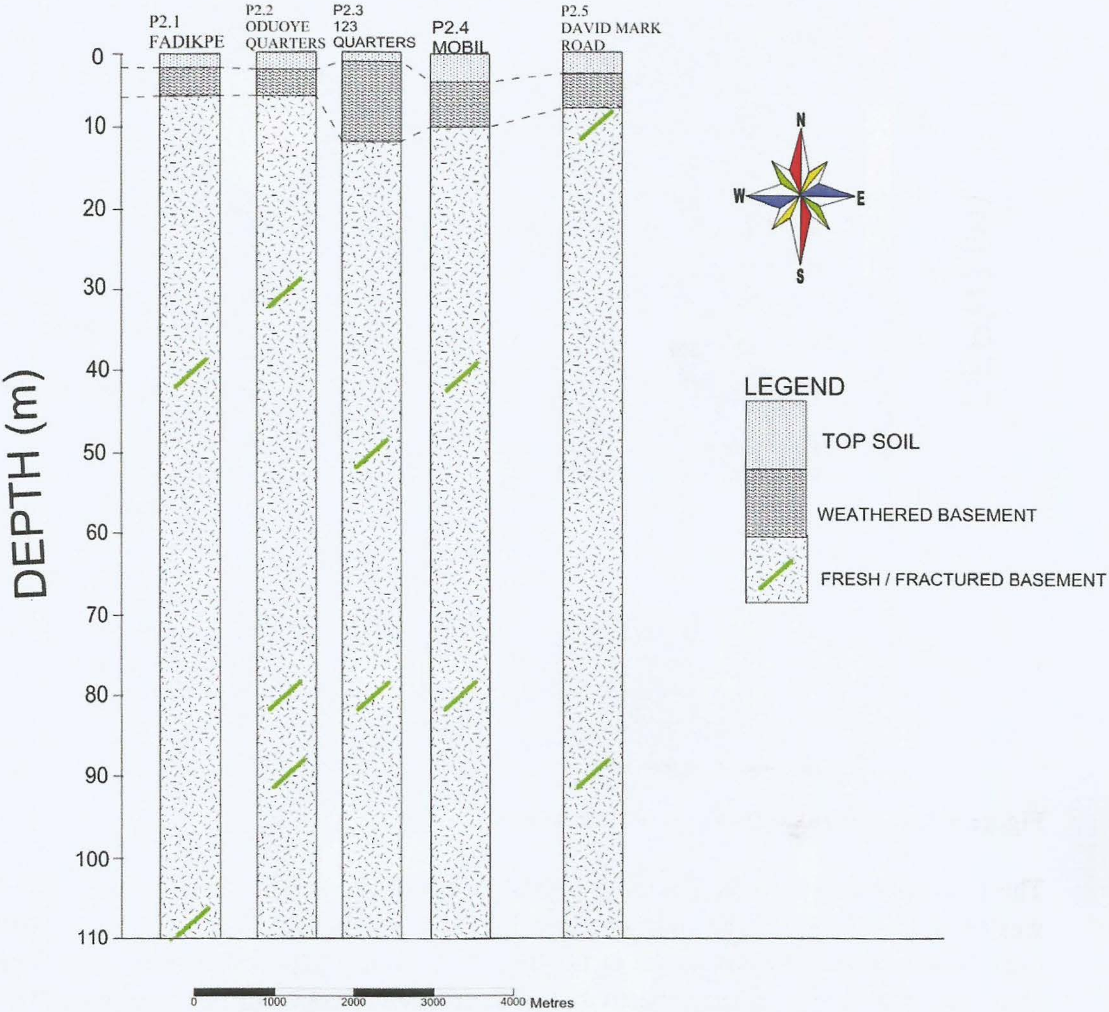

Figure 8: Geoelectric logs of points along profile 2

Figure 9 shows geoelectric logs of points along profile 3. Point 1 of Profile 3 showed slightly thick weathered layer and fracturing at 20 m and 100 m, this imply an area with high groundwater potential; Point 2 have thin soil and weathered layers and fractured at 20m and 60m depths, this will also imply a medium groundwater potential; Point 3 showed a thin soil and weathered layers and fractured at 70m depth,, this point is expected to have a low groundwater potential; Point 4 have a slightly thick weathered layer and fracture at 15m and 80 m depths, this point is expected to have a high groundwater potential; Point 5 have a slightly thick weathered layer and is also fractured at 50 m depth, but expected to have a low groundwater potential.

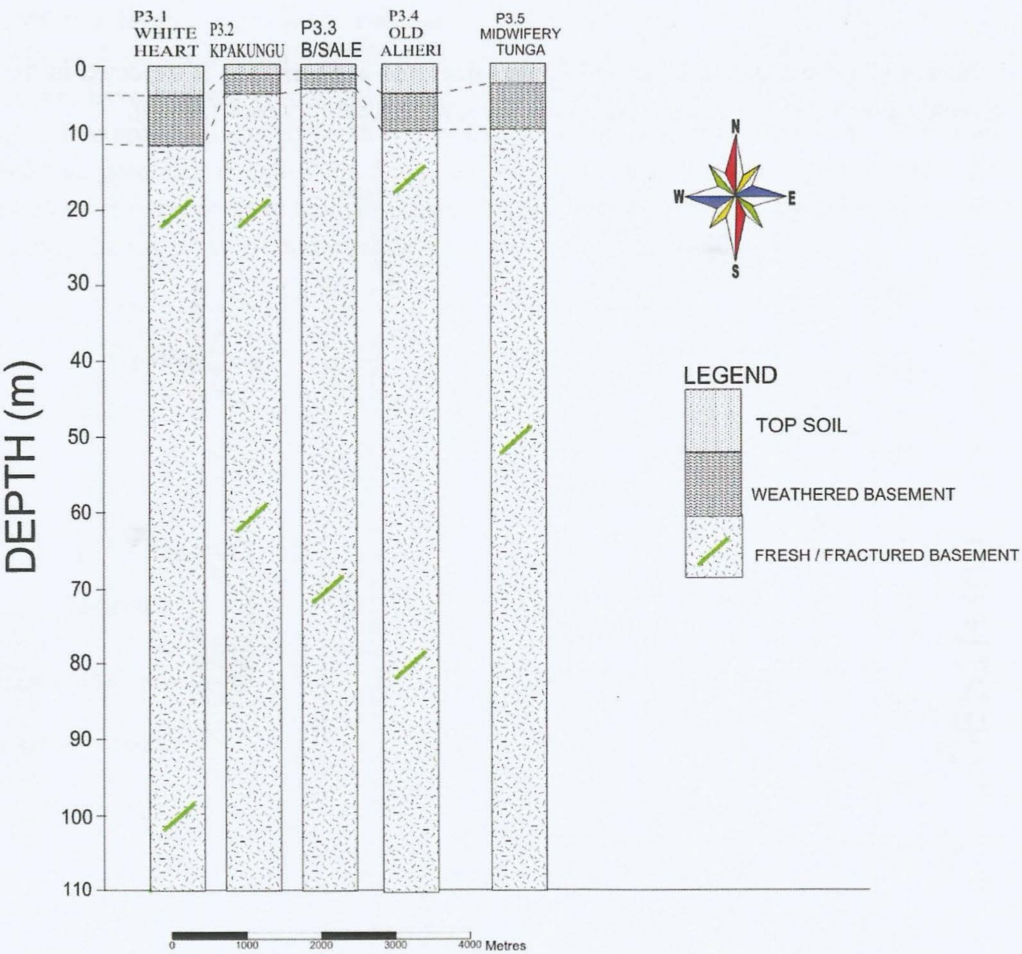

Figure 9: Geoelectric logs of points along profile 3

The resistivity curves yielded three geo-electric layers; the soil/lateritic (upper) layer, the weathered basement and the fresh/fractured basement layers respectively. The soil/lateritic (upper) layer have resistivity ranges of 14 Ωm to 1787 Ωm, depth / thickness ranges of 1 m to 10 m; the weathered layer have resistivity ranges of 7 Ωm to 1188 Ωm, depth ranges of 2 m to 24 m and thickness ranges of 2 m to 22 m while the fresh/fractured layer ranges in resistivity from 33 Ωm to 17904 Ωm, having depth ranges of 5 m to 109 m and thickness ranges of 2 m to 96 m. The study area has undergone slight weathering, varying from place to place with the major portions having a weathering thickness of less than six (6) metres and apparent resistivity values less than 150 Ωm. The thicker the weathering profile of the basement, the more water it accumulates as such, areas with weathered thicknesses above six (6) metres will have more weathered aquifer potential. Figures 10 and 11 shows the soil layer thickness and overburden (soil layer and weathered layer) thickness which are very vital in groundwater potential determination, the thicker they are, the more they accumulate groundwater and the higher the potential of such areas.

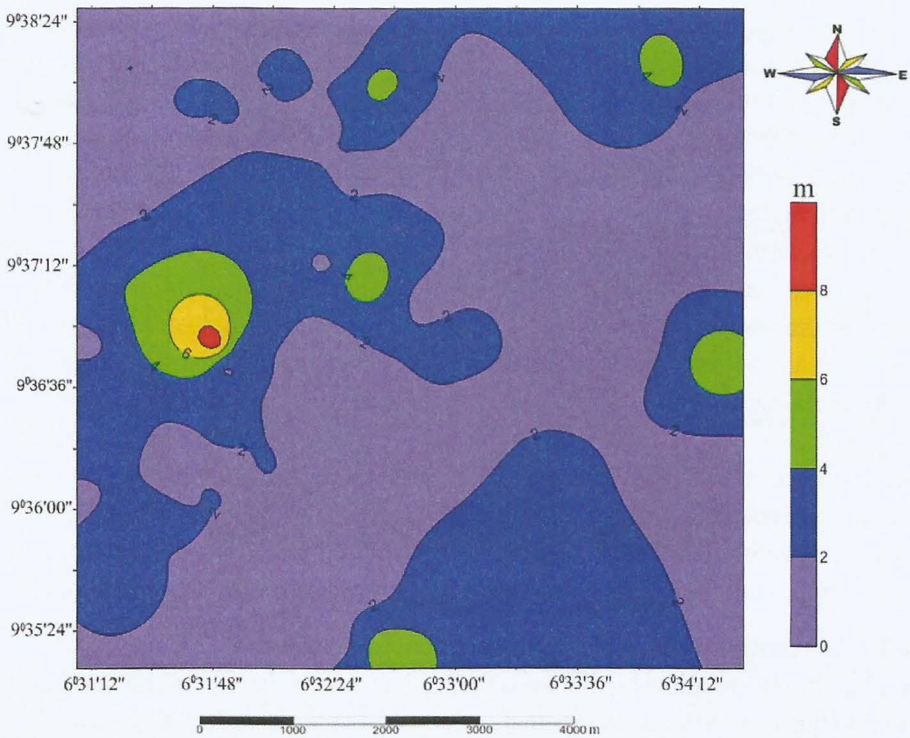

Figure 10: Thickness of top soil in the study area

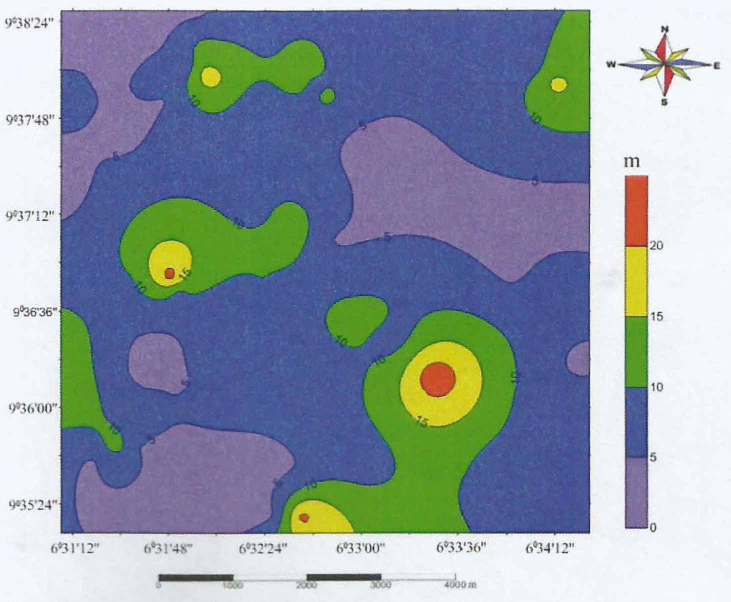

Figure 11: Depth to basement in the study area

Figure 12 shows the isoresistivity contour plot of the fresh/fractured basement layer. There is an increasing trend towards the southern portion from the north-eastern part of the study area. This coincides with the profiling results earlier mentioned. In most parts of the study area, fractures are accessed at over forty (40) metres and westwards at eighty (80) metres depth and above.

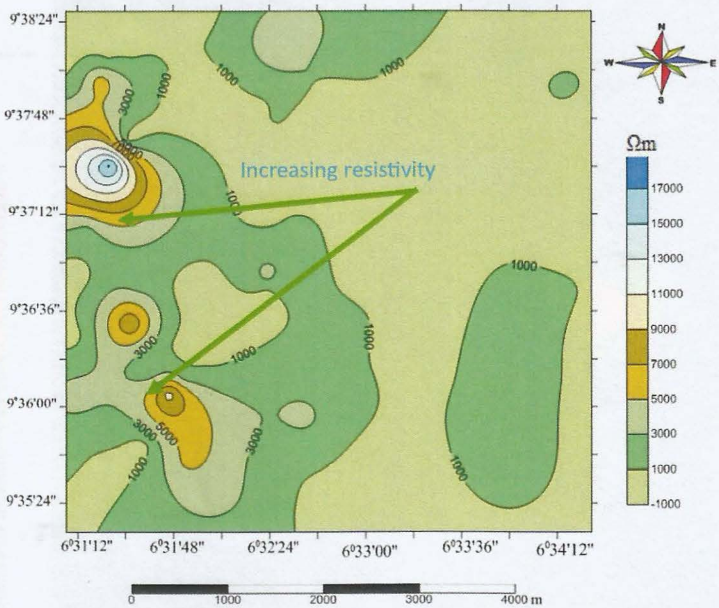

Figure 12: Isoresistivity plot of fresh/fractured basement layer

Figure 13 shows the relationship between the geology and resistivity within the fresh/ fractured basement in the study area, it reveals that rocks found in areas with light green coloration have lower apparent values resistivity (< 1000 Ωm) those with dark green coloration have medium apparent resistivity values (< 3000 Ωm) while others have higher resistivity values. The eastern part has lower resistivity values when compared to the southern part.

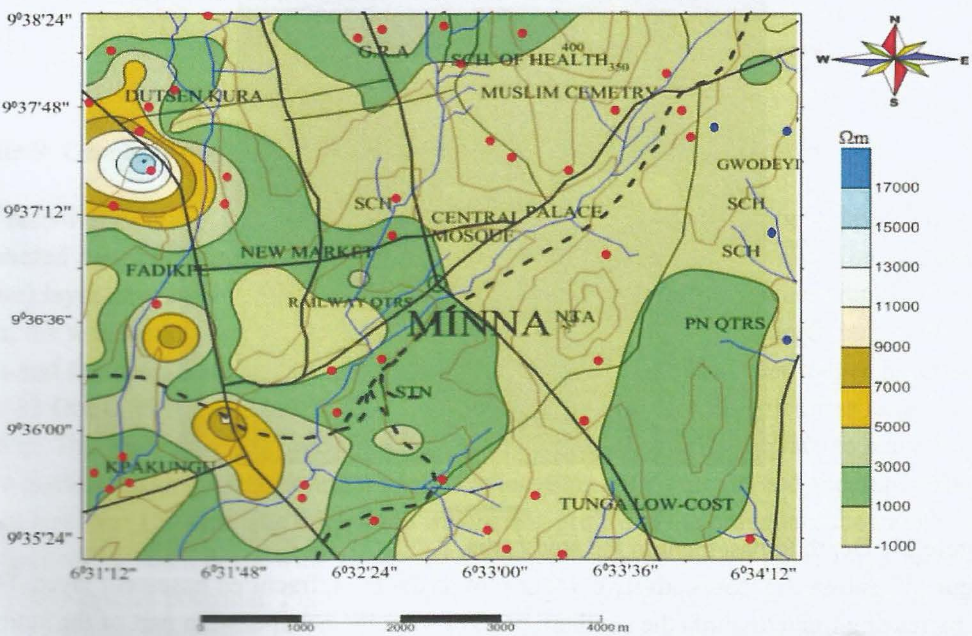

Figure 13: Relationship between geology and resistivity within the study area. Blue and red dots represent schist and granite rocks respectively.

Six curve types were generated from the VES analysis namely: HA, HK, AA, KH, QH and AK portraying various aquifers within the region. The HA-type covers 45%; the HK-type covers 26%; the AA-type covers 11%; the AK-type covers 9% while the remaining 9% of the total surveyed points is covered by the KH and QH-types. The areas marked by HA-type have fractured zone existing directly below the weathered zone (McFarlane, 1989), the groundwater yield in these areas could not be very high because the density of the fractured column is not high (Olorunfemi, 2009). The areas marked by HK type, have the fractured zones concealed beneath the fresh basement, such areas may not have any hydraulic connectivity between the weathered and fractured zones but complements each other if wells are sunk into them, the curve type generally produce prolific wells especially where the weathered and fractured layers are thick. The areas marked by KH type are characterised by very thin top soil/ weathered zones and the fractured zones are confined within the fresh basement as such, these areas may have significant yield of water only when the fracture density is high and the fractured column is thick. The areas marked by QH and AA types have sharp transition between the weathered and the fresh basement, the weathered layer is the sole aquifer unit and groundwater yield here is determined by the degree of shaleliness of the weathered layer, low yield is obtained where underlain by schist or clay (Olugboye, 2008).

Figure 14 shows the groundwater potential map of the study area deduced from superimposing combination of results from the geology and electrical resistivity. Areas that are coloured green have high groundwater potential; those coloured blue have medium groundwater potential while those coloured red have low groundwater potential.

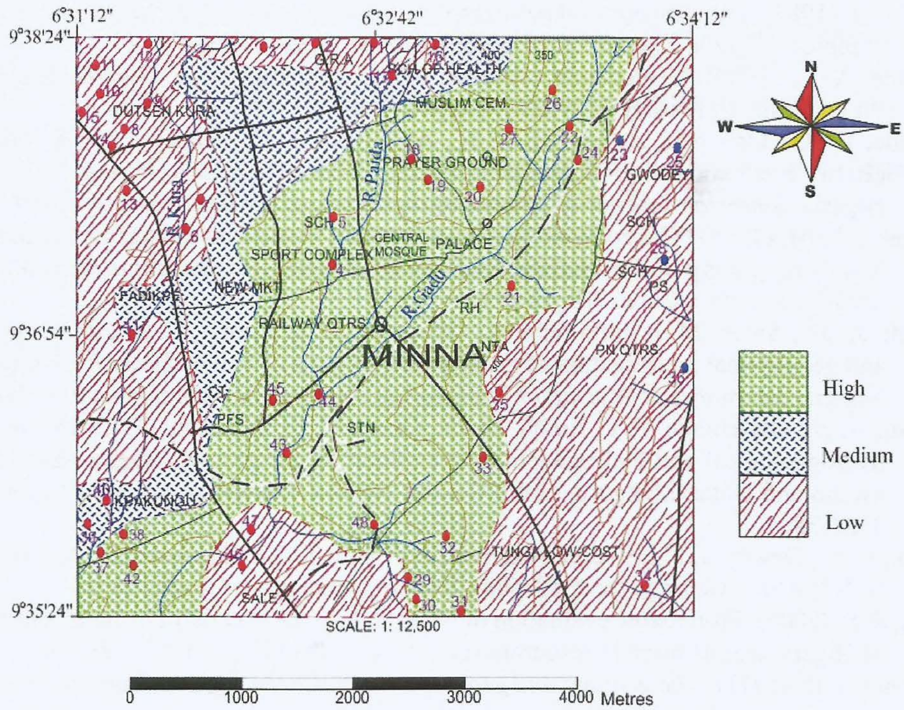

Figure 14: Groundwater potential of the study area

5. Conclusion

Geologic mapping revealed that the study area is underlain predominantly by granite while the eastern area is underlain by rocks belonging to the metasedimentary rocks – amphibolite complex made up of schists. The measurements obtained from joint directions reveals the principal joints trending in the NNE - SSW direction and the minor joints in the W – E directions indicating weaknesses in those directions and thus high potential in that direction. Petrographic studies of rock samples from the area also confirm the rocks as granite and schist. The modal composition of minerals in the rocks reveals an increasing trend in percentage modal composition of quartz and muscovite from the south-western to the north-eastern part and a decreasing trend in the biotite and plagioclase feldspar composition through the same direction implying an increase in weathering along that direction. Geophysical studies involving Horizontal Electrical Profiling (HEP) and Vertical Electrical Sounding (VES) carried out in the study area were used to plot resistivity graphs using MS Excel and the win-resist software from which the geoelectric profiles/sections; contour plots of depth/thickness and isoresistivities of the geoelectric layers were generated. The outcome showed top soil thickness of less than four (4) metres and weathering depths of less than six (6) metres in most places (these supports wells) and an increasing groundwater potential towards the middle portion from the western and eastern parts of the study area, this also coincides with the Horizontal Electrical Profiling results, petrographic studies and the rosette diagram. The study area is divided into high, medium and low groundwater potential zones.

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