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Groundwater Potential Evaluation in the Crystalline Basement of Gidan Kwano Campus, Federal University of Technology, Minna, North-Central Nigeria Using Geoelectric Methods

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Abstract Gidan Kwano campus of the Federal University of Technology, Minna, is located within the basement complex terrain of North-Central Nigeria and is underlain by Pre-Cambrian basement rocks of which granites are predominant. Vertical Electrical Sounding (VES) employing the Schlumberger electrode configuration was used to provide information about the subsurface lithology and structures with the aim of evaluating its groundwater potential. A total of 48 VES was made along eight profiles with six sounding stations per profile within an area of about 10km^2. A combination of VES, Horizontal Resistivity Profile and Sounding – Profiling produced a subsurface geological appraisal of the study area. Results of the interpretations of VES data were used to produce fracture map and isopach map of depth to basement which has a mean value of 35 m. Interpreted fractures coincide with the direction of stream flow suggesting a structurally controlled drainage system. VES curves reveal that the area is generally characterized by three geoelectric layers. Top soil layer thickness range from 0.2m to 7.4 m while the weathered layer thickness range from 0.3 m to 58.8 m. Out of the 48 VES made, 8 VES stations have been selected as priority locations for the development of groundwater resources. The study area has been found to have a very high potential for groundwater development. Despite all the limitations of the VES technique, it has been found to be reliable for groundwater exploration in the basement complex terrain particularly when the Schlumberger Configuration combined with geological and computer - aided interpretation for the survey data is implemented.

Keywords Crystalline Basement, Vertical Electrical Sounding (VES), Horizontal Resistivity Profiling (HRP), Sounding-Profiling (Pseudosection), Groundwater Potential

1. Introduction

Groundwater is an important source of water supply. It plays a major role in the Gidan Kwano Campus of the Federal University of Technology, Minna. The surface water sources are not reliable for adequate and sufficient supplies, as the streams and rivers are seasonal and the development of surface water resources for the campus is rather expensive. Hence, the University has to rely solely on groundwater supplies as its major source. However, some of the boreholes drilled in the University are not able to meet the needs of the University because out of the eleven boreholes drilled at the campus, eight of the boreholes have been abandoned. The reasons for these are not far-fetched. The current paradigm of groundwater exploration in most part of the country is based on a geophysical approach, where most boreholes are sited based only on responses from electrical surveys, often with little or no understanding of the structural geology of the target area [1]. In many areas of complex hydrogeology like the crystalline basement, this technique has proved to be unsuccessful due to a number of reasons. These include but are not limited to:

a. An inadequate understanding of the occurrence of groundwater and the factors affecting permeability in this terrain, leading to inappropriate exploration planning;
b. Siting of boreholes on geophysical anomalies without a conceptual understanding of the geological framework and how it affects the geophysical response;
c. Siting boreholes without an adequate interpretation of the geophysical data.

The present study is targeted at evaluating the groundwater potential of the campus with emphasis on detailed geologic and geoelectric geophysical investigation, through which lasting solution can be found to the water scarcity on the campus and by extension, the host community.

1.1. Description of the Study Area

The Gidan Kwano Campus of the Federal University of Technology, Minna is located along the Minna-Katerigi-Bida road which is about 12 km from the main town. The study area is located in the eastern portion of the campus and lies within Latitudes 9°31'15"N and 9°32'30"N and Longitudes 6°26'15"E and 6°28'00"E and covers an area of about 10 km^2 (Figure 1).

The area falls within the guinea savannah vegetation comprising various species of shrubs and high forest plants along the streams and depressions. The area also consists of short grasses of heights ranging from of 3 to 4.5m and trees of up to 15m high. There are two seasons associated with the area. These include the rainy and dry seasons. The total annual rainfall in this area is between 1086 mm and 1309 mm, spread over the months of April to November. The highest amount of rainfall is recorded in the month of August.

The maximum daytime temperature is about 35^0C in the months of March and April, while a minimum temperature of about 24^0C is recorded in the months of December and January. The mean annual temperatures are between 32^0C to 33^0C [2]. It should however be noted that the climatic conditions are subject to changes.

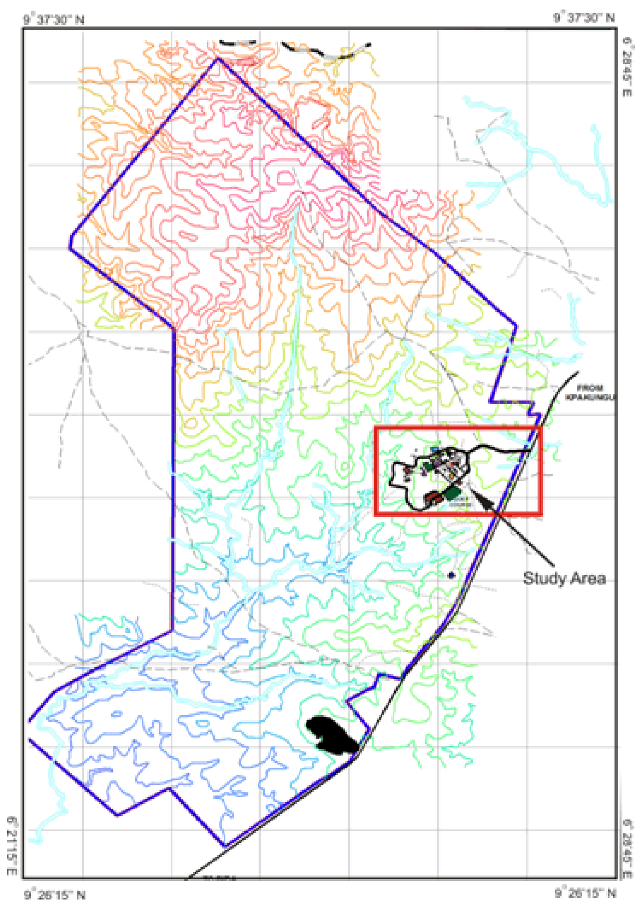

Figure 1. Location of the Study Area.

The study area stands at an elevation of between 190 m and 230 m above sea level in the west and drops slightly to about 220 m in the North-Eastern part. The central part is remarkable for its alternating rugged and undulating landscape which is perhaps responsible for the profuse rock outcrop in this part. Most of these outcrops occur as relatively low-hills and ridges with huge masses of fragmented granite boulders.

Most of the study area is drained by the DaggaRiver system flowing in the NE - SW directions. Two right bank tributaries of the river Weminafia and Kwakodna drain most of the northern and the entire middle area into the main river. These run predominantly north-south. Two other left bank tributaries drain the southern part in a general East-West direction. The streams are seasonal in nature.

1.2. Geological History of Gidan Kwano Area

The study area is underlain mainly by Precambrian rocks. A small portion of it consists of pegmatite intrusions believed to be of Late Pre-Cambrian age [3],[4].These rocks are outcropping within the older granites and a thick overburden of laterites cover parts of the highly schistose rocks (Figure 2).The terrain is predominantly a granite terrain with an east – west boundary between the finer grained granite to the south and the coarser grained granite to the north. There are two outcrops of schist as inlier to the north and to the west of the study area. The numerous granites and gneissose granites in the area vary considerably in their petrography and petro fabrics, but are said to be all belonging to one intrusive cycle [5]. The Older Granites exposed in this region have been fractured at various degrees and intruded by both pegmatite and aplites together with quartz veins as observed on the field. The youngest of all the geologic materials in the area are the thick overburdens of laterites and alluvial deposits of sands believed to be of Tertiary or Recent in age [6].

2. Materials and Methods

Vertical Electrical Soundings (VES) were carried out to locate suitable points in Forty-Eight locations using Schlumberger Array. These stations were pre-selected and spaced at about 500 m apart as shown in Figure 3. These stations were arranged in profiles in such a way that each profile contains six stations each.

The instrument used is PETROZENITH Terrameter. It provides a combined low/high power resistivity unit that is fully self-contained and portable. It is a portable micro-processor controlled integrated receiver and transmitter which provide a digital readout of the current and the potential difference. It has low operating frequency, which makes it to measure deeper. Power is supplied by rechargeable battery pack. Several self-diagnostic checks are in built and error codes displayed for instrument, cable and electrode faults.

Sounding data, in the form of earth resistance, are converted to apparent resistivity values by multiplying with the geometrical factors. The apparent resistivities are then plotted on a log-log graph of standard scale as a function of the half current electrode separation (AB/2). Preliminary interpretation was carried out using partial curves matching involving two-layer master curves and the appropriate auxiliary charts [7],[8]. The layered earth model thus obtained, served as input for an inversion algorithm, WINRESIST, as a final stage in quantitative data interpretation [9].These were processed to obtain the parameters needed to evaluate the groundwater potential of the study area.

3. Results

3.1. Description of Ves Curves

From the interpretation of the electrical sounding curves (Table 1 &2), it has been observed that 70% of all the VES curves in the study area gave the A - type curves, 28% gave the H – type curves and 2% represents the HK and the Q–type curves Hence, almost all the curves reflect a 3 – layer structure (Figure 4(a) & (b)). The layers include the top soil layer, the weathered/fractured layer and the fresh basement. The top layer consists of sandy, clayey sand and loamy soils and has resistivities ranging from 8 Ωm to 256 Ωm. The thickness of the top soil layer ranges from 0.3 m to 7.0 m.

The weathered/fractured layer is the second geoelectric layer and it has resistivities ranging from 14 Ωm to 3076 Ωm. The thickness of this layer varies from 0.9 m to 58.8 m. VES 6.4 has the highest thickness of 58.8 m and VES 7.3 has the least thickness of 0.79 m. Fresh basement rock is characterized by high resistivity value of up to 100,000 Ωm. The depth to fresh rock from the VES soundings is found to range between 4.5 m and 59.5 m.

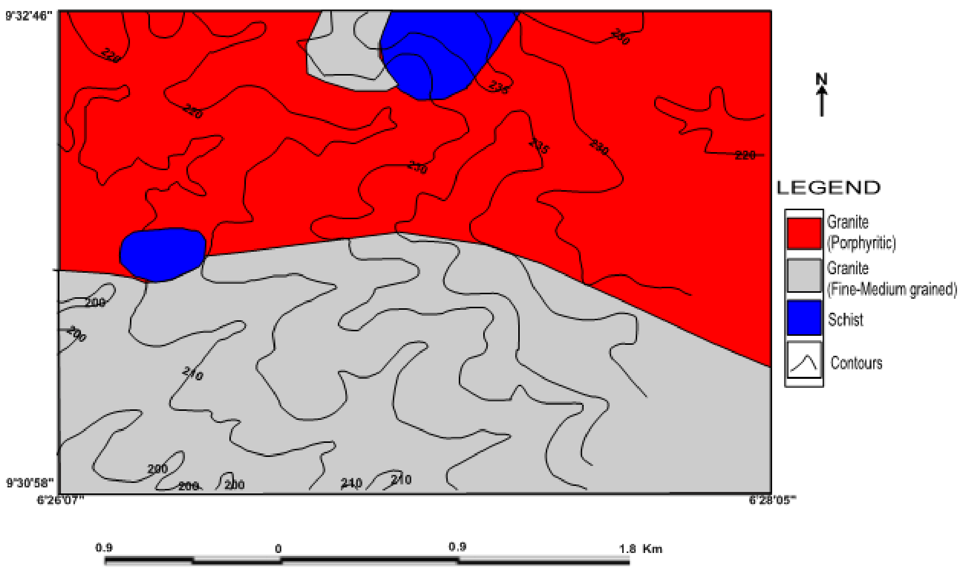

Figure 2. Geology of the study area.

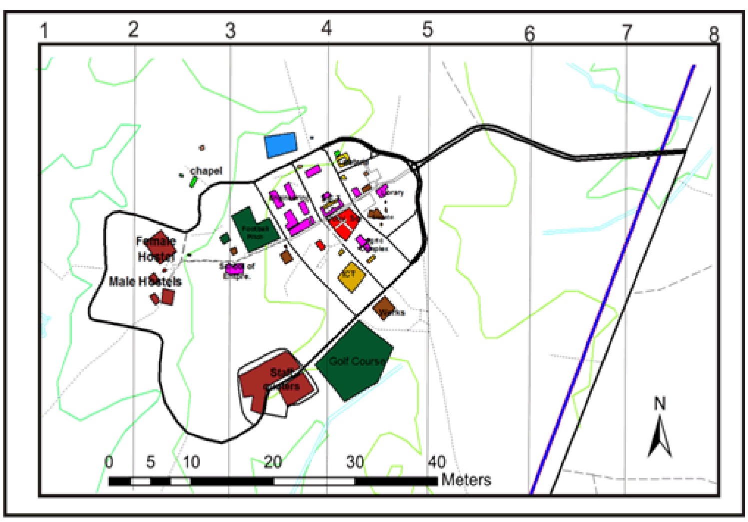

Figure 3. Location of sounding stations and orientation of profiles.

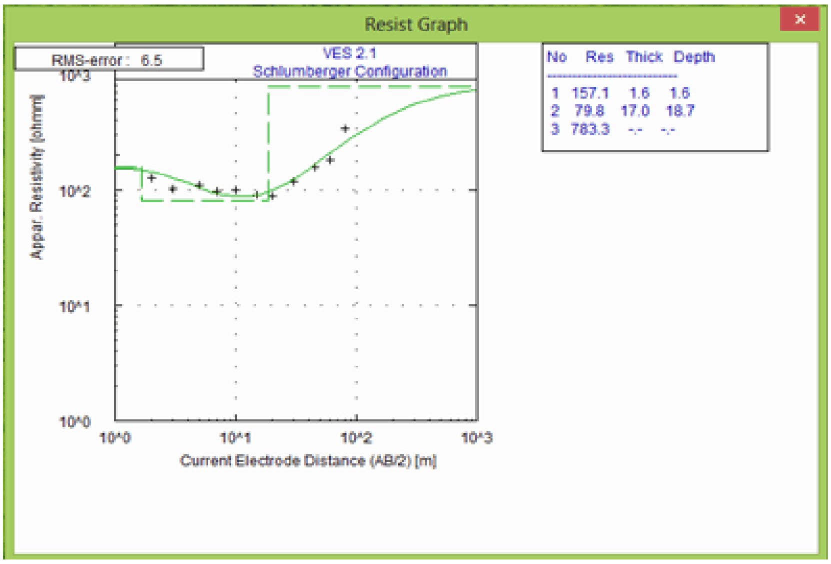

Figure 4(a). Typical VES curve type of the study area.

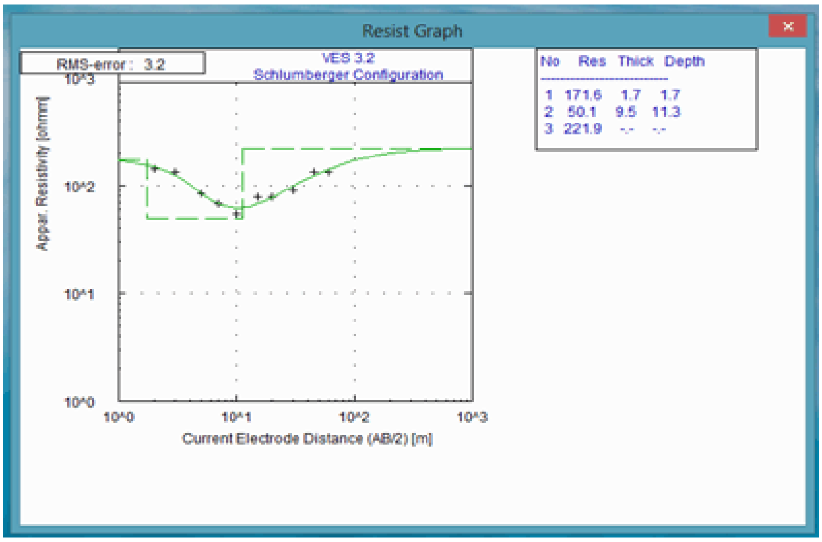

Figure 4(b). Typical VES curve type of the study area.

Table 1. Interpreted Ves Data

PROFILE/VES STATION	VES STATION 1							VES STATION 2							VES STATION 3						
	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type
	ρ1	ρ2	ρ3	d1	d2	d3		ρ1	ρ2	ρ3	d1	d2	d3		ρ1	ρ2	ρ3	d1	d2	d3	
1	132.8	16.0	176.8	0.4	3.0	∞	A	189.6	20.3	1409.0	3.1	7.8	∞	H	256.3	54.4	19913.6	3.8	10.6	∞	H
2	204.3	88.5	1082.5	0.8	22.1	∞	H	86.5	39.3	747.1	1.3	3.2	∞	H	8.2	68.6	737.8	0.4	22.9	∞	A
3	229.8	497.2	133.3	7.4	19.3	∞	Q	172.6	50.4	210.1	1.7	11.0	∞	H	25.2	87.2	759.0	0.6	20.2	∞	A
4	24.2	30.4	1836.9	4.7	8.6	∞	A	86.2	14.2	115.3	1.6	5.1	∞	H	12.6	55.8	267.7	5.1	7.3	∞	A
5	61.4	311.8	8358.1	2.7	20.8	∞	A	187.9	67.6	858.0	1.5	9.5	∞	H	2.8	111.8	153.1	0.3	30.1	∞	H
6	54.2	311.6	965.2	3.6	7.2	∞	A	28.0	237.3	2038.7	2.3	5.0	∞	A	153.2	54.4	8585.4	2.4	5.6	∞	H
7	162.6	20.3	18033.3	1.1	6.5	∞	H	34.5	3076.9	100000.0	0.8	2.3	∞	A	163.1	661.7	100000.0	2.9	3.9	∞	A
8	4.1	109.2	1381.3	0.7	11.8	∞	A	33.9	991.8	24325.2	0.3	29.3	∞	A	211.3	60.7	3497.9	1.4	7.0	∞	H

Table 2. Interpreted Ves Data (Continues)

PROFILE/VES STATION	VES STATION 4							VES STATION 5							VES STATION 6						
	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type	RESISTIVITY(ρ)(Ωm)			DEPTH(m)			Curve Type
	ρ1	ρ2	ρ3	d1	d2	d3		ρ1	ρ2	ρ3	d1	d2	d3		ρ1	ρ2	ρ3	d1	d2	d3	
1																					
2																					
3	133.9	64.0	35831.2	2.0	4.8	∞	A	45.4	397.2	2253.3	2.3	15.8	∞	A	83.7	776.6	63820.6	1.2	5.7	∞	A
4	6.1	626.5	1284.5	0.4	22.5	∞	A	44.4	64.8	10057.3	5.8	8.3	∞	A	28.5	433.6	3839.4	3.7	8.5	∞	A
5	4.5	109.6	1747.7	0.4	9.0	∞	A	28.6	182.1	4051.8	3.9	8.7	∞	A	15.0	340.9	8769.6	2.7	5.7	∞	A
6	36.4	149.3	614.7	0.7	59.5	∞	A	224.3	146.8	11086.7	3.8	10.3	∞	A	27.5	112.1	2443.3	3.6	7.1	∞	A
7	8.1	77.3	2811.3	1.7	7.0	∞	A	106.0	148.0	1372.7	3.1	39.0	∞	H	105.1	17.2	1128.4	1.4	4.1	∞	H
8	123.0	19.1	2945.0	1.1	3.3	27.6	HK	14.4	65.6	481.8	1.5	10.2	∞	A	45.8	115.0	393.5	4.4	10.5	∞	A

3.2. Electrical Resistivity Pseudosections

On the electrical pseudosections, fractures are interpreted at places with tight contours [10], [11]. Profile 1 does not reveal any significant fracturing or intrusions. Profile 2 reveals a highly resistive stratum around VES 2.2 and this is inferred to be a dyke. Fractures are also inferred in profile 3(Figure 5) between VES station 3.3 and 3.4. Profiles 4, 5 and 8, show almost the same image. An interesting 2-D image of the subsurface is found in profile 6 (Figure 6). In the sounding stations between 6.4 and 6.6, an intrusion, inferred to be a dyke, is found to be almost outcropping to the surface. In the sounding station between 6.1 and 6.3, a similar picture is observed, but the dyke here seems to be broader and more deep seated.

3.3. Geoelectric Sections

The geoelectric sections were drawn using the interpreted resistivity values at each sounding station from the North to South of the profile. It can be deduced that the top soil generally has a thickness of about 2m in all the profiles except in profile 5 (Figure 8), where it has a thickness of about 15m in the central portion. The clay layers are 2m - 4m thick in all the profiles except in Profile 4 (Figure 7), where it has thickness of 25m. Thicknesses of laterites in all the profiles are between 10m and 26m. The weathered rock layers have thicknesses ranging from 24m to 50m.The fresh rock has infinite thickness. The geoelectric sections also show that the depth to the basement varies across the sounding stations.

3.4. Isopach Map of Depth to Basement

The isopach map of depth to basement shows that the whole of the study area has undergone varying degrees of weathering (Figure 9). The basement also has undergone an appreciable amount of weathering and fracturing. The northern portion of the basement, especially in profile 3, has been found to have undergone a small amount of weathering, so also in the southern portion between profiles 4 and 6. The isopach map also reveals another small amount of weathering between profiles 4 and 5 in sounding station number 3.

3.5. Fracture Map of the Study Area

The fracture map of the study area was made from the pseudosections (Figure 10). Fractures are interpreted at places of tight contours in the pseudosections. These points were marked and superimposed on the topographic map of the study area. The fracture map shows intense fracturing in profile 6. Other profiles have shown fracturing in varying degrees. In general, the fractures are oriented in the NE-SW direction and they are aligned in the direction of the stream valleys. The Rosette diagram (Figure 11) of the study area has also yielded similar results. Hence, it can be deduced that there is a strong correlation between fractures mapped at the surface and that interpreted in the subsurface using geoelectric methods.

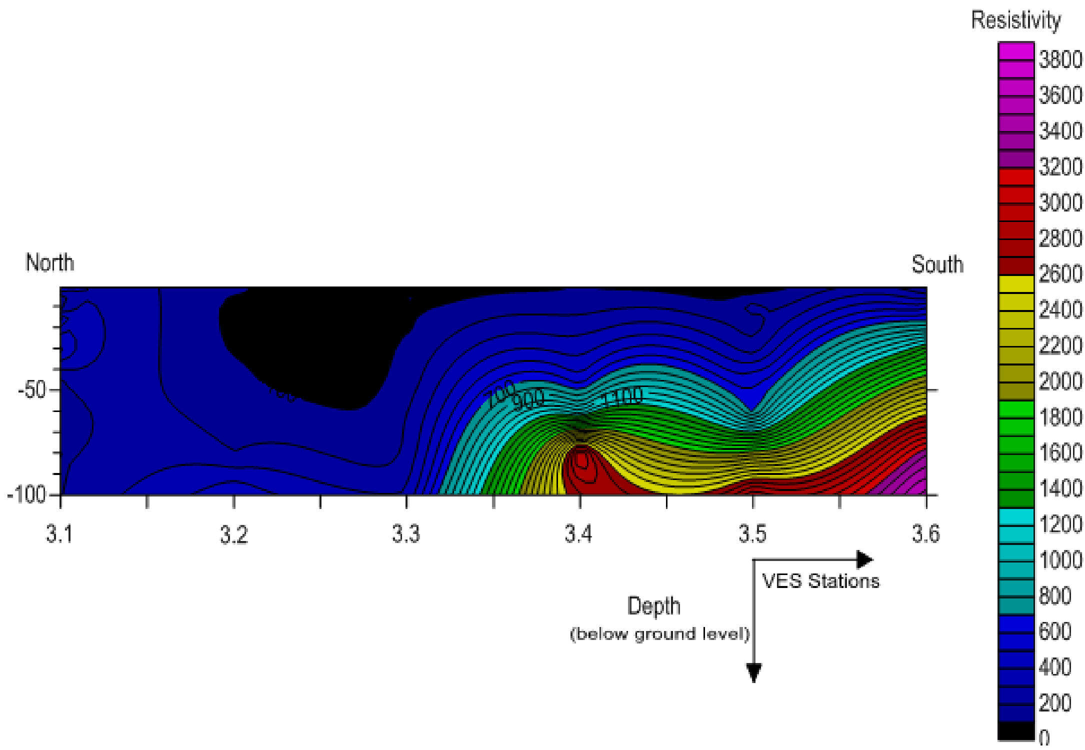

Figure 5. Electrical Resistivity Pseudosection of Profile 3.

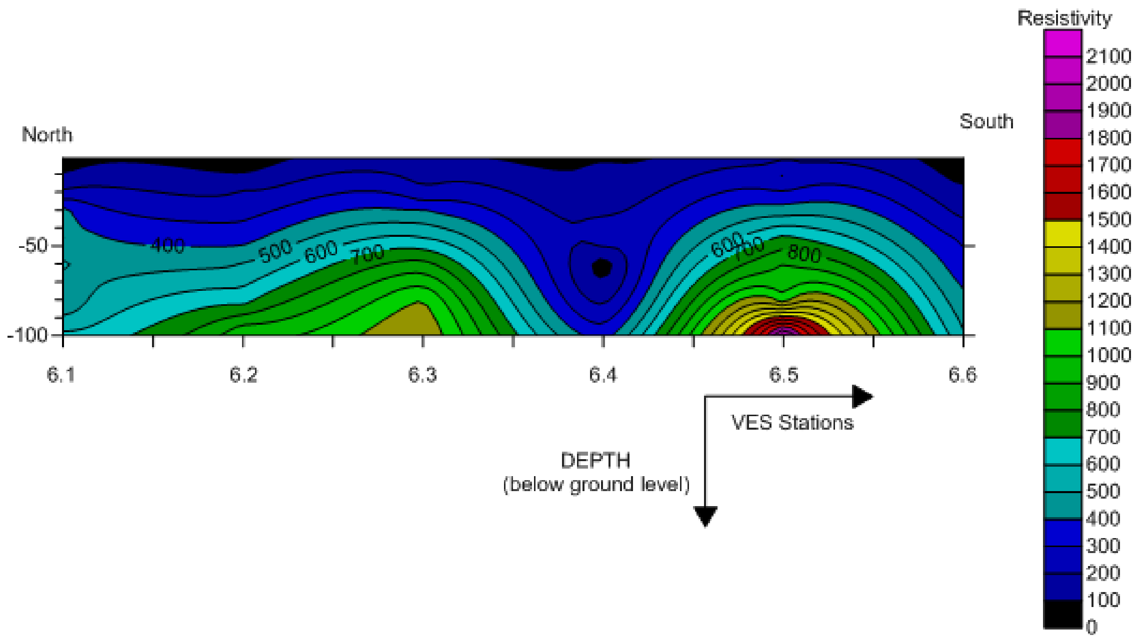

Figure 6. Electrical Resistivity Pseudosection of Profile 6.

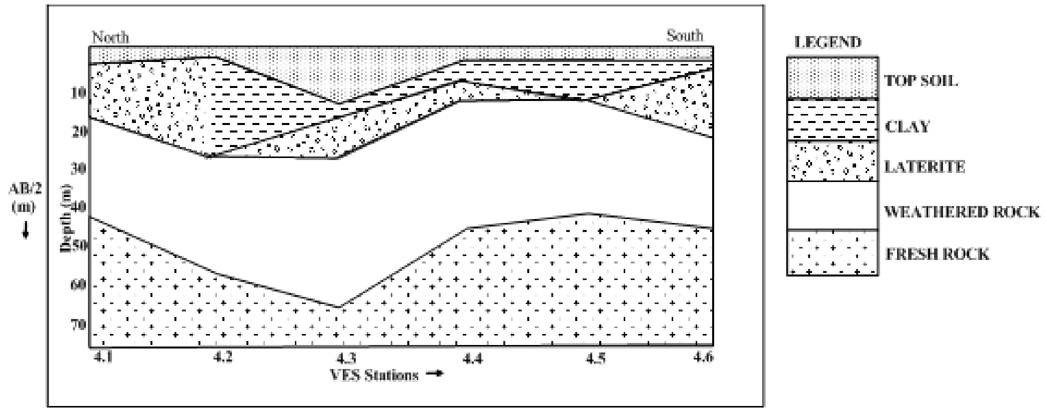

Figure 7. Geoelectric Sections of profile 4.

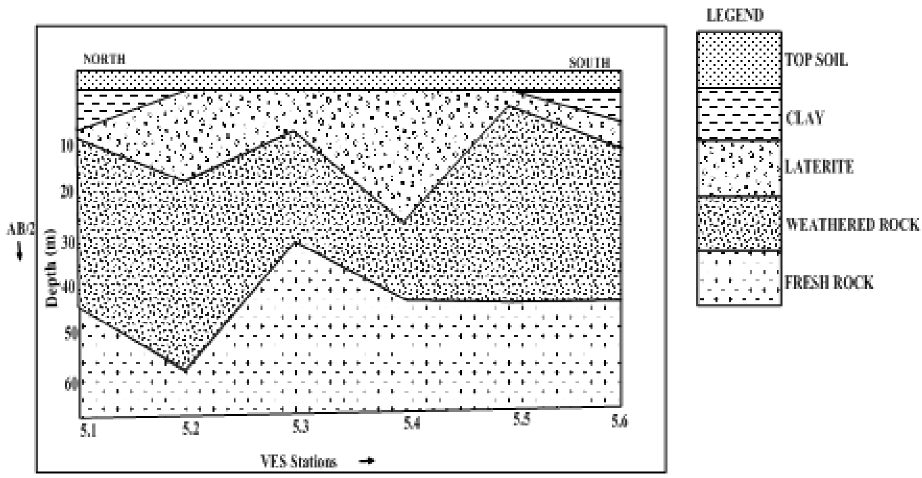

Figure 8. Geoelectric Sections of profile 5.

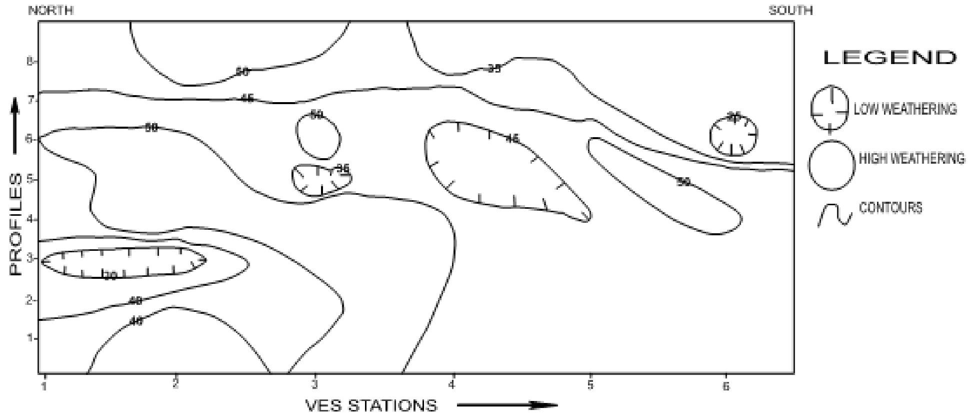

Figure 9. Isopach Map of Depth to Basement.

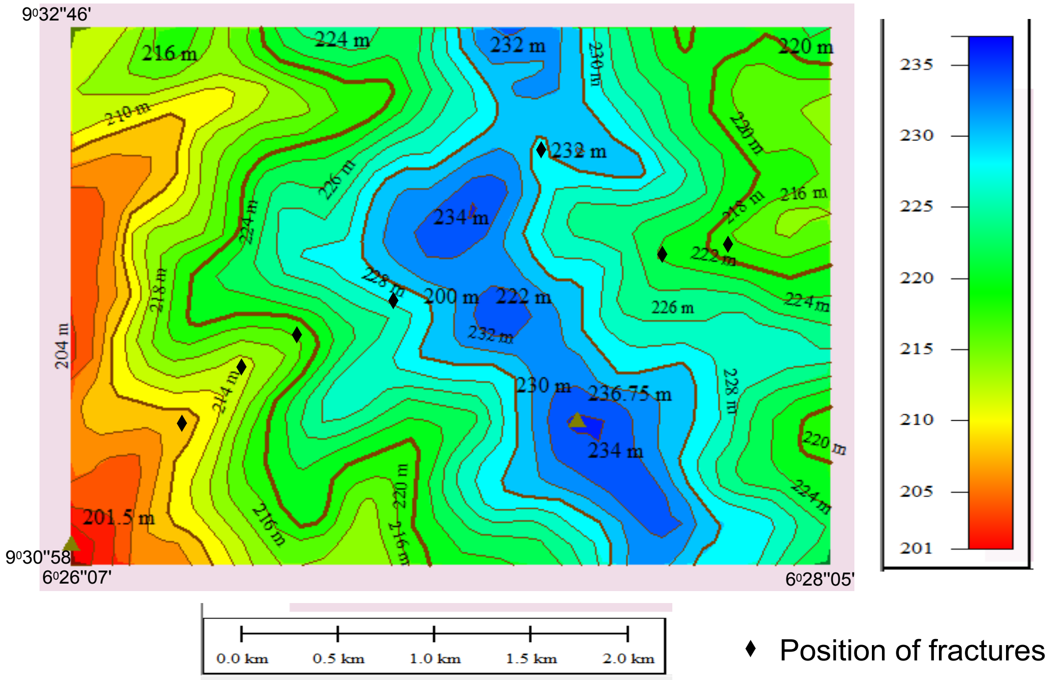

Figure 10. Fracture Map of the study area.

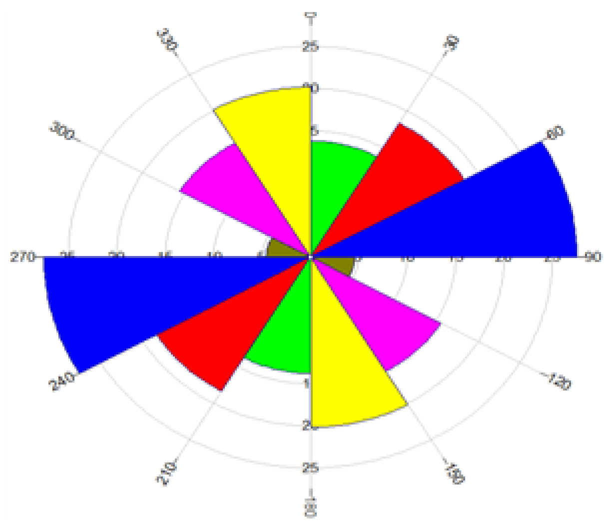

Figure 11. Rosette Diagram showing the frequency of orientation of joints and fractures.

4. Discussion

An in-depth analysis of the various results obtained from the techniques applied in appraising the groundwater potential of the study has yielded very important findings. The difference in the resistivity values of the VES curves especially for the top soil layers is due to the composition and saturation of the top soil. This variation is due to the degree of compaction of the top soil. The thickness of the topsoil layer is an important hydrogeologic consideration in groundwater development in the basement terrain [12].This is because water gets into the saturated zone through the top soil layer. The middle layers also play an important role. This zone, which is the weathered and/or fractured layer is the zone where the likelihood of locating good groundwater storage is quite high. Thicknesses above 15 m are always preferred.

The fresh basement is made up of infinitely resistive rock in all the stations. It forms the bedrock. The rocks in this zone are hard with no permeability and hence, it is not a water bearing zone.

In fresh non – fractured rock, the porosity is often less than 2.5% and as a result, runoff is high and infiltration rate is extremely too low. Hence, accumulation of groundwater is almost non-existent.

When the isopach map is compared with the pseudosections, a good picture emerges. From this, it can be inferred that the areas of low weathering are due to the number of intrusive dykes in that portion. Regions of high weathering in the map can also be attributed to the process of fracturing as observed in the pseudosections. Hence, from all these deductions it is inferred that the regions that have undergone high weathering, which also coincides with regions of fractured rocks, can be best exploited for groundwater. Hence, judging from this result, it can be said that the drainage pattern in the study area is structurally controlled.

5. Summary of Findings and Conclusion

Groundwater exploration in the basement is based on two criteria: weathered regolith and fractured rocks. The VES gives the weathering thickness in each station. Horizontal Resistivity Profile also gives places of low resistivity coinciding with the deep weathered regolith, while high resistivity coincides with shallow weathering and fresh rock. Sounding – Profiling revealed places of fractures and places of weathering, while the Isopach map of depth to basement showed places of low weathering and high weathering. So a combination of Horizontal Resistivity Profile, VES and Sounding – Profiling were used to recommend priority stations for the study area. The interpreted results obtained from the study area are represented by geoelectric layers which show the sequence and relationships between the subsurface lithologies. On the basis of the information obtained from the interpretation of VES data, the area is generally characterized by three geoelectric layers.

Layer 1: The top soil varying from sandy to lateritic soils have thicknesses ranging from 0.2 m to 7.4m

Layer 2: The weathered layer has an average thickness of 0.3 m to 58.8 m.

Layer 3: Basement rocks with infinite resistivities and thickness underlies the weathered regolith.

The mean depth to bedrock has been computed as 35 m. The VES reveal that the basement rocks are either weathered or fractured in some places judging from their resistivity values. But where located, the fractures are deep seated. It is important to note that good prospects for groundwater occur in the intermediate zone. However, the aquifers are more productive at the base of weathered zone where the rocks have been broken down into sand-size and larger fragments that are not subjected to the extensive weathering process.Based on all the findings made in the interpretation of the VES data, eight VES stations have been chosen as the most viable stations for the development of groundwater resources in the study area. These include VES stations 2.1, 2.3, 3.3, 5.1, 5.3, 6.4, 7.5 and 8.2. These VES curves feature a maximum of three geoelectric layers (Table 3).

In conclusion, the study area has a very high potential for groundwater development. Despite all the limitations of the VES technique, it has been found to be reliable for groundwater exploration in the Basement Complex terrain particularly when using the Schlumberger Configuration and combining it with adequate geologic mapping and using computer aided interpretation for the survey data.

Table 3. Summary of findings for viable locations.

VES STATION NO.	GEOELECTRIC LAYERS					
	TOP SOIL		WEATHERED ROCK		BEDROCK	
	RESISTIVITY(Ωm)	THICKNESS (m)	RESISTIVITY(Ωm)	THICKNESS (m)	RESISTIVITY(Ωm)	THICKNESS (m)
2.1	204	0.8	89	21.2	1083	∞
2.3	8	0.4	69	22.9	738	∞
3.3	25	0.6	87	20.2	759	∞
5.1	61	2.7	312	20.8	8358	∞
6.4	6	0.4	627	22.5	1284	∞
7.5	106	3.1	148	39.0	1373	∞
8.2	34	0.3	992	29.3	24325	∞

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