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Groundwater Investigation in Parts of Kaduna South and Environs using Wenner Offset Method of Electrical Resistivity Sounding

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Abstract

The Wenner offset system of electrical resisitivity sounding and its multicore cable was used to carry out resistivity survey, in parts of Kaduna town and environs in the Basement Complex of Northern Nigeria. The study is aimed at preliminary appraisal of the groundwater potential of the study area. Thirteen sounding points were taken at various point of interest using Abem terrameter SAS1000.The readings were at spacings of 0.5, 1, 2, 3, 4, 8, 16, 32, 64, and 128m.
The field obtained were plotted and subjected to quantitative and qualitative analysis. The layers, resistivities, thicknesses, the depth to basement, and the groundwater potential were deduced. The study area revealed four to six geoelectric layers, consisting of topsoil (laterite, sand and clay), lateritic clay, sand and clay), (sandy clay) highly weathered basement, partially weathered/fractured basement rocks units and fresh basement rock or bedrock. The highly weathered basement/partially weathered and fractured layers constitute the main aquifer unit and with varied potentials in the study area.

Keywords: Wenner offset, multicore cable, geoelectric layer, weathered basement, partially weathered basement, main aquifer, and fresh basement.

1 Introduction

The "OFFSET" sounding method is useful for reducing the effects of lateral resistivity variations (Barker, 1981). Further advantages of the system are; decrease in manpower, increase in output, increase in quality of measurements, spacing errors are eliminated and the system is easily portable. The Wenner offset electrical resistivity method was used to

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delineate the different sub-surface structure and its influence on the general hydrogeological conditions in the study area.

The present study started with the review of some previous works (Carpenter and Habberjam, 1956; Barker, 1989; Jatau, 1998, 1999; Jatau and Faladun, 1999; Jatau, and Ajodo, 2005; Jatau et al, 2004) with particular references to ground water geophysical investigation.

2 The Geology and Physiography

The area understudy is underlain by Precambrain rocks of the Nigerian Basement Complex. The weathering of the crystalline Basement Complex rocks under tropical condition is well known to produce a sequence of unconsolidated material whose thickness and lateral extent vary extensively (Dearmaun et al., 1978). Groundwater localization within the Basement Complex occurs either in the weathered mantle or in the fracturing, fissuring and jointing systems of the bedrock (Jones, 1985; Ako and Olorunfemi, 1989; Olayinka and Olorunfemi, 1992). These unconsolidated materials are known to reflect some dominant hydrologic properties, and the highest groundwater yield in Basement Complex area are found in areas of thick overburden overlying fractured zones and are characterized by relatively low resistivity. (Aderinto, 1986; Olorunniwo and Olorunfemi, 1978; Olorunfemi and Fasuyi, 1993).

The area is bounded by latitudes 10^0 25′ 28″ N and 10^0 35′ 53″ N and Longitudes 7^0 21′ 49″ E and 7^0 30′ 00″ E. It lies within parts of Kaduna South, Chikun, Kaduna North, Igabi and Narayi Local Government Areas of Kaduna State. It covers an area of approximately 268.36Km^2, in the Basement Complex of North Central Nigeria (Fig. I).

The Basement Complex rocks in the areas are mostly migmatite, granite gneiss, undifferentiated schists and porphyritic biotite grantite (Fig. 3; GSN Bulletin, 2644).

The study area lies within the Guinea Savannah belt, which experiences the tropical Savannah climate with two distinct seasons.

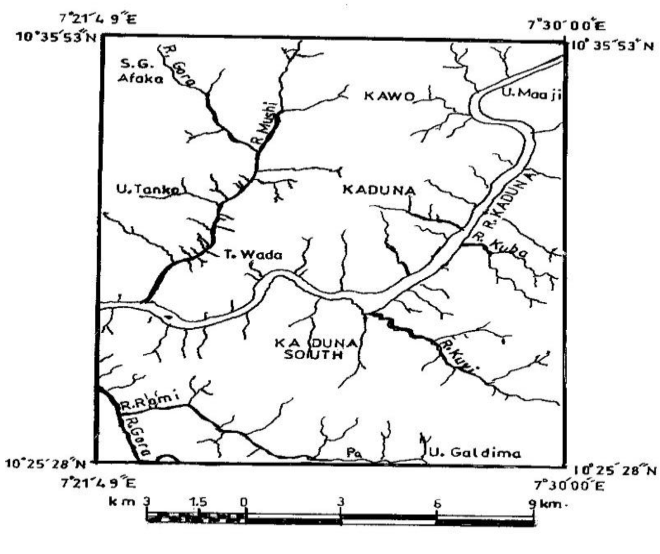


Figure 1: Map of the study area (Extracted and modified from topographical map sheets 123 S.E. and 144 N.E. produced by Federal Survey 1980)

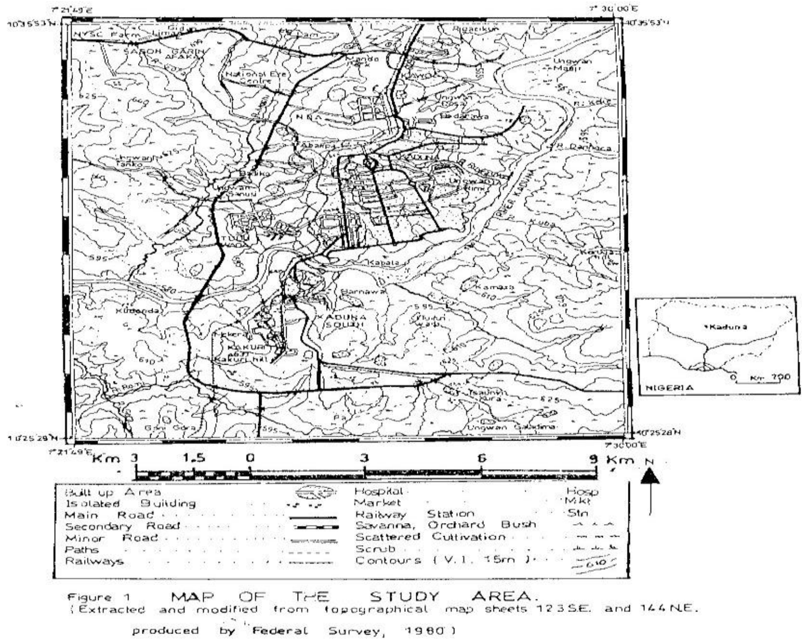


Figure 2: Drainage map of the study area (Extracted from topographical map sheets 123 S.E. and 144 N.E. produced by Federal Survey 1989)

The dry season normally begins in October/ November to March/April, while the wet season occurs between April/May to October/November. The study area is drained by River Kaduna and its tributaries such as Gora, Mushi, Ruwauwei, Keke, Danhora, Kuba, Kuyi and Romi (Figs. 1 and 2).

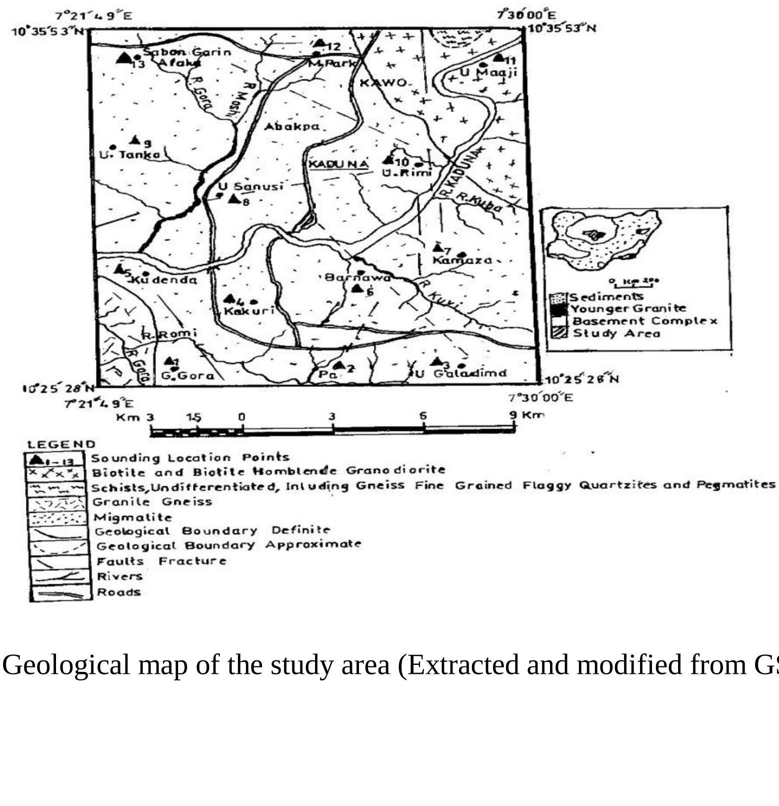


Figure 3: Geological map of the study area (Extracted and modified from GSN, 2644)

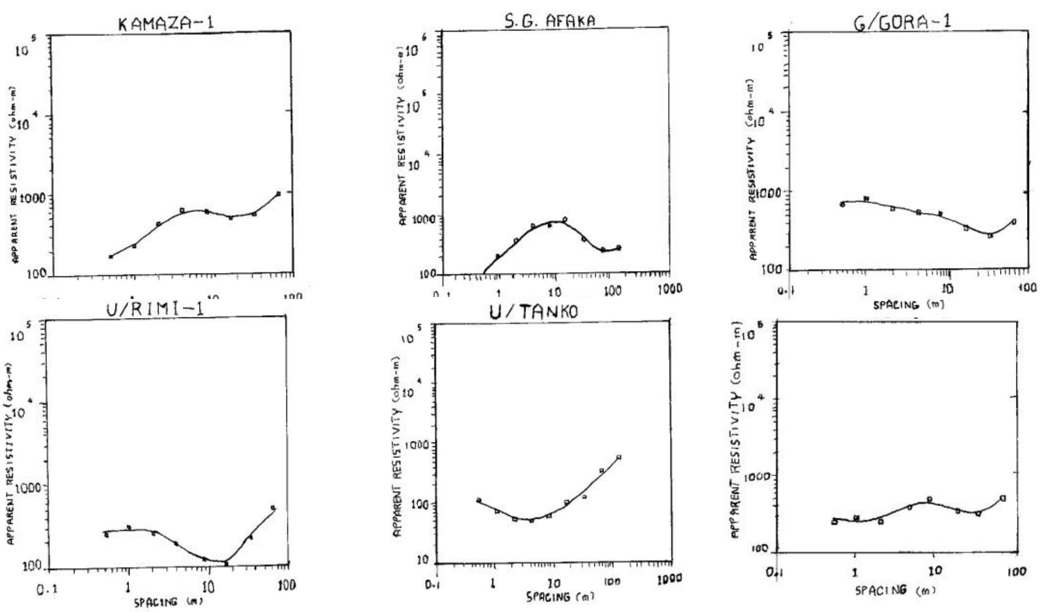
The area is generally part of the extensive but gently undulating peneplain, capped at high elevation by patches of laterised terraces of iron oxides, concentration of broken–up concretion ironstones and some quartz.

3 Method of Study

Thirteen Wenner offset electrical soundings (Fig.3) were conducted in thirteen locations in Kaduna town and environs. The Wenner offset field curves are shown in (Fig. 4). The soundings curves whose geoelectric layers vary from four to six are of the HA, KH QH, HKH, and KQH type (Keller and Frischkneth, 1966). These curves were quantitively interpreted by partial curve matching and computer iteration techniques using a computer programme (Resix Plus v2.20, 1993). The quantitative summary results are presented in Table 1.

Table 1: Quantitative Interpretation Data (Summary) for Offset Wenner

VES Location	**Layer's resistivity (ohm-m)**						**Layer's thickness (m)**					**Depth to base-ment**	**No.of layers & bearing of points**
	1	2	3	4	5	6	1	2	3	4	5		
Pa	737	211	397	121	4015	-	1.1	4.8	6.3	15.7	-	27.9	5 ()
Barnawa	216	202	115	1931	-	-	1.7	2.4	14.4	-	-	18.5	4 ()
Kamazo	147	2857	232	415	4635	-	0.8	1.6	12.9	6.7	-	22.0	5 ()
U/Rimi	303	430	49	106	2489	-	1.0	2.0	5.8	6.3	-	15.1	5 ()
U/Maaji	113	2602	268	156	503	-	0.4	1.1	15.2	16.5	-	33.2	5 ()
Mando Pack	228	32	257	70	799	-	1.5	11.1	16.5	19.7	-	48.8	5 ()
Sabon Garin Afaka		1444	783	103	195	302	0.2	6.0	5.7	13.2	13.0	38.1	6 ()
U/Tanko	129	43	67	107	2673	-	0.6	2.9	4.8	13.5	-	21.8	5 ()
U/Sanusi	143	714	30	31	51	665	0.4	1.6	5.0	8.7	4.7	20.4	6 ()
Kudenda	1357	158	161	88	116	656	1.2	0.9	7.5	10.8	10.1	30.8	6 ()
Goni Gora	772	376	1024	104	200	1046	1.3	2.1	3.7	8.4	15.6	31.1	6 ()
Kakuri	286	140	1701	82	230	2132	0.9	0.9	2.8	70.2	9.9	21.7	6 ()
U/Galadima	1218	950	309	123	125	1621	1.3	2.4	5.4	7.9	12.9	29.9	6 ()



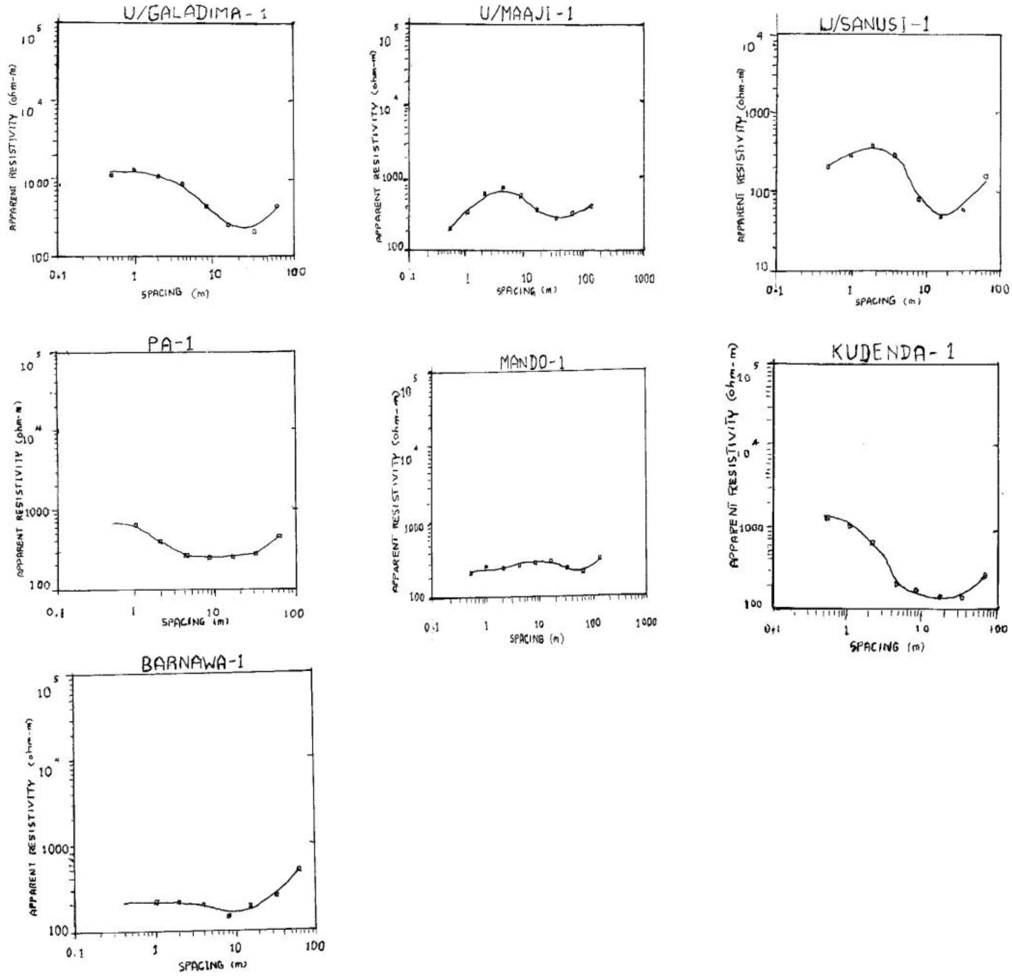


Figure 4: Field curves

4 Result and Discussion

4.1 Geoelectric Parameters

The offset Wenner interpretation results (Table1), revealed four layers case for Barnawa, with topsoil being sandy clay with thickness of 1.7m and resistivity value of 216Ωm. The second layer composed of lateritic clay has a thickness of 2.4m and resistivity value of 202Ωm. The third layer, probably a weathered layer or fractured basement with resistivity values and thickness of 115Ωm and 14.4m respectively, is underlain by fresh basement with resistivity value of 1931Ωm. Kamaza, U/Rimi, U/Maaji, Mando Park, U/Tanko and Pa has five layers consisting of top layer (sandy clay, lateritic clay, clay, clayey sand and sand) with resistivity ranging from 113 to 303Ωm and layer thickness varying from 0.2-1.5m.

The second layers are lateritic, clay and laterite. Their resisitivity ranges from 43Ωm-286Ωm and thickness ranges from 1.1-11.1m. The third layer, probably lateritic clay and sandy clay. Their thickness and resistivity ranges are 4.8-16.5m and 67-397Ωm respectively. The fourth layer, being weathered basement rock units, with resistivity and thickness ranging from 70-415Ωm and 6.3 to 19.7m respectively. The last layer is the fresh basement rock unit with resistivity values of 503- 4635Ωm.

Six layers cases were recorded for U/Sanusi, Kakuri, Gonigora, Kudenda, Sabongari Afaka and U/Galadima. The prevalent topmost layers are sandy clay, clay and laterite. The resistivity ranges are 26-136Ωm and thickness ranges from 0.2-1.3m.

The second layer consists of laterite, sand and clay. The thickness and resistivity value ranges from 0.9-6m and 140-1444Ωm. The third layer consists of laterite, sandy clay and clayey sand. The thickness values ranges from 2.8-7.8m and resistivity values range of 30-1700Ωm.

The fourth layer with thickness and resistitivity ranges between 7.9-13.2m and 31-123Ωm respectively. This consists mainly of highly weathered/ fractured basement rock units. The fifth layer being partially weathered or fracture basement rock units. The thickness and resistivity values range are 4.7-15.6m and 51-230Ωm. The last layers being fresh basement rock unit with resistivity ranges 656-2132Ωm.

This information was plotted as histogram in terms of layer resistivity (Fig. 5a-f) and layer thickness (Fig. 6a-e). In Fig. 5a, the resistivity values vary from 26m-1400Ωm with the highest frequency in the 100-400Ωm range. The low resistivity end (< 400Ωm) is characteristic of sandy clay and laterite clay; on the other hand the high resistivity end (>400Ωm) is diagnostic of compacted sand clay, and laterites. The layer thickness varies from 0.2m to 2.8m (Fig.6a). The resistivity values for the second layer, laterite, lateritic clay, sand and clay (Fig.5b) varies from 500-2900Ωm range. The resistivity value in the 500-1500Ωm range is the most frequent. The low resistivity value in the (<500Ωm) is typical of laterite clay, while the high resistivity end (>1500Ω m) indicates highly compacted sand or simply laterite. The thickness of this zone varies from 2 to 12m (Fig 6b). The resistivity value for the third layer (lateritic clay, sand clay and clayey sand) is shown in Fig. 5c. It varies from 250-1600Ωm. The most occurring resistivity values fall within the 250-1000Ωm range.

The low resistivity values (<100Ωm) is diagnostic of lateritic clay with gravels, while the high resistivity end (>1000Ωm) is typical of compacted sand clay and clayed sand. The thickness varies from 3-18m (Fig.6c). Fig. 5d shows the resistivity histograms for the highly weathered layer/basement. The resistivity frequency value lies between 100-150Ωm. The encountered resistivity values vary between 50 and 150Ωm. The lower limit of the resitivity value is (< 50Ωm) characterized a good degree of weathered basement, while the upper limit (>50Ωm) depicts moderate good weathered basement.

This layer depends on the sand to clay ratio and degree of saturation. The clayey sand-sand layer has a high sand content which increases the resistivity value, and perhaps the hydraulic conductivity and transmissivity (Odusanya and Amadi, 1990). The sand clay layer with high clay content imposes some confining characteristics on the aquifer zone (Dan Hassan and Olorunfemi 1990). A high degree of saturation may be responsible for

the low range of resistivity. The layer thickness varies from 6-14m (Fig.6d). This is the main aquifer zone.
The resistivity values for the moderate weathered basement rock units vary from 100-450Ωm (Fig.5e). The thickness varies from 4-20m (Fig 6e). This may correspond to fractured zones beneath the weathered layer. Fractured zones occur immediately beneath weathered horizon. In these places a relatively high ground water potential exists and can be tapped for boreholes (Dan Hassan and Olorunfemi, 1999). The resistivity value for the moderate weathered/fractured basement rock units varies from 100-450Ωm (Fig 5e). The thickness of these layers varies from 4-20m (Fig. 6e). This correspond to fracture zoned beneath the weathered layer.
The resistivity value for the fresh basement geoelectric units varies from 1000Ωm to 5000Ωm (Fig. 5f). This is in agreement with (Olayinka and Olorunfemi 1992) they stated that fresh bedrock resistivity exceeds 1000Ωm, but where it is fractured and saturated the resisitivity reduces to less than 1000Ωm.
The depth to bedrock in the study area varies from 15m to 49m. These are attributed to differential weathering effect of the basement and depositional processes.

4.2 Iso-Resistivity Map

The aquifer sensitivities of the study area obtained from the result of the processed date Table 1, were plotted and contoured as shown in (Fig. 7). This is the (weathered/fractured basement). The map reveals that River Kaduna and its tributaries flow within the basins of the basement depression. The structural pattern when compared with topographic and drainage maps it shows a good correlation. This gives an indication that the courses of the rivers are being controlled structurally (Dan Hassan and Olorunfemi 1999; Jatau and Ajodo, 2005).
The structural trend also confirms the direction of flow of the rivers and structural control pattern of the drainage system in the area along River Kaduna and other rivers in N-S, S-W, E-W and N-S directions. This tends to agree with (Olugboye, 1974; 1975 and Oluyide, 1988).

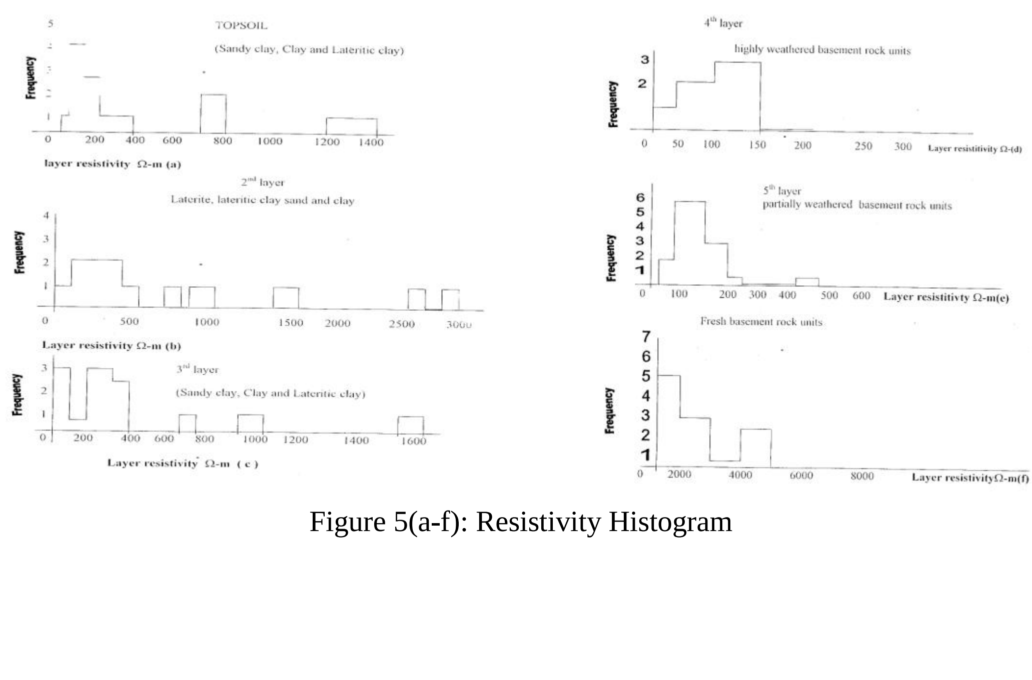


Figure 5(a-f): Resistivity Histogram

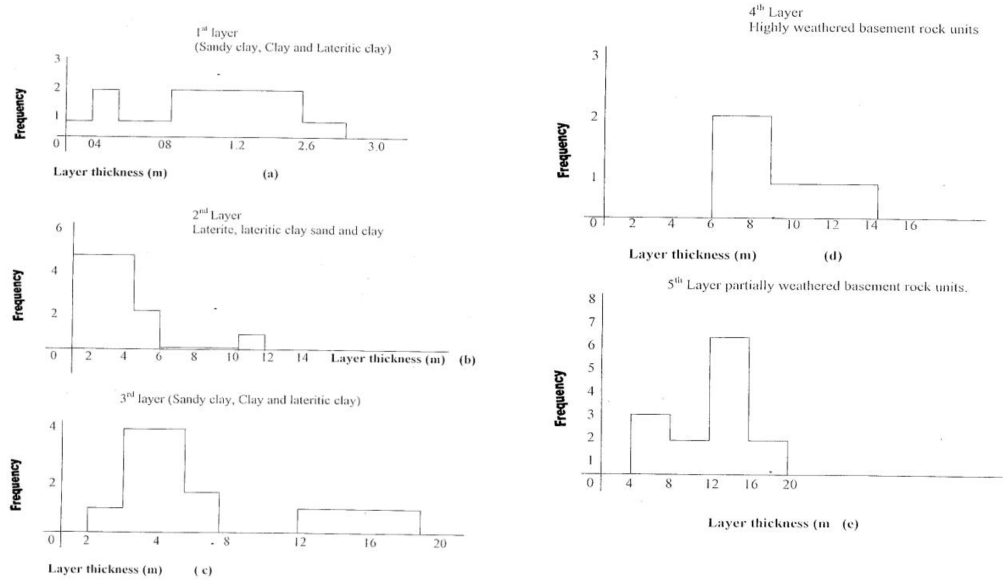


Figure 6(a-e): Layer thickness Histogram

4.3 Piezometric Map of the Study Area

The spot elevation values, obtained by subtracting the overburden thicknesses from the station (sounding points) elevation were plotted and contoured (Fig. 8). The piezometric map reveals six depressions (D_1-D_6) and five ridges (R_1-R_5). The depression trends approximately NE-SW, for D1, D2 and D5 N-S for D_6 and E-W for D_3. The ridges trend approximately NNE- SSW for R_3, ENE-WSW for R_2, NNE-SSW for R_4, NNE-SSW and NE-SW for R_5. This further confirms that the River Kaduna and its tributaries flow within the basement depression (basins) and that the rivers are controlled structurally as shown in the iso-resistivity map (Fig. 7).

4.4 Isopach Map

The depths to the fresh basement rock beneath the sounding points were rounded up to the nearest whole number as obtained from the quantitative analysis (Table 1), and contoured as shown in (Fig. 9) the depth to basement rock varies from 15 to 49m. The result is in a close range agreement with (Dan Hassan and Olorunfemi 1999). Predicted (4.3-64m); (Hassan, 1987) and (Shemang, 1990) both deduced (10-50m) in the study area.The map revealed shallow overburden areas like U/Rimi, Barnawa, U/Sanusi, Kamaza and U/Tanko (15-25m), with medium overburden attributed to areas between U/Maaji and U/Rimi, between kakuri, Pa and between Mando-park and U/Sanusi (26-30m). In areas like U/Galadima, Gonigora, Kudenda, U/Maaji, and Sabon Gari Afaki predicted the high overburden thickness, with the highest recorded for Mando Park. These areas also correspond to the basement depression areas. In the study area, with thick overburden, less percentage of clay, and good degree of porosity and permeability could have relatively good groundwater yield.

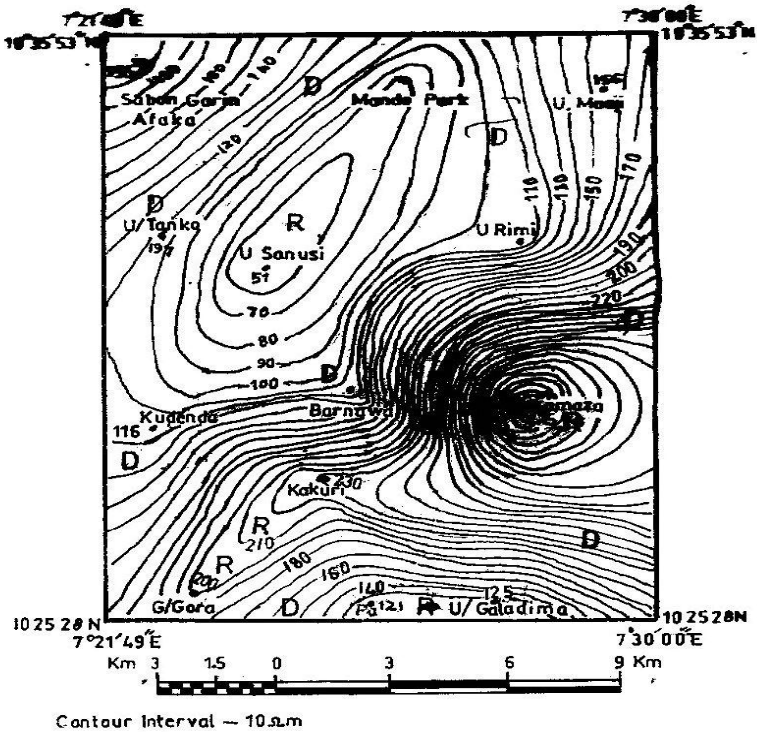


Figure 7: The Iso-resistivity map of the true aquifer

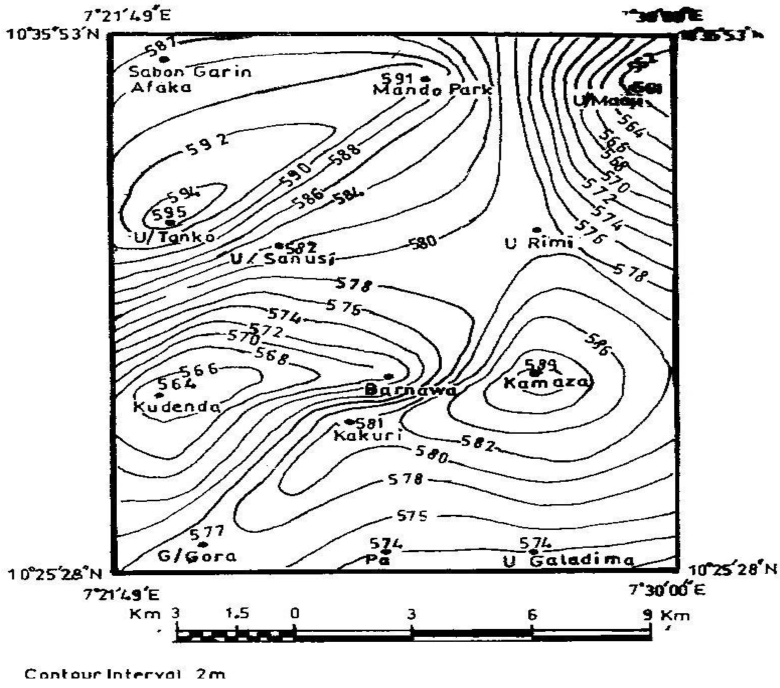


Figure 8: Piezometric map of the study area

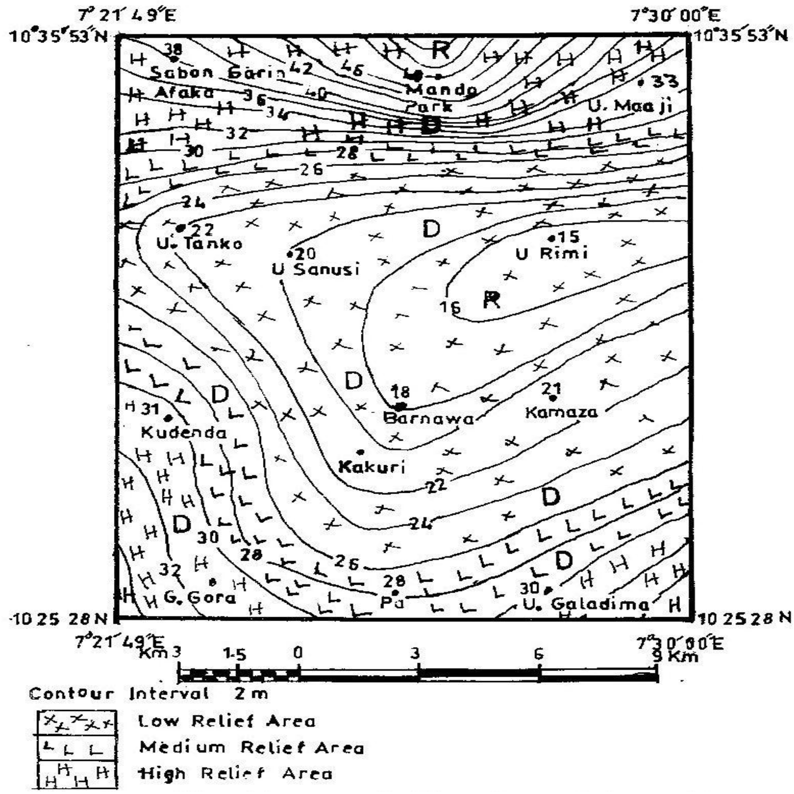


Figure 9: The basement map (depth) of the study area

4.5 Geoelectric/Lithologic Unit

The geoelectric section obtained from the quantitative interpreted results (Table 1) across Sabo Garin Afaka, Mando- park and U/Maaji (E-W) is depicted at (Fig. 10) and compared with a lithologic log obtained near U/Maaji (Latitude 10^0 35’ 53” N and longitude 7^0 30’ 10” E).

The geoelectric layers correlate with lithologic layers. The second geoelectric section was obtained across U/Rimi, Kakuri, and Goni-gora (NE-SW) as shown (Fig. 11) and correlated with a lithologic log near Goni-gora (10^0 25’ 28”N and longitude 7^0 21’ 49”E) revealed five to six geoeletric layers. The borehole log depicts eight different lithologic units implying that some of the geoelectric layers were merged together as a result of similarities in geoelectric properties of the layers.

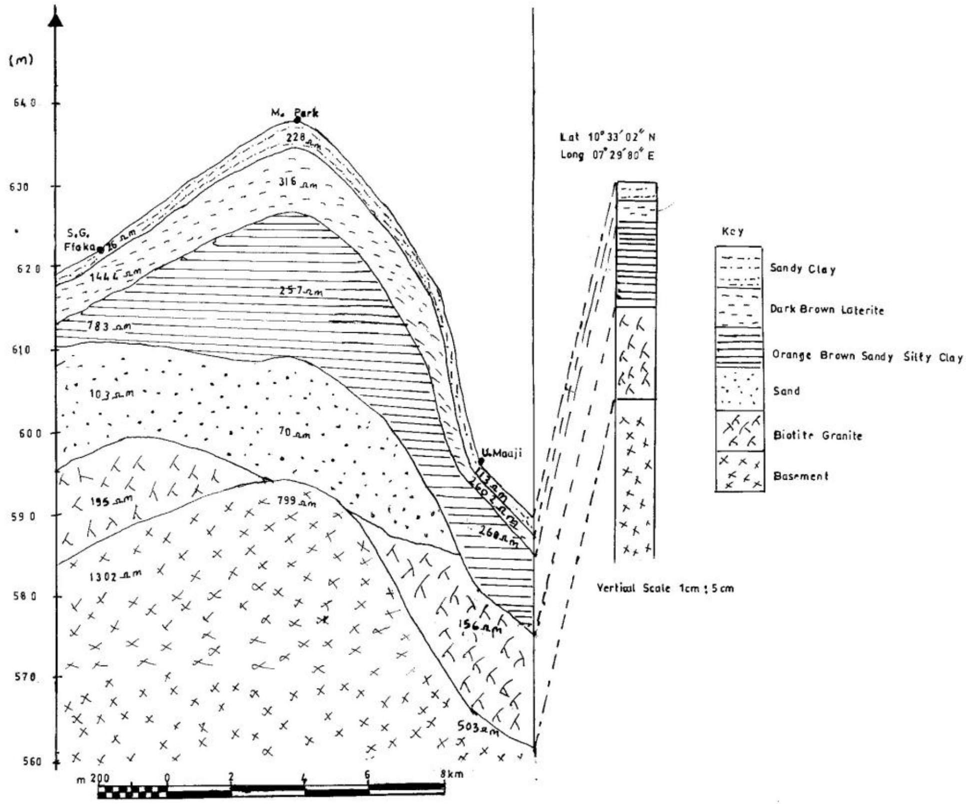


Figure 10: Geoelectric section across Sabon Garin Afaka, Mando Park and Ungwan Maaji and Borehole log (Geologic Section) (E-W)

5 Conclusion

The investigation revealed four to six geoelectric units the weathered fractured basement is believed to be the main aquifer. Two lithologic logs were used for correlation. River Kaduna and its tributaries river in the study area flow within the basement depressions, and are controlled structurally. The depth to basement (bedrock) varies from 15m-49m.

The water potential of the study area varied fro place to place, however high potential is recorded for Mando park, Sabo Gari, Afaka, U/Maaji, Goni-gora, U/Galadima and Pa, with true aquifer resistivity values range (70-700Ωm), overburden thickness range values 30-49m and apparent resistivity at AB/2=32m values range (919-369Ωm).

This is followed by U/Tanko, U/Sanusi, Kudenda, U/Rimi, and Barnawa with main aquifer resistivity values range (51-197Ωm), over burden thickness range values (15-22m) and apparent resisitivity at AB/2=32m being (126-147Ωm).

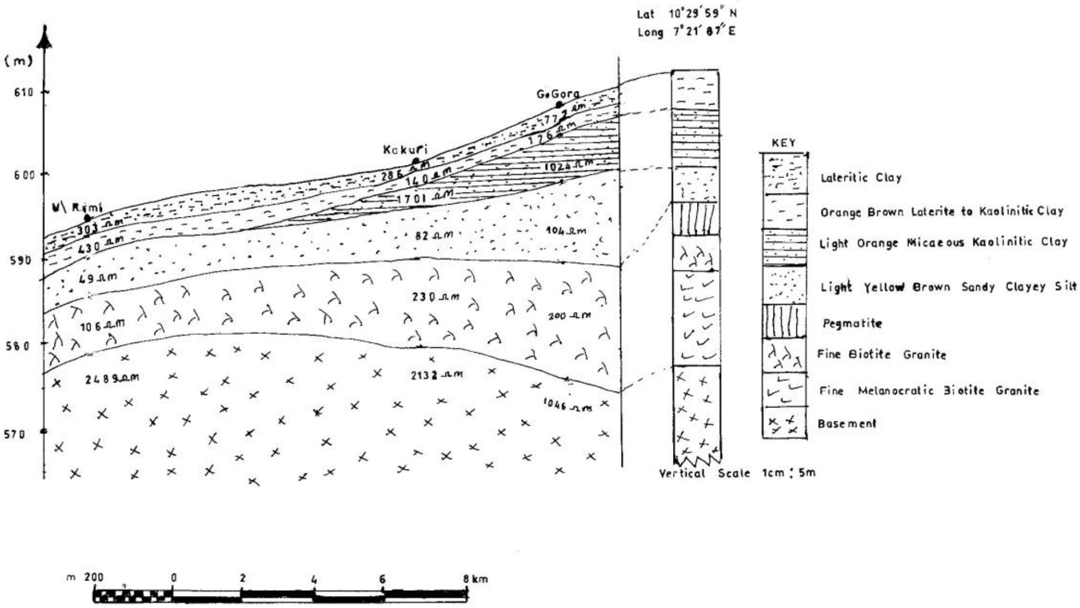


Figure 11: Geoelectric section across Ungwan rimi Kakuri and Goni Gora and a Borehole Log (Geologic Section) (NE-SW)

The areas between U/Rimi and Kamazo, Kamazo and Kakuri with the main aquifer resisitivity values range (230-290m) overburden thickness values range (20-21m) and apparent resisitvity AB/2=32m values range (300-335Ωm). These results favorable correlate with existing geology and some past work.

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