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Research paper

Geoelectric / hydrogeologic characteristics and aquifer types of ground water in the basement rocks of the area south of Zakum bello. Nasarawa state. north-central Nigeria

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Abstract

Interpretation of vertical electrical soundings (VES) and study of lithologic logs were carried out to identify the geoelectric/hydrogeologic characteristics of the Basement Complex rocks in the area south of Zakum Bello. Geoelectric sections drawn from the interpretation results (layer resistivities and thicknesses) reveal mainly four to five layers with the first four layers constituting the weathered basement. Two aquifer types were identified. These are fractured (confined) and weathered (unconfined) aquifer. Ground water yield varies from 0.63 L/S (for the weathered layer aquifer) to 0.28 L/S (for the fractured aquifer) making the weathered basement more prolific. The fracture occurred mainly in the gneiss and thickness ranges from 5 to 10m mainly within the depth of 15 to 40m. Chemical analysis of borehole, well and stream waters which include titrimetric method for chloride and bicarbonate, UV method for nitrate and calorimetric method for sulphate shows the water to be slightly acidic and indicate good water quality throughout the area despite the variation in lithologic units. Prospective borehole sites were recommended for villages or communities without borehole.

Keywords: *Basement Complex; Geoelectric; Aquifer; Chemical Analysis; Nassarawa; Nigeria.*

1. Introduction

The RUSAFIYA project (UNDP/Federal Government funded and World Bank executed demonstration rural water supply and sanitation project) was introduced in the then Plateau State but now Plateau and Nassarawa State in Nigeria in 1988. This is a community mobilization and development project through extension work and provision of portable ground water especially the then guinea worm endemic areas. Geophysical investigation of rock formations were made to assess and develop ground water resources for the purpose of sustainable rural water supply and sanitation facilities for communities. The project was abandoned midway. This work is a further assessment of areas not covered by the defunct RUSAFIYA project. The occurrences of ground water in the basement complex rocks of Nigeria (inclusive of the study area) is in porous and permeable weathered basement zones, or in joints/fractures, and characterized by relatively low resistivity. This forms the basis for the electrical resistivity method used in this study. The electrical resistivity method is one of the most relevant geophysical methods applied in ground water investigation in the basement terrain (Ako and Olorunfemi, 1989; Owoade and Moffat, 1989, etc.). Boreholes in the Nigerian basement complex are drilled to different depths depending on the aquifer thicknesses, fracture frequencies (though fracture frequencies decreases with depth) and depth to unfissured bedrock. Other reasons include choice of client, based on economy. The present study is continuation of work done earlier in providing sustainable rural water supply and sanitation facilities for communities in the area south of Zakum Bello; it involves field geology, geoelectric surveys and accessing borehole information to identify different aquifer types that characterized the basement terrain of the area. The study is also to determine the water quality and recommend borehole points for villages not originally covered by the RUSAFIYA project.

2. Geology

The project area is situated south of Zakum Bello which is in northern part of Nassarawa town in Nassarawa State, Keffi Sheet 208 (1:100,000). It lies between latitudes $8^0 36'$ N and $8^0 44'$ N and between longitudes $7^0 39'$E and $7^0 44'$ E. It covers approximately 35sq km (Fig. 1). The area is underlain by the Precambrian Basement Complex rocks of Nigeria. Identified lithological units include mica and amphibolites bearing gneiss, mica schist and quartzite at the boundary of the study area. Pegmatites also occur as simple pegmatites (dykes and veins) and complex pegmatites occurring as intrusions in the northwest covering about 1.5 sq km (Fig. 2).

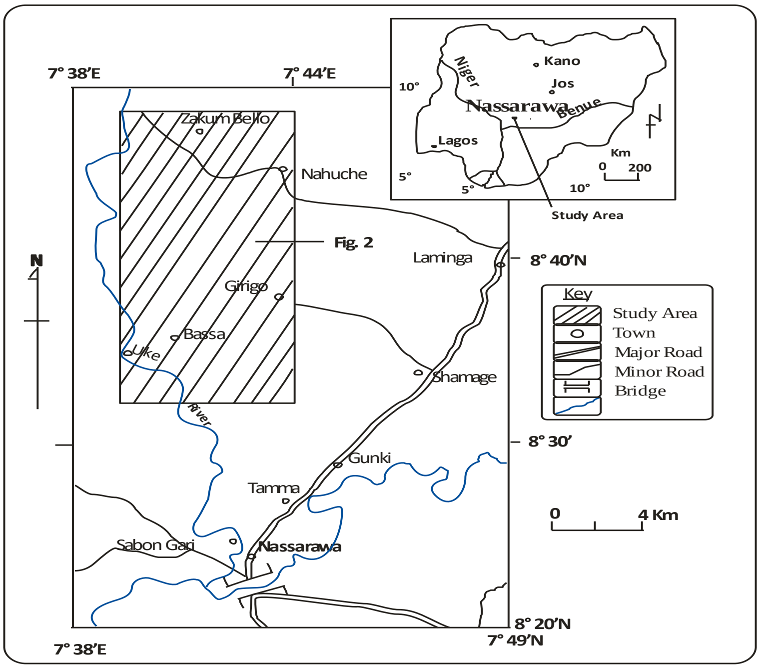

Fig. 1: Location Map of the Study Area.

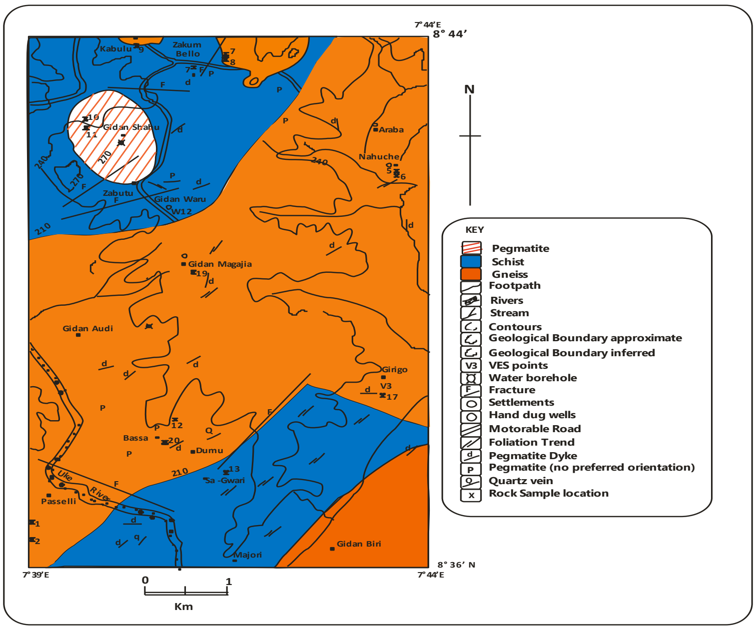

Fig. 2: Geology of the Study Area.

3. The geoelectrical survey

Resistivity survey of the area involved Wenner Vertical Electrical Resistivity Sounding (VES) using an ABEM Terrameter and apparent resistivity data were presented as depth sounding curves. 19 depth sounding stations were occupied (Fig. 3) in three major areas:

i) Areas close to existing boreholes in order to relate the sounding data with the lithologic logs of the borehole.
ii) Areas where schist/gneiss and schist/pegmatite contacts could not readily be ascertained and
iii) Areas where there are no boreholes in order to locate favorable sites for water extraction.

Apparent data were presented as depth sounding curve. A two two-fold interpretative approach, in which qualitative interpretation as outlined by Zohdy et al., (1974) was followed by various quantitative interpretation involving partial curve matching and computer iteration techniques. The VES geoelectric sections and probable geological interpreted results along the profiles (Fig. 2) were correlated with borehole lithological logs for formation (aquifer) identification and aquifer geoelectric parameters determination (Figs. 7 to 14).

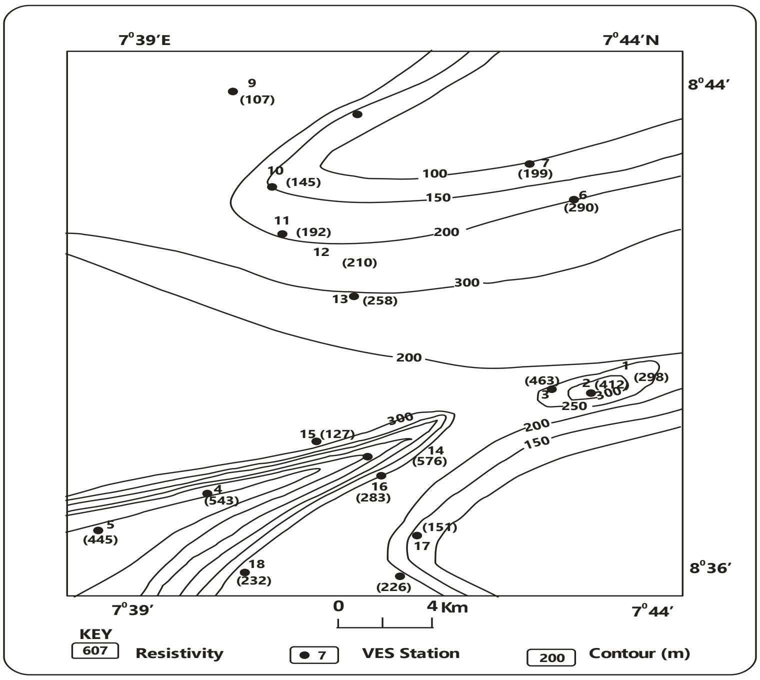

Fig. 3: Map of Apparent Resistivity for AB/2==55m.

3.1. Qualitative interpretation

Qualitative Interpretation was by drawing apparent resistivity maps for current electrode spacing AB/2 of 55m and 95m (Figs. 3 and 4), indicating depths of investigation of approximately 20m and 35m respectively, and by comparison of vertical electrical sounding (VES) along four profiles; A-B, C-D, E-F and F-H (Figs. 6, 7, 8 and 9). The depth sounding curves were classified into different types of curves. The HA type curve is the most predominant. Others are KH, QH, HQA, QHA, HAQH, HQHA and HAQA. The area generally is a four layer structure. However, the HAQA, QHA and HQHA curves are rather interesting since they represent 5 and 6 layer structures. The AB/2 = 55m shows resistivity high (412-1047 Ohm-m) trending SW-NE from Passelli in the south-west to Girigo in the east as well as in the north-western part in Kabulu area which represent areas of basement high. Resistivity low areas (100-300 Ohm-m) are to the central and northern parts which represent basement low (Fig. 4 and 5). The AB/2 = 95m shows resistivity high (400-550 Ohm-m) in the southern part trending NE-SW while the resistivity low (150-300 Ohm-m) is to the NE part, namely; Zakum Bello, Araba, Nahuche and Gidan Shahu (Figs. 3 and 4). The apparent resistivity maps for both electrode spacing indicate areas for resistivity high in the south and areas of resistivity low to the north.

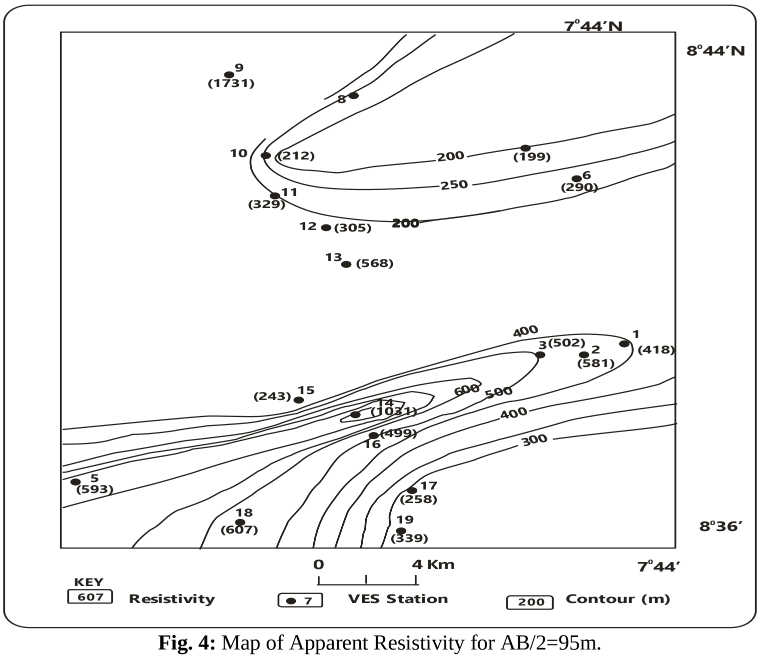

Fig. 4: Map of Apparent Resistivity for AB/2=95m.

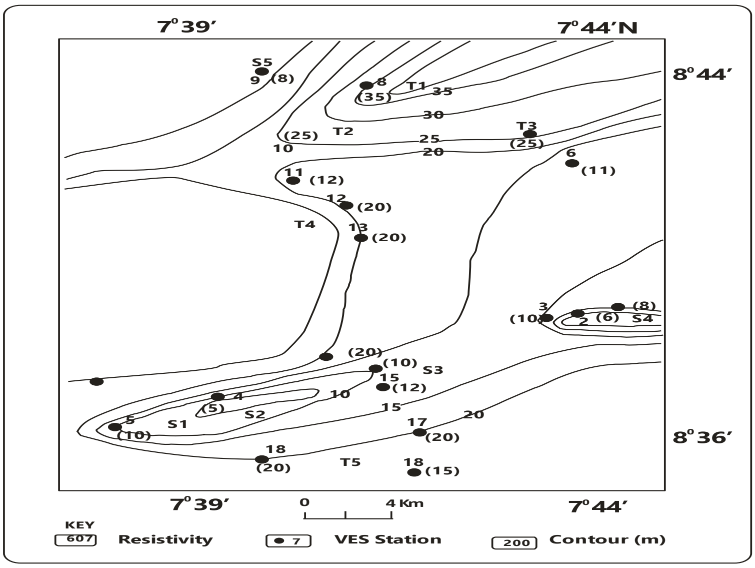

Fig. 5: Basement Configuration Map of the Study Area.

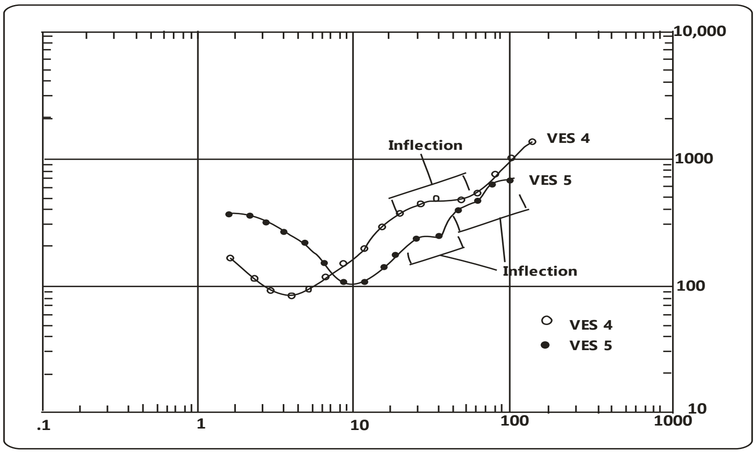

Fig. 6: Depth Sounding Field Curve (Fractured Layers) of the Study Area.

3.2. Quantitative interpretation

The geoelectric sections (Fig. 7, 8, 9 and 10) drawn from interpreted result (layer resistivities and thicknesses) suggest mainly four subsurface layers, even though two, five and six layers were also interpreted. The first layer constitutes the top soil with layer resistivity value that range from 170 – 300 Ohm-m and up to 400 Ohm-m when it is indurated. In some cases these resistivity values represented the weathered pegmatites as found in Gidan Shahu and Adakwu; the layer thicknesses vary from 0.8 – 4.1m. The second layers which has resistivity values varying from 25-90 Ohm-m is presumably clayey sand which is characterized by resistivity value of ≤ 100 Ohm-m. The thickness varies from 0.8 – 19.2m. The third layer, with resistivity values ranging from 100 – 250 Ohm-m constitute the weathered basement. The layer is between 3.3 – 28.2m thick. The fourth layer, constitute the fresh bedrock with resistivity values greater than 300 Ohm-m and in some cases infinitely resistive. In some cases where the basement is fractured, there exists another layer (i.e. fractured basement). The resistivity value ranges from 336 – 737 and 117 - 336 Ohm-m as seen in VES stations 4 and 5 (Profile G-H) (Figs. 2 and 10b). They are generally not thick, about 15.3-22.8m. In some cases the fractured basement may be too thin to be identified as a geoelectric unit.

The recognizable structural features in the geoelectrical sections are the basement depressions beneath VES stations 7 and 8 (Profile A-B); 10, 12 and 13 (Profile C-D); 15, 17 and 19 (Profile E-F) and the basement high underneath VES stations 9 and 11; 14 and 16; 5,4,14,3,2 and 1 in Profiles A-B, C-D, E-F and G-H respectively (Figs. 7a and b, 8a and b, 9a and b, 10a and b,).

The geoelectric sections show basement depressions and “high” which correlate significantly across all the four profiles. The overburden is assumed to include the topsoil, clayey sand, the weathered basement and the weathered pegmatite. The basement configuration map (Fig 5) shows area with thick overburden cover marked T1, T2, T3, T4 and T5 which correspond to the basement depression zones while the zones with relatively thin overburden in (m) marked S1, S2, S3, S4 and S5 correspond to basement highs.

4. Correlation with geology

One major observation is that most areas with resistivity values ranging from 25-90 Ohm-m corresponds to areas of schist as drill logs also confirmed in Figs. 11, 12, 13 and 14. This has helped in understanding that the schist is a cover sequence underlain gneiss with resistivity values of 100 – 250 Ohm-m. This agrees with Jones and Hockey (1964) and Dempster (1965) who described two generations of metasedimentary rock (gneiss complex and cover sequence) and Fitches et al., (1985) who described the schist as Proterozoic cover overlying the basement gneiss. The paucity of the metasedimentary rocks as well as their disappearance at depth of 20m and 35m (as observed from geoelectric sections A-B, C-D, and E-F) shows that they are restricted to depth of less than 20m, indicating a cover sequence i.e. synformal trough folded into the crystalline gneiss complex (Ogezi, 1981).

- PROFILE A-B

This profile runs from about 1 km, from Kabulu to Nahuche. The cover sequence (schist) is as thick as 16m, underlain by weathered gneiss. The superficial unit (topsoil) is continuous across the length of the entire profile but varies laterally (0.8-4.1m).

- PROFILE C-D

This profile is characterized by cover sequence which runs across the profile except at VES stations 13 at SSE (Magajia) which marks geological boundary between stations 12 and 13. Station 13 is predominantly weathered and fresh gneiss.

- PROFILE E-F

This profile is rather complex and has been highly distorted especially at VES 15 (Bassa) where the schist is separated by pegmatite intrusion, disappearing in VES station 14 in Dumu (marking a geological boundary) and reappearing in VES station 16 (Sa-Gwari) which continues to VES station 19 (Adakwu). The thickness varies laterally. It is about 10m in VES 17 (Majori) and probably signifying an arm of fold (as observed from aerial photograph). VES stations 17 and 19 is unconformably overlying the weathered gneiss and its complete disappearance as one moves from VES stations 15 and 14 (a geological boundary) suggest that the area has been folded, fractured and faulted (Fig. 9b).

- PROFILE G-H

The schist as cover sequence appears at extreme sides of the profile at VES stations 5 and 4 in SW and 3, 2 and 1 in NE in between which the schist disappears. The schist thins out in VES station 4 marking the crest of the ridge, suggesting a fold; which is substantiated by fracture in the fresh basement in VES station 5, 4 and 14 (Fig. 10b). Layers between 14 and 3 cannot be correlated probably indicating a fault zone.

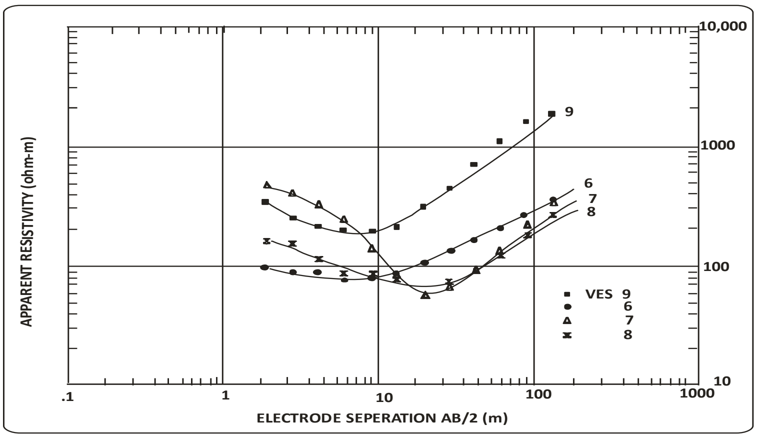

Fig. 7: A) VES Sounding Curves Along Traverse A – B.

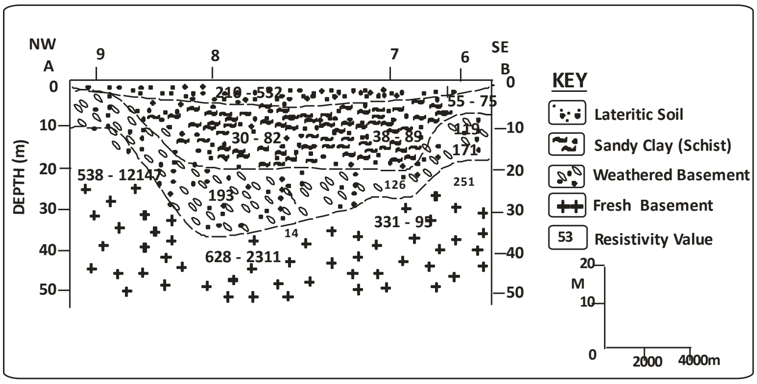

Fig. 7: B) Geoelectric Section and Probable Geological Interpretation Along Profile A – B.

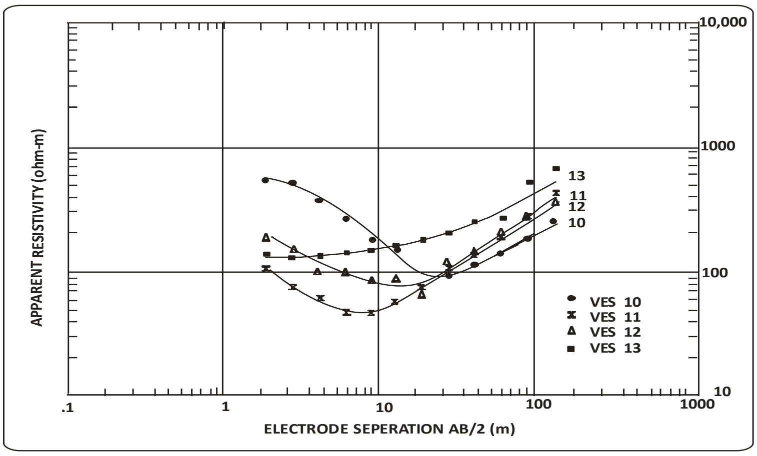

Fig.8: A) VES Sounding Curves Along Traverse C – D.

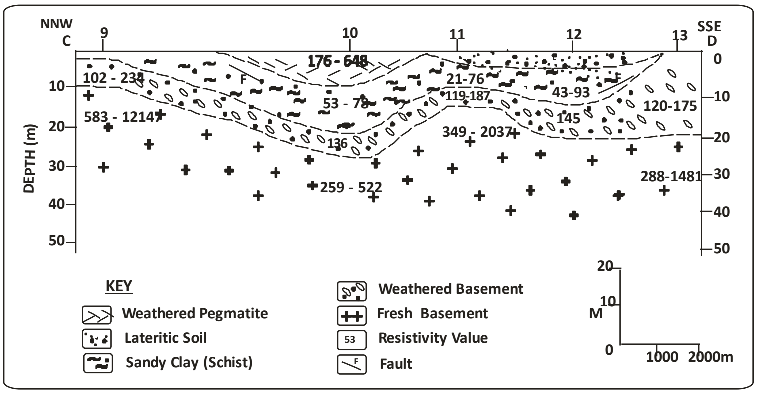

Fig. 8: B) Geoelectric Section and Probable Geological Interpretation Along Profile C – D.

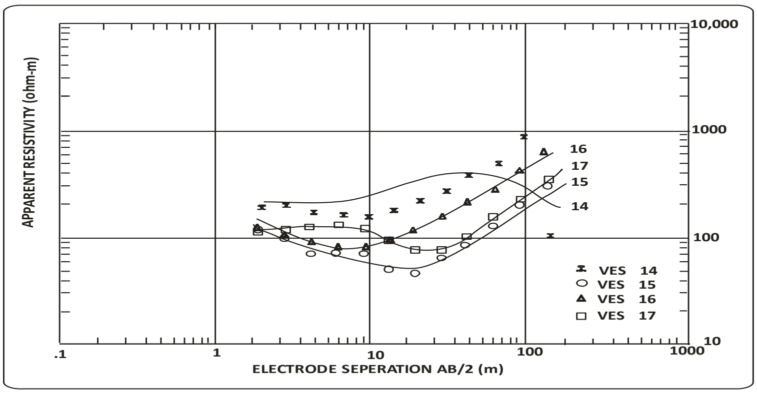

Fig. 9: A) VES Sounding Curves Along Traverse E – F.

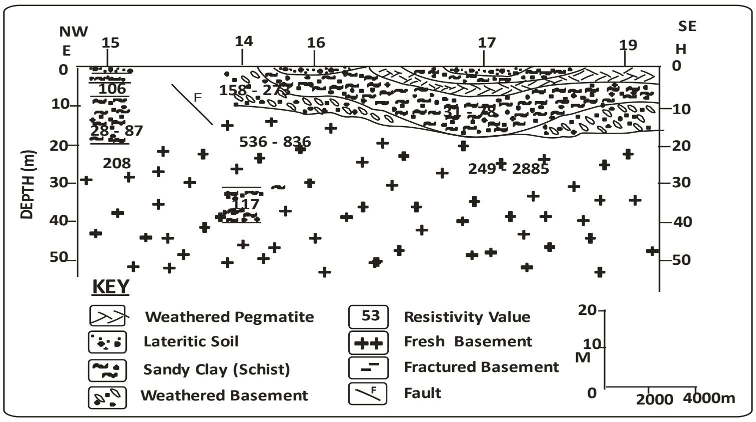

Fig. 9: B) Geoelectric Section and Probable Geological Interpretation Along Profile E – F.

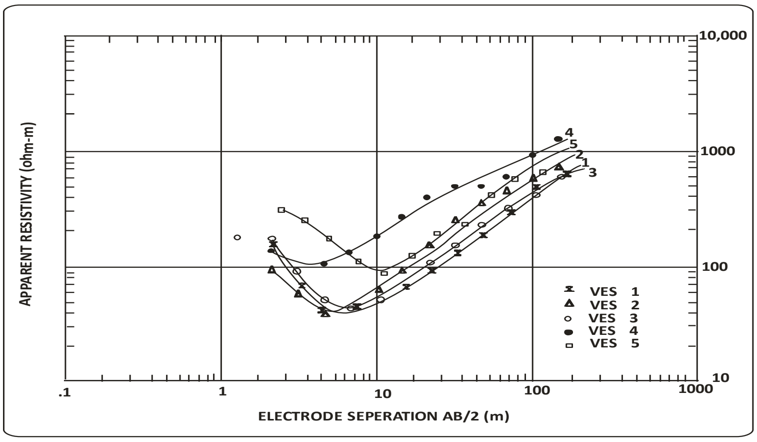

Fig. 10: A) VES Sounding Curves Along Traverse G – H.

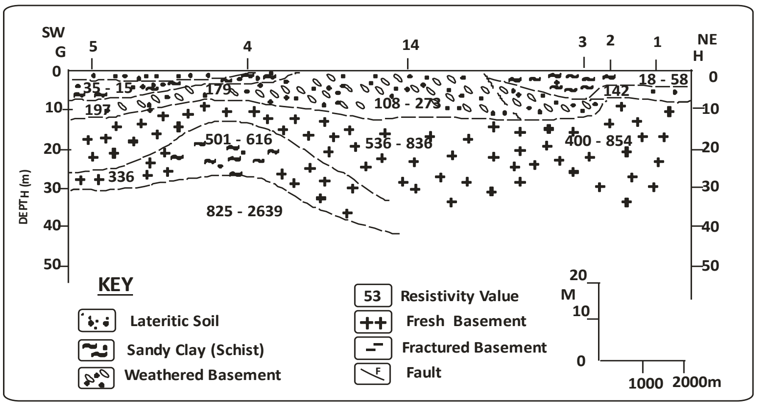

Fig. 10: B) Geoelectric Section and Probable Geological Interpretation Along Profile G – H.

5. Integration of geophysical and hydrogeological data

The integration is based on well information (lithological and hydrological) obtained from four borehole sites in the study area (namely; Zakum Bello, Zabutu, Gidan Shahu and Passelli) after geoelectrical survey. A comparison of integrated geoelectric section/model was made with the resistivity log of borehole close to where sounding was done and adjacent geology thus determined and surface geology classified into lithologic units (figs. 11, 12 13 and 14). The geoelectric model correlates very well with the borehole logs.

5.1. Hydrogeological units

Two aquiferous zones delineated are the weathered and the fractured zones. The weathered layer resistivity ranges from 25 to 90 and 100 to 250 Ohm-m, the former is typical of clayey sand (schist) while the latter is characteristic of weathered basement (gneiss). Both thickness ranges from 5 to 30 (Figs. 11, 12, 13 and 14). The fracture zone has layer resistivities which vary from 366 to737 and 117 to 336 Ohm-m, the former with high resistivity is diagnostic of zones with shallow depth but of considerable thickness as seen in VES 4 (Fig. 6). The low resistivity fracture zone is found at relatively greater depth but of less thickness in VES stations 5 and 14 (Figs. 6 and 10b). These fracture zones are enclosed within the fresh basement and are otherwise referred to as confined fractures; they are also confined to the gneiss of the basement (profile E-F and G-H). Hydrogeological units deduced as aquifers are basically second and third layers (schist and gneiss) referred to as weathered basement and fractured zone.

5.1.1. Weathered aquifer

There are three modes of occurrence of this aquifer type as seen in Figs. 11 - 14. The first is where the schist and gneiss of the weathered basement constitute the aquifer and in most cases shows sharp transition between the weathered layer and the fresh bedrock as seen in VES stations 6, 7 and 8 (Fig 7b) and VES stations 11 and 12 (Fig. 8b). The resistivity depth sounding curve varies from QH, HKH to KQKA. The second is where the schist occurs with weathered pegmatite and/or weathered basement. This aquifer type is characteristics of areas of complex geology (VES station 10 in Fig. 8b and stations 17 & 19 in Fig. 9b) where geologic correlation with adjourning VES station is quite difficult; here transition between weathered basement and fresh bedrock is transitional as seen from resistivity values, of the types QH, QHKH and HKAH.

The third is where there is no schist as cover sequence and the aquifer type is basically the weathered gneiss; here there are no layer boundaries and correlation with adjourning VES stations shows evidence of faulting as found in stations surrounding 13 and 14 (Figs. 8b, 9b and 10b). The resistivity curves vary from HA to QH and KHA. The yield from borehole logs of weathered aquifer ranges between 0.2 and 0.6 litres/sec. The yield from borehole data of Zakum Bello where the overburden is thickest is not available.

5.1.2. Fractured aquifer

This aquifer type is enclosed within the fresh basement. It is characterized by geoelectric signature which is an inflection along the rising (basement) segments of the VES curve (Fig. 6). The fractures occur at 15-40m depth and are found in area underlain by gneiss as seen from borehole log (Figs. 11 and 13) and geoelectric profile (Fig. 7b and 8b). In areas underlain by schist, there are no inflections in the VES curves which imply that schist is rarely fractured. The fracture occurred mainly in the gneiss and thickness ranges from 5 to 10m mainly within the depth of 15 to 40m. The yield from borehole logs for fractured aquifer ranges between 0.2 and 0.33 litres/sec (Habila and Sumla, 1992).

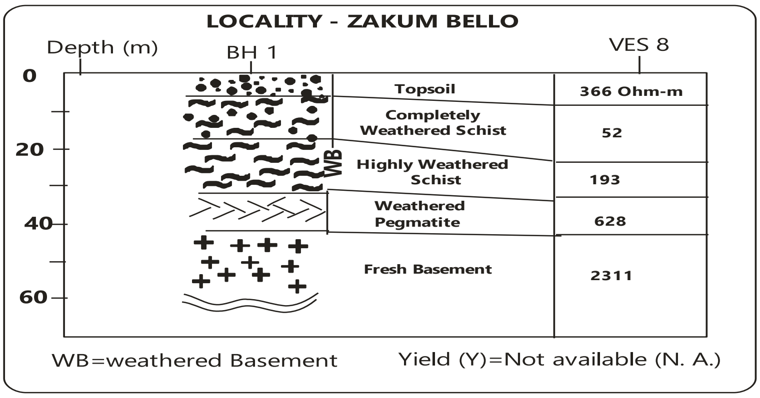

Fig. 11: Comparison of the Interpreted Geoelectrical Section (VES 8) and the Borehole Lithological Section

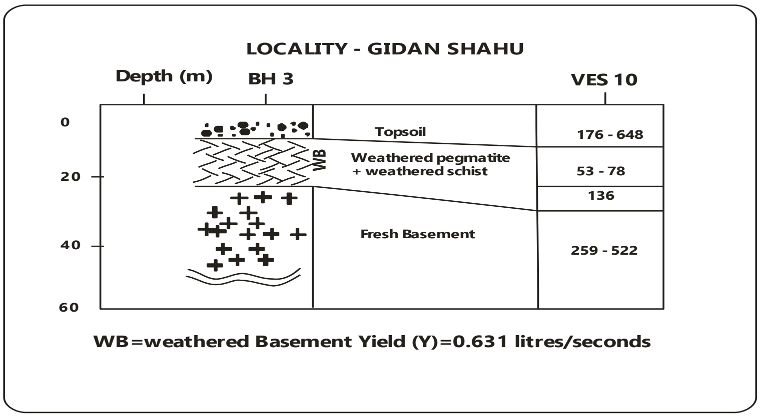

Fig. 12: Comparison of the Interpreted Geoelectrical Section (VES 10) and the Borehole Lithological Section.

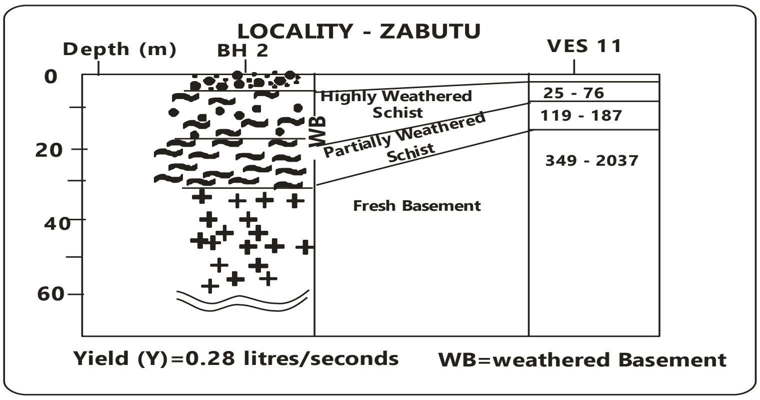

Fig. 13: Comparison of the Interpreted Geoelectrical Section (VES 11) and the Borehole Lithological Section.

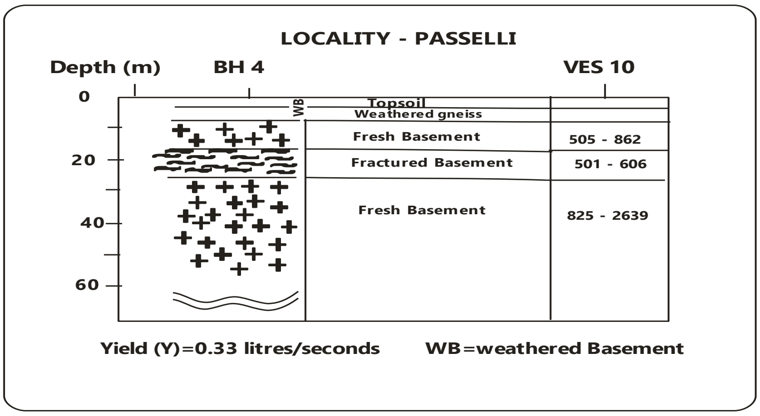

Fig. 14: Comparison of the Interpreted Geoelectrical Section (VES 4) and the Borehole Lithological Section.

6. Ground water quality

There are no data on ground water quality in communities in and around the project area; this necessitated, collecting and analyzing water samples to know their quality and its relationship to rock types. Samples of water were collected from 12 locations and were segregated into 3 categories: (i) Well Water Sample (WWS), (ii) Stream Water Sample (SWS) and Borehole Water Sample (BWS). The contrast in chemical contents of water from the localities is demonstrated in the result sheet for anion and cation determination in Table 1.

6.1. Analytical procedure

Procedures employed include titrimetric method for chloride and bicarbonate, UV method for nitrate and calorimetric method for sulphate. In the cations, the samples were standardized and diluted or undiluted according to a particular element under investigation and element analyzed after Walton (1970).

6.2. Interpretation of chemical analysis

The system of graphical presentation of chemical analysis as proposed by Collins (1923) is widely used. This is represented by vertical bar graph whose total height is proportional to concentration of the cations and expressed in equivalents per million (epm). Two localities were selected each for different water sources namely well, borehole and stream as a representation of the three different types of samples analyzed. Contrast in chemical content of waters from these streams, well and boreholes are determined by water analysis as shown in Table 1 and represented by diagrams in Fig. 15 a & b (Bar and Stiff diagram).

The water is acidic with pH of less than 7 which indicates preponderance of H+ ions. This pH may be associated with small amounts of mineral acids or organic source. Concentration of Ca and Mg is relatively higher in stream water sample except for the well water sample in Sa-Gwari. This Ca might have been derived from weathered minerals such as apatite and various end members of the feldspar, amphibole and pyroxene groups. Also low content in well water may mean that the weathered schist might have absorbed the Ca in water percolating and at the same time, the high Na and K content means it is being taken into solution as the Ca is being absorbed (this is also true for borehole water sample (KBWS 2 in Passelli). Na and K may also have been taken into solution from the release of soluble product during weathering of plagioclase feldspars and orthoclase (microcline and biotite) which is responsible for high Na and K values respectively. The waters from categories C & D shows fairly equal distribution of the cations unlike A & B, and E & F; an indication that water from both well and borehole are somewhat similar in chemical content at depth; but different from surface (stream) water. Also there is little or no anion distribution on the surface water as seen from category D. Borehole and well water shows preponderance of bicarbonate at depth. It is therefore noted that the borehole, well and stream water appears to be a mixture of water from the rock and rain water.

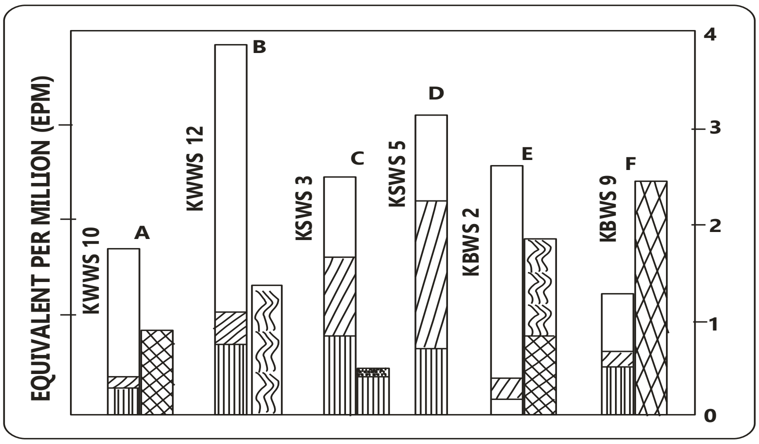

Fig. 15: A) Water Analysis Bar Diagram in the Study Area.

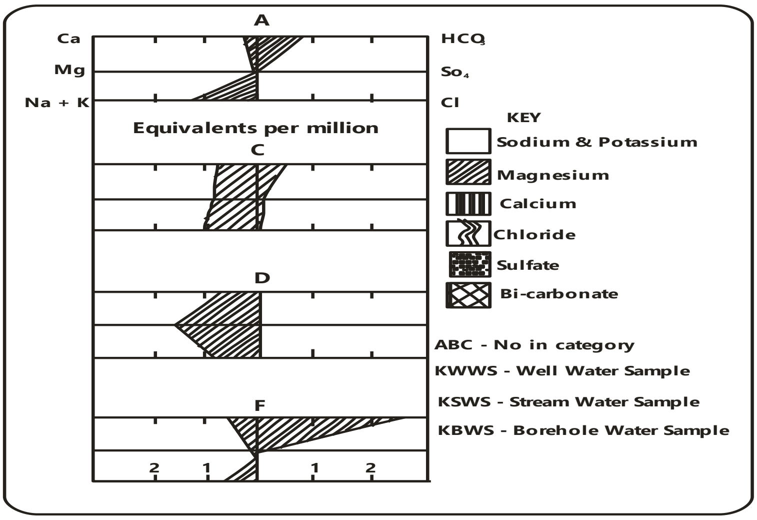

Fig. 15: B) Water Analysis Stiff Diagram in the Study Area.

Table 1: Result Sheet for Cations, Anions and Ph Values for Analyzed Water Samples in the Study Area

SAMPLE NO	LOCALITIES	pH	SO_4^{2-}	HCO_3^-	NO_3^-	CL^-	Na	K	Mg	Ca	Fe
KSWS 1	Girigo	6.4	-ve	24.40	-ve	-ve	13.364	2.445	7.214	12.421	-ve
KBWS 2	Passelli	7.4	-ve	48.80	-ve	35.75	40.916	16.286	2.441	3.681	-ve

KSWS 3	Passelli-Ara	6.3	5ppm	24.40	-ve	-ve	14.661	3.443	10.612	15.398	-ve
KWWS 4	Nahuche	5.9	-ve	73.20	-ve	7.94	30.219	9.611	1.368	8.442	-ve
KSWS 5	Nahuche	6.4	-ve	-ve	-ve	-ve	16.493	4.442	18.114	14.416	-ve
KWWS 6	Araba	6.7	-ve	-ve	-ve	21.84	28.246	12.32	1.265	6.361	-ve
KBWS 7	Zakum Bello	6.7	-ve	24.40	-ve	15.88	20.306	10.389	0.832	5.189	-ve
KWWS 8	Kabulu	6.3	-ve	-ve	-ve	15.88	13.115	9.842	1.681	10.412	0.024
KBWS 9	Gidan Shahu	5.7	-ve	146.40	-ve	-ve	11.219	3.436	1.943	9.326	0.015
KWWS 10	Gidan Magajia	6.3	-ve	48.80	-ve	1.98	20.746	8.003	1.665	6.243	-ve
KSWS 11	Bassa	6.5	-ve	24.40	-ve	-ve	12.418	2.943	11.319	8.114	-ve
KWWS 12	Dumu	5.4	-ve	-ve	-ve	45.66	52.386	11.224	4.215	15.048	-ve

6.3. Relationship of ground water quality to use

For the purpose of this work, ground water data / table are compared to the International Standard for Drinking Water (after World Health Organization, 1958). None of the constituents is in excess of the concentration in World Health Organization table, which may constitute ground for rejection of the water. Therefore it is suitable for public drinking and domestic use.

7. Conclusion

The area is underlain by polymetamorphic basement complex rocks. Major rock types are amphibole bearing gneiss, mica gneiss, mica schist and pegmatites. Combination of photogeology geoelectric section has shown the area to have been highly tectonised with three main foliation trends, NE-SW, NW-SE and N-S. The fractures are also sympathetic with the drainage system. Two aquifer types have been identified, weathered (unconfined) and fractured (confined) aquifers. The weathered layer aquifer consists of schist, gneiss and pegmatite with three modes of occurrences. First is where the cover sequence (schist) and the weathered basement (gneiss) constitute the aquifer and are characterized by QH, HKH to KQKA curves. The second is where the cover sequence occurs with weathered pegmatite and/or weathered basement with complex geology and characterized by QH, QHKH and HKAH curves. The third is where there is no cover sequence and the aquifer type is basically the weathered gneiss with HA to QH and KHA curves. Ground water yield ranges from 0.28 - 0.63 litres/sec for the weathered aquifer to 0.2 - 0.33 litres/sec for the fractured aquifer. The schist is typified by its low resistivity (25 90 Ohm-m) compared to gneiss (100-250 Ohm-m) and good correlation was found to exist between hydrogeological and surface geophysical data. Geochemical data from well, stream and borehole water sampled has shown that the water is acidic but indicates good quality water based on World Health Organization (W.H.O.) standard. Borehole, well and stream water appears to be a mixture of water from the rock and rain water. Based on the conclusion of VES interpretation, it is recommended that borehole be drilled in VES locations earlier mentioned up to a depth of 45m. The most prospective zone is expected to be between 20 and 35m.

Acknowledgement

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