IOSR Journal Of Applied Geology And Geophysics (IOSR-JAGG)
E-ISSN: 2321–0990, P-ISSN: 2321–0982.Volume 13, Issue 2 Ser. I (Mar. – Apr. 2025), 43-51
www.Iosrjournals.Org

Investigation Of Ground Water Potential Zones Using Vertical Electrical Sounding (VES) Method In New Gra, Bauchi, Nigeria

Omar Garba Pan, Abubakar M. Bello, Nasiru Abubakar, Musa Ismail, M. Bello
Department Of Science Laboratory Technology, Federal Polytechnic, Bauchi-Nigeria
Department Of Physics, Aminu Saleh College Education Azare, Bauchi-Nigeria
Department Of Physics, Abubakar Tafawa Balewa University, Bauchi-Nigeria

Abstract
This study delineates ground water potential zones using Vertical Electrical Sounding (VES) method in New GRA Bauchi, Bauchi State. The study area lies geologically within the basement complex of Nigeria, where the commonly found rocks are granite and migmatites. Resistivity data from a total of seventy two (72) VES stations with a maximum current electrode separate of 60 m was acquired using Ohmega resistivity meter. Schlumberger electrode configuration was employed in all the VES stations. The data was analysed using ipi2win computer software, which yielded an automatic interpretation of apparent resistivity, resulting in approximate resistivities and thicknesses of inferred geoelectric layers. A suite of H, K, A, HA, KH, QH, HK, and HKH type resistivity curves were obtained from the processed data. Further analysis of the data produced iso-resistivity contour maps which revealed a heterogeneous nature of the subsurface geology. The range of respective approximate resistivities and thicknesses of four inferred geoelectric layers are: first layer: (30.4 - 35686 Ωm) (0.407 - 5.42m), second layer: (3.63 - 43656 Ωm) and (0.8332 - 22.25m), third layer (2.098 - 74021 Ωm) and (∞m). These values corresponds to inferred lithology of: topsoil (sand mixed with varying content of clay and lateritic material) weathered basement or highly decomposed crystalline basement, partially weathered basemant and fractured to fresh crystalline basement. The potential water bearing zones predicted at the study area mostly weathered and fractured crystalline rocks. Furthermore, some VES stations are recommended for drilling to a depth of 50m to 60m. The study recommends that integrated geophysical techniques should be employed in the study area to further constrain the above interpretation.

Keywords: *Ground water, Vertical electrical sounding (VES), Resistivity, Geoelectric layer, Iso-resistivity contour map,*

Date of Submission: 05-04-2025 Date of Acceptance: 15-04-2025

I. Introduction

Groundwater is a major source of clean drinking water all over the world. It has been an important resource especially in sub-saharan Africa. Groundwater has always been a reliable source of water in Nigeria for many decades (Ang., 1994).

The advent of technology has made the quest for groundwater to drift from crude and unscientific methods such as water dowsing to systematic application of sophisticated electronic tools and subsequent processing and interpretation of the data so obtained.. In Nigeria, groundwater extracted via boreholes provide a sizeable quantity of the total groundwater need of the country. Among the different techniques used for groundwater exploration, the geoelectric method has proven to be very reliable and affordable; hence a preferable choice in most ground water search.

Over the years, the residents of New GRA Bauchi have suffered enormous problems of water supply. These problems are more severe at the peak of dry season when demand for water is most significant - when hand-dug wells dried up. Conducting adequate geological and geophysical investigation, which will reveal the proper understanding of the hydrogeological characteristics of the area before drilling of boreholes or hand-dug wells in the area, can lessen this dire situation.

This study is aimed at delineating the ground water potential zones in New GRA Bauchi using Vertical Electrical Sounding (VES). The results obtained from this study will shed more light on the current knowledge of the hydrogeology of the study area, therefore avert drilling of abortive water boreholes.

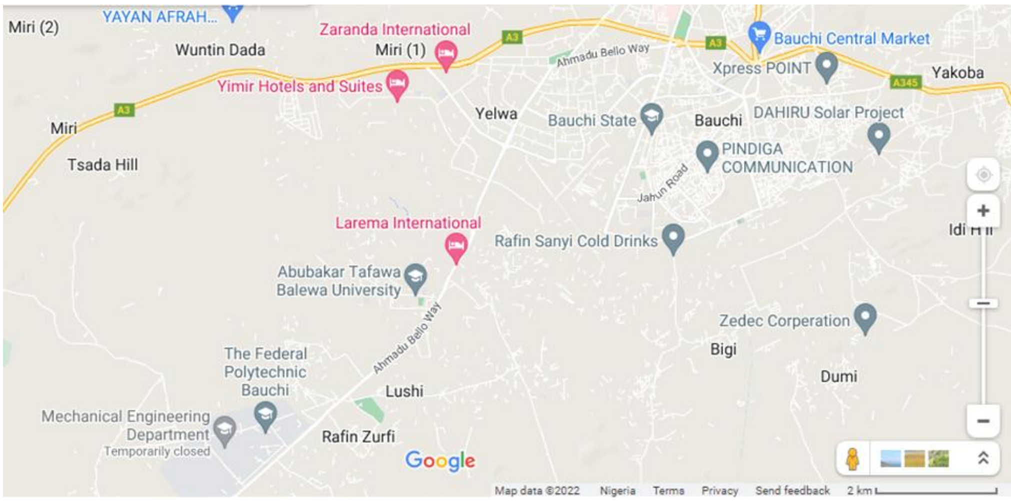

Fig. 1 Location Map of the study area showing important landmarks

II. Geology And Hydrogeology Of The Study Area

It is generally not feasible to make a meaningful interpretation of hydrogeological or petrophysical properties of rock units in the study area without examining its geological framework. Different rock units exist within the study area, each having unique physical properties. This entails different capabilities to store and transmit fluids (in this case water). In addition to differences in rock fabric, the capacity to store and transmit fluid is further modified by the geological history and structural development of the study area. Thus, these will determine the various rock units, their distribution and structural pattern.

In broader context, the geology of Bauchi state can be described in three main zones (Figure 2):

The Basement Complex

This constitutes mainly granitic rocks, outcropping over the southern half of Bauchi state and is found beneath sedimentary rocks in the southeast. The granite is often porphyritic and pegmatitic veining occurring widely. Granite gneisses and migmatites are commonly found in this part of the state, and exposures of diorite were found at Dass. The basement complex is extensively fractured, some of the tectonic lines being traceable over great distances. The basement complex, which is known collectively as the older granite, is of Precambrian to Paleozoic age. The Jos Plateau, which extends into southwest Bauchi state, contains a number of younger granite ring complexes of Jurassic age (Carter et al., 1963).

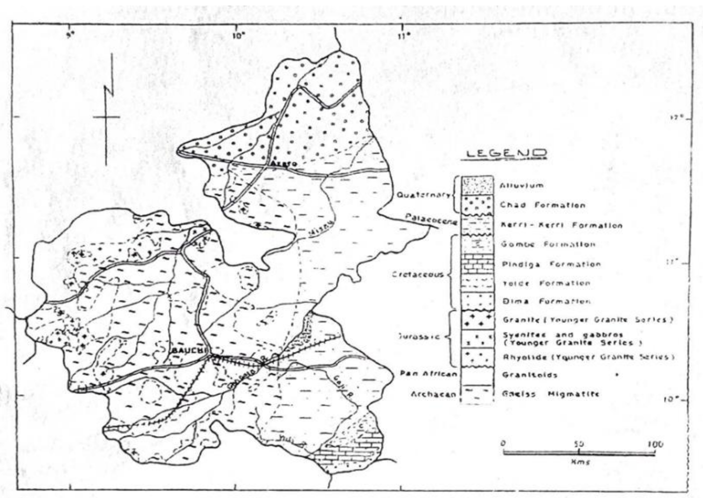

Fig. 2: Geological map of Bauchi State showing important rock types, road networks and drainage patterns.

Kerri - Kerri Formation

The Keri-Keri formation is continental in origin and is generally considered to be Palaeocene in age. It consists of a sequence of flat lying sediments made up of central Bauchi state (Fig. 2), resting on both Cretaceous sediments in the north and the basement complex in the south (Adegoke et al., 1978).

Chad Formation

This is a sequence of lacustrine and fluviatile sands and clays of Pleistocene age. It extends across the northern part of Bauchi state resting on both Kerri-Kerri and cretaceous sediments. It dips gently east toward the Chad basin (Fig. 2).

Geology of the Study Area

The study area is located within the Nigerian Basement Complex, which forms part of the Pan African Mobile Belt and lies between the West African Craton and the Tuareg Shield. Earlier workers have intricately linked the overall emplacement of the Nigerian Basement Complex to the earliest orogenic events that affected the African continent. The Basement Complex rocks include gneisses, migmatites and metasediments of Precambrian ages that have been intruded by a series of Pan African age rocks (Rahman, 1981). These rocks have been variably metamorphosed and granitised through tectonometamorphic cycles, so that they have been largely converted to migmatites and granite-gneiss (Oyawoye, 1964) (Fig. 2).

Younger metasediments believed to be of upper Proterozoic of age were supposedly deposited on this granitised basement, and folded along with it during the Pan African Orogeny. They are low-grade metamorphic rocks, and are now represented as synclinal troughs among older rocks in Northwestern Nigeria.

Intrusives into the Basement rocks and the younger supracrustal cover are series of intermediate and acid plutonic rocks known as the older granite suites. These are charnokites, diorites, fayalites quartz-monzonites (Bauchites) and gabbroic earlier rocks. Migmatisation has differently affected all the earlier rocks as well as the large-scale conversion of Basement gneisses and migmatites (McCurry, 1989).

Hydrogeology of the Study Area

The basement complex rocks of the study area have poor to no primary porosity and apart from localised fractures and joints, they are impermeable. Fracture and joints tend to store and transmit water fairly well and hence considered as good aquifers. Below the topsoil, the crystalline rock is found to be weathered in some locations (Dike et al., 1993). If the depth of water table is sufficient (greater than 8 m) the weathered mantle may contained sufficient water in storage to produce successful borehole with an estimate yield of 75 litres per minute (Dike et al., 1993).

Precambrian fresh rock covers more than half of the country. The main rock type in this geologic terrain includes igneous and metamorphic rocks such as migmatite and granite gneiss, (Carter et al., 1963), generally, in their natural form are categorized as moderately porous and permeable by induction through weathering while secondary permeability induced by tectonic activities serves as conduct movement. Hence, to get highly productive wells, the geophysical investigation becomes imperative as it helps to reveal groundwater-bearing layers in the subsurface.

III. Early Geophysical Survey Carried Out In The Study Area

To date, a variety of studies have been employed to study the groundwater potential of the study area. Schroeter (1976) described the hydrological conditions found in Bauchi and noted that groundwater is stored in the superficial weathered mantle derived from crystalline rocks of the basement complex which form an aquifer of poor quality. Du Preez and Barber (1965) worked on the distribution and chemical quality of groundwater in the Northern Nigeria; they described the basement complex as a poor source of groundwater. The decomposed mantle is often too thin to harbour large quantity of groundwater and is usually clayey, and hence having a low permeability. The joints are normally too poorly developed to compensate for the inadequacy of the zone of weathering overlying them. They described the crystalline rocks of the basement complex as notorious for poor aquifer capability, and the aquifers are usually located in the weathered mantle and fractured rock where porosity and permeability are just sufficient to allow an appreciable amount of water in storage.

Shemang and Umaru (1994) conducted geophysical investigation for groundwater in Bauchi town covering New GRA. The result of the survey indicated that the overburden (Regolith) in Bauchi Metropolis ranges from about 10 to 18 m in most places. The regolith was deducted from VES results to consist essentially of topsoil, highly weathered materials tending towards clay, and weathered basement, all underlain by fresh crystalline basement. Most of the boreholes drilled presently in communities near the study area were sited using electrical resistivity sounding, however, they do not supply adequate water to the community dwellers during drought period.

Geoelectrical resistivity surveys are often used to explore for groundwater in both porous and fissured media. Weathered and fractured crystalline rocks when saturated with water can be easily differentiated from higher resistivity impermeable fresh and unfractured and highly resistive fresh rock (Sharma, 1997).

IV. Methodology

This research utilises Vertical Electrical Sounding (VES) method, where artificially generated current is passed into the ground through a pair of current electrodes (C_1 and C_2) and the potential drop is measured across another pair of potential electrodes (P_1 and P_2) as shown below (Figure 3).

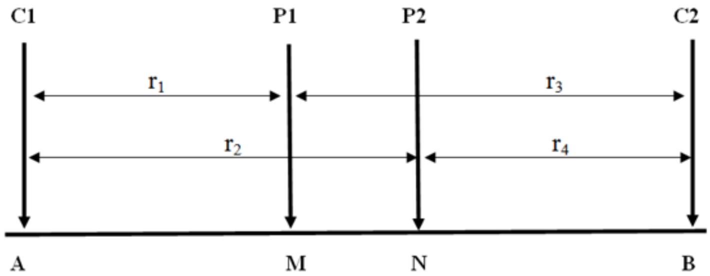

Fig. 3. Four electrodes method of data acquisition used to acquire the data

A proportion of the current penetrate deeply into the ground and the depth of penetration increases with increasing electrode spacing. In a heterogeneous ground in which there exists a vertical variation in resistivity with depth, the apparent resistivity derived in such a ground is influenced among others by the rock density, rock porosity and salinity of the fluid contained in the ground.

In Figure 5 above C_1 and C_2 are the current electrodes, and P_1 and P_2 represent potential electrodes. The current electrodes C_1 and C_2 act as source and sink respectively. In this case there are two points (potentials electrodes position) where we need to find the electrical potential due to the source and the sink electrodes and hence obtain the potential difference between the two points.

Schlumberger Array

The Schlumberger array is one of the most commonly used arrays for resistivity sounding surveys. A modified form of this array that can be used on a system with the electrodes arranged with a constant spacing 'a'. The 'n' for this array is the ratio between the C_1-P_1 (or P_2-C_2) electrodes to the spacing between P_1 and P_2 potential pair. The sensitivity pattern for the Schlumberger array is slightly different from the traditional Wenner array with a slight vertical curvature below the centre of the array. This means that this array is moderately sensitive to both horizontal and vertical structures. In area where both types of geological structures are expected, this array might be a good compromise between the Wenner and the Dipole-dipole arrays. The effective depth of investigation for this array is about 10% larger than Wenner array, for the same distance between the outer (C_1 and C_2) electrodes the signal strength for this array is smaller than that of the Wenner arrays, but is higher than the dipole-dipole array. The horizontal data coverage is slightly better than the Wenner array, but smaller than the dipole-dipole array.

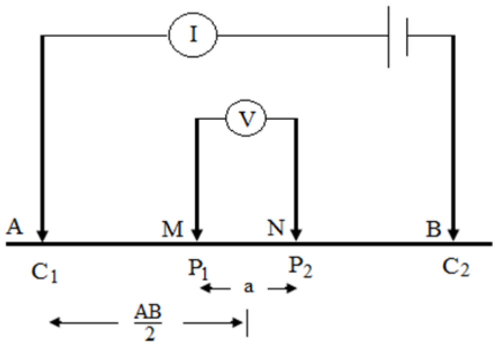

Fig. 4: Schematic configuration of Schlumberger Array.

The theoretical depth of investigation for a Schlumberger array is approximately given as: Zs = 0.125L where L = distance from C_1 and C_2 ($L \geq 51$), and I=distance between P_1 and P_2. For the Schlumberger array, the current electrodes are spaced much further apart than the potential electrodes. In the VES techniques, the potential electrodes are kept constant while the current electrodes spacing is expended symmetrically about the centre of the spread until the potential difference between MN becomes very small and thus falling below the reading accuracy of the voltmeter, hence the distance between the potential electrodes (MN) is increased. The apparent resistivity for Schlumberger configuration is given as:

$\rho_a = \frac{\pi}{4}\frac{V}{I}\left(\frac{L^2-a^2}{a}\right)$ --(1)

$or \qquad \rho_a = \frac{\pi}{4}\ R\left(\frac{L^2-a^2}{a}\right)$ --(2)

Instruments for Data Collection

The resistivity survey measurements were carried out by using an Ohmega resistivity meter. This terrameter is a portable microprocessor controlled integrated receiver and transmitter which provides a direct digital read out of resistance. Power is supplied by a rechargeable battery pack and provision is made for higher current requirements by means of an internal electronic circuitry. The measurement system employs signal-filtering, rejection of self-potential and current transient enabling accurate discrimination of the signal even in high noise environments. Several self-diagnostic checks for instrument, cable and electrodes faults are also inbuilt.

Other accessory tools and instruments that were used include: hammers, crocodile clips, measuring tapes, GPS (Global Positioning System), an umbrella, steel electrodes, connecting wires and field note book.

Method for Data Collection

The usual practice in earth resistance measurement is to pass current into the ground by means of two electrodes and to measure the potential difference between a second pair placed in line between them. From the value of the potential difference, the current applied and also the electrode separation, a quantity termed the apparent resistivity can be calculated. It is the variation of this apparent resistivity with change in electrode spacing and position that give information about the variation in underground layering.

The Vertical Electrical Sounding (VES) employed for this investigation, necessitates using an expanding electrode system, which determine the vertical change in the resistivity of the underground layers and the depth to the discontinuity zones. This involves placing the electrodes in a straight line at a certain distance, and for each measurement, the distance between the electrodes is increased. By multiplying the resistance obtained from each measurement by a factor appropriate to the electrode configuration and separation, a series of apparent resistivities are obtained. The half electrodes spacing of the current electrodes (AB/2) and its corresponding potentials was then recorded.

Seventy two (72) VES points were acquired. Graphs of apparent resistivity versus half the spacing between current electrodes were then plotted and interpretation of the resulting curves yields an estimate of the thicknesses and resistivities, hence conductivity or water bearing potential of the different subsurface layers.

V. Results And Interpretation

Data Processing

Geoelectric data acquired are normally processed to remove noise arising from instrumentation and environmental influence. The apparent resistivity data are presented as sounding curves. The curves are obtained by plotting the apparent resistivity values against half of the current electrode's separation (AB/2). The curve type in each VES station depends on the subsurface layers' sequence. The main purpose of processing the VES data displayed as curve is to graphically visualise the variation of resistivity with depth at each sounding point. The data analysis was performed using *ipi2WIN* software, which apart from the sounding curves gives automated interpretation of number of subsurface layers present, their approximate resistivities as well as their thicknesses. The frequency of the observed curve types is grouped into seven and presented in Table 2.

Table 2: Classification of VES curve types indicating their characteristics, frequencies and percentages.

VES curve type	VES curve characteristics	Frequency	Percent (%)
A	**$\rho1<\rho2<\rho3$**	4	5.55
H	**$\rho1>\rho2<\rho3$**	34	47.22
K	**$\rho1<\rho2>\rho3$**	10	13.88
HA	**$\rho1>\rho2<\rho3<\rho4$**	5	6.94
KH	**$\rho1<\rho2>\rho3<\rho4$**	5	6.94
QH	**$\rho1>\rho2>\rho3<\rho4$**	5	6.94
HK	**$\rho1>\rho2<\rho3>\rho4$**	6	8.33
HKH	**$\rho1>\rho2<\rho3>\rho4<\rho5$**	3	41.66

Data Presentation

Seventy-two (72) depth-sounding points were acquired using Schlumberger array techniques in the study area. A sample of the acquired field data is presented in Table 2, while VES curves were presented in the appendix A.

After the resistance of the Earth's materials is measured using Ohmega resistivity meter, the apparent resistivity calculated. These field data collected were interpreted using the ipi2win based resistivity software.

The computer software automatically displays the layer resistivity, thickness and depth of the layers from the ground (Supplementary material).

The definitions of some terms are:

i. **N** is the layer number
ii. **ρ** is the layer resistivity in (Ωm)
iii. **h** is the layer thickness in meters and
iv. **d** is the interface depth in meters

Therefore, the processed data were interpreted, resulting curve types were assessed and existing subsurface lithological units were established. The results are presented in the form of tables, geo-electric curves (Supplementary material). A summary some of the results of interpretation is shown in the table below (Table 2) and a complete result of the sounding points is presented in Appendix 2.Table 2 comprises of the resistivity of observed layers, the thickness of the layers, the depth of each layer, the curve types of each VES point, and the inferred geoelectric layers.

Table 3: Summary of the subsurface geo-electrical parameters for the interpreted VES points.

VES NO.	COORDINATE(°)	LAYER NO.	APPARENT RESISTIVITY (Ω-m)	THICKNESS (m)	CURVE TYPE	INFERRED LITHOLOGY
01	10.2936N 9.7986E	1 2 3	145 194 60514	2.05 8.15 ∞	A	Topsoil Weathered crystalline basement Fresh basement
02	10.2933N 9.7987E	1 2 3	249 25.2 19174	1.5 1.9 ∞	H	Topsoil Weathered crystalline basement Fresh basement
03	10.2929N 9.7988E	1 2 3 4	52 166 6.89 4461	0.407 0.776 2.05 ∞	KH	Topsoil Decomposed crystalline basement Weathered crystalline basement Weathered – fractured basement
04	10.3083N 9.7949E	1 2 3 4	195 2742 381 2210	0.884 2 4.86 ∞	KH	Topsoil Decomposed crystalline basement Weathered crystalline basement Weathered – fractured basement
05	10.3028N 9.7947E	1 2 3	236 2051 31.6	3.67 16.7 ∞	K	Topsoil Weathered crystalline basement Weathered – fractured basement
06	10.3034N 9.795E	1 2 3 4	606 167 4661 53.1	0.595 5.52 6.96 ∞	HK	Topsoil Decomposed crystalline basement Weathered crystalline basement Weathered – fractured basement
07	10.3083N 9.7902E	1 2 3	318 99.2 73021	0.611 7.75 ∞	H	Topsoil Weathered crystalline basement Fresh basement
08	10.3351N 9.3473E	1 2 3	42.5 10.9 13314	0.899 1.05 ∞	H	Topsoil Weathered crystalline basement Fresh basement
09	10.3082N 9.7965E	1 2 3	19.5 5.81 7665	3.47 2.25 ∞	H	Topsoil Weathered crystalline basement Weathered – fractured basement

Construction of the Geoelectric section

Part of the interpretation of electrical sounding survey data is the construction of geoelectrical section. The results of the interpretation from the several soundings are plotted as a vertical section and if possible, some borehole or other geological information are included. A correlation is then made between the formation recorded in the borehole and layers interpreted from the soundings. At this stage, the problems of suppression and equivalence are often encountered. However once this problem has been resolved, a correlation is made across the whole survey data with construction of several geoelectric section.

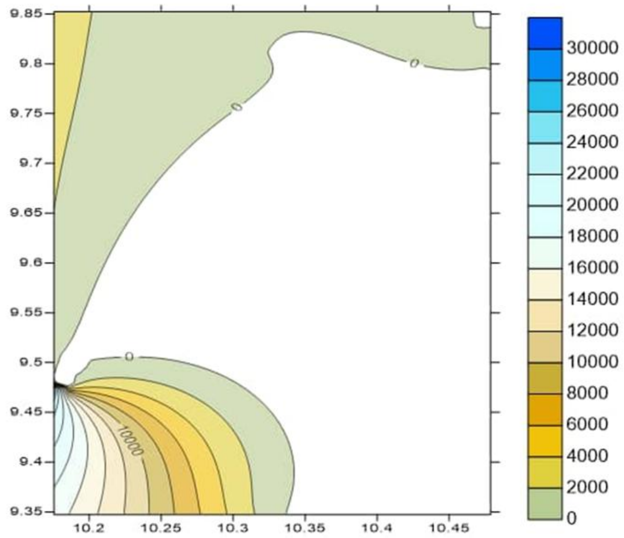

Fig 6: Isoresistivity Contour Map Of The First Layer

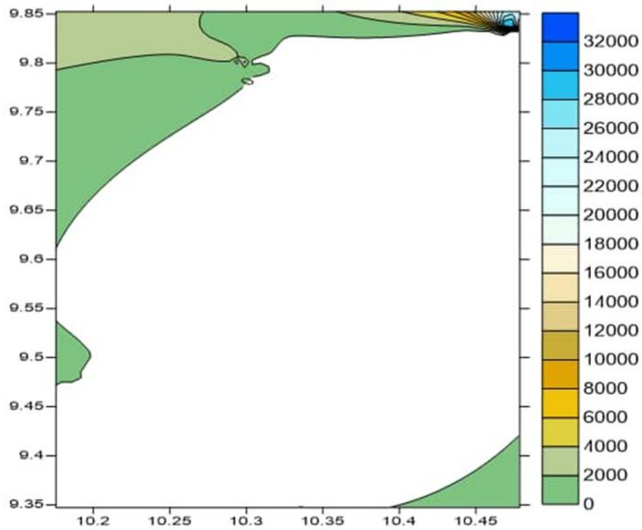

Fig 7: Isoresistivity Contour Map Of The Second Layer

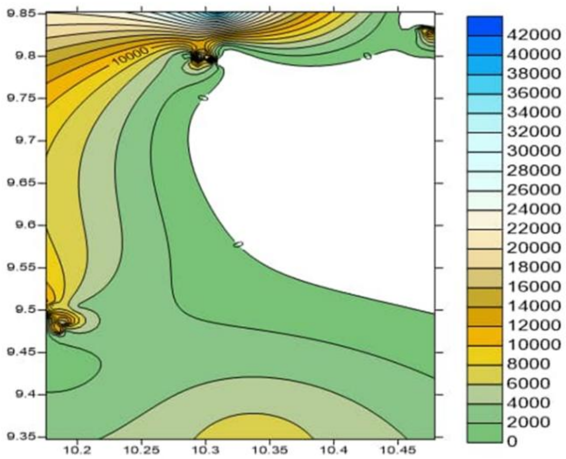

Fig 8: Isoresistivity Contour Map Of The Third Layer

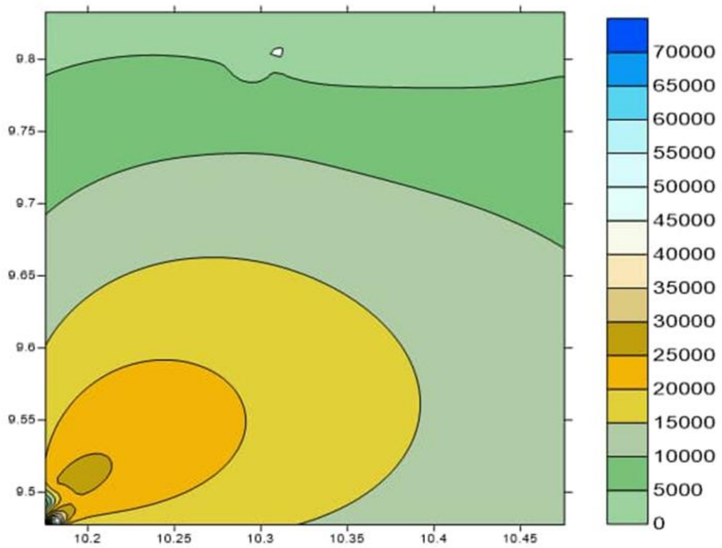

Fig 9: Isoresistivity Contour Map Of The Fourth Layer

VI. Discussion Of Results

Notably, four geoelectric layers, which comprises of topsoil, decomposed crystalline rock, weathered crystalline rock, and fresh/fractured crystalline rock were delineated. The regions of low resistivity exhibiting resistivity values ranging from 30.4 - 35686 Ωm characterized in VES 01, 02, 03, 04, 05, ---------- (Fig 8 and Supplementary material) were inferred to be a region of decomposed crystalline rock. Most sounding curves to the east of the study area exhibited good groundwater potential because of the presence of fractures. This interpretation is in agreement with conclusion of Schroeter, 1976 who opined that the aquifer around this area constitute of decomposed crystalline rock overlying a partially fractured crystalline rock.

The basement rock occurs at depth with absence of fractured rock within it. Central part of the study area exhibits a low to moderate groundwater potential because of thin overburden and absence of deep-seated fractures. Shehu, 2025 (verb. comm.) supports this assertion where they also reported the presence of thin overburden of the order of 2-5m around this area and low yield in most of the boreholes drilled.

About half (48%) of all the sounding curves were found to possess high to very high resistivity values of the fourth layer, particularly well pronounced in VES 03, 04, 15, 29, 42, 49, 51, 56.. This indicates prevalence of fresh and extensive rock at shallow depth. However, moderate to low resistivity values characterize this layer in the eastern part of the study area. Hence, this region is inferred to have the highest ground water potential in the study area.

Shemang and Umaru (1994) conducted geophysical investigation for groundwater in Bauchi town. The result of the survey indicated that the overburden (Regolith) in Bauchi Metropolis ranges from about 10 to 35 m in most places. The regolith was deducted from vertical electrical sounding (VES) results to consist essentially of top soil, highly weathered materials tending towards clay, and weathered basement, all underlain by fresh crystalline basement. Our study area overlapped the western half of their study area and their conclusion agrees well with ours except in certain pockets, which may be attributed to difference in density of data aquired. Our data being denser in terms of acquisition geometry, therefore gives better resolution of the subsurface geology (Fig.

VII. Conclusion

The application of electrical resistivity method to delineate groundwater bearing zones using the variation in resistivity values of different layers due to their varied constituent materials and water content was achieved in this study. This characterization was done using the resistivity values, thickness and depth of the layers inferred from the resistivity sounding curves. This study is important for the selection of viable drilling sites for productive boreholes within the study area. The problem related to low yield and dry boreholes drilled within the area is identified as due to dominance of partially weathered crystalline rock and dry fractured zones.

From analysis and interpretation of the data the following VES points are recommended for drilling: VES 3, 4, 5, 6, 10, 12, 13, 14,15, 16, 18, 19, 21, 25, 26, 27, 28, 30, 33, 34,36, 37, 38, 41,44, 55,59, 60, 64, 67, 68, 69, 71 and 72 to a depth of 50-60 m.

References

[1] Adegoke, O.S.; Jan Du Chene, R.E.; Agumanu, A.E. And Ajayi, P.O. (1978). Paleontologic Age Of The Kerri-Kerri Formation, Nigeria. Rev. Espan. Micropaleontologia, 2: Pp.267-283

[2] Carter, J.D.; Barber, W.D. And Taitt, E.A. (1963). The Geology Of Parts Of Adamawa, Bauchi And Borno Provinces In Northeastern Nigeria. Geological Survey Nigeria Bull., 30: P.108

[3] Dike, E. F.C. And Egbuniwe, I.G. (1993). An Unconformity Between The Kerri-Kerri Formation And The Basement Complex At Mainamaji, Bauchi State. In The Journal Of Mining And Geology 29 (In Press).

[4] Du Preez, J.W & Barber, W. (1965). The Distribution And Chemical Quality Of Groundwater In Northern Nigeria. Geological Survey Of Nigeria Bulletin No.36: 93

[5] Mccurry, P. (1989): A General Review Of The Geology Of The Precambnrian To Lower Palaeozioc Rocks Of Northern Nigeria In: C. A. Kogbe (Ed) Geology Of Nigeria. Rockview Ltd., Jos.

[6] Oyawoye M.O. (1964): The Geology Of The Nigeria Basement Complex. Journ. Nigerian Mining, Geolo. And Metal. Soc., 1, 87-102.

[7] Rahaman, M.A. (1981). Recent Advances In The Study Of The Basement Complex Of Nigeria. Abstract.First Symposium On The Precambrian Geology Of Nigeria.

[8] Schroeter, P.Y. (1976). Hydrogeology Of Bauchi Province Northern Nigeria. Geological Survey Of Nigeria, 8(1), 17-24

[9] Sharma. V. (1997). Environmental And Engineering Geophysics. 237- 241.

[10] Shehu, A. Y. (2025). Verbal Communication. 9th February, 2025

[11] Shemang, E.M. & Umaru, A.F.M. (1994). Geophysical Investigation For Groundwater In The Area Around Bauchi Town. A Journal Of Mining And Geology 30(1), 81-86.