

Combined Electrical Resistivity And Induced Polarisation Methods For Groundwater Exploration At Yelwan Lebura Area Of Bauchi, Northeastern Nigeria

M. Bello, P. Adetoyin, G. Mohammed, Y. Abdulmuminu And A. M. Kaura
(Department Of Physics, A.T. B. University, Bauchi-Nigeria)
(Department Of Geology, A.T. B. University, Bauchi-Nigeria)
(Department Of Geology, Federal University Lafia, Nassarawa State-Nigeria)

Abstract

This study aimed to determine the existence of ground water based on measurement of apparent resistivity and chargeability. Our study inferred geoelectric sections comprising of four subsurface layers. The first layer of thickness range 1.8 to 8.0 m has resistivity ranging from 161 to 869 ohm-m and chargeability range of 3.1 to 4.6 ms and is inferred to be lateritic topsoil. The second geoelectric layer has resistivity values ranging between 21.4 and 59.0 ohm-m; chargeability of 0.01 to 2.99 ms with thicknesses varying between 2.5 and 7.7 m, this layer is interpreted to represent a highly weathered to moderately decomposed crystalline rock. The third geoelectric layer is considered to be the dominant aquifer in the area under investigation and is inferred to be weathered and/or fractured crystalline rock. This layer has moderate electrical resistivity and high chargeability values of 359–567 ohm-m and 3.0–9.77 ms respectively, and could be recognised sometimes as the most extreme depth of current penetration. The fourth geoelectric layer was recognised to have the highest electrical resistivity values (793.7–853.6 ohm-m) and low chargeability values (3.13 -4.13 ms) that depicts fresh crystalline basement. We recommended boreholes to be drilled on VES 03,04,05 and 09 because they contain probable aquifers. The recommended depth of drilling should be between 60m and 90m to take advantage of the basement fractures. In general, the area can be said to be poorly weathered and it cannot support substantial water abstraction of industrial scale when drilled.

Keywords: Electrical resistivity, VES, aquifer, groundwater, Yelwan Lebura, Bauchi

Date of Submission: 17-03-2026

Date of Acceptance: 27-03-2026

I. Introduction

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27'14.1", 7°27'12.5", 7°27'07.9" and 7°27'12.6" and the latitudes 3°53'40.4", 3°53'40.7", 3°53'27.6" and 3°53'36.5" (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27'14.1", 7°27'12.5", 7°27'07.9" and 7°27'12.6" and the latitudes 3°53'40.4", 3°53'40.7", 3°53'27.6" and 3°53'36.5" (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27'14.1", 7°27'12.5", 7°27'07.9" and 7°27'12.6" and the latitudes 3°53'40.4", 3°53'40.7", 3°53'27.6" and 3°53'36.5" (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27'14.1", 7°27'12.5", 7°27'07.9" and 7°27'12.6" and the latitudes 3°53'40.4",

3°53'40.7", 3°53'27.6" and 3°53'36.5" (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

The study area is located in Oshoshun village, in Ifo local government area of Ogun State. It is located within the longitudes 7°27'14.1", 7°27'12.5", 7°27'07.9" and 7°27'12.6" and the latitudes 3°53'40.4", 3°53'40.7", 3°53'27.6" and 3°53'36.5" (Figure 1). The area is accessible through an untarred road, which branches off from the Lagos–Abeokuta Express Road.

The study area lies within the Oshoshun Formation, which is phosphate bearing. The phosphate within the Oshoshun occurs as discrete bands in the shale, which sometimes at some parts could also be glauconitic, while the gypsum appears as mud-supported gypsiferous

Choosing a borehole site is a critical part of the process of providing a safe and reliable supply of groundwater. Drilling abortive water boreholes is prevalent around Yelwan Lebura. However, field experience reveals abundance of clay material in the lithological sections of most of these dry holes. Clays are known to have poor aquifer capabilities due to their high porosity and poor permeability. However, they depict low resistivity values in resistivity surveys. This could be misleading in interpretation of resistivity data, because differentiating between aquiferous weathered/fractured crystalline and non-aquiferous clay layers (highly decomposed crystalline rocks) may be difficult. On the other hand, induced polarisation technique depicts clay layers as higher chargeability sections compared to weathered or fractured crystalline rocks. Therefore, combining Electrical Resistivity and Induce Polarisation techniques could lessen interpretation ambiguity.

This study primarily utilizes electrical resistivity and induced polarization techniques. When these methods are combined, they enable better modeling of subsurface structures, allowing precise identifications of groundwater bearing zones. These techniques measure the resistivity and chargeability of the subsurface across a traverse taken, offering valuable insights into subsurface geoelectrical properties.

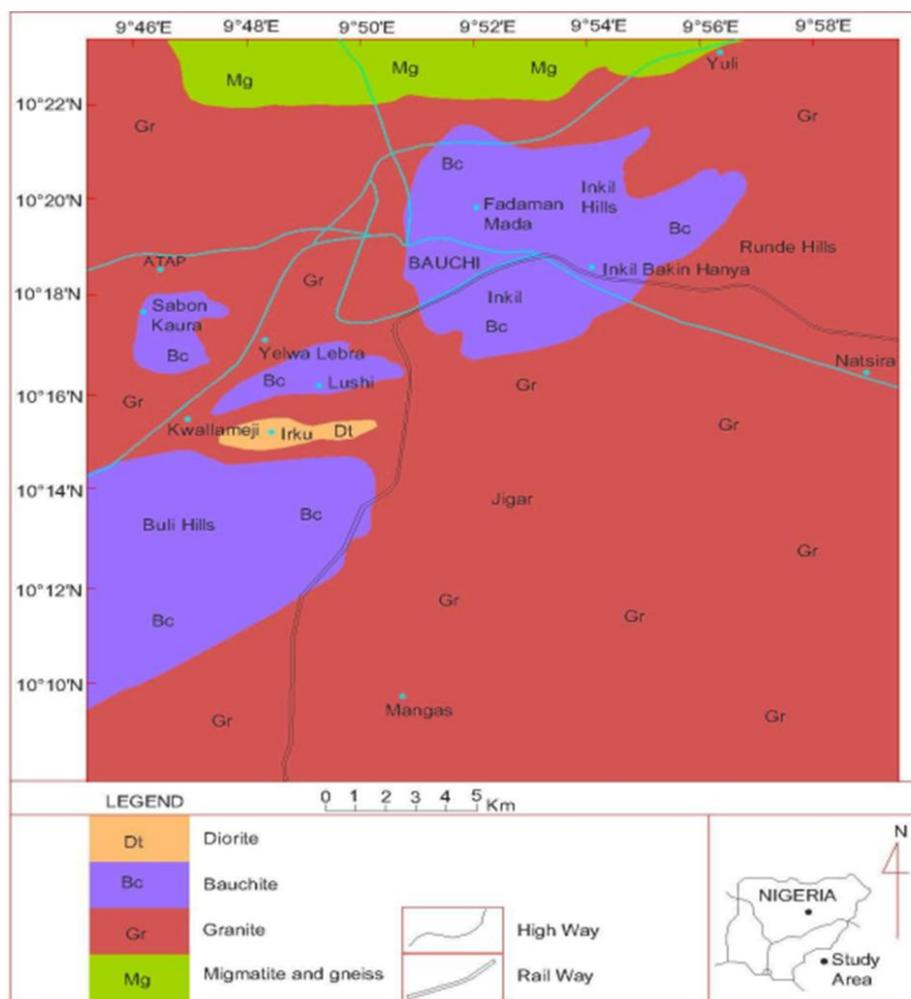


Fig. 1. Location map of the study area showing its relation to major geologic components (after Haruna, 2016).

The electrical resistivity technique is one of the most widely applied geophysical methods for groundwater investigation in crystalline basement terrane (Martinelli, 1978; Dike et al., 1994). This technique estimates the distribution of rock resistivity in the subsurface, which among others can vary with moisture content and lithology. The relevance of this method is based on the noticeable resistivity contrast between water bearing zones (usually weathered and or fractured zones) and very resistive non-water bearing fresh rocks. The extent and nature of the weathered layer and the degree of fracturing of fresh rocks are dependent on the subsurface geology (Martinelli, 1978; Keary and Brooks, 1991). The method has proven to be rapid and effective in providing useful information about hydrogeological conditions and is relatively cheaper when compared to other geophysical techniques.

The induced polarization method (IP) is a geophysical method used to identify subsurface geological bodies by measuring the delayed voltage response (polarization) after the application of an electrical current. This method is useful in groundwater exploration to delineate clayey layers and clayey units or saline aquifers from adjacent rock units (Seara and Granda, 1987). Polarization occurs at the boundary between a metal and a fluid (known as electrode polarization) or between a non-metal (such as silica or clay minerals) and a fluid (traditionally referred to as membrane polarization) (Keary and Brooks, 1991).

The basic aim of this study is to determine the thickness and depth of the water-bearing layer(s) (aquiferous layer) in the study area. The study could also give an insight into the hydrogeological relationship between different parts of the study area. This knowledge may help in future groundwater development of the study area. In this paper, we focus on the presentation of the highest-quality resistivity and chargeability measurements from Vertical Electrical Soundings (VES's) in order to present a first-order picture of the hydrogeological condition of the study area. This study would further explain how resistivity and IP techniques could yield better information of the subsurface and hence improve the chances of drilling productive boreholes

II. Regional And Local Geology Of The Study Area

The regional geology of the study area is characterized by Precambrian rocks of Nigeria basement complex, including granites, gneisses, schists, and quartzites (Oyawoye, 1958). The older gneisses are formed between 2.4 to 3.8 billion years ago, while the younger granite date back 1.1 to 2 billion years (Falconer, 1911). This region features flat and hilly topography, mixed with lateritic soil, alluvial deposits, and significant clay deposits, supports stable construction foundations (Abbas, 1983). The rocks in this region typically appear as flat outcrops in lowland areas. The weathering of crystalline rocks results in laterite and alluvial covers, with decomposed materials forming sand or clayey sand, influenced by the local mineralogy variations of the granite, gneiss, and migmatites (Falconer, 1911; Oyawoye, 1964).

Relatively 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 that now represented as synclinal troughs among older rocks in northwestern Nigeria (Carter et al., 1963; Rahman, 1988; McCurry, 1989).

Intrusives into the Basement rocks and the younger supracrustal cover are series of intermediate plutonic rocks known as the older granite suites. These are chernokites, diorites, fayalites quartz-monzonites (bauchites) and gabbroic earlier rocks. Migmatization has differently affected all the earlier rocks as well as the large-scale conversion of basement gneisses and migmatites (Oyawoye, 1958).

Locally, older granites and fayalite bearing quartz monzonite underlie the study area (Figure 1). The principal rocks outcropping comprises of highly weathered granites featuring remnants of large feldspar crystals and well-defined zones of quartz-rich veins. This type of rock practically constitutes the high elevations of the fairly rugged topography that characterises the terrain. Another major outcrop of importance is fayalite quartz-monzonites (bauchites), which is also characterised by large quartz crystal and a taint of greenish colour when fresh but turns brown upon weathering (Oyawoye, 1961, Oyawoye and Makanjuola, 1972). They have few joints and outcropping as smooth rounded boulders derived from massive unfoliated rocks by weathering. The bauchite usually appear as large intrusions into a more widely spread biotite hornblende granite. The contact between the bauchite and the granite is gradational. This transition coincided with a gradual change in colour from dark green (where bauchite is fresh) or dark brown (where it is weathered) to pink or grey in biotite hornblende granite. The change in colour is also marked with a change in the mineralogy expressed by progressive decrease in fayalite, pyroxene (clino- and ortho-pyroxenes) and increase in biotite (Haruna, 2016). This is attributed to mineralogical changes due to hydration reaction caused by water migrating from the granitic outer rock to the drier bauchite (Eborall, 1974).

III. Hydrogeology Of The Study Area

The occurrence of aquiferous layer in the area is sought within the highly decomposed to partially weathered basement rocks as well as fractured basement rocks, and these are found at depth in excess of 1 meter from the ground surface (BSADP Report, 1983). However, some portions of the basement rocks are not readily

exploitable owing to the poor weathering and/or fracturing on these rocks (Offodile, 1992). Hence yields have been reported to be low in these areas, typically less than 40 litres per minute and more frequently less than 25 litres per minute (Offodile, 1992). The study area comprises of (2) stream channels – likely contributors for aquifer recharge, which occupy the various depressed areas in a rather dendritic to angular drainage pattern. These channels, which are seasonally charged by rain merged into minor tributaries that ultimately feed several ponds around the study area.

IV. Methodology

1D Electrical Resistivity Method

The electrical resistivity survey is one of the earliest geophysical methods used to locate underground water. Its primary goal is to map the distribution of subsurface resistivity by taking measurements on the ground's surface. This method uses four electrodes system, and this is achieved by injecting an electrical current into the ground through the current electrodes (A&B) and the potential difference measured via potential electrodes (M&N).

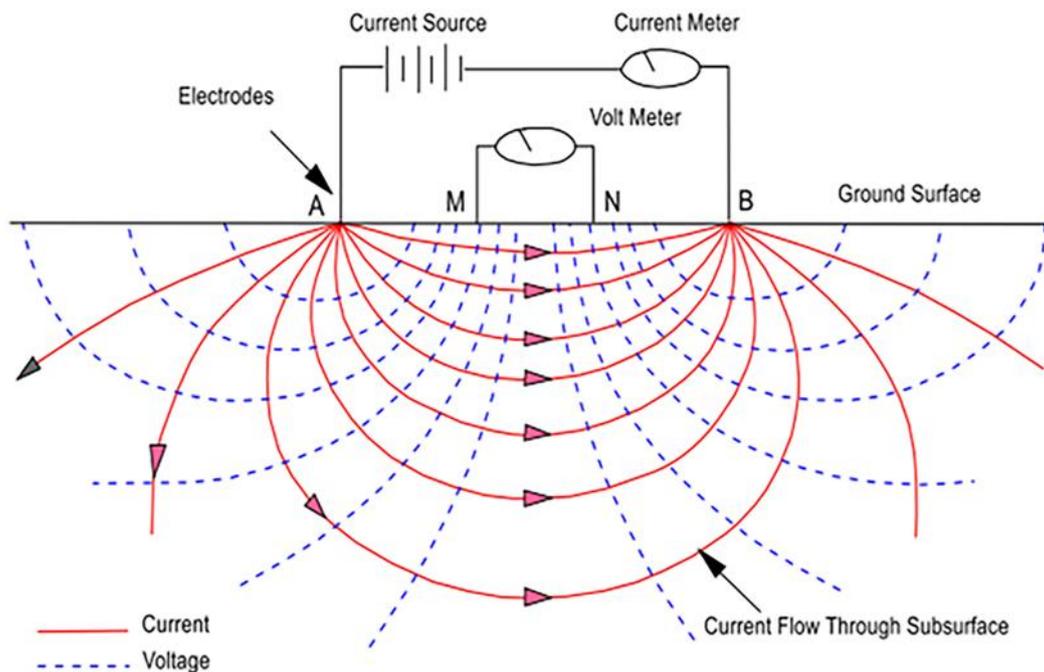


Fig 2. Schematic diagram of electrical resistivity survey. Source (Robinson, 1988)

The electrical resistivity survey relies on Ohm's Law, which describes how the current (I) through a conducting material varies with the potential difference (V) across it. According to Ohm's Law, the potential difference is directly proportional to the current, with the resistance of the material as the proportionality factor.

From ohm's law:

$$V = IR \text{ -----(1)}$$

$$R = \frac{V}{I} \text{ -----(2)}$$

Where R = Resistance

I = Current

V = Voltage

$$\rho_a = k \left(\frac{V}{I} \right) \text{ ----- (3)}$$

ρ_a = apparent resistivity in ohms per meter (Ω/m)

k = geometric factor, expressed as

$$k = 2\pi \cdot \left[\left(\frac{1}{AM} - \frac{1}{MB} \right) - \left(\frac{1}{AN} - \frac{1}{NB} \right) \right]^{-1} \text{ -----(4)}$$

Field Procedure

In this research work, Vertical Electrical Sounding (VES) was employed using Schlumberger electrode configuration. The Schlumberger array method involves placing four electrodes in a straight line on the ground, with the current electrodes (A and B) widely spaced compared to the potential electrodes (M and N), which are positioned closer together. This configuration allows for the measurement of subsurface resistivity by applying an electrical current between A and B and measuring the resulting potential difference between M and N (Fig. 3.). The Schlumberger array is particularly effective for mapping subsurface structures and variations in resistivity.

The apparent resistivity for the Schlumberger configuration setting is give as;

$$\rho_a = \pi \left\{ \frac{[(AB)^2 - (MN)^2]}{MN} \right\} * \frac{\Delta V}{I} \text{-----(5)}$$

$$\rho_a = k * \frac{\Delta V}{I} \text{-----(6)}$$

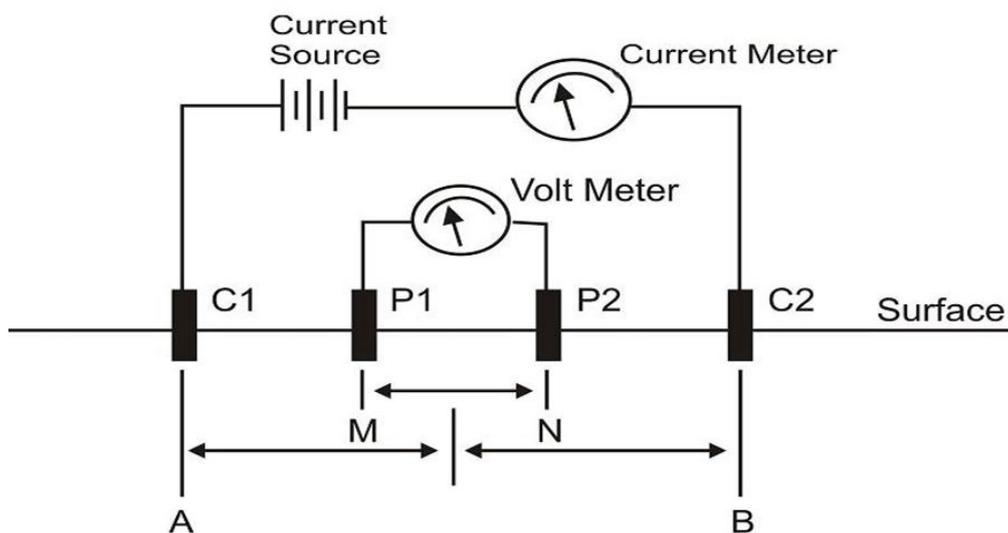


Fig. 3. Schlumberger electrode configuration (Keary and Brooks, 1991).

Resistivity Depth Sounding

Resistivity depth soundings are employed to explore subsurface layering by using electrode arrays where the spacing between the electrodes varied. During the process, apparent resistivities are measured and plotted against electrode spacing using IX1Dv2 software. The software analyses the data, providing automated interpretation of the sounding curves to derive an equivalent n-layer model from each apparent resistivity curve. The shape of each curve at a VES station reflects a sequence of subsurface layers. The primary goal of processing these VES data and visualizing them as curves is to identify the number of subsurface layers, approximate resistivities, and their thicknesses.

Induced Polarisation Method (IP)

The induced polarization method (IP) utilises measurement of delayed voltage response (polarization) after the application of an electrical current. This method is known to be useful in both mineral and water exploration to delineate clayey layers and clayey units (Seara and Granda, 1987). Polarization in the subsurface occurs at a boundary between a metal and a fluid (known as electrode polarization) or between a non-metal (such as silica or clay minerals) and a fluid (traditionally referred to as membrane polarization) (see Fig. 5).

Polarise Ground

When a variable low frequency AC or a direct current DC is introduced into the ground using using a standard four-electrode resistivity spread, then the current is abruptly switched off, the voltage between the potential electrodes does not drop to zero immediately. After a large initial decrease the voltage gradually decays and can take several seconds to reach a zero value (Fig. 4). A similar phenomenon is observed as the current is switched on. After an initial sudden voltage increase, the voltage increases gradually over a discrete time interval to a steady-state value. The ground thus acts as a capacitor and stores electrical charge, thus becomes electrically polarised.

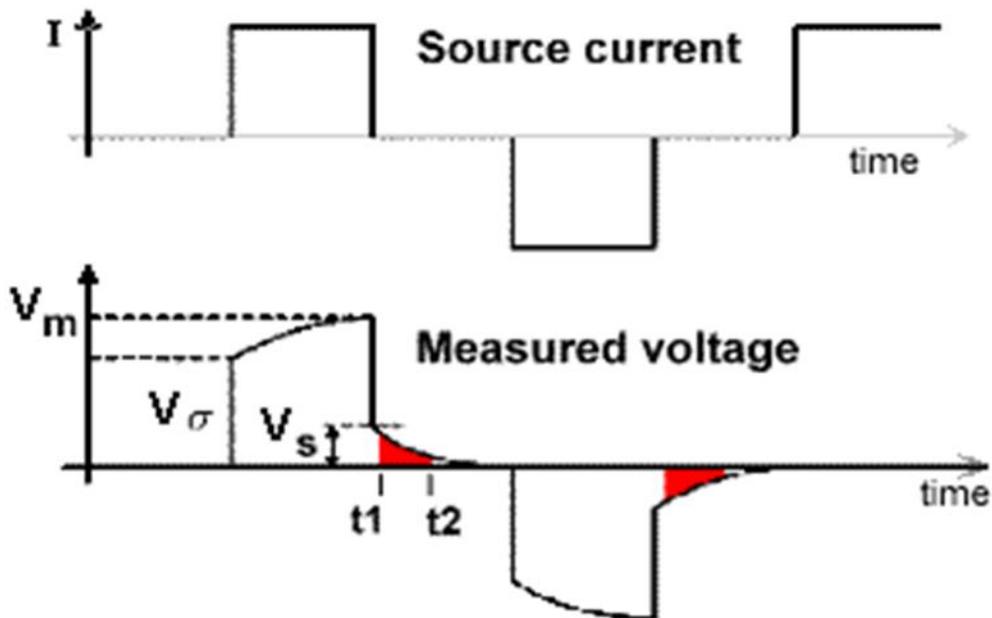


Fig 4. Chargeability of the Earth when current is applied (Seara and Granda, 1987)

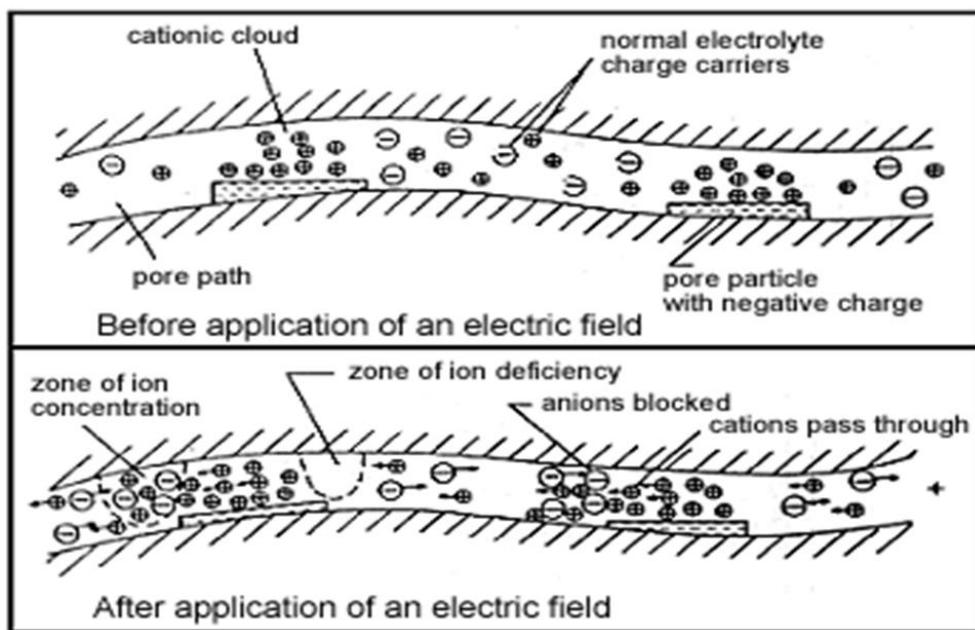


Fig. 5. Membrane Polarization in rock containing clay particles (Ward, 1990)

Induced Polarization (IP) Measurement

The research employs time domain polarisation technique, which deal with the rate of decaying voltage after the current injected is turned off. The key parameter measured is chargeability (Ward, 1990).

$$M = \frac{\int_{t_1}^{t_2} v_s dt}{v_\sigma \Delta t} \quad (7)$$

Where V_s represents the residual voltage integrated over a time window, which starts at time t_1 and ends at time t_2 , following the cessation of an applied current.
 V_σ is the measured voltage.
 Δt is the length of the time window of integration.

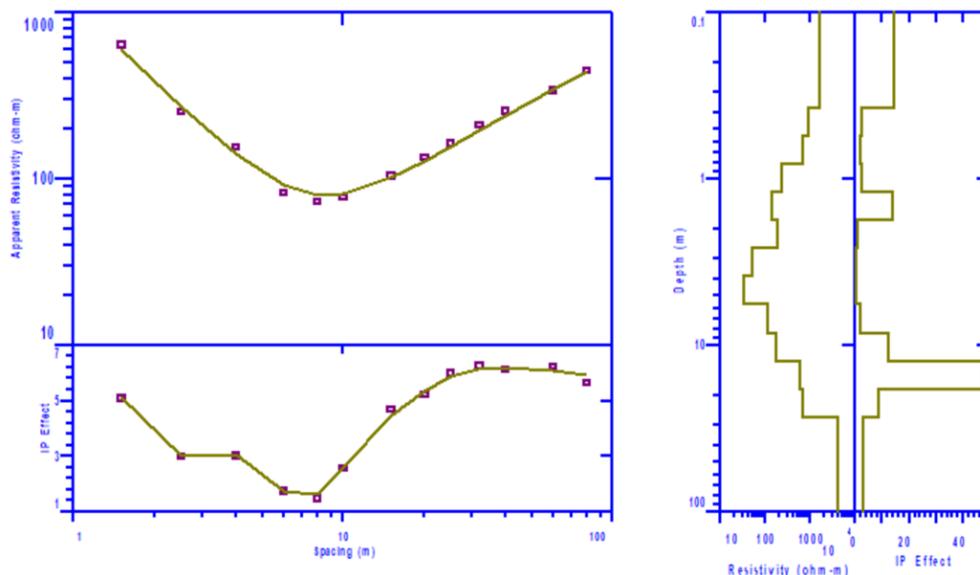
Just like resistivity the IP data can be interpreted by plotting chargeability in (ms) against depth (AB/2) in meters. From the analysis of these curves inference can be made on the subsurface geology.

V. Results And Discussion

The interpretation of both the VES and IP were done quantitatively using computer software IX1Dv2. This was achieved by plotting apparent resistivity (ρ_a) in Ω -m against depth (AB/2) in meters, and chargeability in (ms) against depth (AB/2) in meters in the case if IP. Integrating these techniques reveal a marked variation in subsurface resistivity and chargeability. These variations reveal boundaries of different geological layers with distinct properties. Values of approximate resistivities and/or chargeabilities and thicknesses of these layers are used to delineate and infer groundwater-bearing zones.

After plotting the data, a four-layered model consisting of the topsoil/laterite, decomposed crystalline rock, weathered/fractured crystalline rock and fresh crystalline rock was produced from the field data. Values of thickness and apparent resistivities and chargeabilities were varied until the field and theoretical curves had the least possible misfit. An example result from Figure 5 suggests that the resistivity model whose calculated apparent resistivity chargeability best fit the measurements, with a RMS error of 2.3, is characterized by a top layer with a thickness of 1.3 m and apparent resistivities of 628.21 ohm-m, a value characteristic of lateritic topsoil. The second layer is approximately 7.7 m thick, has an apparent resistivity of 58.6 ohm-m. The range of apparent resistivity values and thickness of the second layer is interpreted as the decomposed crystalline rock depicting overburden saturated with pore water for such, as suggested in Martinelli and Hubert (1985). The third layer has a thickness of 10.2 and an apparent resistivity of 396.1 ohm-m and is presumed to be the decomposed to weathered crystalline bedrock. The fourth layer has an apparent resistivity of 3842 ohm-m and is presumed to be the weathered/fractured to fresh crystalline rock. Martinelli and Hubert (1985) suggested that such thickness of the weathered overburden (i.e. > 19 m) is associated with a borehole success rate of around 25% and thus the groundwater potential in this particular region may be low.

The electrical resistivity method primarily detects the presence of water regardless of its volume. Since clay is known to be very porous but not permeable, making it difficult for it to supply water to a well, resistivity readings will identify clay layers as water bearing strata. By incorporating the IP method, these clayey zones can be fairly delineated as high chargeability/low resistivity zones, which helps in prevent drilling of water borehole at clay prevalent areas.



#	Rho	Fix?	pfe	Fix?	Thick	Depth	Elev
1	628.27	<input type="checkbox"/>	4.3938	<input type="checkbox"/>	1.3001	1.3001	-1.3001
2	58.609	<input type="checkbox"/>	0.23300	<input type="checkbox"/>	7.6948	8.9949	-8.9949
3	396.11	<input type="checkbox"/>	38.411	<input type="checkbox"/>	10.323	19.318	-19.318
4	3842.5	<input type="checkbox"/>	2.6631	<input type="checkbox"/>			

Fig. 6. Example of combined interpreted resistivity and IP data interpretation.

From the data interpreted, it was observed that curve type H is the most prevalent in the study area (see appendix). The ten sounding data points interpreted shows three to four geo-electric layers which are the top soil, highly weathered basement (decomposed layer), fractured basement rock and fresh crystalline bedrock. The weathered-fractured basement was identified as the potential aquifer.

Table 1: Result of interpreted resistivity data.

VES No.	CORDINATE	LAYER NO.	APP. RES (ρ_a) Ω -m	THICKNESS (m)	INFERED LITHOLOGY
01	10° 16' 37''N 09° 48' 12''E	1	161.8	1.3	Top soil
		2	36.9	4.4	Weathered basement
		3	574	18.6	Fractured basement
		4	3687.3	∞	Fresh crystalline bedrock
02	10° 16' 39''N 09° 48' 10''E	1	206.7	1.8	Top soil
		2	21.4	2.5	Weathered basement
		3	1429	20.2	Fractured basement
		4	5997	∞	Fresh crystalline bedrock
03	10° 16' 42''N 09° 48' 09''E	1	176	1.6	Top soil
		2	50.8	4.9	Weathered basement
		3	598	12.3	Fractured basement
		4	4408.	∞	Fresh crystalline bedrock
04	10° 16' 36''N 09° 48' 08''E	1	161.9	1.3	Top soil
		2	37.1	4.4	Weathered basement
		3	532	19.5	Fractured basement
		4	4967	∞	Fresh crystalline bedrock
05	10° 16' 38''N 09° 48' 06''E	1	567	1.2	Top soil
		2	25	1.9	Weathered basement
		3	359	11	Fractured basement
		4	853.6	∞	Fresh crystalline bedrock
06	10° 16' 39''N 09° 48' 07''E	1	392	0.9	Top soil
		2	52.9	3.9	Weathered basement
		3	674.	22.1	Fractured basement
		4	5637	∞	Fresh crystalline bedrock
07	10° 16' 39''N 09° 48' 06''E	1	869.8	0.8	Top soil
		2	34.7	3	Weathered basement
		3	407.9	10.7	Fractured basement
		4	793.7	∞	Fresh crystalline bedrock
08	10° 16' 38''N 09° 48' 05''E	1	628	1.3	Top soil
		2	59	7.7	Decomposed basement
		3	396	10.3	Fractured basement
		4	3842	∞	Fresh crystalline bedrock
09	10° 16' 40''N 09° 48' 07''E	1	505.9	1.1	Top soil
		2	32.8	7.0	Weathered basement
		3	10678	∞	Fractured-fresh basement
10	10° 16' 38''N 09° 48' 06''E	1	374.9	1.1	Top soil
		2	47.5	7.2	Decomposed basement
		3	7877	∞	Fractured-fresh basement

The thickness of the weathered and fractured layers plays a critical role in determining the potential of an exploration site. Therefore, for VES to show promising results, the aquiferous zone must exhibit substantial thickness and apparent resistivity. Based on this consideration, the following were selected as favourable drilling points for ground water exploitation within the study area: VES/IP 03, 04, 05, and 09. The table below show the suitable points and depth to be drilled, which can yield, moderate to maximum yield.

Table 2: Recommended VES points and depth to be drilled.

VES NO	CORDINATES	DRILLING DEPTH (m)
03	10° 16' 42''N, 09° 48' 09''E	60 to 70
04	10° 16' 36''N, 10° 16' 38''N	70 to 80
05	10° 16' 38''N, 09° 48' 06''E	80 to 90
09	10° 16' 40''N, 09° 48' 07''E	70 to 80

To improve understanding of this interpretation, a 2D iso-resistivity and chargeability map of the aquiferous zone is plotted (Figure 7). From this figure, a high resistivity and moderate chargeability the northern central part of the study area suggests the possibility of fresh crystalline rock at shallow depth which could be explained by the occurrence of low lying granitic outcrop around VES 02. A low resistivity and relatively low chargeability zone form the central towards the southern part and western margin of the study area suggests the possibility of groundwater saturation with pockets of high clay content (VES 10, 07, 08) which may be favourable for water abstraction. Nura et al., (Verb, also reported this. Statement, 2025) who stated that the few residential boreholes drilled around these regions of the study area showed higher frequency of clay layers in the upper 30 m of the overburden. The low resistivity region along the southeastern part of the study area may also suggest the presence of a fracture zone in this region. This also agrees with earlier studies by BSADP Report, 1983 which suggested that the geological features of this area consist of weathered and fractured basement in which groundwater tends to occur within residual overburden (regolith) and the fractured zone.

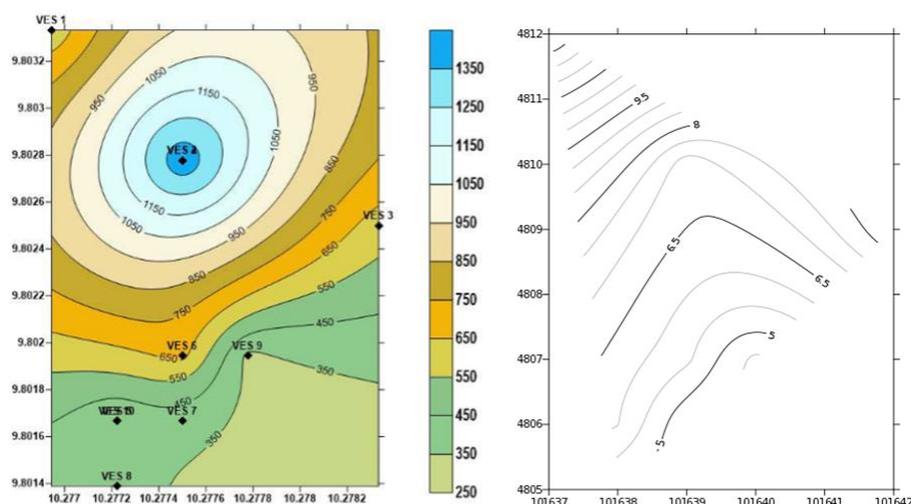


Fig. 7. Iso-resistivity and chargeability map of the aquiferous zone.

VI. Conclusion

Integrating electrical resistivity and IP methods help to accurately reasonably infer rock layers containing large amount of clay. This combined approach provides a clearer indication of areas with substantial water quantities, allowing the differentiation between clay bodies and actual water bearing layers (aquifers).

VII. Acknowledgment

The authors wish to thank the people of Yelwan Leburu for the assistance received during data acquisition. We are equally grateful to Abubakar Tafawa Balewa University, Bauchi for providing the opportunity to carry out this research work.

References

- [1]. Abbas, S.I. (1983). Precambrian Geology of Nigerian.
- [2]. B.S.A.D.P. (1983). Development Area Statistics, Bauchi State Agricultural Development Programme Publication. Arka Carto, England.
- [3]. Carter, J.D., Barber W. and Tait E.A. (1963). The geology of parts of Adamawa, Bauchi and Bornu Provinces in north-eastern Nigeria: Explanation of 1: 250,000 Sheets Nos 25, 36 and 47. Geol. Surv. Nigeria. Bull. No. 30. P108.
- [4]. Dike, E.F.C., Shemang, E.M. and Dan-Hassan, M.A. (1994). Water Exploration in A.T.B.U. main Campus at Gubi using Electromagnetic and resistivity technique. Unpublished report, p 1-3.
- [5]. Eborall, M. I. (1974). Intermediate rock from the Older Granite Complexes of Bauchi area, Northern Nigeria. In: C.A. Kogbe (Ed) Geology of Nigeria 2ND Revised Edition. Elizabethan Publication Company, Lagos, P65-74.
- [6]. Falconer J.D. (1911). The geology and geography of northern Nigeria. MacMillan, London.
- [7]. Haruna, I.V. (2016). Lithology and Field Relationships of the Granitoids of Bauchi District, Northeastern Nigeria. International Research Journal of Earth Sciences, 4(6), 31-40.
- [8]. Kearey, P., Brooks, M., (1991). An Introduction to Geophysical Exploration, second ed. Blackwell Scientific, Oxford Publishing House.
- [9]. Martinelli, E., (1978). Groundwater exploration by geoelectrical methods in Southern Africa. Bull. Assoc. Eng. Geol. 15, 113-124.
- [10]. Martinelli, E., Hubert, G.L., (1985). A report to the ministry of energy and water resources and development. Master plan for rural water supply and sanitation, Norad. Hydrogeology 2, 109-118.
- [11]. McCurry, P. (1989). A General Review of the Geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria In: C. A. Kogbe (ed) Geology of Nigeria. Rockview Ltd., Jos.
- [12]. Offodile, M. E. (1992). An approach to groundwater study and development in Nigeria. First edition, Mecon Services Ltd. P20-28, 204-240.
- [13]. Oyawoye, M. O. (1958). The petrology of the Older Granites around Bauchi, Nigeria. Ph.D. thesis Univ. Durham.
- [14]. Oyawoye, M. O. (1961). On the occurrence of fayalite quartz-monzonite in the basement complex around Bauchi, northern Nigeria. Geol. Mag., 98, 473-482.
- [15]. Oyawoye M.O. (1962). The petrology of the district around Bauchi, northern Nigeria. J. Geol., 70, 604 – 615.
- [16]. Oyawoye M.O. (1964). The geology of the Nigeria basement complex. J. Nigerian Mining, Geolo. and Metal. Soc., 1, 87-102.
- [17]. Oyawoye M.O. and Makanjuola A.A. (1972). Bauchite: a fayalite-bearing quartz monzonite. 24TH Int. geol. Congr., section 2, 251 – 266.
- [18]. Rahaman M. A. (1988). Recent advances in the study of basement complex of Nigeria. Proc. Geol. Surv. Nig. Publication. 8. 17-24.
- [19]. Robinson, E. S. (1988) Basic Exploration Geophysics. John Wiley & Sons, New York, 562p.
- [20]. Seara J. and Granda A. (1987). Interpretation of IP time domain/resistivity soundings for delineating seawater intrusions in some coastal areas of the Northeast of Spain. Geoexploration, 25: 153-167
- [21]. Ward, S. H. (1990). Resistivity and induced polarization methods, in Ward, S. H., Geotechnical and environmental geophysics: Volume I, Review and tutorial, Soc. Explor. Geophysics, 147-190.