

## Original Research Article

# APPLICATION OF INTEGRATED GEOPHYSICAL METHODS IN GROUNDWATER EXPLORATION IN ADAMAWA STATE UNIVERSITY, MUBI.

### ABSTRACT

Integrated geophysical methods was used for ground water study in Adamawa state University Mubi. The method employed are powerful tool Audio Magnetic Telluric (ADMT-600 S-X) with powerful software ZondMT 1D and Electrical resistivity with IXD interpex software. In both case electrical property of subsurface are been measured. The magnetotelluric method or magnetotellurics (MT) is an electromagnetic geophysical exploration technique that images the electrical properties (distribution) of the earth at subsurface depths. The energy for the magnetotellurics technique is from natural source of external origin. When this external energy, known as the primary electromagnetic field, reaches the earth's surface, part of it is reflected back and remaining part penetrates into the earth. Earth acts as a good conductor, thus electric currents (known as telluric currents) are induced in turn produce a secondary magnetic field. While the electrical resistivity is an active geophysical method where electric current is injected into the ground through a pair electrodes. In this study forty three profiles were sounded using the magnetotelluric in which only indicates potential for ground water. The nine profiles were later confirm with electrical resistivity method. the results obtained for drilling optimal Boreholes are as follows: ADMT for the nine profile are: 185 m, 210-300 m, 210 m, 210-300 m, 175 m, 195-300 m, 190-270 m, 215-300 m and 185 m and results from RESISTIVITY for VES 1-VES 9 are as follows; 150 m, 200-400 m, 300 m, 210-300 m, 180 m, 180 m, 200 m, and 250 m. the results indicate the reliability and uniqueness of the integrated geophysical survey.

### KEY WORDS:

Integrated geophysics, Groundwater, Magneto-telluric, , Borehole, Basement, and Electrical resistivity

### 1.0. INTRODUCTION

Groundwater development has increased greatly due to high demand. Today groundwater availability is determined by the presence and hydraulic qualities of groundwater bearing units, while portability is determined by hydro geochemical properties [1]. Water is regarded the most important natural resource in the world for survival; hence its significance cannot be overemphasised. It is however disturbing if this all-important resource is becoming more and more scarce or difficult to explore [2]. [3].. Water scarcity is acute in Adamawa state University,

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due to increase in population of students which may lead to lack of access to safe drinking water on campus. Students that would have access to this unsafe drinking water are vulnerable to water borne diseases.

However, groundwater is difficult to locate, a range of geophysical methods are required to offer data on its occurrence and location. Geophysical methods can be used to map groundwater resources as well as assess water quality [4]. Gravity, magnetics, seismic, electrical resistivity, electrical resistivity tomography, and electromagnetic approaches are just a few of the geophysical techniques that have been used to prospect for groundwater [5].

The electrical and electromagnetic surveys have shown to be very useful in groundwater studies [6]. Many of these geophysical approaches have since been employed to characterize groundwater, but the electrical method has once again proven to be the cheapest and successful [7]. That is why the study seeks to use the Audio Magneto- Telluric (ADMT) and electric resistivity method in the search for groundwater potential zones. In groundwater resource mapping, geophysical technique is used for mapping out subsurface geological structure in which groundwater water occurs [8].

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Mubi and Environs is known to have a lots of failed (aborted) boreholes which are often shallow as a result of the Basement complex terrain. The application of ADMT geophysical technique before drilling of borehole becomes necessary in Adamawa State University Mubi campus since it can image subsurface very deep [6]. and [9]. observed that vertical electrical sounding (VES) approach has been effectively employed in groundwater exploration and the computation of hydraulic properties such as hydraulic conductivity and transmissivity, with very effective and efficient results. [10].

The vertical electrical sounding (VES) technique was proven to be useful in achieving good lateral coverage for mapping aquifer units and drilling productive boreholes, according to the submission[11]. the electrical resistivity approach is a useful tool for identifying locations with good groundwater and development potential. [12]. and [13]. vertical electrical sounding (VES) is a geophysical technique for determining subsurface geology. It's also been frequently utilized for determining aquifer potential in borehole drilling. [14], [15]. have been successful with the vertical electrical approach and used integrated geophysical approaches to prospect for groundwater in a fractured shale aquifer. Also,[16]. geo-electrical survey was conducted

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utilizing the electrical resistivity method to study subsurface layers and determine aquifer features.

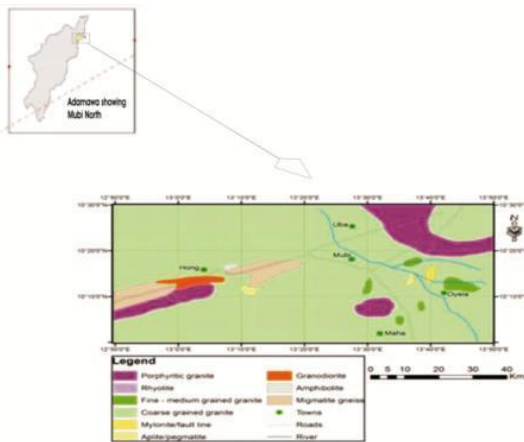
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This work is aimed at carrying out integrated geophysical survey using Audio Magneto-Telluric (ADMT 600S-X) and Vertical electrical sounding by running some profiles alongside resistivity survey on the profiles to delineate optimal drilling point.

ADMT method is a non-destructive, non-invasive, portable, and environmentally friendly technique with a wide range of applications in engineering, environmental science, and subsurface geology, [17]. ADMT approach is a more effective and powerful way for studying both shallow and deep subsurface electrical structures in a variety of situations. [18], [19], [20], [21], [22] groundwater exploration and prospecting, engineering geophysics, and environmental site evaluations have all made substantial use of Audio Magneto-Telluric (ADMT)

The Geology of the study area forms part of the northeast basement complex and comprises of metamorphic gneisses, (migmatitic, amphibolite, mylonites) and igneous (intrusive granitoids and volcanics) rocks. The drainage pattern in the area is typically dendritic and characteristic of igneous metamorphic terrains with streams emanating from areas of high relief and draining into low relief areas. The presence of major road (Mubi to Cameroon through Tsahuda, Madanya to Cameroon through Moduguva) and foot paths makes the area quite accessible. [23]. differentiated the undifferentiated north eastern Nigerian basement rocks into major and minor types based on study of aerial photographs, field and laboratory studies, while [24] mapped and divided the north-eastern Nigerian basement complex into four; the Mandara Mountain, the Alantika Mountain, the Shebshi Mountain and the Adamawa Massif. [25]. investigated the geochemical characters of the main petrographical and structural units of northern Cameroun and assessed its implication for Pan African evolution.

The occurrence, field relationships and petrography of different rock types have been described on a regional scale by some workers ,[26]. and ,[27]. The study of the rocks of Mandara Hills have been made by ,[28], ,[29] and [30] where they documented the petrogenesis and geochemistry of rocks from Gwoza and Madagali areas (located at the northern tip of the study area). Also, ,[31]. studied the occurrences of some ore minerals such as cassiterite, wolframite, galena, chalcopyrite, barite and gem minerals in the ObanObudu-Mandara-Gwoza area in the eastern part of the Nigerian Basement complex. The Mubi area like most basement terrains in Nigeria have experienced extensive tectonism and metamorphism leaving behind imprints, structures and the emplacement of large volumes of granitoid in the Pan-African (600 ±150 Ma) but because of lack of enough geologic data in the area these events were not adequately



documented(Fig.1)..

Figure.1. Geological Map of Mubi Area

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### 1.1. LOCATION OF THE STUDY AREA

The study area lies between longitude  $13^{\circ} 16' 28.11''$  and  $13^{\circ} 17' 15.91''$  E and Latitude  $10^{\circ} 16' 40''$  to  $10^{\circ} 17' 28.11''$  N (Fig.2.). Adamawa state University is located in Mubi town, Adamawa north senatorial district. The town is situated at the foot of Mandara shield, bordered to the East with republic of Cameroon to the North and West with Borno state. (Fig.2)

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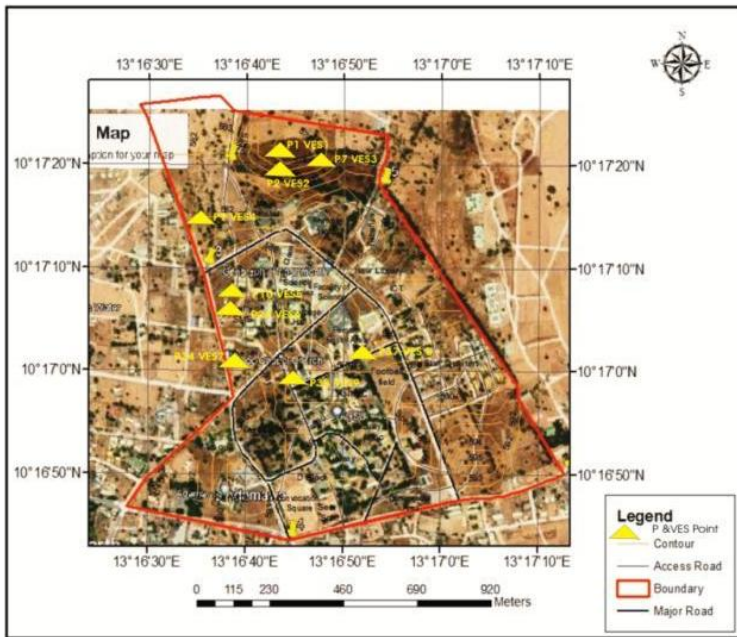


Figure.2. Location Map of the study area

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## 2.1 MATERIALS AND METHODS

### 2.1.1 Magneto telluric

The magneto magnetotellurics (MT) is an electromagnetic geophysical exploration technique that images the electrical properties (distribution) of the earth at subsurface depths. The energy for the magnetotellurics technique is from natural source of external origin. When this external energy, known as the primary electromagnetic field, reaches the earth's surface, part of it is reflected back and remaining part penetrates into the earth. Earth acts as a good conductor, thus electric currents (known as telluric currents) are induced in turn produce a secondary magnetic field.

Magnetotellurics is based on the simultaneous measurement of total electromagnetic field, i.e. time variation of both magnetic field  $B(t)$  and induced electric field  $E(t)$ . The electrical properties (e.g. electrical conductivity) of the underlying material can be determined from the relationship between the components of the measured electric ( $E$ ) and magnetic field ( $B$ ) variations, or transfer functions: The horizontal electric ( $E_x$  and  $E_y$ ) and horizontal ( $B_x$  and  $B_y$ ) and vertical ( $B_z$ ) magnetic field components. According to the property of electromagnetic waves in the conductors, the penetration of electromagnetic wave depends on the oscillation frequency. The frequency of the electromagnetic fields development of the theory determines the depth of penetration. In half a century since its inception, important developments in formulation,

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instrumentation and interpretation techniques have yielded MT as a competitive geophysical method, suitable to image broad range of geological targets.

Magneto telluric method allows the determination of an electric conductivity earth model from the measurements of natural variation of the surface electric (E) and magnetic field (H) over wide frequency range ,[32]. Magneto telluric field that moves through the earth is dependent on the resistivity of the geologic materials and frequency of the equipment ,[33]. Detailed explanation on magneto telluric technique is found in ,[32], ,[16]. ,[34], ,[35]. The inversion was done using ,[36].) with the inversion generated and represented as continuous resistivity progression versus depth. The instrument used is ADMT 600 – SX, it is considered cheap but it has proved useful and effective in delineating natural magneto telluric field within the earth for mineral and groundwater study. ADMT 600 – SX geophysical instrument comprises of two electrodes, connecting cable and main frame with touch screen. Ground electromagnetic waves in the earth and soil follows the Maxwell equation as presented in equations 1 - 8. Assuming that most of the sub-surface geologic formation are non-magnetic and uniformly conductive macroscopically, therefore, no charge accumulation, then, the Maxwell equation can be simplified as:

$$\nabla^2 H + k^2 H = 0 \quad (1)$$

$$\nabla^2 E + k^2 E = 0 \quad (2)$$

Where k is called the wave number (or propagation coefficient)

$$K = [\omega^2 \mu \epsilon - i \omega \mu \sigma]^{1/2} \quad (3)$$

Considering that the propagation coefficient k, is a complex number, let  $k = b + a$

Where: 'a' is called the phase coefficient and b is called the absorption coefficient.

In the electromagnetic frequency range measured by the ADMT series of natural electric field geophysical instruments (0.1Hz to 5 kHz), the displacement current can usually be ignored, and k is further simplified as:

$$K = -i \omega \mu \sigma \quad (4)$$

Wave group resistance and resistivity

A magnetic field with a change in the Helmholtz equation induces a changing electric field, and the magneto electric relationship is:

$$\frac{E}{H} = -\frac{i \omega \rho}{k} \quad (5)$$

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The surface impedance  $Z$  is defined as the ratio of the surface electric field and the horizontal component of the magnetic field. In the case of uniform earth, this impedance is independent of the polarization of the incident field and is related to the earth resistivity and the frequency of the electromagnetic field:

$$Z = \frac{E}{H} = \sqrt{i\omega\mu\rho}^{1/4} \quad (6)$$

Equation (5) can be used to determine the resistivity of the earth:

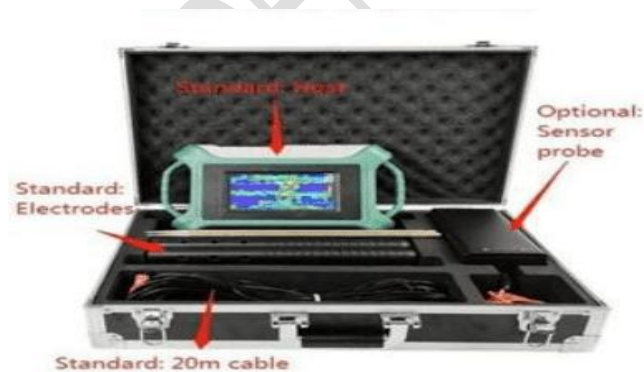
$$\rho = \frac{1}{5f} \left| \frac{E}{H} \right|^2 \quad (7)$$

Skin depth

In non-magnetic media, the skin depth formula is:

$$\delta \approx 503 \sqrt{\frac{\rho}{f}} \quad (8)$$

It can be seen from the above equation that the penetration depth of electromagnetic waves is related to frequency and resistivity. The frequency is certain, the higher the resistivity, the greater the penetration depth, the higher the resistivity, and the lower the frequency, the greater the penetration depth. Through multi-channel simultaneous input measurement, large data with high-density measurement can be obtained, which breaks through the depth's limitation of traditional high density electrical method and enables the maximum exploration depth. Two methods are involved in carrying out the measurement of the subsurface using this equipment below:



Method 1: Electrode measurement

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The measuring points is at the midpoint of the MN electrode as explained in Fig. 4

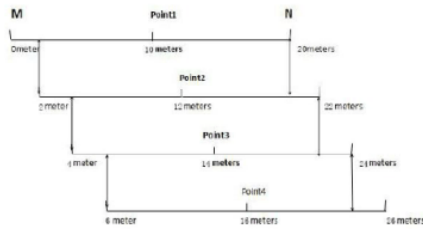


Figure. 3: Electrode measurement, [37].

#### Method 2: Wireless probe measurement

The measurement point of the wireless probe is at the midpoint of the wireless probe when the probe is continuously moved at 2m intervals as presented in Fig. 4

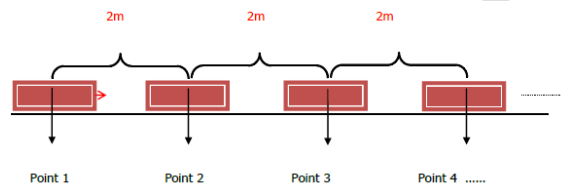


Figure. 4: Wireless probe measurement [37].

In this research a total of forty profiles were sounded and the best nine profiles was used for this paper, this nine profiles were further confirmed using Electrical resistivity method. The measured data transformed from the frequency domain and each corresponding potential difference into depths with each corresponding potential difference to can be interpreted and confirmed.

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#### 2.1.2 Electrical resistivity

The following instruments were used for the data acquisition ABEM SAS1000 digital Terrameter, Personal computer, Global Positioning System (GPS), Hammers, Measuring tape, UPS Battery and Charger, pegs, ABEM SAS external Battery Adapter (EBA), Electrodes, Reels of Cables and Jumpers. The VES stations that were used for the study are indicated in Fig. 5.

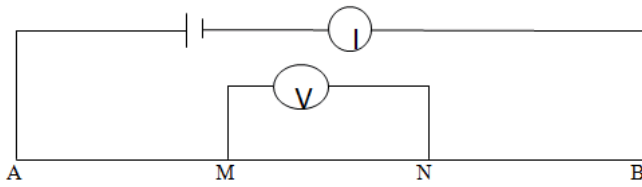


Figure. 5: Schlumberger Array

Electrical resistivity method using Schlumberger array was used for this study, it involves the placing of four (4) electrodes collinearly. The VES stations were carefully selected and the electrical cables were laid along the profile, they were then linked to the ground using the electrodes through the sets of cable jumpers. The contact between the electrode cables, electrode take-outs and cable jumpers were checked for proper connections. The electrode test was performed to ensure that current was flowing through all the electrodes. The inner electrodes are the potential electrodes and the outer electrodes are the current electrodes (Fig 5). Nine (9) vertical electrical resistivity soundings were carried out in the study area corresponding with nine profiles of ADMT to confirm the potentials areas established from ADMT profiles with the aim of delineating the depth to the groundwater, aquifer thickness and lithology of the study area. The Terrameter measures the resistance, voltage and current. The apparent resistivity values were obtained. During soundings, apparent resistivities of the subsurface material were measured as a function of depth. The progressive increase in the distance between the current electrodes causes the current lines to penetrate to greater depths. The acquired vertical electrical sounding (VES) data was processed using IXD interpex software. In this research Schlumberger configuration was adopted. Where apparent resistivity was measured using the formula;

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$$\rho_a = \frac{KV}{I} = KR \quad (9)$$

$$K = \frac{\pi \left[ \left( \frac{AB}{2} \right)^2 - \left( \frac{MN}{2} \right)^2 \right]}{\left( \frac{MN}{2} \right)} \quad (10)$$

and  $\rho_a$  is apparent Resistivity K is Geometric Factor, V is Volt, I is Current R is Resistance, and AB is the Current Electrode Separation.

### 3.0 RESULTS AND DISCUSSION

The results acquired from ADMT survey are presented as images (Fig.6) of the subsurface from which depths, thickness and geoelectric sections was obtained are as follows;

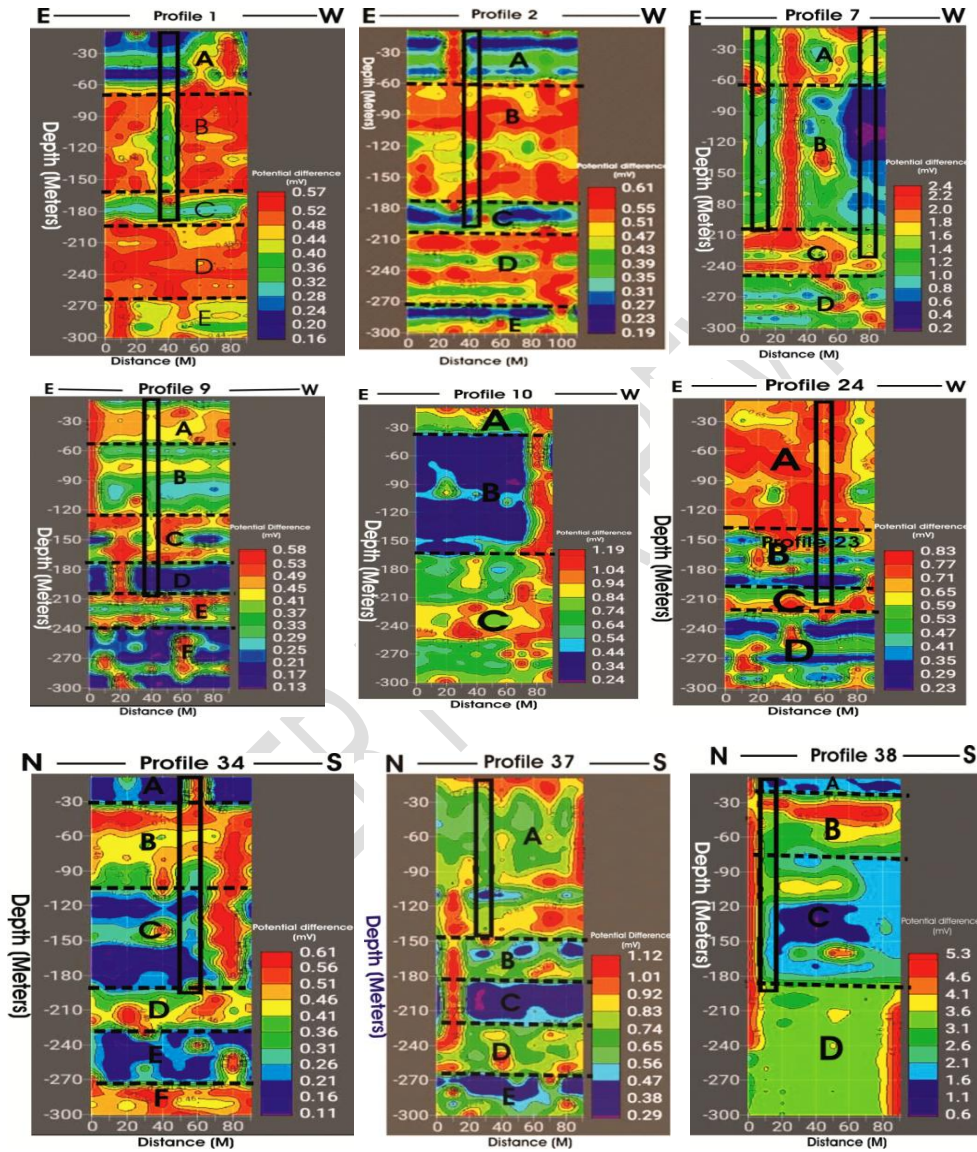


Figure.6. ADMT Profiles of the study area (Nine Profiles)

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**Table 1. Interpretation of Audio Magnetic Telluric Data (ADMT-600 S-X) results**

PROFILES	ZONES	THICKNESS (M)	DEPTH(M)	Pdf(mV)	LITHOLOGIC SECTIONS
<b>Profile 1:</b>	A	0 - 60	60	0.16 - 0.25	Wet topsoil/Overburden
	B	61 - 160	160	0.4 - 0.57	Fresh Basement
	C	161 - 185	185	0.24-0.36	Weathered Basement
	D	186 - 260	260	0.44-0.57	Fresh Basement
	E	261 - 300	300	0.36-0.44	Fractured Basement
<b>Profile 2:</b>	A	0 - 60	60	0.19-0.27	Wet topsoil/overburden
	B	61 - 180	180	0.43-0.61	Fresh Basement
	C	18 - 210	210	0.19-0.35	Weathered Basement
	D	211 - 270	260	0.43-0.61	Fresh Basement
	E	271 - 300	300	0.19-0.35	Weathered/Fractured
<b>Profile 7:</b>	A	0-60	60	1.4-2.4	Dry topsoil/fresh Basement
	B	61-210	210	0.2-1.2	Fractured Basement
	C	211-240	240	1.4-2.4	Fresh Basement
	D	241 - 300	300	0.2-1.6	Fractured Basement
<b>Profile 9:</b>	A	0 - 55	55	0.37-0.58	Wet Clay topsoil
	B	56 -- 120	120	0.13-0.41	Fractured Basement
	C	121-180	180	0.41-0.58	Partially Fractured
	D	181-210	210	0.13-0.25	Weathered Basement
	E	211-240	240	0.37-0.58	Partially Fractured
	F	241 - 300	300	0.13-0.29	Weathered Basement
<b>Profile 10:</b>	A	0-30	30	0.54-1.19	Dry topsoil/overburden
	B	31-175	175	0.24-0.44	Weathered Basement
	C	176-300	300	0.54-1.19	Partially Fractured
<b>Profile 24:</b>	A	0-135	135	0.65-0.83	Dry topsoil
	B	361-195	195	0.23-0.53	Weathered Basement
	C	196 -220	220	0.41-0.47	Fresh Basement
	D	221 - 300	300	0.23-0.53	Weathered Basement
<b>Profile34:</b>	A	0-30	30	0.11-0.21	Wet Clay topsoil
	B	31-105	105	0.41-0.61	Partially Fractured
	C	106-190	190	0.11-0.31	Weathered Basement
	D	196-225	260	0.41-0.56.	Partially Fractured
	E	226-270	270	0.11-0.26	Weathered Basement
	F	271-300	300	0.46-0.61	Fresh Basement
<b>Profile37:</b>	A	0-150	50	0.56-1.12	Dry top/Sandy overburden
	B	151-180	180	0.38-0.92	Partially Fractured
	C	181-215	215	0.29-0.56	Weathered Basement
	D	216-260	260	0.65—1.01	Partially Fractured
	E	261-300	300	0.29-0.47	Weathered Basement
<b>Profile 38:</b>	A	0-30	30	0.0.6-1.6	Wet topsoil

B	31-70	70	3.1-5.3	Fresh Basement
C	71-185	185	0.6-1.6	Weathered Basement
D	186-300	300	0.36-5.3	Fresh Basement

Figure 6, represents the cross-sections of the nine profiles which describe the potential difference contoured sections. The potential difference is directly proportional to the electric resistivity distribution through the area under the profiles where (the highest potential difference equivalent to the highest electric resistivity and Vis versa) so we can identify the properties and the types of the geological formations, geological structures features and groundwater aquifers extensions and properties.

From the interpreted profiles there are several geologic strata differentiated according to the change in their electric properties such as resistivity and potential difference. The nine profiles can be divided into three to six zones each based on their differences in the electric resistivity as shown in Fig.7 and the description of the of the lithological sections and thickness are displayed in table 1 above just as described for profile one below.

For profile 1: first zone (A) has Medium potential difference about ( 0.16 – 0.25 mV ) with thickness of about 50-60 meter and extended into depth of about 0 – 60 meter from the ground surface which composed of a surficial deposits (Wet topsoil/Overburden).

Zone (B) has high potential difference about (0.4 – 0.57 mV) with thickness of about 60 meter and extended into depth of about 61-160 meter which composed of fresh Basement.

Zone (C) has low to medium potential difference about (0.24 – 0.36 mV) with thickness of about 161-185 which composed of weathered Basement.

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Zone (D) has very high potential difference about (0.44 – 0.57 mV) with thickness of about 186 - 260 meter and extended into depth about 290 – 300 meter which composed of shale and mudstone.

Zone (E) has very high potential difference about (0.36 – 0.44 mV) with thickness of about 261 - 300 meter composed of fractured Basement.

The areas observe to have low/medium potential difference due to weathering and fracturing of Basement rocks are considered potential zone for Borehole drilling. While zone of high potential difference are considered not favouring zone for groundwater utilization. For the area surveyed, the nine profiles are potential areas for borehole drilling as confirmed by electrical resistivity

method. Based on the above ADMT results, borehole can be drilled on those nine profiles at the depth of 185 m, 210-300 m, 210 m, 210-300 m, 175 m, 195-300 m, 190-270 m, 215-300 m and 185 m respectively.

Comment [33]: boreholes

To confirm the interpretation of the potential difference cross sections across the ADMT profile, we used Electrical resistivity method from which the apparent resistivity values was interpreted with IXD interplex software to get the true resistivity values and locate the accurate depth to overburden, weathered and fractured basement aquifer, and locate the accurate location for drilling a new wells to increase the water supply on campus. From the electrical resistivity sounding carried out the following results were obtained and interpreted Fig. 7 and table 2.

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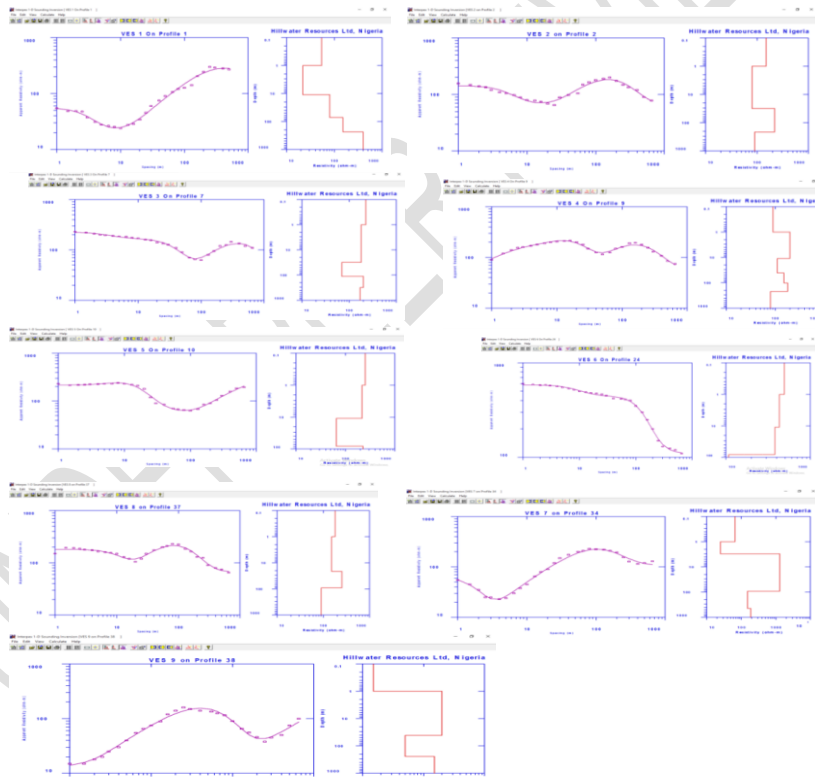


Figure.7. Resistivity Curves of Nine VES points

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Table 2. Interpreted Resistivity data over the Nine Profiles

S/N	Layers	Resistivity ( $\Omega\text{m}$ )	Thickness (m)	Depth (m)	Lithologic Section
VES 1	1	55.00	1.0	1.0	Wet Clay topsoil
	2	25.00	9.0	10.0	Alluvium/Overburden
	3	75.00	50.0	60.0	Weathered Basement
	4	150.00	250.	310	Fractured Basement
	5	400.00	---	---	Fresh Basement
VES 2	1	150.00	1.0	1.0	Dry Topsoil
	2	90.00	29.0	30.0	Weathered Basement
	3	220.00	170.0	200.0	Partially Weathered
	4	90.0	-	-	Weathered Basement
VES 3	1	220.00	1.0	1.0	Dry topsoil
	2	180.00	29.0	30.0	Partially Weathered
	3	60.00	70.0	100.0	Weathered Basement
	4	200.00	200	300.0	Partially Weathered
	5	180.00	----	---	Fractured Basement
VES 4	1	90.00	1.0	1.0	Wet topsoil
	2	200.00	9.0	10.0	Fresh Basement
	3	90.00	50.0	60.0	Weathered Basement
	4	200.00	150.0	210	Partially Fractured
	5	80.00	----	----	Weathered Basement
VES 5	1	220.00	1.0	1.0	Dry Topsoil
	2	200.00	9.0	10.0	Partially Weathered
	3	70.00	170.0	180.0	Weathered Basement
	4	230.00	-	-	Partially Weathered
VES 6	1	500.00	1.0	1.0	Dry Topsoil
	2	450.00	9.0	10.0	Fresh Basement
	3	390.00	70.0	80.0	Fractured Basement
	4	110.00	-	-	Weathered Basement
VES 7	1	55.00	1.0	1.0	Wet Topsoil
	2	25.00	29.0	30.0	Alluvium/Over burden
	3	250.00	60.0	90.0	Partially Weathered
	4	180.00	----	----	Weathered Basement
VES 8	1	180.00	1.0	1.0	Dry Topsoil
	2	120.00	29.0	30.0	Partially Weathered
	3	230.00	60.0	90.0	Fresh Basement
	4	90.00	-	-	Weathered Basement

VES 9	1	15.00	1.0	1.0	Wet Alluvium Topsoil
	2	180.00	34.0	35.0	Partially Weathered
	3	40.00	215.0	250.0	Weathered Basement
	4	170.00	-	-	Partially Weathered

From the resistivity data interpretation, the depths to potential aquifers for drilling new boreholes in Adamawa state University from VES 1-VES 9 are as follows; 150 m, 200-400 m, 300 m, 210-300 m, 180 m, 180 m, 200 m, and 250 m respectively. These shows that the result obtained from electrical resistivity method confirmed what was obtained from ADMT profiles.

#### 4.0. CONCLUSION

From the results and findings of the study, groundwater exploration using integrated geophysical methods gives a better result for groundwater exploration in Basement complex area where groundwater are basically found in over burden, fractures and weathered zones. However, from the survey carried out, forty nine (43) profile was run in Adamawa state University out of which only nine were potential areas, These nine potential areas were followed up with electrical resistivity method to confirm the result of ADMT 600S-X. The results obtained from these two methods which are to be utilized for Borehole drilling : ADMT for the nine profile are:185 m, 210-300 m, 210 m, 210-300 m, 175 m, 195-300 m, 190-270 m, 215-300 m and 185 m and results from RESISTIVITY for VES 1-VES 9 are as follows; 150 m, 200-400 m, 300 m, 210-300 m, 180 m, 180 m, 200 m, and 250 m. From these result one can conclude that application of integrated geophysical method in groundwater exploration is very important as you can see the results of two methods are in agreement with each other.

**Comment [K35]:** The conclusion is to answer the research purpose. After knowing the value or results of data acquisition, what can you get?

**Comment [36]:** is

**Comment [37]:** forty

**Comment [38]:** RESISTIVITY

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#### 5.0 REFERENCES

- [1]. Obiadi, I.I., Obiadi, C.M., Akudinobi, B.E.B., Maduewesi, U.V., and Ezim, E.O., (2016). Effects of coal mining on the water resources in the communities hosting the Iva valley and Okpara coal Mines in Enugu state, south East Nigeria. Sustain. Water Resour. Manag. 2 (3); 207 - 216.
- [2]. Christopher, O., Orubu, (2006). Water resources, environment and sustainable development in Nigeria, Journal of Human Ecology, 19 (3);169-181.

- [3]. Rosen, S. and Vincent, J., (2014), Household water resources and rural productivity in subsaharanAfrica: A review of the Evidence. Harvard Institute for international development Cambridge, MA. 52p
- [4]. Hewaidy, A. A., El-Motaal, E. A., Sultan, S. A., Ramdan, T. M., El khafif, A. A., Soliman, S. A (2015). Groundwater exploration using resistivity and magnetic data at the northwestern part of the Gulf of Suez, Egypt, Egyptian Journal of Petroleum, 255-263.
- [5]. Reynolds, J. M. (1997). An Introduction to Applied and Environmental Geophysics. John Wiley and Sons Ltd. 796p
- [6]. Soupios, P.M., Kouli, M., Vallianatos, F., Vafidis, A. and Stavroulakis, G. (2005). Estimation of aquifer parameters from surficial geophysical methods. A case study of Keritis Basin in Crete. Journal Hydrology (338); 122 - 131.
- [7]. Eke, K. T. and Igboekwe, M. U. (2011). Geoelectrical Investigation of Groundwater in Some Villages in Ohafia Locality, Abia State, Nigeria. British Journal of Applied Science & Technology 1(4); 190-203.
- [8]. Araffa, S. A. S. (2012). Groundwater Management by Using Hydro-Geophysical Investigation: Case Study: An Located at North Abu Zabal City, National Research Institute of Astronomy and Geophysics, Area Helwan, Cairo, Egypt, pp. 181 - 202
- [9]. Ekwe, A.C., ONU, N. & ONUOHA, N. (2006) Estimation of Aquifer Hydraulic Characteristics from Electrical sounding Data: The Case of Middle Imo River Basin Aquifers, Southern Nigeria,” Journal of Spatial Hydrology, 6(2); 121-132.
- [10]. Ojo, J.S., Olorunfemi, M.O. and Omosuyi, G.O. (2007). Geoelectric Sounding to Delineate Shallow Aquifers in the Coastal Plain Sands of Okitipupa Area, Southwestern Nigeria. Online Journal of Earth Science(4); 170-179.
- [11]. Onimisi, M., Daniel, A. and Kolawole, M.S. (2013). Vertical Electrical Sounding Investigation for Delineation of Geoelectric Layers and Evaluation of Groundwater Potential in Ajagba, Asa and Ikonofin Localities of Ola Oluwa Local Government Area of Osun State, South Western Nigeria. Research Journal of Applied Sciences, Engineering and Technology 6(18): 3324-3331
- [12]. Igboekwe, M.U. (2005). Geoelectrical exploration for groundwater potentials in Abia State, Nigeria. Unpublished Ph.D Thesis. Michael Opara University of Agriculture; Umidike, Nigeria.
- [13]. Igboekwe, M. U., Okwueze, E. E., and Okereke C. S. (2006). Delineation of Potential Aquifer zones from Geoelectric Soundings in Akwalbom River Watershed,

Southwestern Nigeria: Journal of Engineering and Applied Science. 1(4); 410 - 421

- [14]. Emenike, E.A., (2001). Geophysical Exploration for groundwater in a sedimentary environment: a case study from Nanka over Nanka Formation in Anambra Basin, Southeastern, Nigeria. *Global Journal of Pure and Applied Sciences* (1); 97-102
- [15]. Onwuemesi, A.G. and Egboka, B.C.E. (2006). 2-D Polynomial curve fitting techniques on watertable, and hydraulic gradients estimations in parts of Anambra Basin, South eastern Nigeria, *Natural and Applied Sci. J.* 7 (1&2); 6 -13.
- [16]. Nejad, H. T., Mumipour, M., Kaboli, R., &Najib, O. A. (2011). Vertical Electrical Sounding (VES) Resistivity Survey Technique to Explore Groundwater in an Arid Region. *Journal of Applied Sciences* 11 (23): 3765 - 3774.
- [17]. Metwaly, M, (2012). Groundwater exploration using geoelectrical resistivity technique at AlQuwy'yia area Central Saudi Arabia. *International Journal of the Physical Sciences*, 7(2); 317 – 326.
- [18]. Hossain, D. (2000). 2D Electrical Imaging survey in hydrogeology, The Bangladesh; *J. Sediment. Res.* 18(1); 57–66
- [19]. Suzuki, K., Toda, S., Kusunoky, K., Fujimitsu, Y., Mogi, T. and Jomori, A. (2000). Case studies of electrical and electromagnetic methods applied to mapping active faults beneath the tick Quaternary; *Eng. Geol.* (56); 29–45
- [20]. Demanet, D., Pirard, E., Renardy, F. and Jongmans, D., (2001). Application and processing of geophysical images for mapping faults; *Comput. Geosci.* 27; 1031–1037
- [21]. Adepelumi, A. A., Yi, M. J., Kim, J. H., Ako, B. D., and Son, J. S., (2006). Integration of surface geophysical methods for fracture detection in crystalline bedrocks of southwestern Nigeria; *Hydrogeology Journal.* (14); 1284–1306
- [22]. Gokturkler, G., Balkaya, C., Erhan, Z. andYurdakul, A. (2008). Investigation of a shallow alluvial aquifer using geoelectrical methods: A case fromTurkey; *Environ. Geol.* 54; 1283–1290
- [23].Islam , M. R.;S. Ostaficzuk and S. Baba.(1986). A report on the Geological studies and Exploration of industrial rocks and minerals in the northern part of Mandara HillsNigeria. *Annals of Borno*, 3, 279-281.
- [24]. Islam , M. R.;S. Ostaficzuk and S. Baba.(1989).The Geology of the Basement Complex of the Northern part of Mandara hills. *Annals of Borno*, 6,7, 99-105
- [25]. Toteu, S. F. (1990). Geochemical Characterization of the main petrographical and structural Units of the Northern Cameroon: Implication for the Pan-African evolution. *Journal of Earth sciences*, 10, 4,615-624

- [26]. Carter, J.D., Barber, W., Tait, E. A. & Jones G. P. (1963). The geology of parts of Adamawa, Bauchi and Borno Provinces in North-Eastern Nigeria. Geological Survey, Nigeria. Bulletin., 30: 1-99.
- [27]. McCurry, P. (1971). Pan African Orogeny in the Northern Nigeria. Geological society of America Bulletin, 82, 3251-3262.
- [28]. Islam, M. R. Baba, S. (1990). The mineral potential of northern part of Mandara Hills, Nigeria. *Berg- und Huttenmanische Monatshefte (BHM)*, 135, 4, 95-98
- [29]. Baba, S.; S.I. Abaa and S. S. Dada. (2006). Preliminary petrographic study of some rocks from Gwoza Area, NE Nigeria. *Global Journal of Geological Science*, 4, 2, 147-156.
- [30]. Siddig, A. A. A. (2012). Geochemistry of granitoids from Madagali area Mandara Hills, Northeastern Nigeria. Unpublished Ph.D theses University of Maiduguri, Nigeria 143p.
- [31]. Abaa, S.I. and Najime, T. (2006). Mineralization in Precambrian rocks of central Nigeria: Implication for the Oban-Obudu-Mandara –Gwoza complex of eastern Nigeria. *Global Journal of Geological Sciences* 4(2): (2):121-128
- [32]. Vozoff K. The magnetotelluric method in the exploration of sedimentary basins. *Geophysics* 1972: 37: 98-141
- [33]. Agyemang VO. Application of magneto-telluric geophysical technique in delineation of zones of high groundwater potential for borehole drilling in five communities in the Agona East District, Ghana. *Appl Water Sci* 2020; 10:1–6.
- [34]. Kaufman AA, Keller GV. The magnetotelluric sounding method. In: *Methods in geochemistry and geophysics*, Elsevier, New York, NY, Vol. 15, p 595, 1981.
- [35]. Berdichevsky MN, Zhdanov MS, Pyankova T. *Advanced theory of deep geomagnetic sounding*. Elsevier, Amsterdam, Netherlands, 1984, p 408.
- [36]. Bostick FX. A simple almost exact method of magnetotelluric analysis. In *Workshop on Electrical Methods in Geothermal Exploration*, US Geological Survey, Salt Lake City,
- [37]. AIDU. ADMT 600S-X Manuel. 2020.