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# Application of Integrated Geophysical Methods in Groundwater Exploration in Adamawa State University, Mubi

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Mubi area falls within the Hawal Precambrian basement terrain where groundwater occurs within the overburden, fractures and weathered basement. In this area a lot of boreholes were drilled and failed due to the geology and ambiguity in geophysical data interpretation. Based on these challenges and the increase in population of students on campus necessitated the application of integrated geophysical methods to investigate groundwater potentials in Adamawa State University Mubi campus. The survey is to locate potential areas for borehole drilling. The method employed are Audio Magnetic Telluric (ADMT 600S-X) with powerful software ZondMT 1D and Electrical resistivity with IXD interpex software for data interpretation. The technique has provided information on the subsurface lithology & structures up to 300 m deep (Passive). While the electrical resistivity is an active geophysical method, this was used to confirm the potential areas identify by magnetotelluric profiles. In this study forty three (43) profiles were sounded using the magnetotelluric in which only nine (9) profiles indicates potential for groundwater. The nine (9) profiles were later confirmed with electrical resistivity method, this is to validate the results obtained

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from ADMT 600S-X. The results obtained are as follows: ADMT 600S-X for the nine (9) 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 (1-9) are; 150 m, 200-400 m, 300 m, 210-300 m, 180 m, 180m, 200 m, 250 m and 215. The study shows that the groundwater occurrence in the study area is confined to over burden, fractured and weathered zones. The results obtained from both case correlate well and these nine (9) points are recommended for drilling borehole to alleviate water scarcity on campus for students.

*Keywords: Integrated geophysics; groundwater; magneto-telluric; borehole; basement and electrical resistivity.*

## 1. INTRODUCTION

Water is the most important and abundant natural resource on earth but yet it is not available. It is an essential source for the existence of life on the planet earth. It is widely used for various purposes such as drinking, washing, bathing, cleaning, cooking, irrigation, and other industrial and domestic uses.

There are various sources of water since about 97% of the water on the Earth's surface is covered with water. The three main sources of water are; Rainwater, Groundwater; this includes water bodies like Wells and springs. Surface water; this includes different water bodies like Reservoirs, Rivers, Streams, Ponds, Lakes.

"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 overemphasise. It is however disturbing if this all-important resource is becoming more and more scarce or difficult to explore" [2-4].

Water scarcity is acute in Adamawa State University Mubi due to the geology and an increase in population of students. These 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, Mubi and Environs is known to have a lots of failed (abortive) boreholes which are often shallow as a result of the Basement complex terrain. Groundwater is difficult to locate, that is why a range of geophysical methods are required to offer data on its occurrence and location. Geophysical methods used in groundwater exploration are; Gravity, magnetics, seismic, electrical resistivity, electrical resistivity tomography, and electromagnetic just to mention few of the geophysical techniques that have been used to prospect for groundwater" [5].

In this research we use the Audio Magnetotelluric (ADMT 600S-X) and Electric resistivity method to delineate groundwater potential zones to locate potential areas for borehole drilling. This geophysical method (ADMT) is good in exploring ground water very deep [6]. It is also used for mapping out subsurface geological structure in which groundwater water occurs [7].

The application of integrated geophysical technique before drilling of borehole becomes necessary in Adamawa State University Mubi. Yusuf et al. [8] made an assertion that the application of ADMT in groundwater exploration in basement complex is very important and necessary and [9] observed that vertical electrical sounding (VES) approach has been effectively employed in
groundwater exploration in and the computation of hydraulic properties such as hydraulic conductivity and transmissivity, with very effective and efficient results in Mubi.

"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" [10]. "ADMT approach is a more effective and powerful way for studying both shallow and deep subsurface electrical structures in a variety of situations in Precambrian basement of Ekiti" [6,11]. Sundaramoorthy et al. [5] explained that "groundwater exploration and prospecting, engineering geophysics, and environmental site evaluations have all made substantial use of Audio Magneto- Telluric (ADMT 600S-X)". Abaa and Najime [12] used integrated geophysical method ADMT 600S-X and Electrical resistivity to investigate groundwater potential in Mubi where deep fractures, weathered zones were established and confirmed with resistivity method. All the Eight points investigated were drilled with productive boreholes. This validate the role of integrated geophysical methods in groundwater exploration.

"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" [5]. The electrical resistivity approach is a useful tool for identifying locations with good groundwater and development potential [13,7]. 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. Lazarus et al. [14]; Sunday and Usman [9] have used Vertical Electrical Sounding in groundwater investigation in Mubi and environs, where they established the occurrence of groundwater in fractures and weathered zones. Also [7] geo-electrical survey was conducted Utilising the electrical resistivity method to study subsurface layers and determine aquifer features.

The Geology of the study area forms part of the Northeast Basement complex which 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. [Islam, et al 1986] differentiated the undifferentiated north eastern Nigerian basement rocks into major and minor types based on study of aerial photographs, field and laboratory studies, while [Islam, e al. 1989] mapped and divided the north-eastern Nigerian basement complex into four; the Mandara Mountain, the

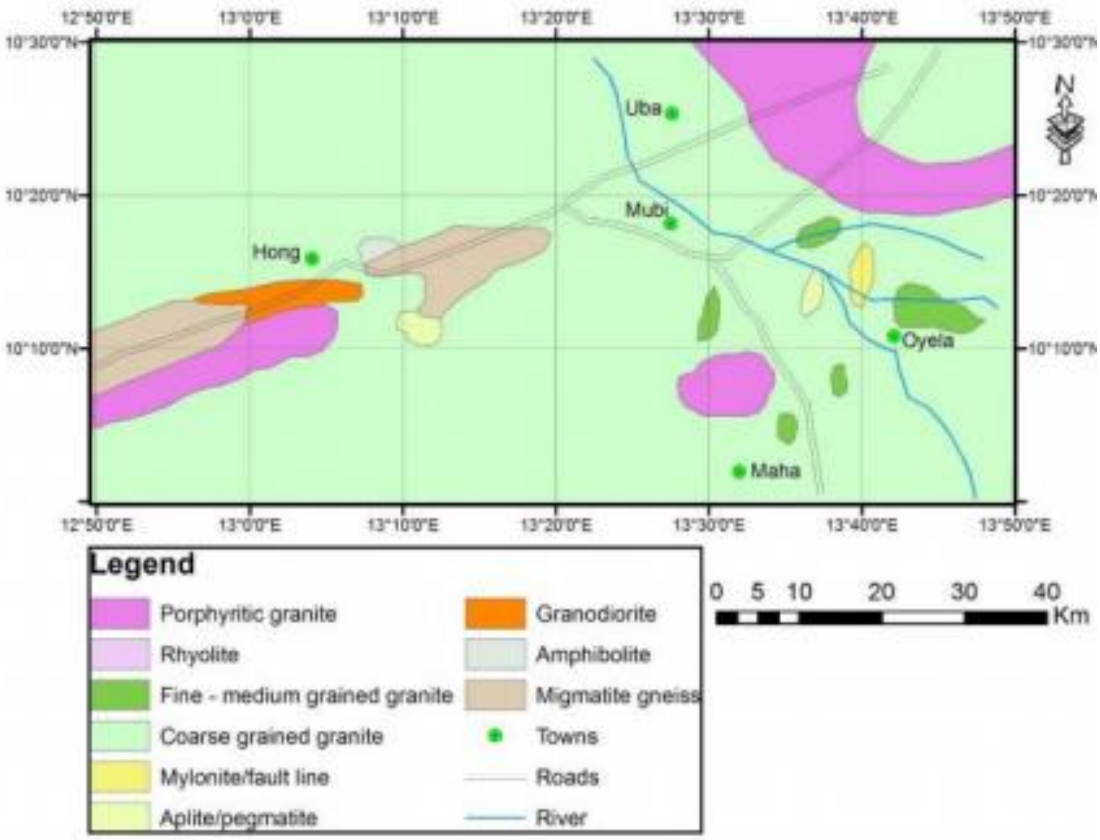



**Fig. 1. Geological Map of Mubi Area**

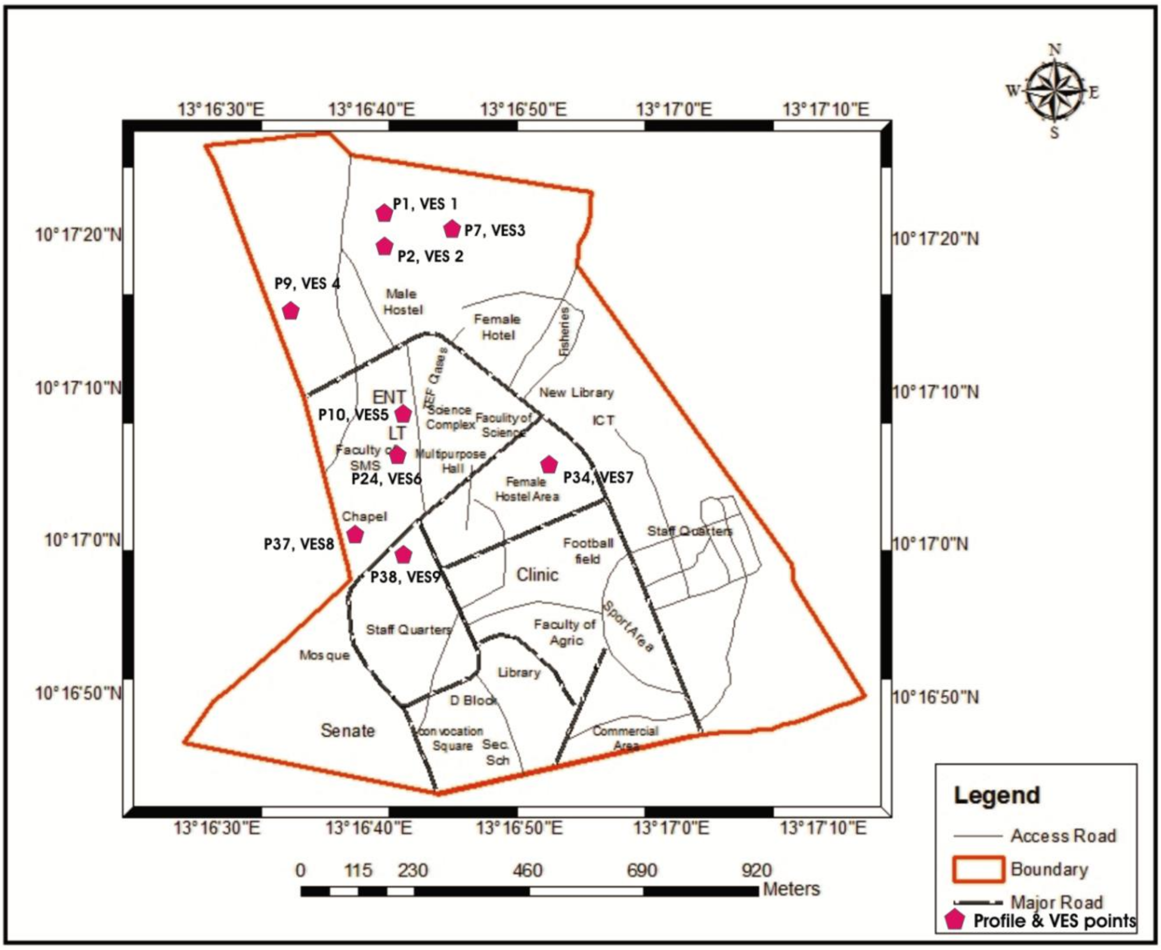



**Fig. 2. Location Map of the study area (Adamawa State University, Mubi**

Alantika Mountain, the Shebshi Mountain and the Adamawa Massif. Carter et al. [15] 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, [15], and [16], The study of the rocks of Mandara Hills have been made by Islam et al. [17]; Baba [18]; Siddig [4] where they documented the petrogenesis and geochemistry of rocks from Gwoza and Madagali areas (located at the northern tip of the study area). Also, [12]. 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).

## 1.1 Location of the Study Area

The study area lies between longitude 13˚ 16' 28.11" and 13˚ 17' 15.91" E and Latitude 10˚ 16' 40" to 10˚ 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). The survey points are shown with a mark (profile and VES point which spread around the University as (PI, VES 1, P2, VES 2, P7, VES 3, P9, VES 4, P10, VES 5, P24, VES 6, P34, VES 7, P37, VES 8 and P38, VES 9.

## 2. MATERIALS AND METHODS

### 2.1 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 [8].

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 (Ex and Ey) and horizontal (Bx and By) and vertical (Bz) magnetic field components [8]. According to the property of electromagnetic waves in the conductors, the penetration of electromagnetic waves 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, instrumentation and interpretation techniques have yielded MT as a competitive geophysical method, suitable to image broad range of geological targets.

Magnetotelluric 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 [8]. Magneto telluric field that moves through the earth is dependent on the resistivity of the geologic materials and frequency of the equipment, [19]. Detailed explanation on magneto telluric technique is found in [6,19]. The inversion was done using ADMT 600 S-X with the inversion generated and represented as continuous resistivity progression versus depth. The instrument used is ADMT 600 S-X, 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. Kasidi [19] used ADMT-600S-X in groundwater exploration of Tsahuda road campus. ADMT 600S-X 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's equation as presented in equations 1 - 8. Assuming that most of the sub-surface geologic formations 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)

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

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:

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

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 polarisation of the incident field and is related to the earth resistivity and the frequency of the electromagnetic field:

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

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 methods 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

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

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. 5.


**Fig. 3. ADMT 600S-X instrument**

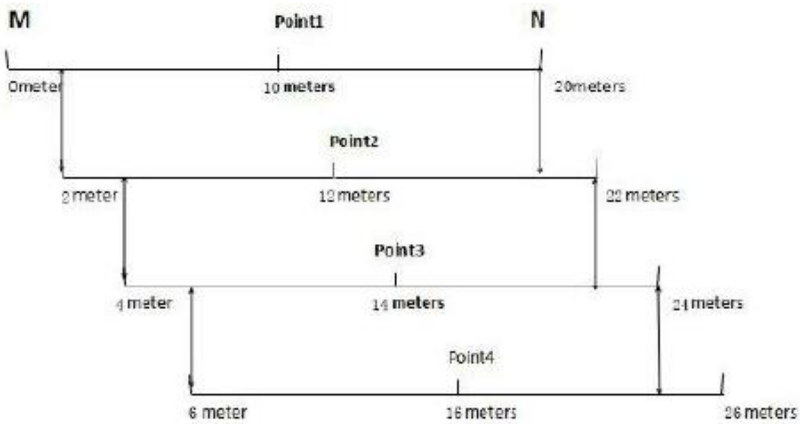



**Fig. 4. Electrode measurement, Adopted after [8]**

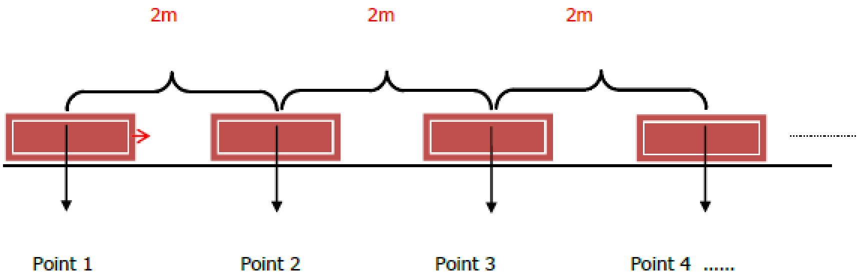



**Fig. 5. Wireless probe measurement Adopted after [8]**

In this research a total of forty Profiles were sounded and the best nine profiles was selected and used for this paper. These 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 be interpreted and confirmed.

## 2.2 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. 6.

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 6). 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 [14]. 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;

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

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

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.

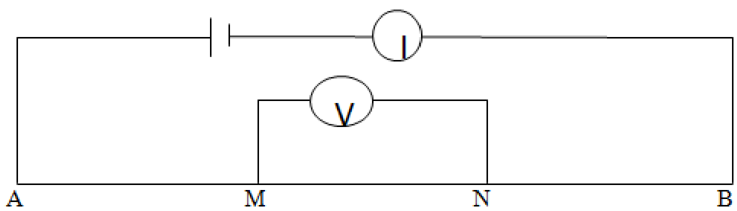



**Fig. 6. Schlumberger Array Adopted after [9]**

## 3. RESULTS AND DISCUSSION

### 3.1 Results

#### 3.1.1 ADMT 600S-X results

The results of all the magnetotelluric profiles conducted are presented as 2D images; Y axis represent the depth and X-axis represent the distance on the ground (Fig. 7).

These results were interpreted by comparing the geology of the area with electrical resistivity of earth materials. The colour bar indicates the range of potential difference of electric current that passed through the earth. The color legend scale is a logarithmic and consistent with contour interval. Cool color i.e. blue represent areas of low resistivity values, warm color (i.e. red) represent areas of high resistivity values [20]. The blue, green and purple reveals lower resistivity. Light green to yellow color shows slightly weathered geologic materials and red color shows fresh Basement.

Fig. 7, 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) this can enable us identify the properties and the types of the geological formations, geological structural 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. 8 and the description of the of the lithological sections and thickness are displayed in Table 1.

In Fig. 7, Profile 1(P1) Table 1, shows the conductive layer i.e low resistivity from 161 -185 m and moderate conductivity at 261-300m. P2 showed the conductive layer at 180-210 m and fresh basement at 61-180 and 211-270 m. P7 show the moderate conductive zone at 61-210 m and 241-300 m with fresh basement at 2110-240 m. P9 show the high conductive layer at 181-210 m and 241-300m with moderate conductive layer at 121-180 m and 211-240 m. P10 show high conductive layer at 31-175 m and moderate at 176-300 m. P24 show high conductive layer at 161-195 m and 271-300 m with fresh Basement at 196-220 m. P34 show the high conductive layer at 106-190 m and 226-270 m with moderate at 196-225 m and fresh basement at 271-300 m. P37 show a high conductive layer at 181-215 m and 261-300 m with moderate at 151-180 m and 216-260 m. P38 show high conductive layer at 71-185 m and fresh Basement at 31-70 m and 186-300 m. These can further be interpreted in terms of zones of saturation;

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.

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. And so it continued for the other profiles.

#### 3.1.2 Resistivity results

The results for resistivity investigation over the nine profiles are presented and interpreted below (Fig. 8.) and Table 2:

From the resistivity curves (VES 1-9) Fig. 8. VES 1 shows a high conductive layer at 150 m and fresh Basement from 200m to infinity. VES 2 show a high conductive layer from 200-400 m and above. VES 3 show high conductive layer at300 m. VES 4 show conductive layer at 210-300 m and above. VES 5 show a conductive layer 180 m, VES 6 show conductive layer at 180m. VES 7 show high conductive layer at 200 m. VES 8 Show a high conductive layer at 250 m and VES 9 showed at 215 m.

### 3.2 Discussion

The 2D ADMT model reveals a conductive nature of the study area with varying conductivities across the nine profiles. The nine profiles shows the highest conductivity zones at depth ranges of 161 -185 and 211-270 m, 61-210 m and 241-300 m, 61-210 m and 241-300 m, 181-210 m and 241-300m, 31-175 m, 161-195 m and 271-300 m, 106-190 m and 226-270 m, 181-215 m and 261-300 m, 71-185 m. The low resistivity high conductivity nature of the subsurface materials can be explained with various subsurface mechanisms, such as the presence of fluids within interconnected pore spaces and fluids in high permeability zones associated with faults/fractures, weathered Basement and even alluvium/ overburden. The results obtained is line with what was obtained by Kasidi [19]; Sundaramoorthy et al. [5]; Solomon et al. [21]. Therefore in all the profiles it clearly indicate the positive sign of potential borehole points. According to Solomon et al. [21]. ground water investigation in Basement using integrated geophysical method ADMT and Vertical electrical sounding can provide the best solution to water.

These nine profiles as confirmed by Vertical electrical sounding delineate groundwater potentials. The depths range from 150 m, 200-400 m, 300 m, 210-300 m, 180 m, 180 m. 200 m, 250 m and 215 m. These results correlate with what was obtained using ADMT. The depth range is in line with what was obtained in Mubi south by Sunday and Usman [9]; Lazarus et al. [14]; Aweda et al. [20]. The nine points investigated are potential site for borehole drilling in Adamawa State University Mubi to improve water supply on campus for Students.

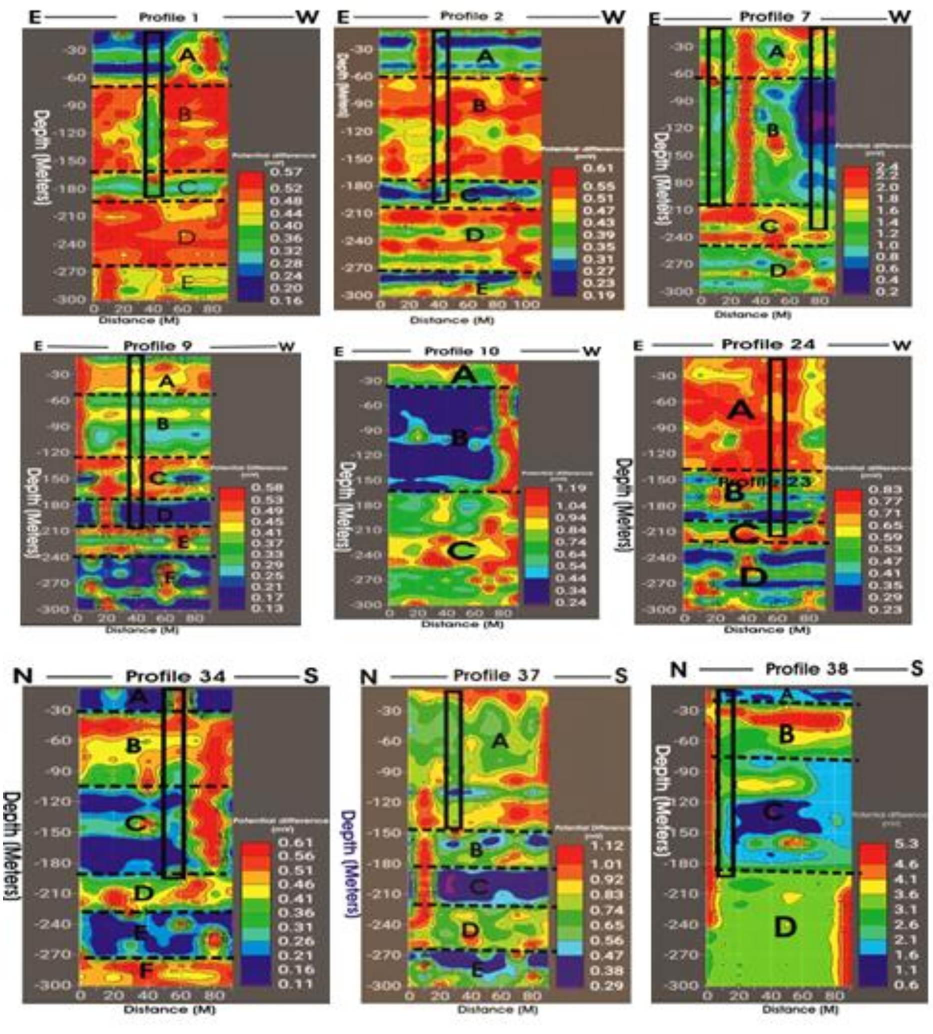


**Fig. 7. ADMT Profiles of the study area (P1, P2, P7, P9, P10, P24, P34, P37 and P38)**

**Table 1. Interpretation of Audio Magnetotelluric Data (ADMT-600 SX) results**

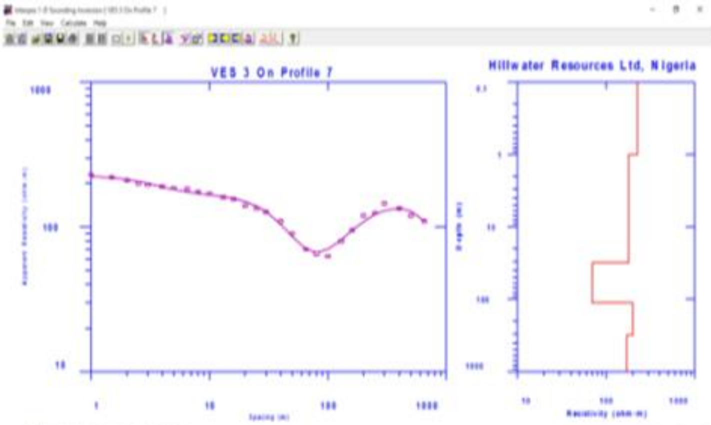
| Profiles | Zones | Thickness(M) | Depths(M) | Potential difference(Pdf) | Lithologic sections |
|---|---|---|---|---|---|
| *Profile 1:* | A | 0 – 60 | 60 | 0.16 – 0.25 | Wet top soil/Overburden Fresh |
| | B | 61 – 160 | 160 | 0.4 – 0.57 | Basement |
| | C | 161 – 185 | 185 | 0.24 – 0.36 | Weathered Basement |
| | D | 186 – 260 | 260 | 0.44 – 0.57 | Fresh Basement |
| | E | 261 - 300 | 300 | 0.36 – 0.44 | Fractured Basement |
| *Profile 2:* | A | 0 – 60 | 60 | 0.19 – 0.27 | Wet top soil/Overburden |
| | B | 61 – 180 | 180 | 0.43 – 0.61 | Fresh Basement |
| | C | 181 – 210 | 210 | 0.19 – 0.35 | Weathered Basement |
| | D | 211 – 270 | 260 | 0.43 – 0.61 | Fresh Basement |
| | E | 217 - 300 | 300 | 0.19 – 0.35 | Weathered Basement |
| *Profile 7:* | A | 0 – 60 | 60 | 1.4 – 2.4 | Dry top soil/ 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 |
| *Profile 9:* | A | 0 – 55 | 55 | 0.37 – 0.58 | Wet Clay/Top soil |
| | 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 Basement |
| | F | 241 - 300 | 300 | 0.13 – 0.29 | Weathered Basement |
| *Profile 10:* | A | 0 – 30 | 30 | 0.54 – 1.19 | Dry top soil/ Overburden |
| | B | 31 – 175 | 175 | 0.24 – 0.44 | Weathered Basement |
| | C | 176 - 300 | 300 | 0.54 – 1.19 | Partiallt Fractured |
| Profile 24: | A | 0 - 135 | 135 | 0.65 – 0.83 | Dry top soil |
| | B | 136 – 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 |
| *Profile 34:* | A | 0 – 30 | 30 | 0.11 – 0.21 | Wet Clay top soil |
| | B | 31 – 105 | 105 | 0.41 – 0.61 | Partially Fractured |
| | C | 106 – 190 | 190 | 0.11 – 0.31 | Weathered Basement |
| | D | 191 – 225 | 260 | 0.41 – 0.56 | Partially Fractured |
| | E | 226 – 270 | 270 | 0.11 – 0.26 | Weathered Basement |

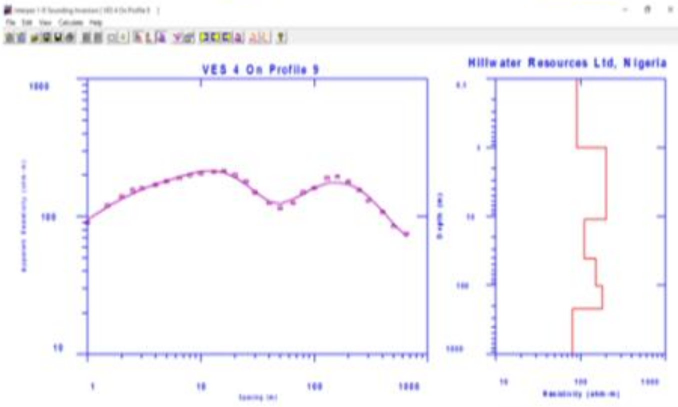
| Profiles | Zones | Thickness(M) | Depths(M) | Potential difference(Pdf) | Lithologic sections |
|---|---|---|---|---|---|
| | F | 271 - 300 | 300 | 0.46 – 0.61 | Fresh Basement |
| *Profile 37:* | A | 0 – 150 | 150 | 0.56 – 1.12 | Dry top soil / Overburden |
| | B | 151 – 180 | 180 | 0.38 – 0.92 | 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 |
| Profile 38: | A | 0 – 30 | 30 | 0.6 – 1.6 | Wet top soil |
| | 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 |

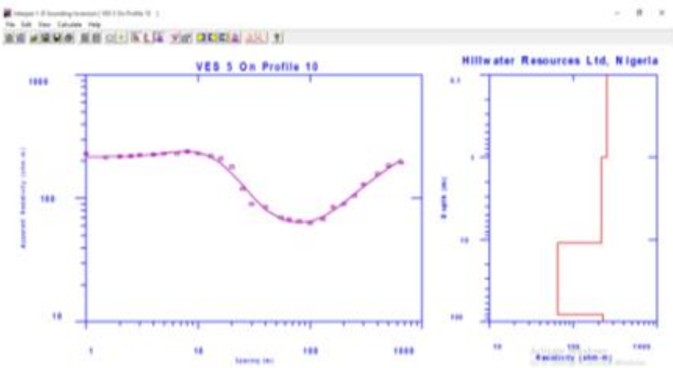
**Table 2. Interpreted resistivity data over the nine profiles**

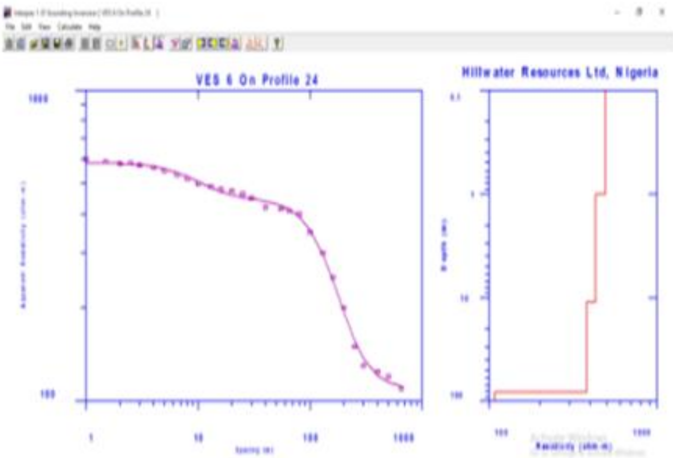
| S/N | Layers | Resistivity (Ωm) | Thickness (m) | Depth (m) | Lithologic Section |
|---|---|---|---|---|---|
| | 1 | 55.00 | 1.0 | 1.0 | Wet Claytopsoil |
| | 2 | 25.00 | 9.0 | 10.0 | Alluvium/Overburden |
| **VES 1** | 3 | 75.00 | 50.0 | 60.0 | Weathered Basement |
| | 4 | 150.00 | 250. | 310 | Fractured Basement |
| | 5 | 400.00 | --- | --- | Fresh Basement |
| | 1 | 150.00 | 1.0 | 1.0 | Dry Topsoil |
| | 2 | 90.00 | 29.0 | 30.0 | Weathered Basement |
| **VES 2** | 3 | 220.00 | 170.0 | 200.0 | Partially Weathered |
| | 4 | 2 90.0 | - | - | Weathered Basement |
| | 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 |
| **VES 3** | 4 | 200.00 | 200 | 300.0 | Partially Weathered |
| | 5 | 180.00 | ---- | --- | Fractured Basement |
| | 1 | 90.00 | 1.0 | 1.0 | Wet topsoil |
| | 2 | 200.00 | 9.0 | 10.0 | Fresh Basement |
| **VES 4** | 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 |
| | 1 | 500.00 | 1.0 | 1.0 | Dry Topsoil |
| | 2 | 450.00 | 9.0 | 10.0 | Fresh Basement |
| **VES 6** | 3 | 390.00 | 70.0 | 80.0 | Fractured Basement |
| | 4 | 110.00 | - | - | Weathered Basement |
| | 1 | 55.00 | 1.0 | 1.0 | Wet Topsoil |
| | 2 | 25.00 | 29.0 | 30.0 | Alluvium/Over burden |
| **VES 7** | 3 | 250.00 | 60.0 | 90.0 | Partially Weathered |
| | 4 | 180.00 | ---- | ---- | Weathered Basement |

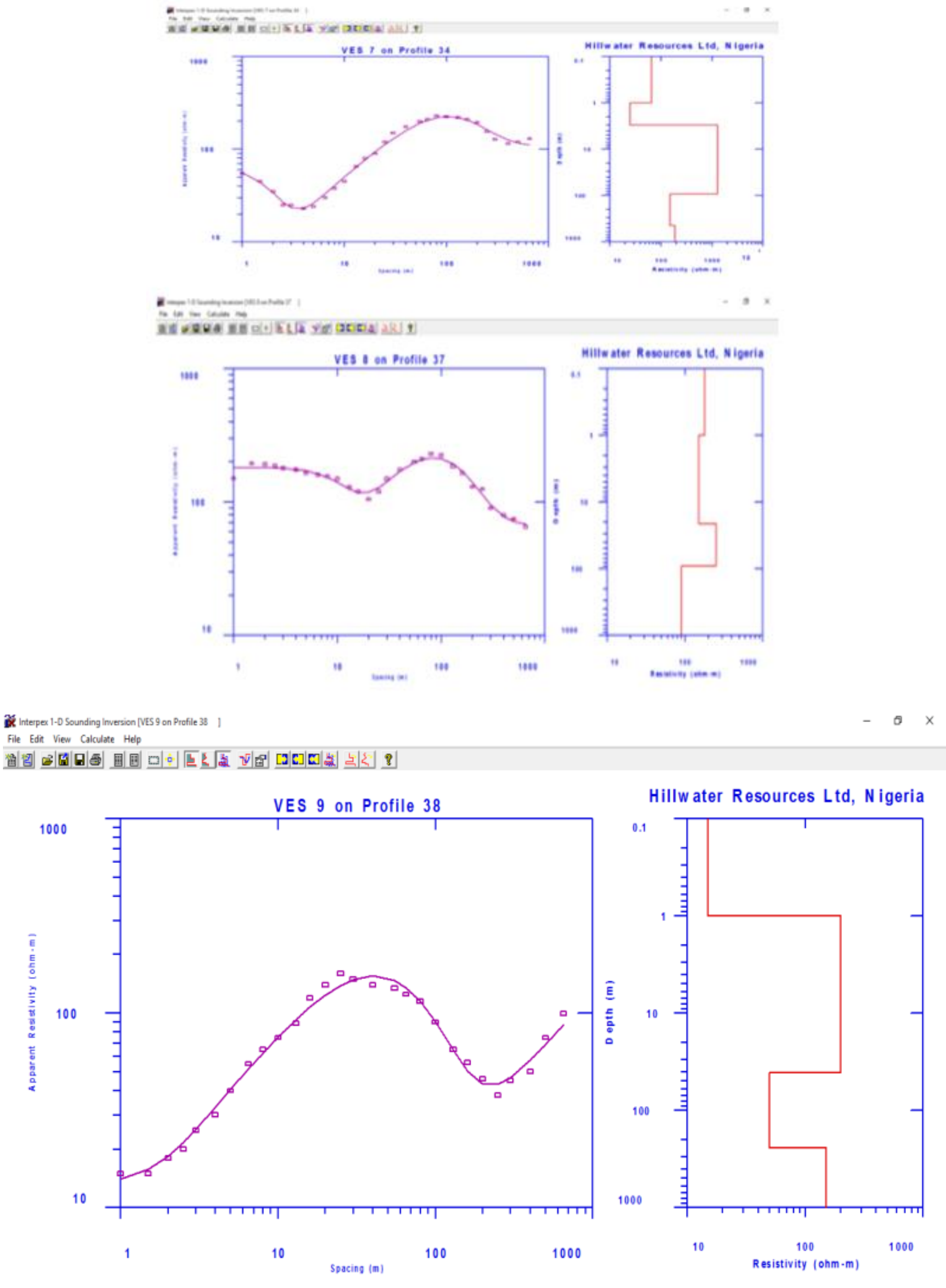
| S/N | Layers | Resistivity (Ωm) | Thickness (m) | Depth (m) | Lithologic Section |
|---|---|---|---|---|---|
| | 1 | 180.00 | 1.0 | 1.0 | Dry Topsoil |
| | 2 | 120.00 | 29.0 | 30.0 | Partially Weathered |
| **VES 8** | 3 | 230.00 | 60.0 | 90.0 | Fresh Basement |
| | 4 | 90.00 | - | - | Weathered Basement |
| | 1 | 15.00 | 1.0 | 1.0 | Wet Alluvium Topsoil |
| | 2 | 180.00 | 34.0 | 35.0 | Partially Weathered |
| **VES 9** | 3 | 40.00 | 215.0 | 250.0 | Weathered Basement |
| | 4 | 170.00 | - | - | Partially Weathered |


VES 3 On Profile 7
Hillwater Resources Ltd, Nigeria


VES 4 On Profile 9
Hillwater Resources Ltd, Nigeria


VES 5 On Profile 10
Hillwater Resources Ltd, Nigeria


VES 6 On Profile 24
Hillwater Resources Ltd, Nigeria




**Figures. 8. Resistivity Curves (VES1-9) over nine profile**

## 4. CONCLUSION

The present study demonstrates that the integrated use of geophysical techniques is an efficient tool for assessing groundwater potential, based on which suitable locations for borehole drilling. Geophysical investigation revealed the underlying lithology to be made up of top soil/overburden, weathered, fractured and fresh basement. The 2D audio magnetotelluric geophysical technique has successfully been applied to delineate potential zones of aquifers, potential in terms of location and depth saturated zones. The technique has provided information on the lithology and structural relationships within the investigative depth up to 300m for hydrogeological purpose.

The study shows that the groundwater occurrence in the area is mainly controlled by fractured and weathered zones. The integrated geophysical exploration AMT and Vertical electrical sounding methods is effective in the exploration of groundwater in any kind of sub surface Geological environment. These methods is effective and relatively cheaper.At the end of this exploration, nine potential point for borehole drilling was established to meet up the water demand of students on campus.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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