Geophysical Investigation of Groundwater Potential Using Advance Magneto Telluric (Admt-200s-X) Around Pindiga and Environs, Upper Benue Trough, Northeastern Nigeria

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Abstract- Water scarcity for domestic use is a pressing challenge in Pindiga and its surrounding areas due to limited water sources and a rapidly growing population. The objective is to delineate potential aquifer zones with good yield using Advanced Magnetotelluric (ADMT-200S-X) surveys. A total of 20 profiles were investigated across the study area in Pindiga, Akko Local Government, Gombe State. The acquired data were processed into 2D inversion models, which reveal the electrical distribution and lithological variations of the subsurface. Results indicate that 13 of the 20 profiles exhibit low-resistivity zones consistent with saturated layers of good transmissivity, suitable for groundwater development. These findings highlight the presence of promising aquifer systems capable of sustaining borehole drilling. The study contributes to improved groundwater exploration strategies and recommends siting boreholes within the delineated high-yield zones to enhance water supply in Pindiga and its environs.

Index Terms- Aquifer, Ground Water Potential, Transmissivity, Magnettelluric Method

I. INTRODUCTION

Groundwater is a vital complement to the insufficient surface water; it has become a valuable resource in most Nigerian towns. Where available, surface waters are frequently seasonal and susceptible to pollution owing to anthropogenic impacts (Adelusi,2009). Groundwater is thus a great resource for resolving this threat. It must be investigated to establish a management database for improved city planning and, most importantly, for the survival of life. In some regions, it is generally kept in sediments or with cracks, fissures, or whom sections of indurated rocks under high hydrostatic pressure. Aquifer features, host rocks, dominant geological structures, porosity, and degree of water saturation, among other geological parameters, govern the presence and circulation of groundwater beneath the subsurface in every location. (Majumdaretal, 2009). Access to safe drinking water is a key ingredient for better health and reducing poverty (MacDonald et al. 2005). Reliable groundwater potential data is very significant and fundamental for the development of groundwater (Singh, 1984).

Increased demands for water by the world's fast-growing population have stimulated the need to identify and establish the source of safe drinking water and determine its suitability for human consumption. The assessment and determination of groundwater quality for human consumption is important for the wellbeing of the ever-increasing population (Ishaku, 2011). Good quality water will enhance the sustainability of socio-economic development, by significantly bringing down government's expenditure towards combating outbreaks of water borne diseases due to consumption of contaminated groundwater. Water is considered as an important necessity in the sustenance of life. However, the availability of good quality water for both industrial and domestic use has been characterized by some problems ranging from to inadequate information on how to exploit it for use. Water is also available in many forms pollution such as ice caps, glaciers, ocean water, as well as surface and groundwater. The electrical resistivity method is the most widely used groundwater exploration technique in many arid terrains in recent years. It is efficient, inexpensive, and provides valuable information about aquifer characteristics such as aquifer type, lithology, depth to ground water, and thickness, among other things (Afuwai,2013).

The ADMT-200-SX is designed for in-situ groundwater measurements, providing real-time data on parameters such as water depth, temperature, conductivity, and turbidity. These measurements are crucial for assessing aquifer characteristics and monitoring changes in groundwater quality (Kumar et al., 2021). Comparative analyses have demonstrated the effectiveness of the ADMT-200-SX compared to traditional groundwater exploration methods. For instance, research conducted by Ngugi et al. (2021) highlighted that the ADMT-200-SX offers higher accuracy in measuring groundwater fluctuations and quality parameters, making it a preferred tool in regions like Gombe State.

STUDY AREA

The area of study is part of Futuk sheet 172 NE located in Akko area (Pindiga and environs) of Gombe state, Northeastern, Nigeria. It is situated at the Southwestern part of Gombe and lies between latitudes N 9º57'0'' and N10º00' and longitudes E 10º56'00'' and E10º59'00''(Fig. 1). Prominent villages within the study area include Sumbe, Garin Dawa, Garin Alkali, Tudun Wada, and Pindiga. The area is accessible by a few Motor able roads and a network of footpaths .The major road to the main town is Gombe - Kashere, and the road junction along Gombe - Yola main road. The adjoining villages are linked to the main town Pindiga by motorable untarred roads .The study area is characterized by two prominent topographic features-the highlands that occupy the west to the northwestern part with an elevation of about 420-600 m above main sea level and the low lands. These high topographic expressions correspond to areas underlain by the Gombe Formation. The Pindiga Formation underlies the lowlands, which form Eastern and Northern part of the area.

The drainage pattern is dendritic with Pindiga as the main channel stream and Its tributaries (Sabon Kaura, Sumbe and Garin Alkali tributaries) which all have their sources from the hilly site and subsequently joined the main stream channel East of Pindiga town. The rivers are virtually seasonal and the general direction of flow is SW, NW- SE.

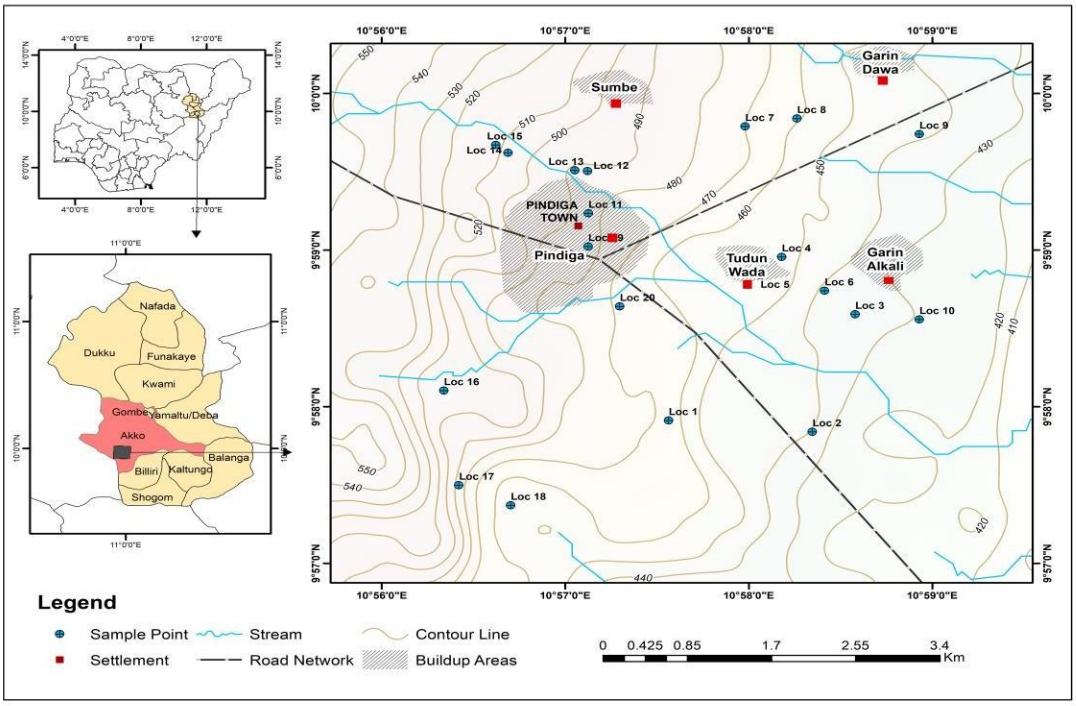

Fig.1 MAP THE STUDY AREA MATERIALS AND METHOD

The success of groundwater exploration using the ADMT 200-SX hinges on the appropriate selection of materials. The following items are essential for conducting effective resistivity surveys:

1. ADMT 200-SX Resistivity Meter: This portable device is capable of measuring electrical resistivity in the ground (plate 1). It provides real-time data, allowing for immediate analysis during fieldwork.
2. Electrodes: Current Electrodes (N) these electrodes are responsible for injecting electrical current into the ground. Potential Electrodes (M) these electrodes measure the voltage drop, which is critical for calculating resistivity.
3. Cables and Connectors: High-quality cables and connectors ensure reliable connections between the resistivity meter and electrodes, minimizing signal loss and ensuring accurate readings.
4. Field Notebook and Data Sheets: These tools have used for recording observations, measurements, and environmental conditions during the survey.
5. Safety Equipment: Personal protective equipment (PPE), such as gloves and safety goggles, ensures the safety of personnel during field operations.

The exploration of groundwater using the ADMT 200-SX involves a combination of advanced technology and systematic methodologies. By employing the appropriate materials and following a structured approach to data collection and analysis, researchers can effectively assess groundwater resources. This process not only aids in sustainable water management but also contributes to understanding the geological characteristics of an area, ensuring that groundwater exploration is both efficient and environmentally responsible.

Fig.2 ADMT200S-XEQUIPMENTS

The methodology for groundwater exploration using the ADMT 200-SX consists of several systematic steps:

1. Site Selection: The first step involves selecting appropriate sites for groundwater exploration based on preliminary geological surveys and existing hydrological data. Factors such as land use, geological formations, and groundwater availability are considered during this stage.
2. Equipment Setup: After the site was selected, the ADMT 200-SX and electrodes are set up. The arrangement of electrodes vary based on the desired survey configuration, commonly using Wenner or Schlumberger arrays. Proper spacing between electrodes is crucial to optimize data collection and ensure accurate resistivity readings.
3. Measurement Procedure

-Calibration: Before commencing measurements, the ADMT 200-SX was calibrated to ensure accurate readings. This step is essential to eliminate any discrepancies that might arise from equipment variability.

- Current Injection: The next step involves activating the current electrodes (N) to inject a controlled electrical current into the ground. This current flow generates an electrical field that interacts with the subsurface materials.
- Voltage Measurement: Using the potential electrodes (M), the voltage drop is measured. This voltage information is necessary for calculating the resistivity of the subsurface materials.
- Data Recording: As measurements are taken, the resistivity values was recorded along with the corresponding electrode configurations and GPS locations. It is crucial to also note any relevant environmental conditions, such as soil moisture and surface characteristics.

4. Data Analysis: After data collection, the

recorded resistivity values have been processed to create a resistivity profile of the subsurface. Software tools have been utilized to analyze the data, interpret geological formations, and identify potential groundwater zones. The resistivity values are correlated with known geological and hydrological parameters to assess water-bearing formations.

5. Quality Control: Throughout the survey, quality control measures was implemented to ensure the reliability of the data. Regular checks on equipment functionality, as well as repeated measurements at selected locations, help validate the consistency and accuracy of the findings.

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 (Vozoff, 1972). Magneto telluric field that moves through the earth is dependent on the resistivity of the geologic materials and frequency of the equipment (Agyemang, 2020). Detailed explanation on magneto telluric technique is found in (Vozoff, 1972, Kaufman and Keller 1981, Berdichevsky and Zhdanov 1984). The inversion was done using Bostic, 1977 with the inversion generated and represented as continues 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 formations are non-magnetic and uniformly conductive macroscopically, therefore, no charge is accumulated, then, the Maxwell equation can be simplified as:

$\nabla 2H+k2H=0$ (1)

$\nabla 2E+k2E=0$ (2)

Where k is called the wave number (or propagation coefficient) K= $[\omega 2\mu\varepsilon - i\omega\mu\sigma]1/2$ (3)

Considering that the propagation coefficient k is a complex number, let k = b + i 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 = $-i\omega\mu\sigma$ (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:

$EH=-i\omega\rho k$ (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 polarization of the incident field and is related to the earth resistivity and the frequency of the electromagnetic field:

Z = $EH= \sqrt{i\omega\mu\rho}$ iπ/4 (6)

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

ρ=15$f|EH|2$ (7) Skin depth

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

$\delta\approx 503\sqrt{\rho f}$ (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. The equipment used is shown in (plate1).

ADMT 200S-X was used for the investigation, ADMT geophysical instrument comprises of two electrodes, connecting cable and main frame. The principles of the instrument is based on electrical resistivity method which is measured through the potential electrode and the result presented as 2D image Two methods are involved in carrying out the measurement of resistivity of the subsurface using this equipment, these includes:

Method 1: 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 6 below

Method 2: Electrode measurement

The measuring point is at the midpoint of the MN electrode as demonstrated in Fig 5 below But In this research Method 1 (fig 5) was adopted.

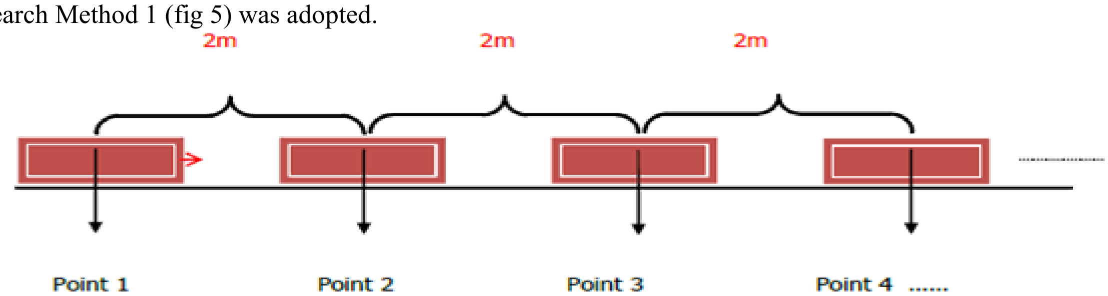

Figure 3: Wireless probe measurement (AIDU, 2020)

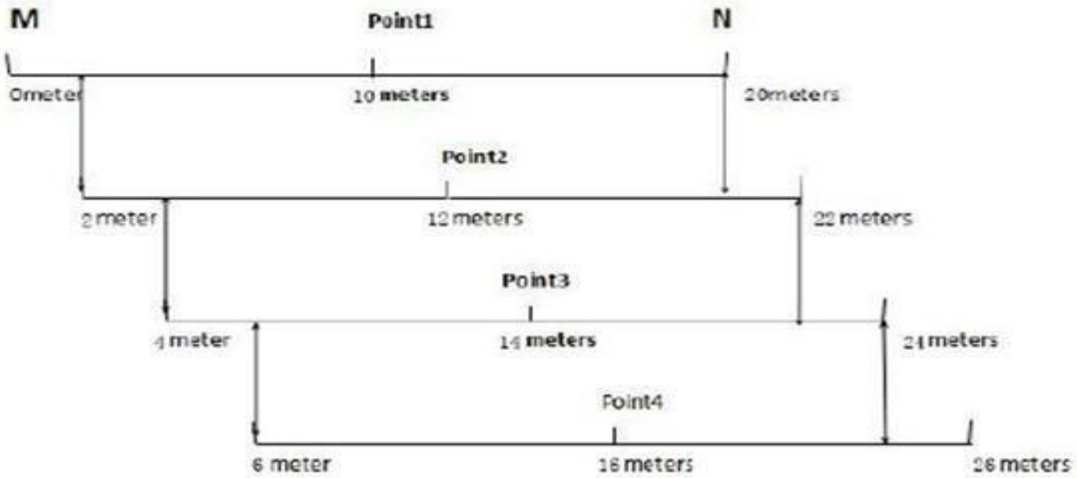

Figure 4: Electrode measurement (AIDU, 2020)

II. RESULTS

The result of the investigations conducted are presented as 2D image, Y axis representing depth in meters (M) (vertical values) while the X-axis is representing the distance on ground in meters (M) used as Profile line. The Blue color represents loose sediment/weathered materials which are conductive in nature with low resistivity values while the (light green to red color) represent geologic formation that are consolidated (resistive) in nature with higher resistivity values. The black rectangular lines on the profile on some certain points on the ground represent where Borehole should be located and the corresponding depth to aquifer. The 2D images of ADMT 200S-X profiles acquired in the study area defines subsurface geologic formation in Pindiga and environs (Fig 8-14).

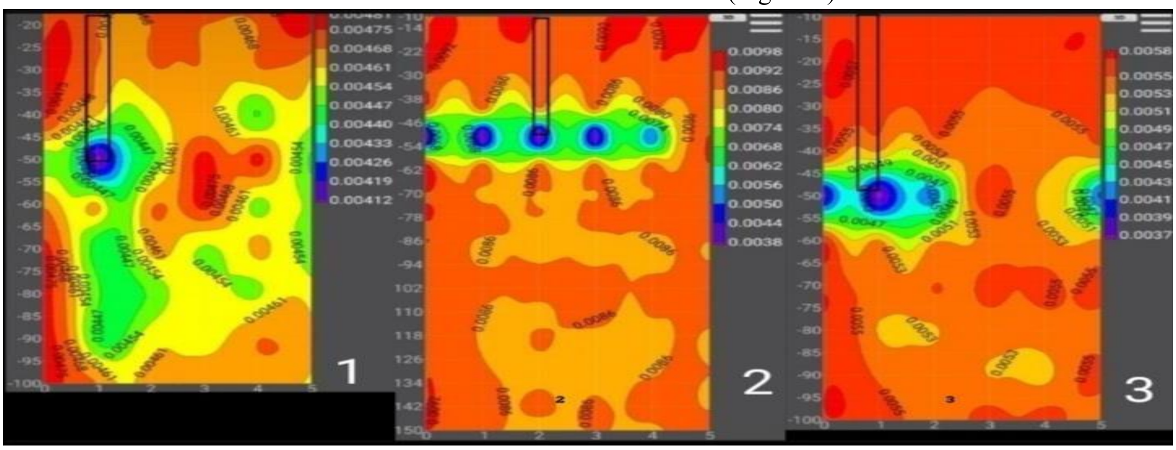

Figure 5: profile 1, 2 and 3 shows the weathered sediment at a depth of 50, 54 and 50 meters respectively where the bore point is directly on them.

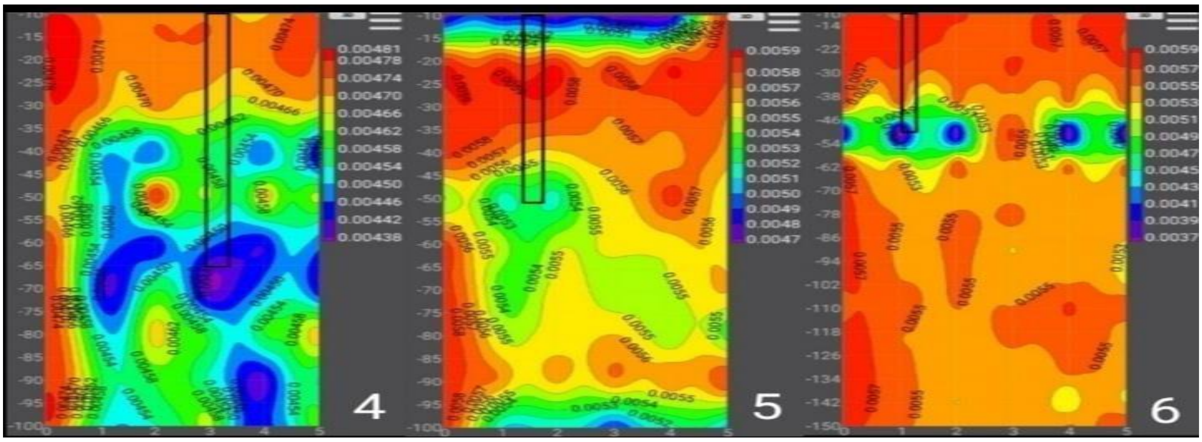

Figure 6: Profile 4, 5 and 6 Shows a weathered sediments at a depth of 65, 50 and 54 meters where bore point is directly on them at point 3, 2 and 1 respectively on the ground i.e good groundwater potentials

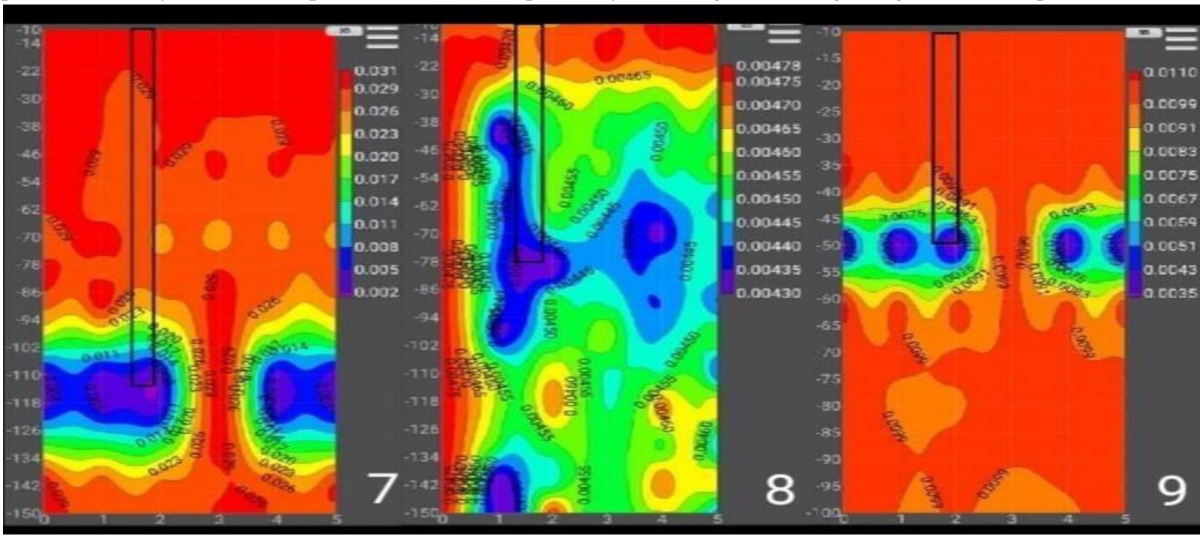

Figure7: Profile 7 and 8 shows thick aquiferous layer at a depth of 102 and 46 meters respectively, and profile 9 shows aquifer with 10 meter thickness.

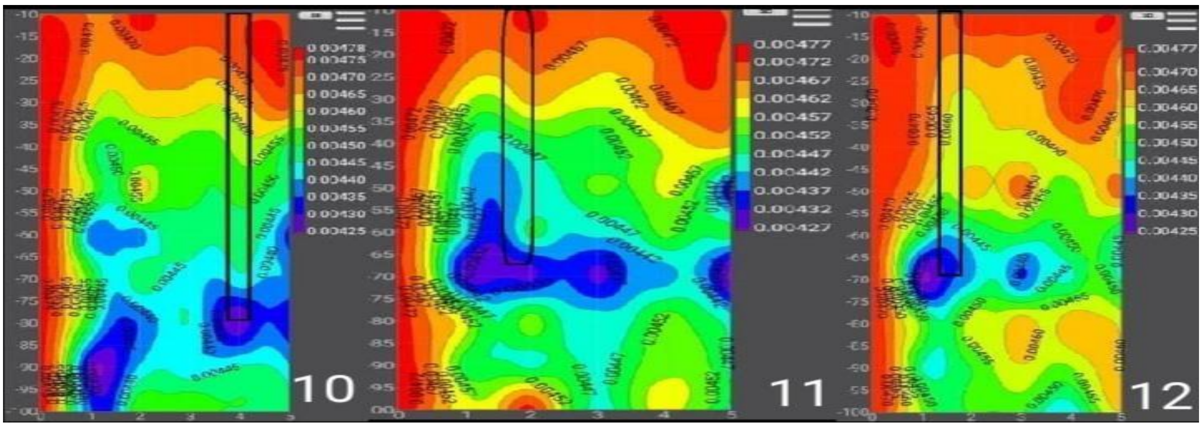

Figure 8: Profile 10, 11 and 12 shows weathered sediments at a depth of 65, 45 and 60 meters respectively where bore point is directly on them.

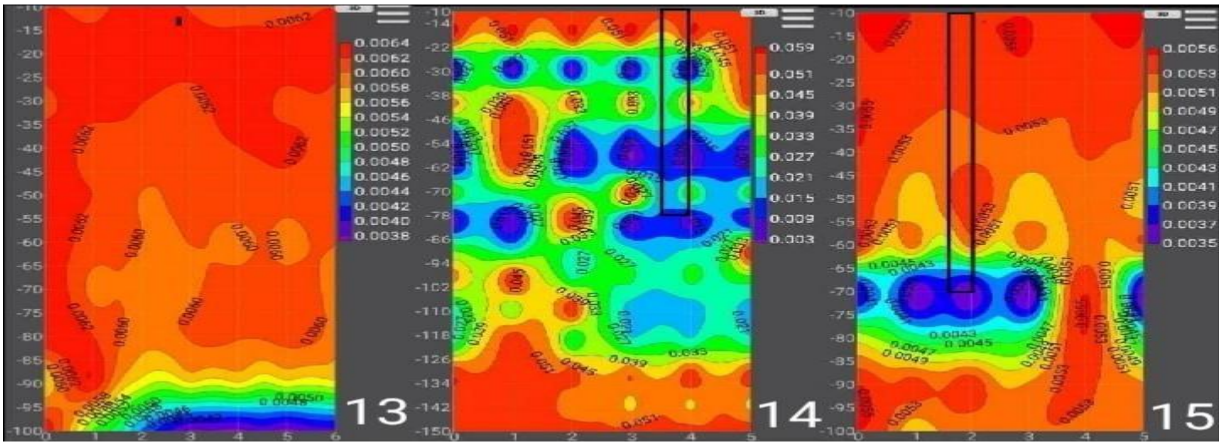

Figure 9: Profile 13 shows thick overburden area up to 90 meters depth, while profile 14 and 15 shows weathered sediments at a depth of 46 and 65 meters respectively.

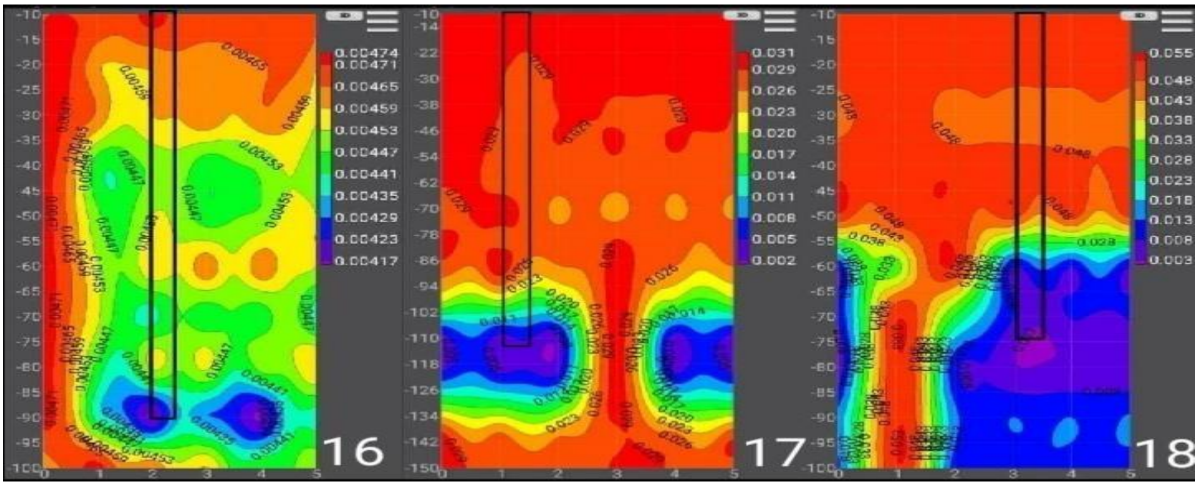

Figure 10: Profile 16, 17 and 18 shows a weathered sediments at a depth of 75, 102 and 60 meters respectively were bore point directly on them and profile 18 has a thick aquifer.

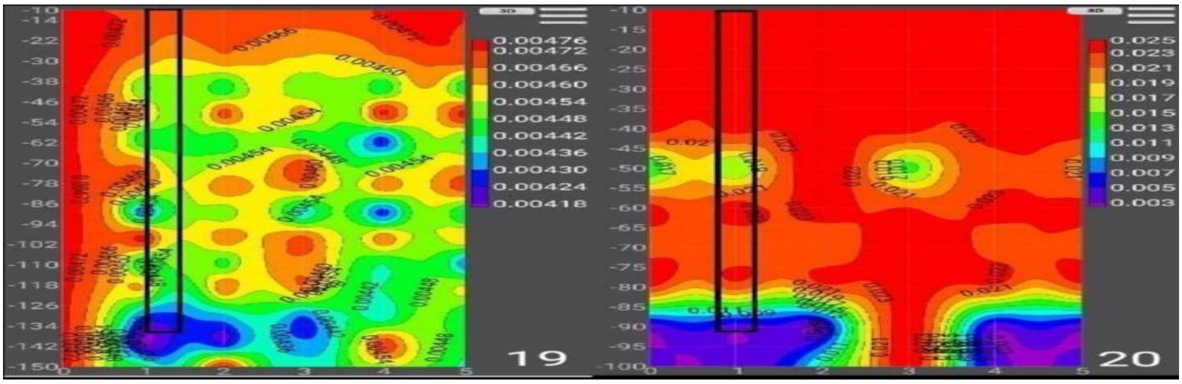

Figure 11: profile 19 show a weathered sediment at a depth of 126 meters while profile 20 show a thick overburden layer up to 85 meters depth.

Table 1: Summary of depth of potential points from the profiles and aquifer characteristics

PROFILES	Coordinates	Transmissivity(m2/ Day)	Expected Borehole Depth	Hydraulic conductivity (m/day)	Elevation
Profile 1	N 9°57′54′′ E 10°57′33.8′	8565.15	50m	856.51	460m
Profile 2	N 9°57′50′′ E 10°58′20.6′′	5901.15	54m	737.64	425m

Profile 3	N 9°58′35.59′′ E 10°58′34.7′′	8876.54	70m	887.65	473m
Profile 4	N 9°58′57.18′′ E 10°58′10.5′′	45569.11	65m	1012.65	491m
Profile 5	N 9°58′50.11′′ E 10°58′3.44′′	26308.71	50m	751.68	455m
Profile 6	N 9°58′44.18′′ E 10°58′24.1′′	7101.24	54m	887.65	442m
Profile 7	N 9°59′47.42′′ E 10°57′58.5′′	11419.55	110m	475.81	442m
Profile 8	N 9°59′50.4′′ E 10°58′15.9′′	53188.18	78m	831.07	442m
Profile 9	N 9°59′44.45′′ E 10°58′55′′	7241.43	50m	724.14	442m
Profile 10	N 9°58′33.7′′ E 10°58′55.5′′	54598.23	80m	839.97	442m
Profile 11	N 9°59′14.33′′ E 10°57′13.9′′	54365.09	65m	836.39	490m
Profile 12	N 9°59′23.8′′ E 10°57′7.2′′	41998.64	70m	839.97	495m
Profile 13	N 9°59′30.6′′ E 10°57′3.6′′	4339.62	100m	867.92	495m
Profile 14	N 9°59′37.3′′ E 10°56′41′′	10588.49	78m	264.71	530m
Profile 15	N 9°59′40′′ E 10°56′37.3′′	13950.69	70m	930.05	535m
Profile 16	N 9°58′6.24′′ E 10°56′20.6′′	56066.44	90m	862.56	530m
Profile 17	N 9°57′30.2′′ E 10°56′25′′	11419.55	110m	475.81	530m
Profile 18	N 9°57′22.4′′ E 10°56′42′′	13613.19	75m	302.52	493m
Profile 19	N 9°59′1.23′′ E 10°57′7.5′′	40755.85	142m	849.08	491m
Profile 20	N 9°58′38.6′′ E 10°57′17.9′′	8083.99	90m	538.93	473m

III. DISCUSSION OF RESULTS

The aim of the magneto-telluric survey is to ascertain the resistivity distribution of the surrounding rock materials to determine potential groundwater sources, low frequencies are generated and supplied into the sub-surface resulting potential difference were measured and the results obtained are processed and presented as resistivity pseudo sections (Teoh, et al, 2018), known and presented as 2D images, where Y axis representing depth while the X-axis is representing the distance on ground. The data were interpreted by comparing geology of the area with electrical resistivity of earth materials. The color bars indicates the range of electrical resistivity values in ohm-meters, the color legend scale is logarithmic and consistent with contour intervals. Cool colors (i.e., blue) represent areas of low resistivity values, warm colors (i.e red) represent areas of high resistivity values (Rungroj, et al, 2020). The green, blue and purple color reveals lower resistivity zones which are conductive and most of its resistivity values varies from one profile to the other, light green to yellow color shows slightly weathered geologic materials and red colors shows fresh terrain (Fig 8-14).

The result of magneto-telluric survey, indicated by colored legend with blue to green color shows areas with lower resistivity values from 0.0433-0.00412 Ωm for profile 1 and 0.0056-0.0036 Ωm for profile 2 and 0.0045-0.0037 Ωm for profile 3 and 0.00450-0.00438 Ωm for profile 4 and 0.0051-0.0047 Ωm for profile 5 and 0.0043-0.0037 Ωm for profile 6 and 0.0014-0.002 Ωm for profile 7 and 0.00445-0.00430 Ωm for profile 8 and 0.0067-0.0035 Ωm for profile 9 and 0.00440-0.00425 Ωm for profile 10 and 0.00442-0.00427 Ωm for profile 11 and 0.00440-0.00425 Ωm for profile 12 and 0.0044-0.0038 Ωm for profile 13 and 0.021-0.03 Ωm for profile 14 and 0.0041-0.0035 Ωm for profile 15 and 0.00435-0.00417 Ωm for profile 16 and 0.011-0.02 Ωm for profile 17 and 0.018-0.003 Ωm for profile 18 and 0.0042-0.00418 Ωm for profile 19 and 0.011-0.003 Ωm for profile 20.

The depth to potential point for drilling varies between 50m to 142m. The light green to yellow color indicates slightly milled fracturing in basement and red colors represents fresh basement (Loke, 2004).

Hydraulic conductivity (K) values range from 264m/day to 1012.65m/day with an average value of 638.33m/day, whereas computed transmissivity values show values from 5901.15m^2/day to 56066.44m^2/day, which indicates high groundwater potentials.

IV. ACKNOWLEDGMENT

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