Adamawa State University Journal of Scientific Research
Volume 10 Issue 1, 2022; Article no. ADSUJSR 1001007
ISSN: 2705-1900 (Online); ISSN: 2251-0702 (Print)
http://www.adsujsr.com

Groundwater exploration using Advance Magneto Telluric (ADMT-600S-X) in Tsahuda Road Campus Adamawa state University Mubi, Adamawa State

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(Received in March 2022; Accepted in May 2022)

Abstract
Advance magneto-telluric (ADMT-600S-X) equipment used for this surveying is becoming more popular and common in Nigeria, this because the equipment is cheaper and user friendly when compared to other geophysical tools used for groundwater exploration. In this research, ADMT-600S-X was used and set to transmit signal into ground for the depth of 300 m for each and a horizontal distance on the ground to 100 m. In this regard electric current is sent into the ground to investigate the subsurface. The result of each profile are presented in 2D inversions which makes it easy to interpret in terms of electrical distribution and variation within the subsurface. Total of 20 profiles of Magneto – telluric data were investigated in Adamawa State University Tsahuda Road Campus and environs. This geophysical method is basically used in basement terrain which makes it easy and quickly delineate areas for groundwater exploration. The results obtained from profile shows that, out of the 20 profile 14 shows to potential profiles for Borehole drilling. This means that the study area has good groundwater potentials since majority of the profile gives a positive results. However, the potentials points shows that the depths to be drilled varies from 140 m to 200 m depending on the profile. If those points are drilled it is believe that groundwater problem in Tsahuda road campus would be a thing of the past.

Keywords: Electrical Conductivity, Groundwater, Advance Magneto-telluric, Wireless Measurement

Introduction

Groundwater development has increased greatly in developed countries. Today groundwater availability is determined by the presence and hydraulic qualities of groundwater bearing units, while portability is determined by hydro geochemical properties (Obiadi, *et. al*, 2016). 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 (Christopher, 2006). (Rosen and Vincent, 2014). Water scarcity is acute especially in the developing countries, which suggest that 67% of the rural population lacks access to safe drinking water. This is due to the fact that people in rural regions rely on surface water from lakes, streams, ponds, and rivers to survive. Surface water bodies, on the other hand, are unreliable due to high evaporation rates, which are common in high temperate regions, and they are often polluted and infected with waterborne diseases (Gyau-Boakye, et. al., 2008). Treatment is required to supply water from these sources, primarily for domestic use towns (Rosen and Vincent, 2014). People that have access to this good drinking water are vulnerable to water borne diseases which may lead to guinea worm infestation and bilharziasis. Because groundwater is difficult to locate, a range of geophysical methods are required to offer data on its occurrence and location. (Thapa *et. al*, 2008) proposed that many criteria such as lithology, slope, lineaments, hydro geomorphology, land use, and land cover should be understood in order to estimate groundwater potential zones of a region. Soil information is also crucial for determining groundwater potential zones. Coarse soils, for example, are generally permeable, but fine-grained soils have a lower permeability hindering recharge of groundwater (Amaresh, *et. al*, 2006). For instance, geophysics can be used to map groundwater resources as well as assess water quality (Hewaidy, *et. al*, 2015). 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 (Reynolds, 1997). The electrical and electromagnetic surveys have shown to be very useful in groundwater studies (Soupios, *et. al*, 2005). 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 (Eke and Igboekwe, 2011). That is why the study seeks to use the Advance Magneto- Telluric (ADMT) or popularly known as electric resistivity tomography in the search for groundwater potential zones Basement complex area in Mubi Tsahuda Road Campus, Adamawa state University, Mubi South Local government area, Nigeria. In groundwater resource mapping, geophysical technique is used for mapping out subsurface geological structure in which groundwater water occurs (Araffa, 2012). 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 Tsahuda road campus of Adamawa State University Mubi.The presence of basement complex formation in this area is arbitrary difficult to drill a productive borehole while the hand dug wells are always shallow due to the difficulty in digging deeper wells. (Salem, 2001, Soupios, *et. al*, 2005 and Ekwe, *et. al*, 2006) the 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. (Ojo, *et. al*, 2007).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, (Onimisi, *et. al*, 2013) the electrical resistivity approach is a useful tool for identifying locations with good groundwater and development potential. (Igboekwe, 2005 and Igboekwe, *et. al*, 2006) 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. (Emenike, 2001, Onwuemesi and Egboka, 2006 and Okoro, *et. al*, 2010) have been successful with the vertical electrical approach and used an integrated array of geophysical approaches to prospect for groundwater in a fractured shale aquifer. Also, (Nejad, *et. al*, 2011) geoelectrical survey was conducted utilizing the electrical resistivity method to study subsurface layers and determine aquifer features. The work is aimed at carrying out geophysical survey using Advance Magneto-Telluric (ADMT) by running some profiles (2D survey) to delineate optimal drilling point in the area for groundwater production. During the course of this work, twenty profile were conducted and the result presented as 2D images in the result section.

ADMT method is a non-destructive, non-invasive, portable, and environmentally benign technique with a wide range of applications in engineering, environmental science, and subsurface geology (Metwaly, 2012). Two-dimensional electrical resistivity tomography has proven to be effective. (Loke, 2013) even in the presence of geological and topographical difficulties, The ADMT results provides a more accurate 2-D resistivity model of the subsurface, where resistivity variations in the vertical as well as horizontal directions along the survey line are recorded continuously. (Yang, et. al., 2002, Hauck, et. al., 2003, Cheng, et. al., 2008, Crook, *et. al*, 2008) 2D ADMT approach is a more effective and powerful way for studying both shallow and deep subsurface electrical structures in a variety of situations. (Hossain, 2000, Suzuki, et. al., 2000, Demanet, *et. al*, 2001, Daily, *et. al*, 2004, Adepelumi, *et. al*, 2006, Gokturkler, *et. al*, 2008 and Andrade, 2011) groundwater exploration and prospecting, engineering geophysics, and environmental site evaluations have all made substantial use of Advance Magneto- Telluric (ADMT).

The Study Area

The Adamawa State University Sahuda Road Campus is siyuated in Mubi South Local Government Area of Adamawa Sate and lies between Latitudes 10°14'00"N and 10°15'30"N of the Equator and between Longitudes 13°17'30"E and 13°21'00"E of the Prime Meridian (Figure 1), covering a total area of 6.49 km^2 with a perimeter of 11.41 km.

The area forms part of the northeast basement complex and comprises of metamorphic (migmatitic gneisses, amphibolites, mylonites) and igneous (intrusive granitoids and volcanics) rocks. The study area also formed parts of Nigerian Basement Complex. 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 *et al* 1989) mapped and divided the north-eastern Nigerian basement complex into four; the Mandara Mountain, the Alantika Mountain, the Shebshi Mountain and the Adamawa Massif. (Toteu, 1990) 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 (Carter *et al*, 1963 and Mc Curry, 1971). The study of the rocks of Mandara Hills have been made by (Islam and Baba, 1990, Baba *et al*, 2006 and Siddig, 2012), where they documented the petrogenesis and geochemistry of rocks from Gwoza and Madagali areas (located at the northern tip of the study area). Also, (Abaa and Najime 2006) studied the occurrences of some ore minerals such as cassiterite, wolframite, galena, chalcopyrite, barite and gem minerals in the Oban-Obudu-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. This work is aimed at delineating groundwater potential in Adamawa State University Mubi, Tsahuda road Campus in Mubi.

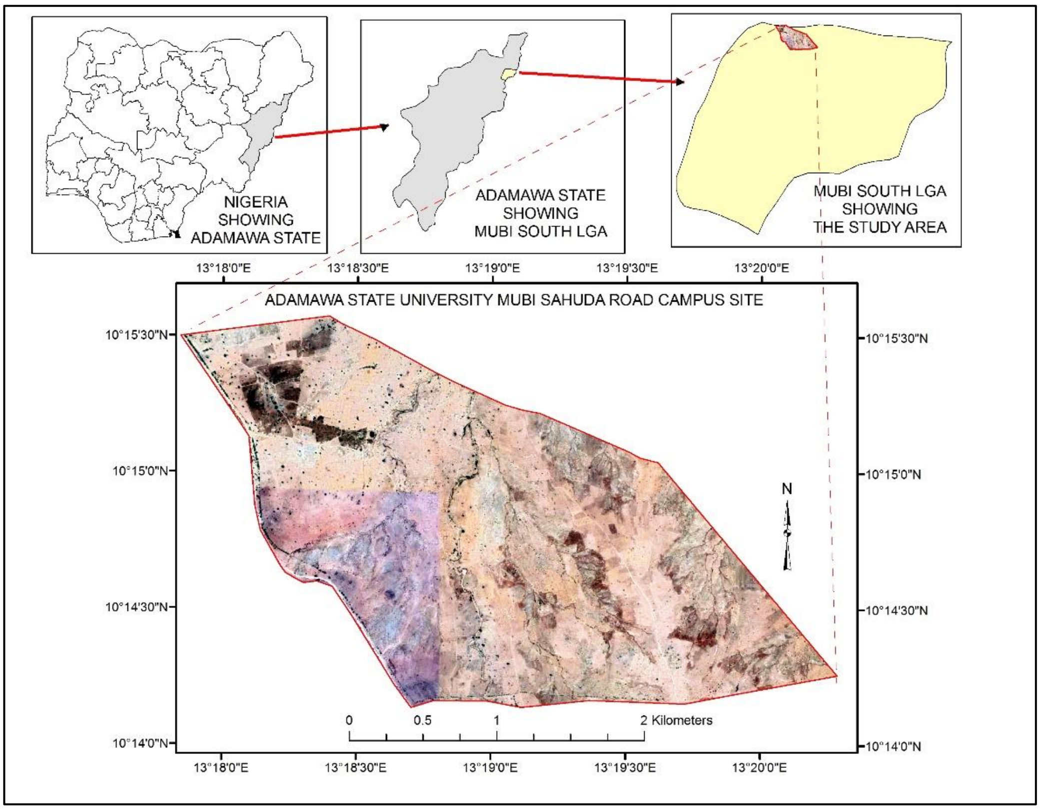

Figure 1: The Study Area

Materials and Methods

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 formation are non-magnetic and uniformly conductive macroscopically, therefore, no charge is accumulated, then, the Maxwell equation can be simplified as:

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

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

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

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

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:

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

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:

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

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:

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

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

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

Skin depth

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

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

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 on Fig.2.

Figure 2: ADMT 600S-X Equipment

ADMT 600S-X 300 was used for the investigation, ADMT geophysical instrument comprises of two electrodes, connecting cable and main frame with touch screen. The principles of the instrument is based on electrical resistivity method which is measured through the potential electrode and the result presented as 2D imageTwo methods are involved in carrying out the measurement of resistivity of the subsurface using this equipment, these includes;

Method 1: Electrode measurement

The measuring points is at the midpoint of the MN electrode as demonstrated in Fig. 3 below:

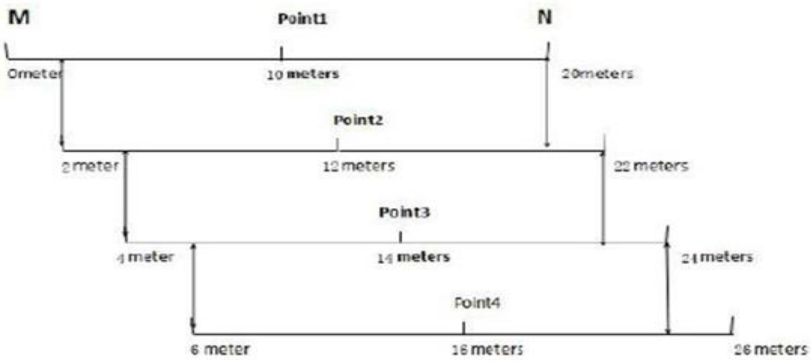

Figure 3: Electrode measurement (AIDU, 2020)

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. In this research Method 2 was adopted because of its simplicity (One person can can do measurement)

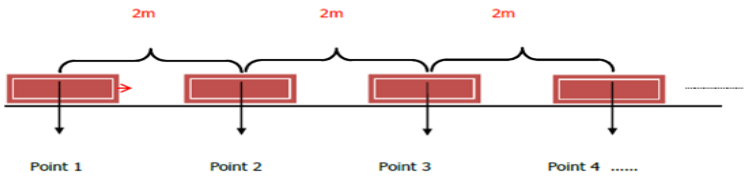

Figure 4: Wireless probe measurement (AIDU, 2020)

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 meteres (M) used as Profile line. The Blue colour represents loose sediment/weathered materials which are conductive in naturewith low resistivity values while the (light green to red colour) represent geologic formation that are consolidated (resistive) in nature with higher resistivity values.The black rectangular lines on the profile on some certainpoints on the ground represent where Borehole should be located. The 2D images of ADMT 600S-X profiles acquired in the study area defines subsurface geologic formation in **Tsahuda road Campus**, Adamawa State University Mubi (Fig.5-11)

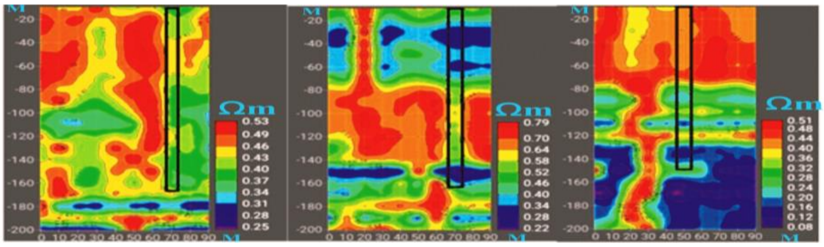

Figure 5: Profile 1, 2 &3 Thick over burden area at point 70m and 50 m and weathered basement with potentials for groundwate

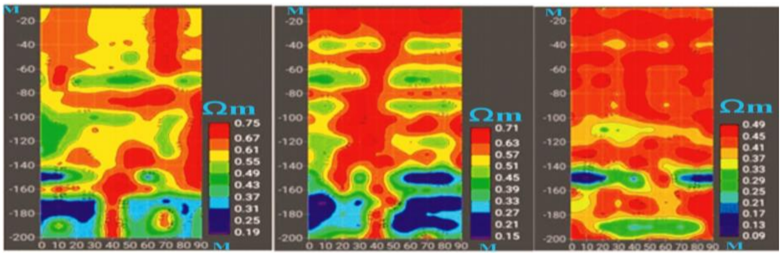

Figure 6: Profile 4, 5 & 6 Shows a highly resistive geologic formation with patched aquifers of conductive regions

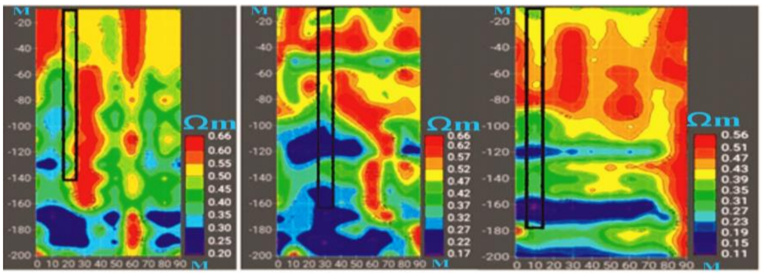

Figure 7: Profile 7, 8 & 9 Shows a weatherd basement where bore points are directly on them i.e Good groundwater potentials.

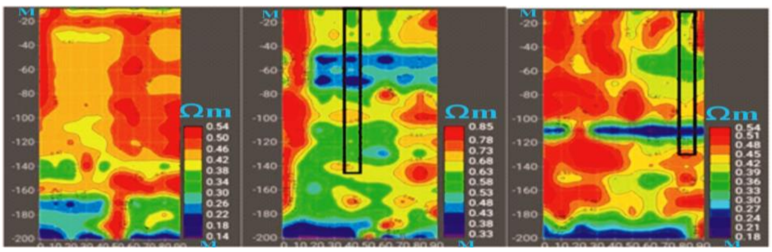

Figure 8: Profile 10, 11 & 12 possible water bearing region and high resistive geologic formation with pockets of weathered area which may sustain hand pump Borehole.

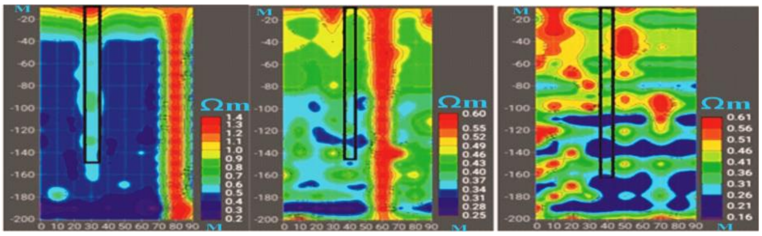

Figure 9: Profile 13,14 & 15 Shows potential ares on each profile with thick aquifer on the first profile on point 40

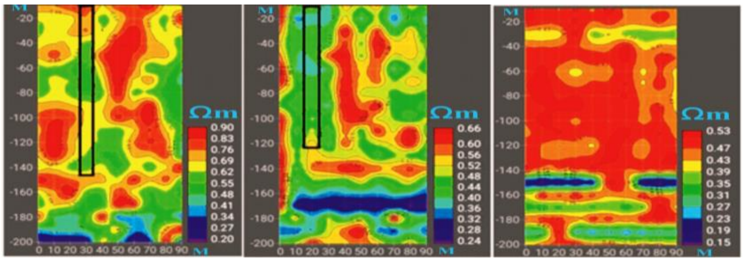

Figure 10: Profile 16, 17 &18 Show very low groundwater potential and resistive geologic formation (low yield)

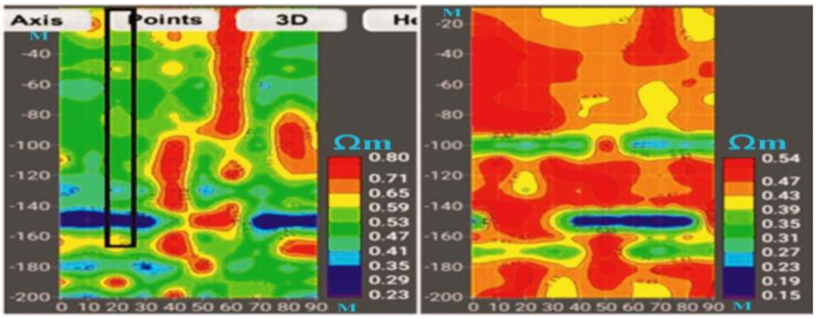

Figure 11: Profile 19, &20 Show very low groundwater potential and resistive geologic formation

Table.1. Summary of depth of potential points from the profiles

S/No	Profiles	Point on Profile	Expected Borehole Depth
1.	Profile 1	70	180 m
2.	Profile 2	70	160 m
3.	Profile 3	50	170 m
4.	Profile 7	20	170 m
5.	Profile 8	30	180 m
6.	Profile 9	10	200 m
7.	Profile 11	40	140 m
8.	Profile 12	80	120 m
9.	Profile 13	40	160 m
10.	Profile 14	40	150 m
11.	Profile 15	30	160 m
12.	Profile 16	20	200 m
13.	Profile 17	20	170 m
14.	Profile 18	20	150 m

Discussion of Results

The aim of the magneto-telluric survey is to ascertain the resistivity distribution of the surrounding rock materials to delineate 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 not 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 basement (Fig. 1-11)

The result of magneto-telluric survey, indicated by colored legend with blue to green color shows areas with lower resistivity values from 0.08- 0.34 Ωm for Fig 1, 2 and 3, 0.11- 0.34 Ωm for Fig 7, 8 and 9, 0.18- 0.43 Ωm for Fig 11 and 12, 0.16-0.31 Ωm for Fig 13, 14 and 15, 0.20-0.32 Ωm for Fig 16 and17, and 0.23-0.35 Ωm for Fig 19. The depths to potential points for drilling varies between 140 m to 200 m. The light green to yellow colour indicates slightly milledfracturing in basement and red colors represents fresh basement (Loke, 2004). The resistivity of potential area in Fig. 9; Profile13 range from 0.20-0.40 Ωm, this profile shows an exceptional case of very thick overburden weathered granite, it has a thickness of more than 160 m.In basement terrain, weathered basement are known to enhance groundwater recharge in boreholes. Inview of the above ground water exploration can be carried out in those points with black rectangular vertical colums on the figures. The results of all the profiles shows clearly the advantage of low frequency equipment over current based in delineating deep groundwater sources in basement terrain. With these method groundwater exploration in basement terrain is made easy. The depth of investigation using this equipment is subject to choice of investitigation depth but could not exceed 600 m.

Conclussion

Magneto-telluric equipment (ADMT 600 SX equipment) are relatively new in Nigeria but are becoming more common due to low cost and ease of field application and its precision. Groundwater exploration using Advance Magneto-telluric method has proved to be the most recent and useful tool in delineating deep groundwater depending the on the depth of investigating settings in basement terrain areas. The results of the surveys are positive for groundwater exploration, more especially in rural areas where there are no or less interferences. This equipment is prone to interferences if used close to power lines and communication mask. Caution must be taken to achieve desired result.

Aknowledgement

The author is grateful to Adamawa State University Mubi for funding the survey.

References

.Amaresh, K.S., Raviprakash, S., Mishra, D., and Singh, S., (2006). Groundwater potential modeling in Chandraprabha Subwater shed, UP using Remoting sensing, geo electrical and GIS.www.gisdevelopment.net.

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.

Andrade, R., (2011). Intervention of Electrical Resistance Tomography (ERT) in resolving hydrological problems of a semiarid granite terrain of southern India; *Journal of. Geological Society of India* 78(4); 337–344.

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

Cheng, P. H., Ger, Y. I., and Lee, S. L. (2008). An electrical resistivity study of the Chelungpu fault the Taichung area, Taiwan, Terr. Atmos. Ocean. Sci. 19, 241-255

Christopher, O., Orubu, (2006). Water resources, environment and sustainable development in Nigeria, *Journal of Human Ecology*, 19 (3);169-181.

Croock, N., Binley, A., Knight, R.., Robinson, D. A., Zarnetske, J. and Haggert, R. (2008). Electrical resistivity imaging of the architecture of substream sediments, Water Resour.Res. 44 W00D13.doi:10.1029/2008WR006968

Demanet, D., Pirard, E., Renardy, F. and Jongmans, D., (2001). Application and processing of geophysical images for mapping faults; Comput. Geosci. 27; 1031– 1037

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.

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.

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

Gokturkler, G., Balkaya, C., Erhan, Z. and Yurdakul, A. (2008). Investigation of a shallow alluvial aquifer using geoelectrical methods: A case from Turkey; Environ. Geol. 54; 1283–1290

Gyau-Boakye, P., Kankam-Yeboah, K., Dapaah-Siakwan, S. and Darko, P. K., (2008). Groundwater as vital resource for rural development: An example from Ghana. In: A. M. Segun Adelana, ed. Applied groundwater studies in Africa Taylor & Francis, 149-170.

Hauck, C., Muhll, D. V. and Maurer, H. (2003). Using DC resistivity tomography to detect and characterize mountain permafrost, Geophysical Prospecting. (51); 273-284.

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.

Hossain, D. (2000). 2D Electrical Imaging survey in hydrogeology, The Bangladesh; J. Sediment. Res. 18(1); 57–66.

Igboekwe, M.U. (2005). Geoelectrical exploration for groundwater potentials in Abia State, Nigeria. Unpublished Ph.D Thesis. Michael Opara University of Agriculture; Umidike, Nigeria.

Igboekwe, M. U., Okwueze, E. E., and Okereke C. S. (2006). Delineation of Potential Aquifer zones from Geoelectric Soundings in Akwa Ibom River Watershed, Southwestern Nigeria: *Journal of Engineering and Applied Science*. 1(4); 410 - 421

Loke, M.H., Chambers, J.E., Rucker, D.F., Kuras, O. and Wilkinson, P.B. (2013). *Journal of Applied Geophysics* (95); 135-156

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.

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.

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.

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.

Okoro, E.I., Egboka, B.C.E., Anike, O.L. and Enekwechi, E.K. (2010) Evaluation of Groundwater Potentials in Parts of the Escarpment area of South Eastern Nigeria. *International journal of Geomatics and geosciences*, 1(3), 544 - 551

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

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.

Reynolds, J. M. (1997). An Introduction to Applied and Environmental Geophysics. John Wiley and Sons Ltd. 796p

Rosen, S. and Vincent, J., (2014), Household water resources and rural productivity in sub-saharanAfrica: A review of the Evidence. Harvard Institute for international development Cambridge, MA. 52p

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.

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

Teoh, Y.J., Bruka, M.A., Idris, N.M., Ismail, N.A., and Muztaza, N.M., 2018, Subsurface investigation using 2D Resistivity and ground penetration radar at Teluk Kumbar, Penang, Journal of Physics: conference series 995 012097, doi 10.1088/172 1-14

Thapa, R., Ravindra, K. and Sood, R.K. (2008). Study of Morphotectonics and Hydrogeology for Groundwater Prospecting using Remote and GIS in the North West Himalaya, District sirmour, Himachal Pradesh India. International Achieve of the Photogrammetry Remote Sensing and spatial Information Sciences, 37 (B4) Beijing. 227- 232.

Yang, C. H., Chang, P. H., You, J. I. and Tsai, L. L. (2002) Significant resistivity changes in the fault zone associated with the 1999 Chi-Chi earthquake, west central Taiwan, Tectonophysics. (350); 299-313