Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

# Geophysical Survey for Groundwater Development: A Case study of Aero Gardens Estate, Abuja Nigeria

***Maju-Oyovwikowhe G. E[a]*, Tahiru I.T[b]***

[a]Geology Department, University of Benin, Benin City, Edo State, Nigeria.

[b]Physics Department, University of Benin, Benin City, Edo State, Nigeria.

[a]Author email: efetobore.maju@uniben.edu +2348039568446

**Article Info**

*Received 18 July 2021*
*Revised 28 July 2021*
*Accepted 7 August 2021*
*Available online 31 August 2021*

**Keywords**: Geophysical survey, Vertical Electrical Sounding, groundwater development

https://doi.org/10.37933/nipes.e/3.3.2021.3

**https://nipesjournals.org.ng**


**Abstract**

*Geophysical survey methods are applied in a wide variety of areas. They are used for oil and mineral prospecting, for solving groundwater and engineering problems, and in logging. The geophysical method employed in this study is strictly for groundwater development. The aim of the geophysical survey is to locate a suitable point for the drilling of a borehole that will be capable of meeting the safe water requirement for domestic purposes and to proffer solutions to the low yield of groundwater encountered around the survey area. This was actualized with the determination of the bedrock, determination of the degree of fracturing of the bedrock, delineation of the various lithological units encountered during the survey, and lastly, the evaluation of the aquifer potential of the subsurface. Field method employed for the survey is the Vertical Electrical Sounding (VES). The geophysical survey indicates a total weathering profile of 5m underlying the weathered to fractured granitic basement. This shows that the weathered overburden is not expected to yield any appreciable quantity of water to the well due to its shallow nature and high resistivity values. Water is therefore expected only within the basement which shows indication of fracturing at depths between forty and seventy meters (40— 70m). Drilling is recommended on the strength of the presence of fractures to a minimum depth of 70 meters and an optimum depth of 80 meters. Point of terminating the well will be at the discretion of the supervising geologist based on the water yield. However, it is important to know that accurate water yield of wells are determined only after the conduct of a pump test to establish the true aquifer characteristics. Care should also be taken in the design, construction and completion of the well as poor design and construction may lead to a reduced well yield and shorter lifespan for the borehole. Sanitary land fill should be installed at the contact with the basement to exclude infiltration of surface water into the borehole and also a cement grout should be placed from 0– 3 meters to ensure maximum sanitary condition in the vicinity of the borehole. The completed well is expected to be installed with a submersible pump.*

## 1. Introduction

According to [1, 2]; [3]; [4]; [5]; [6] water is described as the most indispensable natural resource which life depends on. It can be obtained from the troposphere as rain, surface flow as rivers and streams, and subsurface flow as groundwater [4]; [5]. Rain and surface water are easily contaminated by human activities and at times insufficiently distributed for human use [2][7]. Shortage of surface water has been predicted over the next decades, especially in sub Saharan African countries due to exhaustion of existing supplies, increase in consumption and contamination [1]. This has made groundwater a proven substitute for human use [8]. It has been found useful in domestic and industrial settings, as well as agricultural sectors [9]. The term “groundwater” can be described as the water beneath the ground surface; in pore spaces in sedimentary rocks and/or in the fractures in basement rocks. Groundwater is one of the reservoirs of the hydrologic cycle. The study of groundwater occurrences and its movement has become very important in view of acute shortage of pipe borne water supply and surface water in many places.

[10] especially in municipal areas like the FCT municipal area council, Abuja. **Groundwater in Nigeria** is widely used for domestic, agricultural, and industrial supplies. The Joint Monitoring Programme for Water Supply and Sanitation estimate that in 2018 60% of the total population were dependent on groundwater point sources for their main drinking water source: 73% in rural areas and 45% in urban areas.[11]. In 2013, there were around 65,000 boreholes in Nigeria extracting an estimated 6,340,000 $m^3$/day [12 ][13]. The majority of these (almost 45,000) were equipped with hand pumps and used for water supply in rural areas and small towns.[12]. Estimates of total renewable groundwater resources in Nigeria are variable. The United Nations Food and Agriculture Organization (FAO) estimates that Nigeria has 87,000 Million $m^3$/year of renewable groundwater resources [14]. Japan International Cooperation Agency (JICA) estimate that total annual groundwater recharge is 155,800 Million $m^3$/year. Recharge is variable across the country and largely controlled by climate: recharge is lower in the north of the country due to higher evapotranspiration and lower rainfall. Groundwater plays a very important and fundamental role in human life. Most groundwater is often associated with low yield. The expanding demand for water and the cost involved in drilling boreholes therefore require the application and the proper use of groundwater investigation techniques to locate high yielding aquifers. Identification of fractures in the bedrock and/or thick overburden, as well as the degree of pore spaces and interconnectivity of the subsurface rocks have been described as the most relevant variables to understand groundwater accumulation in PreCambrian basement terrain [15]; [16]; [4]

The evaluation, development and management of groundwater for water supply involve different stages which include: exploration, drilling, development, and well completion. This study focuses on the exploration stage. The proper exploration of groundwater involves deep and comprehensive techniques to provide valuable information with respect to distribution, thickness, and depth of groundwater bearing formation. Various surface geophysical techniques are used in groundwater exploration which includes the electrical resistivity method, seismic refractive method, magnetic method, radioactivity method, gravity method, and electromagnetic method. These techniques are capable of mapping overburden thickness, aquiferous zones, as well as bedrock architecture and topography [17]; [18], [19]; [20]; [21]. Aquifers in crystalline rocks are housed by weathered layers or fractured bedrock. In some cases, combination of weathered layers and fractured bedrock are needed for optimum groundwater accumulation [22]; [15]; [23]; [4]. The electrical resistivity method is one of the most adopted techniques in geophysical campaigns for groundwater exploration. Though applications of 2D and 3D electrical resistivity surveys to groundwater exploration and other near surface features have been reported by some authors [7] [24]; [25]; [26], VES has been the most widely used configuration out of other electrical resistivity configurations, especially in the developing nations [27]. This is justified by its cost effectiveness, usefulness in deep subsurface mapping, and ability to image large expanse of land through geoelectrical parameters [28]; [27]. Although VES only measures resistivity variations in one-dimension, it has been found very effective in the characterization of basement geology as well as groundwater exploration [29]; [30]; [31]; [27]. This justifies adopting VES for groundwater exploration in the study area.

Due to the fact that Abuja is the capital of Nigeria, the city tends to attract large population and industries. This has led to the high demand for potable water supply. The Abuja municipal area derives its portable water for consumption from treated water from Lower Usman Dam and boreholes drilled by various organizations and individuals in the area. The shortage of portable water for domestic use is very rampant and has led to dependence on water vendors that sell at very exorbitant prices. Hence, the need for individuals to locate and develop suitable groundwater supply around their residential areas to complement the existing supply for domestic uses.

The aim of this study is to use Vertical Electrical Sounding (VES) to establish drillable zone for groundwater and recommend the appropriate depth to which boreholes can be sunk in the study area to exploit an appreciable volume of water in the subsurface for domestic purposes. This method has been the most widely used electrical resistivity array in groundwater investigation due to its ability to map the subsurface structures and lithologic variations at satisfactory depths [5].

### 1.1. Geology and Hydrogeology of the Study Area

The study area is located in the centre of the country. It covers an approximate area of about 7400sqm. It is bounded in the North by Kaduna, in the East by Nassarawa, in the southwest by Kogi and in the west by Niger State. The general elevation of the study area varies considerably. Several rivers and their tributaries drain the area; the major rivers include River Usman, Jabi and Dwako. The climate of the area is made up of two major seasons; a dry season which usually last from November to February with warm sunshine and hazy harmattan around December and January, and a rainy season which lasts from April to November. Mean monthly temperature range from about 27o to 30o C and the annual precipitation is about 1,131m. The study area is a plot located in Aero Gardens Estate, along airport road, FCT Abuja. It is underlain by rocks belonging to the Pre Cambrian basement complex rocks of Nigeria. These are a group of crystalline (hard) rocks generally represented by Granites, Schist, Migmatite, Gneiss, Quartzite and a host of others. These rocks have undergone various stages of metamorphism, tectonism and weathering to produce secondary structures like jointing, fracturing, foliations and weathered zones that tend to modify their original form and structure. The specific rocks type that underlies the area is Biotite Granite, Gneiss and Schist from the physical observation of the outcrops in the area. The rocks include different textures of granites, coarse to fine, consisting essentially of biotite, feldspars and quartz. In most cases the rock have weathered into reddish micaceous sandy clay to clay materials capped by laterites. [32]. Generally, only small amount of water can be obtained in the freshly unweathered bedrock below the weathered layers. Groundwater is found mainly in the variable weathered/ transition zone and in fractures, joints and cracks of the crystalline basement. Fissure systems in Nigeria rarely extend beyond 50m, as evidenced by the available drilling data. [33]. The local water table depth is controlled by textural and compositional changes within the regolith vertical profile and the bedrock [34].
The capability of a rock to hold and transmit water in sufficient quantity to be considered economical determines the hydrogeological potential of such a rock. The properties of the rock that determines such a potential include porosity, permeability and degree of jointing in crystalline rock. These in turn determine the Transmissivity, storability and specific yield of the aquifer. In crystalline (hard) rocks these properties are represented by fracturing within the rock and the degree of weathering of the overburden. Surface geophysical surveys, such as the one conducted here, is targeted at determining the level and total depth of weathering as well as the presence of fracturing within the rock, depth of the fracture and the extent of fracturing. A combination of these will generally give an indication of the groundwater potential of the area been surveyed. Areas that are deeply but not intensely weathered and also deeply fractured will tend to give higher indication of groundwater potential than areas that are only moderately weathered. Lower groundwater yields are obtained

where only one of the zones serves as the aquifer. Geophysical surveys is therefore designed to determine such locations where the two conditions will exist, failing which fracturing at deeper levels will be targeted.

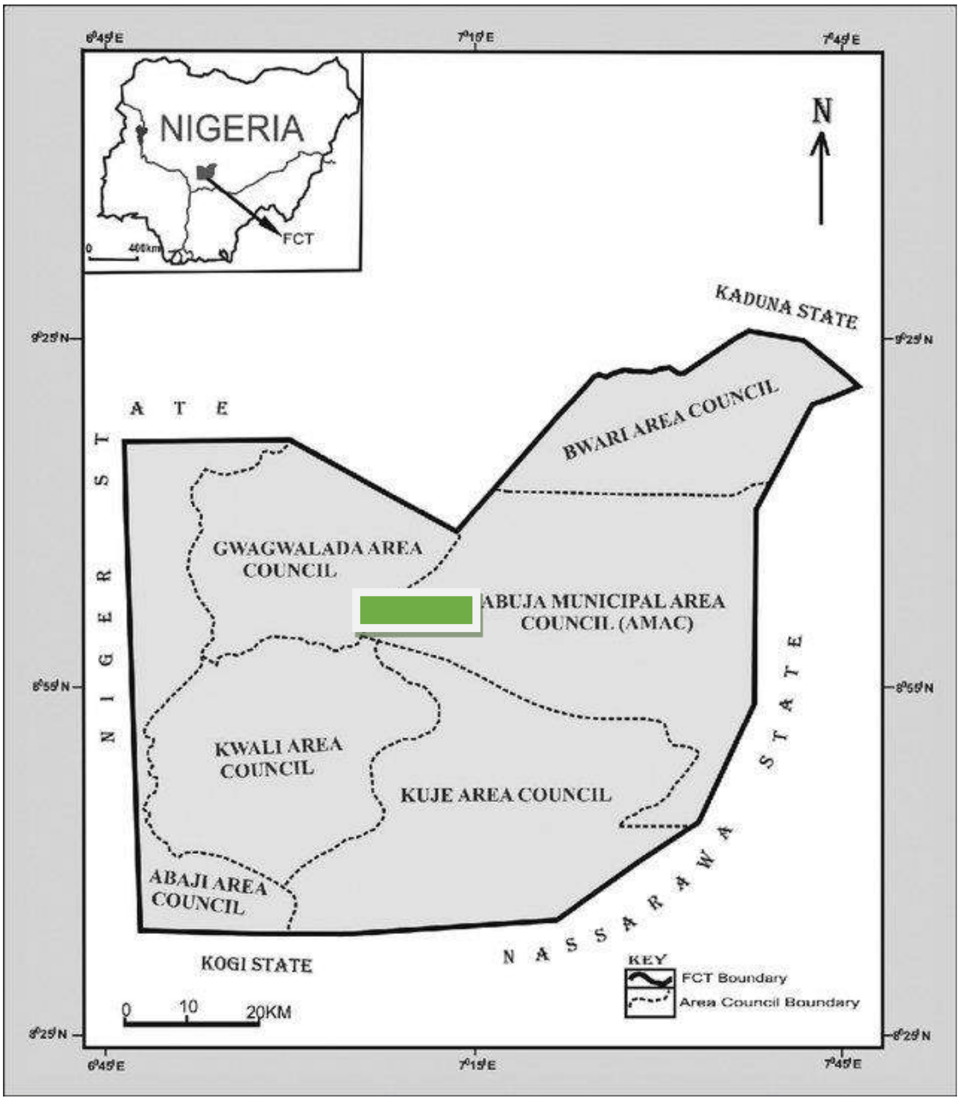


Figure 1. Map showing Abuja municipal Area Council of the FCT Nigeria. Source: Adapted from [35]

## 2. Materials and Method

Geophysical survey was conducted using the electrical resistivity method. The resistivity survey method has been in use for more than 100 years and is one of the most commonly used geophysical exploration methods [36]. It has been used to image targets from the millimeter scale to structures with dimensions of kilometers [37]; [38]. The method involves sending of electrical currents of known voltage through two point electrodes (AB) known as the current electrode and then measuring the potential difference between the two electrodes through two inner electrodes (MN) known as the potential electrode. Geological materials have different responses to this electrical current passing through them. Their response depends on the chemical composition of the material, degree of compactness, presence of conductive zones or fluids (e.g. water), presence of surfaces of discontinuity (such as fractured zones) as well as other geological phenomena that may be considered to be anomalies. Note that no single geophysical method can give a conclusive indication

*Table 1. Schlumbeger vertical electrical sounding data sheet*

**Location: AERO GARDENS ESTATE, ABUJA.**

**Geologic Terrain: BASEMENT COMPLEX**

| ELECTRODE SPACING AB/2 | ELECTRODE SPACING MN/2 | GEOMETRIC FACTOR | RESISTANCE R1 (Ω) | RESISTANCE R2 (Ω) | RESISTANCE R3 (Ω) | RESISTIVITY $\rho_1$ (Ω-m) | RESISTIVITY $\rho_2$ (Ω-m) | RESISTIVITY $\rho_3$ (Ω-m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.2 | | | | | 262 | | |
| 2 | | | | | | 84 | | |
| 3 | | | | | | 90 | | |
| 5 | | | | | | 65 | | |
| 7 | | | | | | 45 | | |
| 7 | 1.0 | | | | | 37 | | |
| 10 | | | | | | 47 | | |
| 15 | | | | | | 74 | | |
| 20 | | | | | | 112 | | |
| 25 | | | | | | 137 | | |
| 30 | | | | | | 167 | | |
| 30 | 5.0 | | | | | 159 | | |
| 40 | | | | | | 207 | | |
| 50 | | | | | | 272 | | |
| 60 | | | | | | 310 | | |
| 70 | | | | | | 340 | | |
| 80 | | | | | | 370 | | |
| 100 | | | | | | | | |
| 100 | | | | | | | | |
| 120 | | | | | | | | |
| 150 | | | | | | | | |
| 200 | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

of the presence of water in any particular geological terrain; rather what is indicated is the presence of fractures that may be capable of storing and transmitting water to wells placed in them. It therefore follows that the fractures may be there but may not hold any water.

During the course of the Geophysical exploration, field methods employed for the survey was the Vertical Electrical Sounding (VES) which was used to determine the vertical variations in resistivity presented in Table 1. The half-Schlumberger array was used for the VES in view of the limited space available for the surveys. VES 1was conducted from AB/2 Separation of 1m to 80m and MN/2 of 5m. The equipment used for the survey is the ***Ohmega Resistivity Meter***. The Ohmega resistivity meter is a high quality portable earth resistance meter capable of accurate measurement over a wide range of conditions.

## 3. Results and Discussion

VES 1 displayed KH-type curve (Figure 2). Therefore, quantitative partial curve matching method was adopted in this study. This technique involved two main steps. A sort segment of the curve was cross matched with a 2-layer master curve. From the most appropriate matching, the value L (apparent resistivity of the first layer), the depth to the top of the second layer h1 and h2, the apparent resistivity of the second layer was obtained. Computer software WINRESIST version 2004 was used to improve the quality of the interpretation. The interpretations are as shown in Table 2.

*Table 2: Drillers Guide for VES 1[13]*

| **VES 1** | **Resistivity** | **Depth** | **Lithology** |
|---|---|---|---|
| Layer 1 | 311.1 | 0.0 – 0.7 | Sandy clay |
| Layer 2 | 45.0 | 7.8 – 8.5 | Sandy clay |
| Layer 3 | 1937.8 | 28.0 – 36.5 | Weathered Basement |
| Layer 4 | 1009.5 | 37.4 – 73.9 | Fractured Basement |
| Layer 5 | 716.8 | 73.9 - >>>> | Basement |

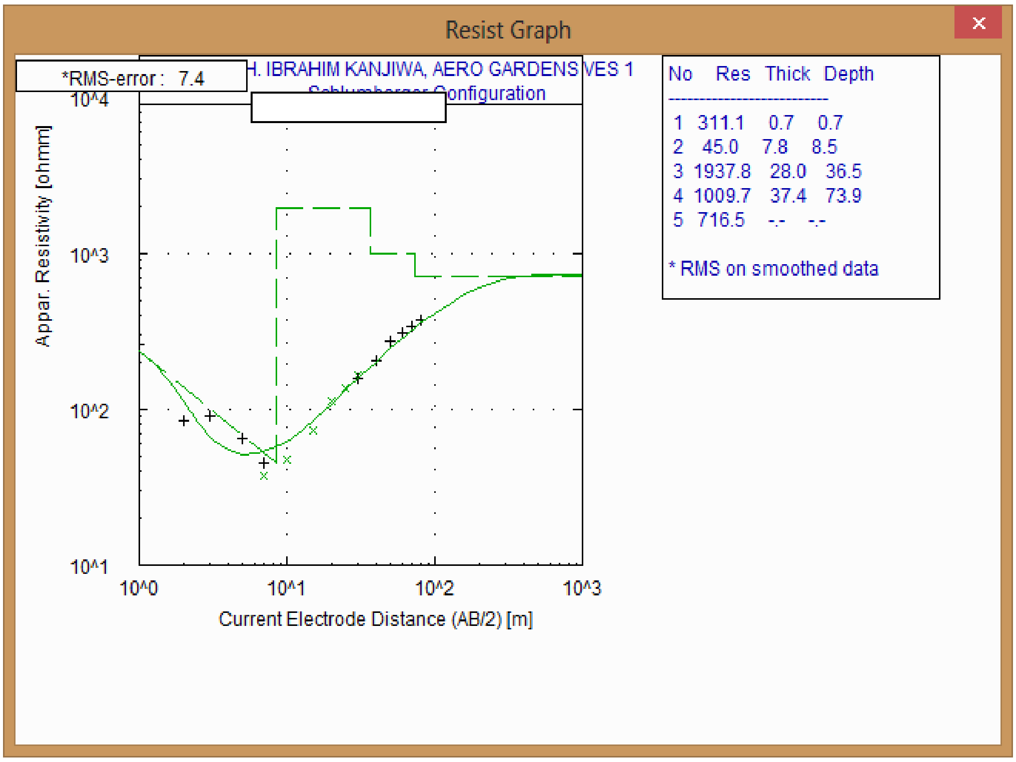


*Figure 2. Field Curve for VES 1*

The data set analysis revealed 5 distinct layers before basement for VES 1. Layers 1 and 2 are composed of sandy clay which is underlain by weathered rock and slightly fractured basement. A total weathering profile of 5m underlying the weathered to fractured granitic basement was

identified in this survey. This shows that the weathered overburden is not expected to yield any appreciable quantity of water to the well due to its shallow nature and high resistivity values[38]. Water is therefore expected only within the basement which shows indication of fracturing at depths of between forty and seventy meters (40— 70m). The zone of low resistivity that has been interpreted as a weathered zone at depth is only slightly defined. Estimated overburden thickness at VES 1 is within 7 and 12 meters. VES 1 has positive inference in terms of aquifer viability and as such, possesses requisite hydrogeologic characteristics capable of supplying underground water to well when drilled [28]. The location is therefore viable. This point (VES 1) represents the best point with the highest groundwater potential in the area based on the systematic profiling that was done prior to conducting VES'.
Drilling is recommended on the strength of the presence of fractures to a minimum depth of 70 meters and an optimum depth of 80 meters. Point of terminating the well will be at the discretion of the supervising geologist based on the water yield. However, it is important to know that accurate water yield of wells are determined only after the conduct of a PUMP TEST to establish the true aquifer characteristics**.** Care should also be taken in the design, construction and completion of the well as poor design and construction may lead to a reduced well yield and shorter lifespan for the borehole. Sanitary land fill should be installed at the contact with the basement to exclude infiltration of surface water into the borehole and also a cement grout should be placed from 0– 3 meters to ensure maximum sanitary condition in the vicinity of the borehole.

## 4. Conclusion

Geophysical survey is only an indirect method of studying the subsurface. Conditions indicated may differ slightly or even significantly from what actually obtains. The water yield expected from this well may be low to sufficient. In as much as the result of the geophysical survey indicated a slightly positive groundwater potential at shallow levels, the fractures at deeper depths should be able to contain and transmit sufficient quantity of water to sustain the water requirement for the intended domestic purpose only, if properly regulated and managed. The method used in this study has been able to achieve over 80% success rate in similar terrain. Professional judgments and recommendations are presented in this study. They are based partly on evaluation of the technical information gathered, partly on historical report and on general experience with subsurface conditions in the area. From the result of the Geophysical survey, the overburden/weathered layer is fairly thick (12m) and saturated. Thus, high pressure casing pipe is required to case this layer to withstand the pressure and prevent the well from collapsing.

## References

[1] Oladejo, O. P., Sunmonu, L. A., Ojoawo, A., Adagunodo, T. A., and Olafisoye, E. R. (2013). Geophysical investigation for groundwater development at Oyo state housing estate Ogbomosho, southwestern Nigeria. Res. J. Appl. Sci. Eng. Technol. 5, 1811–1815. doi: 10.19026/rjaset.5.4943

[2] Oladejo, O. P., Sunmonu, L. A., and Adagunodo, T. A. (2015). Groundwater prospect in a typical precambrian basement complex using Karous-Hjelt and fraser filtering Techniques. J. Ind. Eng. Res. 1, 40–49.

[3] Badejo, A. A., Ndambuki, J. M., Kupolati, W. K., Adekunle, A. A., Taiwo, S. A., and Omole, D. O. (2015). Appraisal of access to safe drinking water in Southwest Nigeria. Afr. J. Sci. Technol. Innov. Dev. 7, 441–445. doi: 10.1080/20421338.2015.1096669.

[4] Akinrinade, O. J., and Adesina, R. B. (2016). Hydrogeophysical investigation of groundwater potential and aquifer vulnerability prediction in Basement complex terrain – a case study from Akure, southwestern Nigeria. RMZ-M G 63, 55–66. doi: 10.1515/rmzmag-2016-0005.

[5] Anomohanran, O., Ofomola, M. O., and Okocha, F. O. (2017). Investigation of groundwater in parts of Ndokwa district in Nigeria using geophysical logging and electrical resistivity methods: implications for groundwater exploration. J. Afr. Earth Sci. 129, 108–116. doi: 10.1016/j.jafrearsci.2016.12.008.

[6] Emenike, C. P., Tenebe, I. T., Omole, D. O., Igene, B. U., Oniemayin, B. I., Omeje, M., et al. (2017). Accessing safe drinking water in sub-saharan africa: issues and challenges in South-West Nigeria. Sustain. Cities Soc. 30, 263–272. doi: 10.1016/j.scs.2017.01.005.

[7] Tahiru I.T, Osaiyumw E.A, Ogwaro E.S. (2017). 2-D Electrical resistivity investigation of Solid waste dumpsite at Oluku in Benin City, Edo State. Journal of Nigeria Association of Mathematical Physics Journal, Volume 43:403 - 408.

[8] Adagunodo, T. A. (2017a). "Groundwater contamination: performance, effects, limitations and control," in Groundwater Contamination: Performance, Limitations and Impacts, ed A. L. Powell (New York, NY: Nova Science Publishers, Inc), 33–64.

[9] Olafisoye, E. R., Sunmonu, L. A., Ojoawo, A., Adagunodo, T. A., and Oladejo, O. P. (2012). Application of very low frequency electromagnetic and hydrophysicochemical methods in the investigation of groundwater contamination at Aarada waste disposal site, Ogbomoso, Southwestern Nigeria. Aust. J. Basic Appl. Sci. 6, 401–409.

[10] Maju-Oyovwikowhe, G.E. and Shuaib, I.I. (2019): Physiochemical Characteristics and Heavy Metal Levels of Water from Hand Dug Wells in Ikiran-Ile, Akoko Edo Local Government Area, Edo State, Nigeria. Journal of Applied Science and Environmental Management. Vol. 23, No 2, pp 283-290.

[11] Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (2019). Estimates on the use of water, sanitation and hygiene in Nigeria.

[12] JICA (2014). The project for review and update of Nigeria national water resources master plan; Vol.2.

[13] Ministry of Water Resources (2013). National Water Resources Master Plan.

[14] FAO (2016). AQUASTAT Main Database. Food and Agriculture Organisation of the United Nations
.

[15] Adagunodo, T. A., Sunmonu, L. A., Ojoawo, A., Oladejo, O. P., and Olafisoye, E. R. (2013a). The hydro geophysical investigation of Oyo state industrial estate Ogbomosho, southwestern Nigeria using vertical electrical soundings. Res. J. Appl. Sci. Eng. Technol. 5, 1816–1829. doi: 10.19026/rjaset.5.4944

[16] Adelusi, A. O., Ayuk, M. A., and Kayode, J. S. (2014). VLF-EM and VES: an application to groundwater exploration in a PreCambrian basement terrain SW Nigeria. Ann. Geophys. 57:s0184. doi: 10.4401/ag-6291

[17] Adagunodo, A., and Sunmonu, A. (2013). The Study of Basement Pattern of an Industrial Estate. Saarbrucken: LAP Lambert Academic Publishing GmbH & Co. KG Heinrich-Bocking. Available online at: https://www.lap-publishing.com.

[18] Adagunodo, T. A., Sunmonu, L. A., and Oladejo, O. P. (2014). Effect of constructing high-rise buildings without a geophysical survey. Nigerian J. Phys. Spec. Edition 2014, 91–100.

[19] Adagunodo, T. A., Adeniji, A. A., Erinle, A. V., Akinwumi, S. A., Adewoyin, O. O., Joel, E. S., et al. (2017). Geophysical investigation into the integrity of a reclaimed open dumsite for civil engineering purpose. Interciencia J. 42, 324–339.

[20] Joel, E. S., Olasehinde, P. I., De, D. K., Omeje, M., and Adewoyin, O. O. (2016). Estimation of aquifer transmissivity from geo-physical data. A case study of Covennat University and environs, Southwestern Nigeria. Sci. Int. 28, 3379–3385.

[21] Oyeyemi, K.D., Aizebeokhai, A. P., Adagunodo, T. A.,Olofinnade,O.M., Sanuade, O. A., and Olaojo, A. A. (2017). Subsoil characterization using geoelectrical and geotechnical investigations: implications for foundation studies. Int. J. Civil Eng. Technol. 8, 302–314.

[22] Sunmonu, L. A., Adagunodo, T. A., Olafisoye, E. R., and Oladejo, O. P. (2012). The groundwater potential evaluation at industrial estate Ogbomoso, Southwestern Nigeria. RMZ Mater. Geoenviron. 59, 363–390.

[23] Adepelumi, A. A., Akinmade, O. B., and Fayemi, O. (2013). Evaluation of groundwater potential of Baikin Ondo state, Nigeria using resistivity and magnetic techniques: a case study. Univ. J. Geosci. 1, 37–45. doi: 10.13189/ujg.2013.010201

[24] Aizebeokhai, A. P. (2010). 2D and 3D geoelectrical resistivity imaging theory and field design. Sci. Res. Essays 5, 3592–3605. doi: 10.5897/IJPS2013.4017

[25] Loke, M. H., Chambers, J. E., Rucker, D. F., Kuras, O., and And Wilkinson, P. B. (2013). Recent developments in the direct-current geoelectrical imaging method. J. Appl. Geophys. 95, 135–156. doi: 10.1016/j.jappgeo.2013.02.017

[26] Adagunodo, T. A., Sunmonu, L. A., and Adeniji, A. A. (2015). Effect of dynamic pattern of the saprolitic zone and its basement on building stability: a case study of a high-rise building in Ogbomoso. J. Appl. Phys. Sci. Int. 3, 106–115.

[27] Abudulawal, L., Amidu, S. A., Apanpa, K. A., Adeagbo, O. A., and Akinbiyi, O. A. (2015). Geophysical investigation of subsurface water of Erunmu and its environs, southwestern Nigeria using electrical resistivity method. J. Appl. Sci. 15, 741–751. doi: 10.3923/jas.2015.741.751

[28] Riss, J., Fernandez-Martinez, J. L., Sirieix, C., Harmouzi, O., Marache, A., and and Essahlaoui, A. (2011). A methodology for converting traditional vertical electrical soundings into 2D resistivity models: applications to the Saiss Basin, Morocco. Geophysics 76, B225–B236. doi: 10.1190/geo2010-0080.1

[29] Olayinka, A. I., Amidu, S. A., and Oladunjoye, M. A. (2004). Use of electromagnetic profiling and resistivity sounding for groundwater exploration in the crystalline basement area of Igbeti, southwestern Nigeria. Global J. Geol. Sci. 2, 243–253. doi: 10.4314/gjgs.v2i2. 18701

[30] Nwankwo, L. I. (2011). 2D resistivity survey for groundwater exploration in a hard rock terrain: a case study ofMAGDAS observatory, UNILORIN, Nigeria. Asian J. Earth Sci. 4, 46–53. doi: 10.3923/ajes.2011.46.53

[31] Adagunodo, T. A., Sunmonu, L. A., Oladejo, O. P., and Ojoawo, I. A. (2013b). Vertical electrical sounding to determine fracture distribution at Adumasun Area, Oniye, Southwestern Nigeria. J. Appl. Geol. Geophys. 1, 10–22. doi: 10.9790/0990-0131022

[32] Offodile, M. E. (1992): An Approach to Groundwater Study and Development in Nigeria, Mecon Services Ltd. Jos. Pp224-227.

[33] Clark, L (1985): Groundwater abstraction from the basement complex area of Africa. Q.J. Engineering Geology London Vol.18 pp. 25-34.

[34] David, L. M. and Ofrey, O. (1989): An in direct method of estimating groundwater Level on Basement complex regoliths. Water Resources - Journal of Nigeria Association of Hydrogeologists. Vol. 1, No. 2 pp61-164.

[35] Abuja Geographic Information System (AGIS) Abuja FCT, Nigeria 2016. Environ. Health Rev.

[36] Reynolds, J. M., 1997. *An Introduction to Applied and Environmental Geophysics*. England: Wiley.

[37] Linderholm, P., Marescot, L., Loke, M. H., and Renaud, P., 2008. Cell culture imaging using microimpedance tomography. *IEEE Transactions on Biomedical Engineering*, **55**, 138–146.

[38] Storz, H., Storz, W., and Jacobs, F., 2000. Electrical resistivity tomography to investigate geological structures of the earth's upper crust. *Geophysical Prospecting*, **48**, 455–471.