Structural analysis of subsurface stability using aeromagnetic data: a case of Ibadan, southwestern Nigeria

O.P. Oladejo 1, T.A. Adagunodo 2, L.A. Sunmonu 3, M.A. Adabanija 4, N.K. Olasunke 5, M. Omeje 2, I.O. Babarimisa 2, H. Bility 2

1 Department of Physics, Emmanuel Alayande College of Education, Oyo, Nigeria
2 Department of Physics, Covenant University, Ota, Nigeria
3 Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
4 Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
5 Department of Physics and Materials Science, Kwara State University, Malete, Nigeria

Corresponding email: theophilus.adagunodo@covenantuniversity.edu.ng

Abstract. This study is aimed at investigating the subsurface stability of Ibadan against tremor occurrence and to check how safe the subsurface is for civil engineering constructions. High resolution aeromagnetic data of Ibadan (Sheet 261) were processed using automated approach. The data were further enhanced using the Total Horizontal Derivative (THDR) in order to determine the orientations of the lineaments in the study area. The orientations of the lineaments obtained from the THDR map revealed that the Pan African orogeny constitutes 50%; Kibaran orogeny constitutes 33%, while Liberian orogeny constitutes 17% lineaments in the study area. Based on orientation of faults on magnetic fault map obtained from the superposition of the lineaments extracted from THDR map on the geological map of the study area, three distinct set of sinistral/dextral faults were recognized in Ibadan. These include: NE-SW, ENE-WSW and NW-SE fault trend. This suggests that NE-SW and ENE-WSW fault-set could be responsible for the tremor experienced in Ogun state and Ibadan respectively. It is concluded that the study area is not immune from experiencing occurrences of tremors from time to time.

Keywords: Subsurface stability, Structural analysis, aeromagnetic data, Ibadan, Tremor

1. Introduction

The African continent is made up of stable PreCambrian basement rocks [1]. These rocks are either igneous, meta-igneous or meta-sedimentary in nature. Above the basement rocks lie series of geologic structures such as volcanic, sedimentary sequence and unconsolidated cenozoic structures. Nigeria, one of the key nations in Africa resides on the remobilized part of West African basement rocks, which are believed to be aseismic for long ago has now been challenged with series of minor earthquakes (known as tremors) from year 1933 till date. A tremor occurs when there is vibration of
the Earth surface as a result of the sudden release of energy from the lithosphere [2]. As documented by [2], an earthquake occurs where there is sufficient (stored) energy to drive fracture propagation along a fault plane.

In Nigeria, 39 tremors have been recorded for about 85 years of occurrence [2-5]. Out of the total events, 7 occurrences have been documented about Ibadan [2], while other microseismic activities have been experienced within the city without instrumental account about such incidence. Some of the early warning signs of earthquake occurrence that have not been scientifically endorsed include: variations in borehole/hand-dug well water level, unusual behaviour of animals, change in taste of groundwater, tilting/bulging of Earth surface, gas emissions from subsurface, change in colour of sky, and occurrences of foreshocks [6]. Being a major town in southwestern Nigeria with series of activities, it is imperative to carry out structural analysis on the subsurface structures of Ibadan in order to know how stable the underlying bedrock are for construction of civil engineering structures.

Subsurface mapping for civil engineering worthiness is highly important and serves as a major way of mitigating the incessant failure and collapses of physical structures such as dams, bridges, roads and buildings [7-9]. Incessant failure of physical structures has posed a significant hazard on the lives and properties of people living around such locations in Nigeria. It has become imperative for the geophysicists in Nigeria to carry out pre-foundation as well as post-foundation studies, especially in some mega cities where “Urban Renewal Projects” are being embarked on by the state governments. This will serve as a way of mitigating structural failure occurrences in the country. Foundation study using geophysical approach provides information about the near surface features that serves as guide for civil engineers when designing foundation for civil engineering structures [10]. It is also a proven economical approach in comparison with geotechnical method in terms of the financial implication and the area of coverage during site investigation [11-12]. Several authors have documented the importance of geophysical methods in civil engineering [10, 13-17]. Among these methods are: electrical resistivity, seismic refraction, gravity, magnetic and electromagnetic methods [10]. In this present study, magnetic method was adopted to investigate the subsurface stability in Ibadan, Nigeria, with the aim to assist the construction engineers in order to understand the geostuctural settings of this study area. In general, the three types of magnetic survey that exist are: ground magnetic, aeromagnetic and marine magnetic survey. Each of these survey types have been discussed by [18] and [19]. Of all these three types of magnetic method, aeromagnetic survey has been known for its effectiveness in regional study, because it is fast, it does not encounter obstructions (such as mountain, water, forest/vegetation, sacred places and so on), and could cover large area within few hours of survey [20]. This advantage has been the choice of using high resolution aeromagnetic data for the structural analysis of Ibadan, southwestern Nigeria.

Analysis of aeromagnetic data has been found useful in the interpretation of buried features in PreCambrian basement rocks as well as Sedimentary terrain [21] such as location of lineaments and structures, which could be host for resources like minerals, hydrocarbon and groundwater [22]. It has also been used to map igneous rocks, metamorphic rocks and related structures due to their high magnetization when compared to other rocks [23]. Aeromagnetic survey has been able to reveal the geospatial distribution and trend of magnetic and nonmagnetic bodies in the upper region (probably up to 10 km) of the Crust [24]. Some of the previous works from the study are listed in Refs. [25-28].

2. Location and geological settings of the study area

Ibadan – the capital of Oyo state, which is located in southwestern zone of Nigeria is bounded by Kwara state in the north, Osun state in the east, Ogun state in the south, and partly bounded in the west by Ogun state and Republic of Benin (Fig.1). The study area is the largest indigenous city in West
Africa, with the total area of 3023 km² (that is, 55 by 55 km). Its coordinates extend from latitude 7° 00’ to 7° 30’ N and longitude 3° 30’ to 4° 00’ E (Fig. 2).

The geology of Ibadan is within the Basement complex rocks of southwestern (SW) Nigeria, which are of PreCambrian in age. Some of the previous works from the Basement complex terrain of SW Nigeria could be found in Refs. [25-46]. These rocks are crystalline or metamorphic in nature, which are over 550 million years old. The crystalline rocks of Ibadan are chiefly divided into series of units, which include: gneiss-migmatite complex, quartz, pegmatite, amphibolites, xenoliths and aplites [47]. The subunits of gneiss-migmatite complex in the study area are migmatite and banded gneiss, quartzite of meta-sedimentary series, augen gneiss and granite gneiss. Banded gneiss shares the largest distribution of the rock units with and around Ibadan (about 75%), while quartzite and augen gneiss constitute the remaining 25% [47]. The generalized geological map of Ibadan showing the suburbs of the mega city is presented in Fig. 3.

![Fig. 1: Map of Nigeria showing the study area – the capital of Oyo state.](image-url)
Fig. 2: Layout of the study area (Adapted from [28]).

Fig. 3: The geology of the study area and its suburbs (Adapted from [46]).
3. Material and Methods

The Total Magnetic Intensity (TMI) aeromagnetic data of Ibadan (Sheet 261), southwestern Nigeria was used for this study. The TMI data was acquired by the Nigerian Geological Survey Agency (NGSA) popular geophysical campaign, which was done by Fugro Airborne Survey Limited, between 2003 and 2009 [48]. The data acquisition mode and necessary data corrections during the field campaign are in line with the NGSA rule for aeromagnetic data acquisition [49]. The acquired data were de-cultured, levelled, corrected for International Geomagnetic Reference Field, and gridded in such a way that enables enhancement of signal-to-noise ratio and suppression of latitudinal effects [50]. The aeromagnetic data was recorded in x, y, z format (that is, x and y are the coordinates, while z is the TMI for that point) and delivered in Oasis Montaj enabled package, which is the major automated machine used for data processing of this study.

In order to have a meaningful interpretation, it is imperative to apply data reduction technique on the TMI [51]. This will enable the residual and regional field data to be separated from the TMI. To achieve this, the Fast Fourier Transform was used for data conversion and reduction, which was used to produce the residual magnetic data of the study area. The Reduction to Magnetic Equator (RTE) approach was adopted, since the location of study is close to the Equator. This approach is in agreement with the one used by [48] and [52]. As reported by [53], data processing and reduction is essential when dealing with shallow magnetic sources and rock types that have relatively large contrast in magnetization. The beauty of aeromagnetic data is that its resultant residual data can be compared with the geological map of that area for meaningful interpretation. The magnetic source edges were further enhanced using Total Horizontal Derivative (THDR). The THDR is used to delineate boundaries of intrusive bodies [54], faults and other lateral variations based on adage detection technique [29, 55]. Theoretical relationships of this enhancement technique have been discussed by [56]. The THDR is related to other derivatives by Eq. (1).

\[
THDR = \frac{VDR}{\tan \theta}
\]

where VDR is the Vertical Derivative, while \( \theta \) is the Tilt Derivative.

4. Results and Discussion

The TMI, regional and RTE residual maps are presented in Figs. 4 - 6. It is revealed that after the regional field has been remove from the TMI, there is no pronounced variation from the pattern of magnetic anomalies produced on both the TMI (Fig. 4) and RTE residual map (Fig. 6) maps. As revealed in Fig. 6, the study area is characterized by high (H), medium (MED) and low (L) magnitude magnetic anomalies. The high magnitude magnetic anomalies signatures designated by red and pink colours have magnetic field intensity which ranged from 19.5 to 109.1 nT. They are scattered over Ibadan forming two parallel ridges in northwest-southeast direction (Fig. 6). These areas coincide lithologically with contrasting basement rocks comprising granite gneiss, migmatite and banded gneiss in Ibadan as shown in Fig. 3. These zones are of relatively shallow depth to magnetic sources as classified by [16].

The intermediate magnetic anomalies signature designated by green colour varied in magnetic susceptibility from 3.2 to 19.5 nT. They are mainly along northwest-southeast direction. These signatures are separated by depression and uplift, but sandwiched in between two parallel NW-SE magnetic high ridges. These areas are considered as of medium depth to magnetic source and lithologically correlate with quartzite/quartz-schist and quartzite as
presented in Fig. 3. As found in the literature, quartzite and quartz-schist are known to possess intermediate magnetic susceptibilities [16].

The magnetic field intensity of low magnetic anomalies (depicted by blue colour) varied between -83.6 to -3.2 nT. They are most prominent at northern/northeastern part where they occur in a recumbent fold-like structure but as depression at west-southwestern, central and north central in Ibadan. They represent areas of deep depth to magnetic source and are sometimes due to granitic intrusion in basement complex [57-59] as exemplified by intrusion of quartzite/quartz-schist by migmatite and banded gneiss on the geologic map (Fig. 3) of Ibadan.

Fig. 4: TMI map of the study area.
Fig. 5: Regional magnetic field of the study area.

Fig. 6: RTE residual map of the study area.
4.1 Magnetic Lineament Analysis

The THDR map produced from RTE residual magnetic map (Fig. 6) is as depicted in Fig. 7. Two different structural domains were recognized within the study area by differences in the inferred contact patterns such as general orientation and spacing. The THDR map of Ibadan shows major orientation in the eastern, western and southern directions and the amplitude of the gradient ranges between 0.02 to 0.039 nT/m.

Magnetic lineaments analysis involves extraction of lineaments from the THDR map. The extracted lineaments map is as depicted in Fig. 8; the pie-chart distribution of varied lengths of the lineaments is as depicted in Fig. 9; and the rose diagram showing trend and orientation of the lineaments is as shown in Fig. 10. The distributions of the orientations of the lineaments and the associated orogenies are presented in Table 1. The lineaments are of varied lengths between 2.0 and 9.0 km with a mean of 1.796 ± 0.9 km. The structural style as indicated by rose diagram revealed that 53 lineaments are extracted from THDR of Ibadan (Fig. 10); NE-SW is most dominance constituting 50% (Table 1); and E-W is the least revealing 17% of the distribution. The three orogenies identified in the study area are Pan-African orogeny, which trend in NE-SW orientation; Liberian orogeny, which trend in E-W orientation; and Kibaran orogeny, which trend in NW-SE orientation (Table 1).

Fig. 7: The THDR Map showing the locations of Magnetic contacts as Peak Amplitude of the study area.
Fig. 8. Magnetic lineaments map extracted from the THDR signatures

Fig. 9: Pie-chart distribution of long and short lineaments

Fig. 10: Rose diagram showing orientations of the lineaments

Table 1: Classification of Lineaments extracted from THDR map and associated orogeny

| LINEAMENT (%) | TREND                | OROGENY   |
|---------------|----------------------|-----------|
| 50%           | Northeast-Southwest  | Pan African|
| 17%           | East-West            | Liberian  |
| 33%           | Northwest-Southeast  | Kibaran   |
4.2 Structural Analysis

The structural framework of the study area was further investigated using magnetic fault map obtained from the superposition of the lineaments extracted from THDR map (Fig. 11) on the modified geologic map of Ibadan (Fig. 12) using arc-GIS 10.3 software. The magnetic faults are faults that are mainly due to offset of similar magnetic domains/gradients [29, 60-61]. These faults are in red/purple colour and blue colour respectively. They are at different orientations: NE-SW, NW-SE and ENE-WSW on the composite map (Fig. 12). Faults that are depicted by red/purple colour are known as sinistral, while those that are depicted by blue colour are known as dextral [29, 48, 52]. Thus, based on this classification, three distinct set of sinistral/dextral faults can be recognized in Ibadan. These include: NE-SW, ENE-WSW and NW-SE fault trend. This suggests that NE-SW and ENE-WSW fault-set could be responsible for the tremor experienced in Ogun state and Ibadan, as corroborated by the vibration of September 11, 2009 of magnitude 4.4 with epicenter at Allada, Republic of Benin, 128 km west of Lagos Nigeria as reported by [62]. As revealed on the composite map (Fig. 12), there are also major faults noticed towards the southern and southwestern parts of University of Ibadan (UI). This fault trends in NE-SW orientation. This could probably be part of Zungeru-Ifewara fault or its synthetic, which is believed to be a suture of Kibaran age [63-64], while the NW-SE fault around UI could be regarded as antithetic.

![Fig. 11: Superimposition of the lineaments on the RTE residual map](image-url)
5. Conclusion

High resolution aeromagnetic data of Ibadan (sheet 261) has been processed, enhanced and interpreted using Geosoft Oasis Montaj 6.4.2 (HJ) data processing and analysis software purposely to investigate the subsurface stability of Ibadan against tremor occurrence and to check the safe locations for civil engineering construction. Based on orientation of faults on magnetic fault map obtained from the superposition of the lineaments extracted from THDR map on the geological map of the study area, three distinct set of sinistral/dextral faults were recognized in Ibadan. These include: NE-SW, ENE-WSW and NW-SE fault trend. This suggests that NE-SW and ENE-WSW fault-set could be responsible for the tremor experienced in Ogun state and Ibadan, as corroborated by the vibration of September 11, 2009 of magnitude 4.4 with epicenter at Allada, Republic of Benin, 128 km west of Lagos Nigeria. The NE-SW fault-set obtained in Ibadan is probably an extension of NE-SW trending fracture, which is considered as synthetic with part of NE-SW trending Zungeru-Ifevara fault from the Atlantic Ocean to which Nigeria Earth tremors have been attributed. The identified synthetic magnetic faults at south and southwest of UI could be synthetic to Ifewara-Zungeru fault when tectonically activated. These suggest that Ibadan is not immune from experiencing at least earth tremors (minor earthquakes).
Acknowledgment

We appreciate the partial conference support received from the Centre for Research, Innovation, and Discovery, Covenant University, Nigeria.

References

[1] Adagunodo T.A., Lüning S., Adeleke A.M., Omidiora J.O., Aizebeokhai A.P., Oyeyemi K.D., Hammed O.S. (2018). Evaluation of $0 \leq M \leq 8$ Earthquake Data Sets in African-Asian Region during 1966 – 2015. Data in Brief, 17C: 588 – 603. https://doi.org/10.1016/j.dib.2018.01.049.

[2] Nwankwoala H.O. and Orji O.M. (2018). An overview of earthquakes and tremors in Nigeria: occurrences, distributions and implications for monitoring. Int. J. Of Geology and Earth Sci., 4(4): 56-76.

[3] Ofonime O.A. and Yakubu T.A. (2010). A review of earthquake occurrences and observations in Nigeria. Earthq. Sci., 23: 289-294.

[4] Eze C.L., Sunday V.N., Ugwu S.A., Uko E.D., Ngah S.A. (2011). Mechanical model for Nigeria intraplate earth tremors. Articles, Disasters, Management Theme, Earth Observation, Portharcourt. IEEE Oceanic Engineering Society.

[5] Nwankwoala H.O. (2018). Geoethics: georisk management for a safer and more resilient society. A lead paper presented at the first Nigeria conference of the International Association for Promoting Geoethics (IAPG), held between 18-19 October, 2018 at the Faculty of Law Auditorium, Rivers State University, Portharcourt, Nigeria.

[6] Cicerone R.D., John E.A. and Britton J. (2009). A systematic compilation of earthquake precursors. Tectonophysics, 476: 371-396.

[7] Hammed O.S., Awoyemi M.O., Igboama W.N., Fatoba J.O., Bayode J.O., Oluring O.T., Arogundade A.B., Fatade S.C., Aroyehun M. (2018). Ground magnetic attributes for subsurface structural analysis of foundation beds in sedimentary terrain in south-western Nigeria: OSUSTECH Permanent Site as a case study. FUOYE Journal of Engineering and Technology, 3(1): 33-37.

[8] Adagunodo T.A., Sunmonu L.A., Oladejo O.P. and Ojoawo I.A. (2013). Vertical Electrical Sounding to Determine Fracture Distribution at Adumasun Area, Oniye, Southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics, 1(3), 10–22.

[9] Adagunodo T.A., Sunmonu L.A. and Oladejo O.P. (2014). Effect of Constructing High-Rise Buildings without a Geophysical Survey. Nigerian Journal of Physics. Special Edition September 2014, 91–100.

[10] Hammed O.S., Adagunodo T.A., Aroyehun M., Badmus G.O., Fatoba J.O., Igboama W.M. and Salami A.J. (2017). Geoelectric Survey of Foundation Beds of the Proposed Faculty of Engineering Building, OSUSTECH Permanent Site, Okitipupa, Nigeria. FUOYE Journal of Pure and Applied Sciences, 2(1): 126 – 137.

[11] Adagunodo T.A., Sunmonu L.A., Oladejo O.P., Hammed O.S., Oyeyemi K.D., Kayode O.T. (2018). Site Characterization of Ayetoro Housing Scheme, Oyo, Nigeria. IOP Conference Series: Earth and Environmental Science, 173: 012031. https://doi.org/10.1088/1755-1315/173/1/012031.

[12] Adagunodo T.A., Adeniji A.A., Erinle A.V., Akinwumi S.A., Adewoyin O.O., Joel E.S., Kayode O.T. (2017). Geophysical Investigation into the Integrity of a Reclaimed Open Dumpsite for Civil Engineering Purpose. Interciencia Journal, 42(11): 324 – 339.

[13] Ozcep F. And Ozcep T. (2011). Geophysical analysis of the soils for civil (Geotechnical) engineering and urban planning purposes: some case histories from Turkey. International Journal of the Physical Sciences, 6(5): 1169-1195.

[14] Oyeyemi K.D., Aizebeokhai A.P., Adagunodo T.A., Olofinnade O.M., Sanuade O.A., Olaajo A.A. (2017). Subsoil Characterization using Geoelectrical and Geotechnical Investigations:
Implications for foundation Studies. International Journal of Civil Engineering and Technology, 8(10): 302 – 314.

[15] Adagunodo T.A., Sunmonu L.A., Erinle A.V., Adabanija M.A., Oyeyemi K.D., Kayode O.T. (2018). Investigation into the types of Fractures and Viable depth to Substratum of a Housing Estate using Geophysical Techniques. IOP Conference Series: Earth and Environmental Science, 173: 012030. https://doi.org/10.1088/1755-1315/173/1/012030.

[16] Telford W.M., Geldart L.P., Sheriff T.E., Keys D.A. (1976). Applied Geophysics 2nd Edition. Cambridge University Press, Cambridge, U.K.

[17] Adagunodo Aanuoluwa and Sunmonu Ayobami (2013). The Study of Basement Pattern of an Industrial Estate. LAP Lambert Academic Publishing GmbH & Co. KG, Heinrich-Bocking. Str. 6-8, 66121 Saarbrucken, Deutschland, Germany. ISBN: 978-3-659-39530-9.

[18] Keary P. and Brooks M. (1991). An introduction to geophysical exploration. Second Edition. Blackwell Scientific Publication, London.

[19] Adagunodo T.A., Sunmonu L.A. and Adeniji A.A. (2015). An Overview of Magnetic Method in Mineral Exploration. Journal of Global Ecology and Environment, 3(1), 13–28.

[20] Adagunodo T.A., Sunmonu L.A. and Adabanija M.A. (2015). Geomagnetic Signature Pattern of Industrial Layout Orile Igbon. Advances in Architecture, City and Environment, 1(3), 14–25.

[21] Okpoli C.C. and Eyitoyo F.B. (2016). Aeromagnetic study of Okitipupa Region, southwestern Nigeria. International Basic and Applied Research Journal, 2(7): 1-20.

[22] Nettleton L.L. (1971). Elementary Gravity and Magnetics for geologists and seismologists. Society of Exploration Geophysicists, Monograph Series, (1)121.

[23] Reynolds L.R., Rosenbaum J.G., Hudson M.R., Fishman N.S. (1990). Rock magnetism, the distribution of magnetic minerals in the Earth Crust and aeromagnetic anomalies: U.S: Geological Survey, Bulletin 1924, 24-25.

[24] Gunn P.J. (1975). Linear transformation of gravity and magnetic fields. Geophysical Prospecting, 23(2): 300-312.

[25] Sunmonu L.A., Olasunkanmi N.K., Alagbe O.A. (2013). Aeromagnetic data interpretation for geostuctural analysis of Ibadan, southwestern Nigeria. International Journal of Engineering Research and Technology, 2(10): 3058-3065.

[26] Okpoli C.C. and EKERE v. (2017). Aeromagnetic mapping of the basement architecture of the Ibadan region, south-western Nigeria. Discovery, 53(264): 614-635.

[27] Badmus B.S., Awoyemi M.O., Akinyemi O.D., Saheed G.A., Olurin O.T. (2013). Magnetic gradient techniques on digitized aeromagnetic data of Ibadan area, south-western Nigeria. Central European Journal of Geosciences, 5(3): 387-393.

[28] Ganiyu S.A., Olurin O.T. (2013). Upward continuation and reduction to pole process on aeromagnetic data of Ibadan area, south-western Nigeria. Earth Science Research, 2(1): 66-73.

[29] Oladunjoye M.A., Olayinka A.I., Alaba M., Adabanija M.A. (2016). Interpretation of high resolution aeromagnetic data for lineaments study and occurrence of Banded Iron Formation in Ogbomoso area, southwestern Nigeria. Journal of African Earth Sciences, 114: 43-53.

[30] Adagunodo T.A., Akinloye M.K., Sunmonu L.A., Aizebeokhai A.P., Oyeyemi K.D., Abodunrin F.O. (2018). Groundwater Exploration in Aaba Residential Area of Akure, Nigeria. Frontiers in Earth Science, 6: 66. https://doi.org/10.3389/feart.2018.00066.

[31] Adagunodo T.A., Sunmonu L.A., Ojoawo A., Oladejo O.P. and Olafisoye E.R. (2013). The Hydro Geophysical Investigation of Oyo State Industrial Estate Ogbomosho, Southwestern Nigeria Using Vertical Electrical Soundings. Research Journal of Applied Sciences, Engineering and Technology, 5(5), 1816–1829.

[32] 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. Research Journal of Applied Sciences, Engineering and Technology, 5(5), 1811–1815.
[33] Olafisoye E.R., Sunmonu L.A., Ojoawo A., Adagunodo T.A. and Oladejo O.P. (2012). Application of Very Low Frequency Electromagnetic and Hydro-physicochemical Methods in the Investigation of Groundwater Contamination at Aarada Waste Disposal Site, Ogbomoso, Southwestern Nigeria. *Australian Journal of Basic and Applied Sciences*, 6(8), 401–409.

[34] Oyeyemi K.D., Aizebeokhai A.P., Ndambuki J.M., Sanuade O.A., Olofinnade O.M., Adagunodo T.A., Olaajo A.A., Adeyemi G.A. (2018). Estimation of Aquifer Hydraulic Parameters from Surficial Geophysical Methods: a case study of Ota, Southwestern Nigeria. *IOP Conference Series: Earth and Environmental Science*, 173: 012028. https://doi.org/10.1088/1755-1315/173/1/012028.

[35] Oyeyemi K.D., Aizebeokhai A.P., Sanuade O.A., Ndambuki J.M., Olofinnade O.M., Olaojo A.A., Adagunodo T.A. (2018). The use of Geological-based Geophysical surveys for Groundwater Distribution in Crystalline Basement Terrain, SW Nigeria. *IOP Conference Series: Earth and Environmental Science*, 173: 012029. https://doi.org/10.1088/1755-1315/173/1/012029.

[36] 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-Materials and Geoenvironment*, 59(4), 363–390.

[37] Adagunodo T.A., Sunmonu L.A., Oladejo O.P. and Olafisoye E.R. (2013). Groundmagnetic Investigation into the Cause of the Subsidence in the Abandoned Local Government Secretariat, Ogbomoso, Nigeria. *ARPN Journal of Earth Sciences*, 2(3), 101–109.

[38] Adejumo R.O., Adagunodo T.A., Bility H., Lukman A.F., Isibor P.O. (2018). Physicochemical Constituents of Groundwater and its Quality in Crystalline Bedrock, Nigeria. International Journal of Civil Engineering and Technology, 9(8): 887 – 903.

[39] Adagunodo T.A., Sunmonu L.A., Oladejo O.P., Olanrewaju A.M. (2019). Characterization of Soil Stability to withstand Erection of High-Rise Structure using Electrical Resistivity Tomography. In: Kallel A. et al. (eds.). Recent Advances in Geo-Environmental Engineering, Geomechanics and Geotechnics, and Geohazards. Advances in Science, Technology and Innovation (IEREK Interdisciplinary Series for Sustainable Development). https://doi.org/10.1007/978-3-030-01665-4_38 © Springer Nature Switzerland AG 2019. Print ISBN 978-3-030-01664-7, Online ISBN 978-3-030-01665-4.

[40] Adagunodo T.A., Adejumo R.O., Olanrewaju A.M. (2019). Geochemical Cassification of Groundwater System in a Rural Area of Nigeria. In: Chaminé H., Barbieri M., Kisi O., Chen M., Merkel B. (eds) Advances in Sustainable and Environmental Hydrology, Hydrogeology, Hydrochemistry and Water Resources. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham. https://doi.org/10.1007/978-3-030-01572-5_31.

[41] Adagunodo T.A., Sunmonu L.A., Adabanija M.A., Omeje M., Odetunmibi O.A., Ijeh V. (2019). Statistical Assessment of Radiation Exposure Risks of Farmers in Odo Oba, Southwestern Nigeria. *Bulletin of the Mineral Research and Exploration*, http://dx.doi.org/10.19111/bulletinofmre.495321.

[42] Adagunodo T.A., Sunmonu L.A., Emetere M.E. (2018). Heavy Metals’ Data in Soils for Agricultural Activities. Data in Brief, 18C: 1847 – 1855. https://doi.org/10.1016/j.dib.2018.04.115.

[43] Adagunodo T.A., Sunmonu L.A., Adabanija M.A., Suleiman E.A., Odetunmibi O.A. (2017). Geoexploration of Radioelement’s Datasets in a Flood Plain of Crystalline Bedrock. Data in Brief, 15C: 809 – 820. http://dx.doi.org/10.1016/j.dib.2017.10.046.

[44] Adagunodo Theophilus Aanuoluwa (2017). Groundwater Pollution and Control: An Overview. Chapter 1 in Book: Groundwater Contamination: Performance, Limitations and Impacts, 1 – 135. ISBN: 978-1-153611-017-3; 978-1-53611-003-6. Editor: Anna L. Powell © 2017 Nova Science Publishers, Inc. Pp. 1 – 12.
[45] Adagunodo Theophilus Aanuoluwa (2017). Groundwater Contamination: Performance, Effects, Limitations and Control. Chapter 3 in Book: Groundwater Contamination: Performance, Limitations and Impacts, 1–135. ISBN: 978-1-153611-017-3, 978-1-53611-003-6. Editor: Anna L. Powell © 2017 Nova Science Publishers, Inc. Pp. 33–64.

[46] Adetoyinbo A.A., Popoola O.I., Hammer O.S., Bello A.K. (2010). An assessment of quarry blasting vibration impacts in Ibadan and Abeokuta, Nigeria. European J. Of Scientific Research, 4(2): 228-252.

[47] Ganiyu S.A., Badmus B.S., Olurin O.T., Ojekunle Z.O. (2018). Evaluation of seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in Ajakanga area, Ibadan, Nigeria. Applied Water Science, 8:35. https://doi.org/10.1007/s13201-018-0677-y.

[48] Olasunkanmi N.K., Sunmonu L.A, Adabanija M.A., Oladejo O.P. (2018). Interpretation of high resolution aeromagnetic data for mineral prospect in Igbeti-Moro area, southwestern Nigeria. IOP Conf. Series: Earth and Environmental Science, 173: 012033.

[49] Nigerian Geological Survey Agency (NGSA) (2008). Airborne geophysical survey: total magnetic intensity map of Ibadan (Sheet 261) area.

[50] Patterson N.R., Reeves C.V. (1985). Effects of the equatorial electrojet on aeromagnetic data acquisition. J. Int. Geophys., 65(2): 55.

[51] Wynn J. (2002). Evaluating groundwater in arid lands using airborne magnetic and airborne electromagnetic methods – an example in the southwestern U.S. and northern Mexico. The Leading Edge, 62–65.

[52] Olasunkanmi N.K., Olufemi S.B., Aina A. (2017). Exploration for Iron ore in Aghado-Okudu, Kogi State, Nigeria. Arab. J. Geosci., 10(541). doi.org/10.1007/s12517-017-3250-3.

[53] Cooper G.R. and Cowan D.R. (2004). Filtering using variable order vertical derivatives. Computers and Geosciences, 455-459.

[54] Damaceno J.G., de Castro D.L., Mocitaiba L.S.R. (2015). Geophysical study of volcanic bodies, Potiguar Basin (RN): preliminary results. In: 14th International Congress of the Brazilian Geophysical Society Rio de Janeiro Brazil August 3-6 2015: 1-4.

[55] Li L., Han L., Huang D. (2014). Normalized edge detection and the horizontal extent and depth of geophysical anomalies. Appl. Geophys. 11(2): 149-157.

[56] Blakely R.J. (1996). Potential theory in gravity and magnetic applications. Cambridge University Press.

[57] McEnroe S. A., Skilbrei J. R., Robinson P., Heidelbach F., Langenhorst F., Brown L. L. (2004). Magnetic anomalies, layered intrusions and Mars, Geophys. Res. Lett., 31, L19601

[58] Adabanija, M. A., Olasehinde, P. I., Ologunaye, B. T. and Ojetunde, L. A., (2013) Investigation of subsurface geologic features of Oke-Alapata Area, Ogbomoso, Southwestern Nigeria. Journal of Environment and Earth Science 3(14): 119-151.

[59] Biyiha-Kelaba, W., Ndougsa-Mbara, T., Yene-Atangana, J. Q., Ngoumou, P. C. and Tabod, T. C., (2013). 2.5D Models Derived from the Magnetic Anomalies Obtained by Upwards Continuation in the Mimbí Area, Southern Cameroon. Journal of Earth Sciences and Geotechnical Engineering, 3(4): 175-199.

[60] Gunn P.J. and Dentith M.C. (1997). Magnetic responses associated with mineral deposits. AGSO Journal of Geology and Geophysics 17: pg. 145-155.

[61] Paananen M. (2013). Completed lineament interpretation of the Olkiluoto region. Posiva 2013-02 ISBN 978-951-652-234-3.

[62] Ofonime U., Akpan, Monday A. I., Tahir A. Y., Abraham A. A., Chiedu S. O., Adetola S. O. and Michael I. O. (2014). An Evaluation of the 11th September, 2009
Earthquake and Its Implication for Understanding the Seismotectonics of South Western Nigeria.

[63] Hubbard F. A. (1975). Precambrian crustal development in Western Nigeria: indications from the Iwo region. Bulletin of Geological Society of America, pg. 86, 548-554.

[64] Burke, K., Dewey J., and Kidd W. S. F. (1977). World distribution of sutures – the sites of former oceans. Tectonophysics, pg. 40, 66-99