Geoelectrical investigation of foundation failure in Akowonjo, Ogbomoso, Nigeria

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Abstract. An electrical resistivity investigation was carried out in Akowonjo, Ogbomoso, Nigeria with the aim to obtain various lithological units and subsurface geological features within the study area. Fifty-four sounding points adopting Schlumberger array, with 100 m as the maximum value for half-current electrode spacing were occupied in the study area. Partial curve matching technique and automated platform (known as WinResist) were used to interpret the obtained data qualitatively and quantitatively. The resulting final layers parameters involving resistivity and thickness of each layer were used to map the two-dimensional geoelectric variations beneath the study area. The curve types obtained from iterations of WinResist, which is based on 1-D forward modelling approach include H, KH, HA and QH. Four subsurface layers were identified. These layers are topsoil, laterite, weathered/partly weathered layer and fractured/fresh bedrock. The topsoil had resistivity and thickness values ranging from 76 – 1858 Ω m and 0.4 – 4 m respectively. The lateritic layer lies under the topsoil with resistivity and depth values ranging from 649 – 2021 Ω m and 0.7 – 1.9 m, followed by a weathered/partly weathered layer with resistivity and depth values ranging from 17 – 880 Ω m and 1.9 – 25.2 m, respectively. The fourth layer is the fractured/fresh bedrock which depict varying resistivity from 260 – 33385 Ω m. It is revealed that thick clayey materials dominate the first and second subsurface layers within the study area. This is known to be the major cause of cracks experienced in the buildings in Akowonjo community, Ogbomoso, Nigeria. It is recommended that further foundations for civil engineering works in the study should be extended beyond the zone of water content fluctuation.

Keywords: Foundation failure, Geoelectrical investigation, Competent subsoil, Geoelectric section, Building collapse

1. Introduction

The structure’s foundation is a medium that transmit the structure’s load to the supporting ground without generating unnecessary vibrations, which could lead to differential settlement in the structure after construction. Most of these structures are constructed on pads (or isolated footing), combined footings, strips, rafts (or mats) for shallow foundations. When deep foundation is required to support massive structures, the foundations are either pile or caissons (or drilled shaft). Structural collapses have been on increase in the recent time. Most of these failures have occurred as a result of variations in subsurface geological sequence [1-2]. Geophysical techniques are capable of producing three-dimensional subsurface imaging without causing physical disturbances to the subsoil, while
geotechnical assessment can only be used to access information about the point tested for in the subsurface [3-4].

Foundation failures resulting to building collapses have been one of the alarming issues in Nigeria for over four decades to date. Faulting in rocks and other geological formations has been reported to be one of the causes of these collapses [5]. Other geologic features that could have contributed to this differential settlement and total failure include faults, buried cavity as a result of decayed roots beneath a foundation, joints and subsurface inhomogeneity [6-18].

It is however imperative to carry out near surface geophysical investigations prior to construction of civil engineering structures (pre-foundation study) in order to avert the losses that usually accompany their failure [19]. The information gathered during the pre-foundation geophysical campaign is capable to provide aerial and subsurface information that could assist building engineers, town planners, civil engineers and other construction officials in order to know the appropriate design, exact location and type of foundation that suites individual structure [2]. Geophysical technique is also a proven tool in investigation into the cause of post-foundation deficiencies if such incidence occurs [7, 12, 20-21]. Some of the geophysical techniques that have been found useful independently or integratedly with other geophysical techniques for civil engineering purposes include electrical resistivity, electromagnetic, seismic refraction and magnetic. These techniques have been used in Engineering Geophysics to determine the overburden thickness, map subsurface structures and/or evaluate near surface competency for civil engineering constructions [10-18, 22-24].

Akowonjo is a developing community in Ogbomoso, facing rigorous challenge of cracks on the buildings around the community. The members of the community complained about rigorous cracks running through their buildings during the dry season and it roughly closes up during the wet season. This has necessitated the use of geophysical approach to investigate the cause of this problem. In this present study, geoelectrical investigation into the subsurface geology for civil engineering worthiness in Akowonjo, Ogbomoso, Nigeria was carried out with the aim to determine the cause(s) of foundation failure within the community. Some of the previous works from Ogbomoso (the proximity of the study area) can be found in Refs. [25-38]. All these studies have suggested presence of clayey unit within the weathered layer overlying the water table.

2. Study area location and geology

The study area is bounded by latitude 08° 8.998333’ to 08° 9.018333’ and longitude 04° 16.440000’ to 04° 16.386667’, which falls within the southwestern (SW) zone of Nigeria. Roads and footpaths networks serve as means of accessibility in the study area. Akowonjo community in Ogbomoso is within the tropical climate which is characterized by rainy and dry seasons. The rainy season varies from April to October, with a little break in August. The dry season varies from November to March. The annual mean estimation of temperature in the study area is about 27°C, with varying relative humidity from 60 to 80%.

The study area is embedded within the SW Basement Complex of Nigeria (Figure 1). This rock is an integral part of the Proterozoic Schist belt in western half of Nigeria [39]. The geologic sequences noticed in the study location include banded gneiss, quartzite and granite gneiss. The minerals of gneisses are arranged in bands, which are of mafic minerals that have been transformed under the actions of temperature and pressure. The quartzites has light colour and are mainly composed of quartz, which may be categorized as part of the migmatite-gneiss quartzite complex [40].
3. Materials and Method

The resistivity meter with its accessories was used to execute the current study. Fifty-four (54) Vertical Electrical Sounding (VES) points using Schlumberger configuration were occupied randomly in the study area (Figure 2), with a maximum of half electrode spacing of 100 m. Direct current was injected into the near surface via the current electrodes, while the potential difference across its terminals were received via the potential electrodes. This analogy is based on Ohm's law, which was adopted in order to acquire information about the electrical properties of the subsurface. VES is known for its simplicity, conveniency both on field and during interpretation, and its non-destructiveness in determination of depth to rock head (overburden) for formation purpose and investigation into the degree of saturation within the subsurface [42].

The VES data were plotted on a bilogarithm graph with the apparent resistivity ($\rho_a$) values on the ordinate and the electrode separation (AB/2) along the abscissa. Qualitative field interpretation known as partial curve matching was first carried out on the data set [43] in order to get the first layers parameters. An automated package known as WinResist was used to generate the final layers parameters, which were used for the subsurface interpretation in the study area.

4. Results and Discussion

The VES results in the present study are summarized in Table 1. Four different curve types present in the study area are H, KH, QH and HA. H curve-type takes 52% of the 54 VES sounding points. Other curve types are KH, QH and HA, with the percentage distribution of 22, 7 and 19% respectively. The maximum subsurface geoelectric layers delineated in this current research varied from 3 to 4 units. These layers are topsoil, laterite, weathered/partly weathered layer, and fractured/fresh bedrock.
Figure 2: The study area location

Table 1: Classification of Resistivity Sounding Curves

| Type of Curves | Resistivity Model | Number of Stations | Curve Type Percentage (%) |
|----------------|-------------------|--------------------|---------------------------|
| H              | $\rho_1 < \rho_2 \leq \rho_3$ | 28                 | 52                        |
| KH             | $\rho_1 < \rho_2 > \rho_3 \leq \rho_4$ | 12                 | 22                        |
| HA             | $\rho_1 < \rho_2 \leq \rho_3 < \rho_4$ | 10                 | 19                        |
| QH             | $\rho_1 > \rho_2 > \rho_3 \leq \rho_4$ | 4                  | 7                         |
| Total          |                   | 54                 | 100                       |

The depth sounding interpretation results are presented as geoelectric sections in order to have insight about the geologic sequence and structural disposition beneath the study area. Three geoelectric sections mapped in the study area trend in SW–NE, W-E and NW-SE orientation, respectively.

4.1 Geoelectric section along SW–NE direction

Figure 3 shows the geoelectric section which relates VES 24, 43, 17, 42, 6, 41, 8, 40 and 13 along SW-NE trending profile. The geoelectric section along this trend reveals four lithologic units. Topsoil,
which is made up of sandy clay/clay with varying layer resistivity from 76 to 340 $\Omega\text{m}$ formed the first layer. The depth of topsoil varies between 0.4 and 1.3 m. Laterites formed the second layer depicting resistivity values which vary between 649 and 732 $\Omega\text{m}$. This layer’s depth ranges between 1.0 and 1.2 m. The third layer which is weathered layer shows resistivity value ranging between 23 to 276 $\Omega\text{m}$. The depth of the third layer varies between 2.0 to 17 m which is made of clay/sandy clay. The fourth layer is presumed to be the fractured/fresh bedrock. The resistivity values vary between 439 and 6540 $\Omega\text{m}$. The only geologic structure observed in this section is the basement depression beneath VES 8.

4.2 Geoelectric section along W-E direction

Figure 4 shows the geoelectric section which relates VES 27, 28, 45, 19, 54, 2, 35, 36 and 9 along W–E trending profile. The geoelectric section along this trend reveals four lithologic units. The first layer constitutes the topsoil and is made up of sandy clay with layer resistivity ranging between 147 and 750 $\Omega\text{m}$. The depth beneath this unit varies between 0.6 and 1.4 m. The second layer constitutes the laterite and has a resistivity values ranging between 880 and 1151 $\Omega\text{m}$. The second layer’s depth ranges between 1.0 and 7.5 m. The third layer which is weathered/partly weathered layer is having resistivity values that vary between 49 and 249 $\Omega\text{m}$ which comprise of clay/sandy clay. The depth of the third lithologic unit ranges between 3.1 and 20.9 m. The fourth layer is presumably the fractured/fresh basement which has varying resistivity value between 479 and 3490 $\Omega\text{m}$. The only geologic structure observed in this section is the basement depression beneath VES 45, 19, 2, and 36.

![Figure 3: Geoelectric Section along SW-NE direction.](image-url)
Figure 4: Geoelectric Section along W-E Direction.

4.3 Geoelectric section through NW-SE trend

Figure 5 shows the geoelectric section which relates VES 5, 4, 3, 52, 2, 1, 6, 7 and 48 along NW–SE trending profile. The geoelectric section along this trend reveals four lithologic units. The first layer constitutes the topsoil and is made up of sandy clay/clay, with layer resistivity ranging between 93 and 1858 Ωm. The layer thickness ranges between 0.4 and 1.4 m. The second layer constitutes the lateritic layer with a resistivity value ranging between 681 and 1629 Ωm. The depth of the second layer ranges between 1.6 and 1.3 m. The third layer which constitutes the weathered layer has resistivity values which vary between 32 and 760 Ωm. The depth of the third layer ranges between 2.1 and 19.4 m, which is made up of clay/clayey sand. A layer which is interpreted as fractured/fresh bedrock is mapped as the fourth layer, with resistivity value ranging between 425 and 6202 Ωm. The only geologic structure observed in this section is the basement depression beneath VES 4, 3, 52, 2, and 6.
Figure 5: Geoelectric Section along NW-SE.

5. Conclusion

Geoelectrical investigation was done in Akowonjo area, Ogbomoso, SW Nigeria, where cracks were noticed on the columns of buildings, which could affect the stability of the structures in the study area. In doing this, a total of 54 VES points were carried out randomly with the utilization of Schlumberger array in the study area. Four geoelectric sequences were mapped. The topsoil has resistivity and thickness that varies from 74 – 1858 Ωm and 0.4 – 4 m. The second layer which is presumably clay/sandy clay (and in some zones which is revealed as laterite) has resistivity values varying between 649 and 2021 Ωm, and thicknesses from 0.7 to 1.9 m. The third layer is the weathered/partly weathered layer having resistivity values varying between 17 and 880 Ωm, with depth ranging from 1.9 to 25.2 m. The fourth layer which is presumably fractured/fresh bedrock with layer resistivity values between 260 and 33385 Ωm.

Pronounced low resistivity values were noticed across the topsoil and weathered layer, which is an indication that the upper lithologic sequences in the study area are incompetent to support mega structures. Low resistivity and high overburden of the study area indicates the incompetency of the subsoil for erection of engineering structures. From the interpretations of the data collected within the study area, it is affirmed that the cracks on the buildings’ column is as a result of presence of clay and inhomogeneity within each stratum. Clay is known with high porosity and low permeability, which results to swelling and shrinking of weathered layers during the rainy and dry season respectively.

It is advisable to extend structures’ foundation in the study area beyond the zone of water fluctuation. This will provide required skin friction adhesion beneath the dried zone and help to avoid possible damage that could be done through expansive soils to the structures. It will also inhibit upward transit of water during the rainy season, when the weathered layers are wet and swelling. Based on the types of structures to be constructed in the study area, in-situ compaction and dewatering ground treatments could be adopted before the reinforced concretes would be used for construction of shallow foundation, while piles could be considered for deep foundation in case of mega structures.
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References

[1] Blyth F.G.H. and de Freitas M.D. (1988). A Geology for Engineers. Butler and Tannar Ltd, Frome and London. Pp. 292-293.
[2] Omoyoloye N.A., Oladapo M.I. and Adeoye O.O. (2008). Engineering Geophysical Study of Adagbakuja Newtown Development, Southwestern Nigeria. Medwell Online Journal of Earth Science, 2(2): 55-63.
[3] Adewoyin O.O., Joshua E.O., Akinwumi I.I., Omeje M., Joel E.S. (2017). Evaluation of Geotechnical parameters using geophysical data. J. Eng. Technol. Sci., 49(1): 95-113.
[4] Adewoyin O.O., Joshua E.O., Akinyemi M.L., Omeje M., Akinwumi S. (2019). Predicting dynamic geotechnical parameters in near-surface coastal environment. Cogent Engineering, 6: 1588081. https://doi.org/10.1080/23311916.2019.1588081.
[5] 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.
[6] Adenika C.I., Ariyibi E.A., Awoyemi M.O., Adebayo A.S., Dasho O.A., Olagunju E.O. (2018). Application of geotechnical approach to highway pavement failure: a case study from basement complex terrain southwestern Nigeria. International Journal of Geo-Engineering, 9:8. https://doi.org/10.1186/s40703-018-0076-0.
[7] Aroyehun M.T., Akintorinwa O.J. (2018). Application of geophysics in post foundation study: a case study of the Faculty of Social Science Building, Phase I, Federal University, Oye-Ekiti, Southwestern Nigeria. Journal of Geology and Geophysics, 7:1.doi.10.4172/2381-8719.1000324.
[8] Ako B.D. and Olorunfemi M.O. (1989). Geoelectric Survey for Groundwater in the Newer Basalts of Vom, Plateau State. Journal of Mining and Geology, 25 (1 & 2): 247-250.
[9] Adelusi A.O., Akinlalu A.A. and Daramola B.W. (2014). Integrated Geophysical methods for Post-Construction Studies: Case Study of Omuo Comprehensive High School, Omuo Ekiti, Southwestern Nigeria. Global Journal of Science Frontier Research: Environmental and Earth Sciences, 14; 49.
[10] Adagunodo Aanuoluwa and Sunmonu Ayobami (2013). The Study of Basement Pattern of an Industrial Estate. ISBN: 978-3-659-35930-9. Published by LAP Lambert Academic Publishing GmbH & Co. KG, Heinrich-Bocking. Str. 6-8, 66121 Saarbrucken, Deutschland, Germany.
[11] Adagunodo T.A. and Sunmonu L.A. (2012). Groundmagnetic Survey to Investigate on the Fault Pattern of Industrial Estate Ogbomoso, Southwestern Nigeria. Advances in Applied Science Research, 3(5), 3142–3149.
[12] 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.
[13] 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. Journal of Applied Physical Science International, 3(3), 106–115.
[14] 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.
[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] 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.

[17] Oyeyemi K.D., Aizebeokhai A.P., Adagunodo T.A., Olofinnade O.M., Sanuade O.A., Olaojo 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.

[18] 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.

[19] Hammed O.S., Adagunodo T.A., Aroyehun M., Badmus G.O., Fadoba 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.

[20] Fajana A.O., Olaseeni O.G., Bamidele O.E., Olabode O.P. (2016). Geophysical and geotechnical investigation for post foundation studies, Faculty of Social Sciences and Humanities, Federal University Oye Ekiti. FUOYE Journal of Engineering and Technology, 1(1): 62-66.

[21] Bayode S., Omosuyi G.O., Abdullai H.I. (2012). Post-foundation Engineering Geophysical Investigation in part of the Federal University of Technology, Akure, southwestern Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences, 3(1): 203-210.

[22] Adagunodo T.A. and Sunmonu L.A. (2012). Estimation of Overburden Thickness of Industrial Estate Ogbomoso, Southwestern Nigeria. Advances in Applied Sciences Research, 3(5), 3129–3141.

[23] Burland J.B. and Burbidge M.C. (1981). Settlement of Foundations on Sand and Gravel. Proceedings of the Institution of Civil Engineers, 78(1): 1325-1381.

[24] Sunmonu L.A., Adagunodo T.A., Bayowa O.G. and Erinle A.V. (2016). Geophysical investigation for groundwater potential around Ladoke Akintola University of Technology Campus, Ogbomoso, Southwestern Nigeria. Journal of Earth Science and Climatic Change, 9:8. Doi: 10.4172/2157-7617.1000485.

[25] Akinola M.A., Akinlalu A.A., Adelusis O.A. (2017). Integrated geophysical investigation for pavement failure along a dual carriage way, southwestern Nigeria: a case study. Kuwait J. Sci., 44(4): 135-149.

[26] Sunmonu L.A. (2018). The good and the bad of faults: A geophysical perspective. 25th Inaugural Lecture Series, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. ISBN: 978-2902-82-9.

[27] Sangodiji E.E., Olorunfemi M.O. (2013). Geophysical investigation of a suspected foundation failure at Ogbomoso, southwestern Nigeria. The pacific Journal of Science and Technology, 14(2): 522-536.

[28] Bayowa O.G., Fashola D.K., Adegoke A.B., Agesin A.A., Oyeniyi S.A. (2018). Geophysical investigation for groundwater potential around Ladoke Akintola University of Technology Campus, Ogbomoso, Southwestern Nigeria. Journal of Earth Science and Climatic Change, 9:8. Doi: 10.4172/2157-7617.1000485.

[29] Adewoye A.O., Adegbola A.A., Bolaji A.A., Opebiyi D.F. (2004). Engineering properties of foundational materials of Oyo-Ogbomoso road in southwestern Nigeria. Science Focus, 9: 42-47.
[30] Adabanija M.A., Oladunjoye M., Adeboye O. (2013). Groundwater prospecting and exploration in a low potential hard rock aquifer: case study from Ogbomoso North, southwestern Nigeria. Journal of Environmental and Earth Sciences, 3(14): 84-102.

[31] Adegbola A.A. and Adewoye A.O. (2012). On investigating pollution of groundwater from Atenda abattoir wastes in Ogbomoso, Nigeria. International Journal of Engineering and Technology, 2(9): 1570-1585.

[32] Adabanija M.A., Afolabi A.O., Olatunbosun A.T., Kolawole L.L. (2014). Integrated approach to investigation of occurrence and quality of groundwater in Ogbomoso North, southwestern Nigeria. Environ. Earth Sci., doi:10.1007/s02665-014-3401-8.

[33] Adabanija M.A., Adetona E.A., Akinyemi A.O. (2016). Integrated approach for pavement deterioration assessments in a low latitude crystalline basement of south-western Nigeria. Environ. Earth Sci., 75:289. Doi:10.1007/s12665-015-5030-2.

[34] 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.

[35] Olafisoye E.R., Sunmonu L.A., Adagunodo T.A. and Oladejo O.P. (2013). Groundwater Contaminant’s Investigation at Aarada Waste Disposal Site Using Geophysical and Hydro-Physicochemical Approach. IOSR Journal of Environmental Science, Toxicology and Food Technology, 2(4), 01–10.

[36] 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.

[37] 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.

[38] Adagunodo T.A., Sunmonu L.A. and Oladejo O.P. (2014). Electromagnetic Investigation into the cause(s) of Road Failure along Takie-Ikoyi Road, Ogbomoso. International Journal of Business and Applied Sciences, 1(1), 78–85.

[39] 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.

[40] Afolabi O.A., Abimbola A.F., and Kolawole L.L., (2011) Preliminary study of the geology and structural trends of Ogbomoso Township, Southwestern Nigeria. Science Focus: an International Journal of Biological and Physical Sciences, 2 (2): 21.

[41] Omeje M., Adagunodo T.A., Akinwumi S.A., Adewoyin O.O., Joel E.S., Husin W. and Mohd S.H. (2019). Investigation of Driller’s Exposure to Natural Radioactivity and its Radiological Risks in Low Latitude Region using Neutron Activation Analysis. International Journal of Mechanical Engineering and Technology, 10(1): 1897 – 1920.

[42] Keary P. and Brooks M. (2002). An Introduction to Geophysical Exploration, KLBS Blackwell Sci. Publ., Oxford. Pp. 296.

[43] Keller G.V. and Frischknecht F.C. (1966). Electrical methods in geophysical prospecting. Pergamon Press, Oxford.