International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume –05, Issue – 11, November 2020, PP – 08-18

Investigating Subsurface Structures Using Geoelectrical Resistivity Technique on Portion of GAEC Site, Accra, Ghana

Edmund O. Amartey, Emmanuel Mensah Teye*, Ruth A. T. Annan, Prince A. Larbi, Linda Osei-Poku and Paulina E. Amponsah

National Data Centre - Ghana, National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC), P.O. Box LG 80, Legon, Accra, Ghana.

Abstract: In the crystalline basement rock environment of Kwabenya, Accra in Ghana, geoelectrical resistivity technique involving horizontal electrical profiling (HEP) and vertical electrical sounding (VES) were conducted on Ghana Atomic Energy Commission (GAEC) site. In order to determine the thickness of the overburden and subsurface structures, 1-dimensional geoelectrical resistivity survey was carried out at the site using Abem Terrameter System and adopting the Schlumberger electrode configuration. From fourteen anomalous points obtained from HEP, the VES surveyed was carried out and the data modelled using the Resist 87 software. The results showed that the area is underlain by 3, 4 and 5 resistivity layers with the 3-layer being dominant. Also, the modelled VES curves indicated H, Q, A, HK, KH and HKH type resistivity curves, with the H-type being dominant at about 57% occurrence. The underlain bedrock was encountered at resistivity values between 114.2 Ωm and 898.4 Ωm, with the overburden layer thickness varying from 2.9 m to 38.6 m. There was an observed lower bedrock apparent resistivity values at the gently hilly northern section compared to the small valley at the southern section, that suggests there is more development of fractures within the bedrock of the northern part. These observed varying overburdern thickness and multiple layers, and the inferred fracture system in the northern section of the area shall require engineering ground improvement to withstand the load of any high rise building during any possible infrastructural expansion at the site.

Keywords: Geoelectrical resistivity technique, subsurface structure, anomalous point, depth-to-bedrock, GAEC

1. Introduction

Geophysical techniques play essential roles in the investigation of subsurface geological conditions such as the weathered zone thickness and bedrock topography, delineation of structural and tectonic features that control groundwater movement and potential of different geological formations, and assess quality of groundwater [1, 2, 3, 4, 5]. The geoelectrical resistivity method as a geophysical technique is simple to deploy, economical and considered to be suitable in most geological environment for groundwater investigation and geotechnical survey applications. The technique has been globally applied extensively by researchers and investigators [5, 6, 7, 8, 9, 10, 11] among others. Depth sounding method of the resistivity technique provides information about the variations in resistivity with depth whereas the horizontal profiling method provides lateral changes in resistivity [12]. Hence, these two common field techniques were applied in this geoelectrical resistivity survey investigation. In urban environment like Accra, the capital of Ghana where tall structures are being constructed primarily because of limited land space. Over the years, isolated cases of pits dug for local quarrying materials in different parts of Accra and subsequently reclaiming these areas without due regard for proper consolidation of the grounds at these reclaimed areas is a course of worry. As a result, undetected subsurface structures can be a source of hazard in building structures [13]. Therefore, characterizing the subsurface structures using a non-destructive test like resistivity technique can provide an estimate of the subsurface conditions which influence decisions that need to be taken for the design and construction of building foundation. With the recent increase in research activities for socio-economic development, Ghana Atomic Energy Commission (GAEC) is gradually undergoing infrastructural expansion to meet this demand. The construction of such facilities on various parts of the Commission requires among others, the knowledge of subsurface structures which includes the depth to bedrock of the underlying rocks in the area. Thus, the study on portion of GAEC compound, Kwabenya using the geoelectrical resistivity technique to investigate the subsurface structures of the area, and the variation in depth-to-bedrock.

2. Study Area

The GAEC site is located in Kwabenya within the Ga East Municipality of the Greater Accra region. The study area is located on GAEC compound between longitudes 000°13.158 W and 000°13.242 W and latitudes 05°40.070 N and 05° 40.566 N(Fig. 1A). The site is bounded by the entrance and exit roads to the commission's offices on the eastern and western sides respectively, Haatso to Dome Kwabenya road on the southern side and the commission's car park and offices on the northern side (Fig. 1B). The area is underlain by rocks belonging to the Togo Structural Unit which could be underlain by the Dahomeyan Supergroup [14, 15]. The Dahomeyan Supergroup in the area is the Acidic gneiss which comprises muscovite-biotitic gneiss, quartz-feldspar gneiss, augen gneiss and minor amphibolites, that weather to slightly permeable calcareous clays [15]. Togo Units comprise highly folded arenaceous rocks of quartzite, mica-schist, quartz-schist, sandstone, shale, sericite-schist and phyllite. In these crystalline rocks, the development of secondary porosities such as the presence of fractures, joints and faults are the principal controlling factors for groundwater occurrence [16]. The study area lies within the relief ranges from 43 to 60 m above mean sea level (MSL). The area has moderately flat topography with portions Northeast gently hilly and valley towards the middle to Southern part with a drain running west-eastwards into the Onyasia stream that flows distance away from the study area. The area also has mango and palm oil trees planted on portions of the land, with seasonal farming activities done on some portions of the land to grow maize, tomatoes, pepper, okra among others.

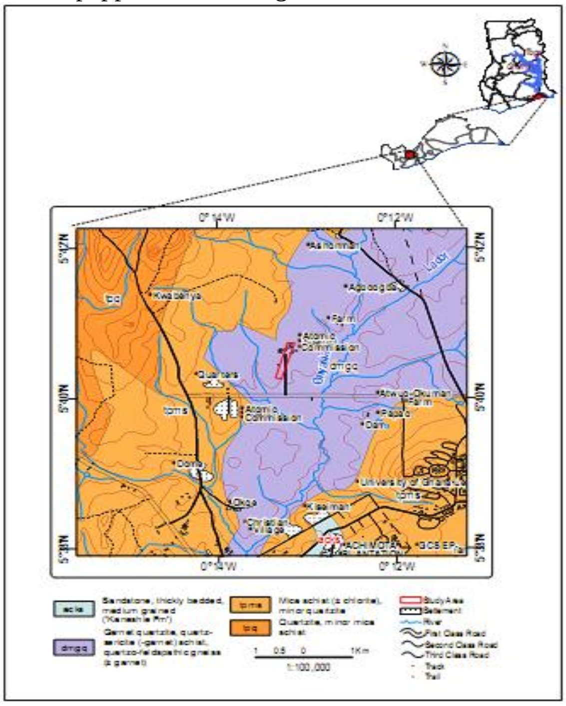


Fig. 1: (A) Map showing the location of GAEC at Kwabenya, Accra

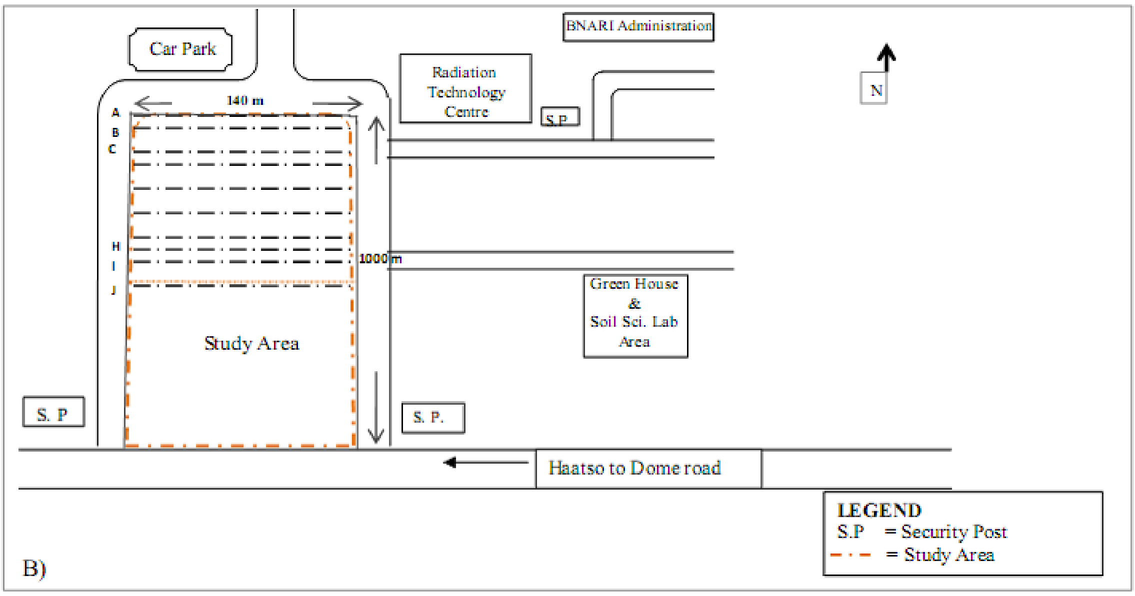


Fig. 1: (B) Sketch map showing the study area on GAEC compound

3. Materials and Methods

3.1. Geoelectrical Data Acquisition and Analyses:

This investigation applied geoelectrical resistivity technique, involving the two field techniques, namely horizontal electrical profiling (HEP) and vertical electrical sounding (VES) for subsurface studies [17, 18, 19]. Firstly, ten evenly distributed traverse lines (A to J) at 50 m interval from north to south at locations within the study area (Fig. 1B) were pegged. In the profiling survey, the Schlumberger configuration was used and the spacing between the electrode pairs (current and potential) remained fixed and connected to a resistivity meter, the ABEM Terrameter System SAS 1000 manufactured in Sweden. Measurements were taken at 10 m interval from west to east along the 140 m profile for the array spread at each measuring point. Half current electrodes spacing of 20 m and 40 m respectively with a potential electrode spacing of 5m were employed consecutively for each profile traversed during the survey. This gave information about lateral changes in the subsurface formation resistivities, resulting in the identification of the anomalous points [17, 20]. Upon identifying an anomalous point in the 10 m interval survey, it was then narrowed down to small intervals of 2 m around the point of interest. The vertical electrical sounding (VES) survey was also performed using the Schlumberger electrode configuration. During the VES survey, the potential electrodes were moved only occasionally, and current electrodes were moved systematically outwards about a fixed central point in steps [17, 20, 21]. The half current electrode spacing ranges from a minimum of $AB/2 = (L/2) = 1.5$ m to a maximum of $AB/2 = (L/2) = 83$ m, while the half potential electrode spacing varies between $MN/ 2 = (a/2) = 0.5$ m and $MN/ 2 = 5$ m. Fourteen VES measurements were conducted at points taking from the anomalous points identified in the HEP measurement curves plotted. For the profiling and vertical electrical sounding, measurements were recorded when the standard deviation of the data displayed on the equipment read less than 1%. Where standard deviations of measurements were more than 1%, measurements were repeated, electrodes were properly grounded or both to ensure measurements recorded have standard deviations less than 1%.

With the recorded resistance value, $R = V/I$ equation (1),

the apparent resistivity (ρ_a) value was calculated using

$$\rho_a = kR$$ equation (2),

where k is the geometric factor, which depends on the arrangement of the four electrodes; current (I) and voltage (V) parameters[4, 5].

So the geometric factor, k for the electrode configuration;

- Schlumberger :

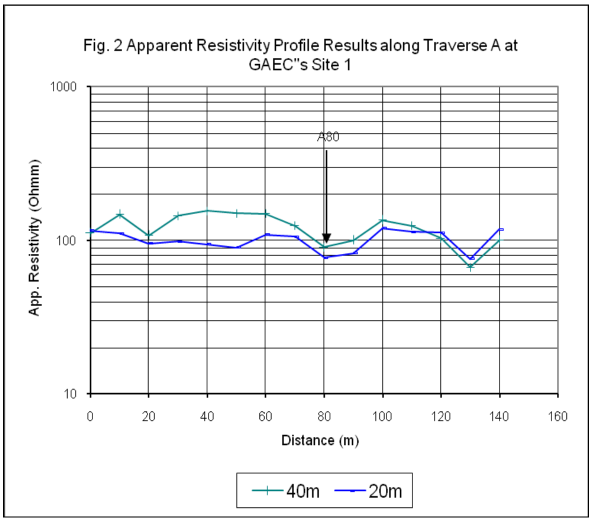
$$k = \frac{\pi}{a}\left[\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2\right]$$ equation (3).

The resistivity data obtained were initially analyzed and interpreted manually, and then used in a computer iteration modelling process using the Resist 87 software [1, 22, 23]. Thus, a graph of apparent resistivity against half current electrode spacing was used to determine vertical variation in subsurface resistivity modelled.

4. Results and Discussion

4.1. HEP Survey

The purpose of the horizontal electrical profiling (HEP) survey was to determine the lateral subsurface resistivity distribution of the investigated area. The ground resistivity is strongly influenced by a number of geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock and soil of the formation [17, 19, 24, 25]. From the survey anomalous points identified during lateral measures (Figs. 2 to 11) were delineated as follows A80, B10, B90, C80, C120, D60, E70, E120, F80, G100, H60 H100, I50, I100 and J50. These resistivity contrasts along the traverses may be created due to the presence of fractures, joints, varying weathered zones, and rock and soil formation contacts which may be filled with fluid or mineral, resulting in change in resistivity values from that measured from the background geology. The overall apparent resistivity values of the anomalous points vary from 25 Ωm to 470 Ωm with a mean of 147.27 Ωm. The resistivities of the anomalous points B10, B90, C120, D60 and H60 fall within the range 120 Ωm to 210 Ωm. The anomalous points C80 and G100 measured relatively higher resistivity values between 400 Ωm to 470 Ωm. However, lower resistivities were measured at the anomalous points A80, E70, E120, F80, H60 and J50 with values between 25 Ωm to 110 Ωm. Also, generally the profiling along traverse E and J measured low resistivity values. Most of the anomalous points were identified at A80, B90, C80, D64, E74 and F80. These points formed a trend of weak zone that run midway of the traverses A to F. Similarly, a limited lineal weak zone pattern was identified at points C120, D120 and D120 along the traverses C to E. This limited trend of weak zones runs north-southwards on the northeastern side of the study area.



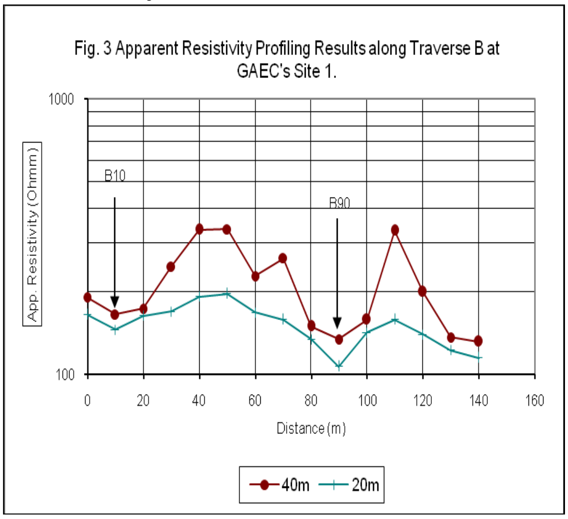


Fig. 4 Apparent Resistivity Profiling Results along Traverse C at GAEC's Site 1.

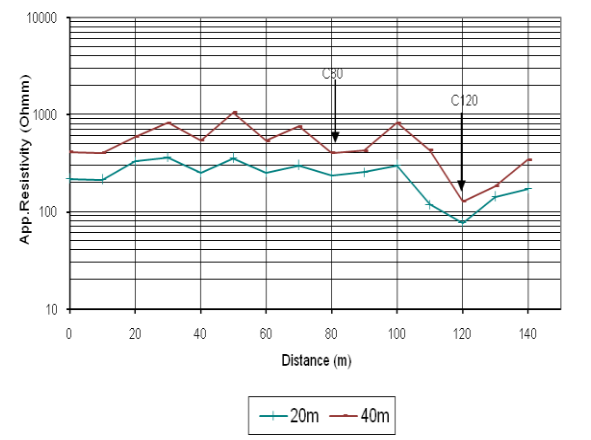


Fig. 5 Apparent Resistivity Profiling Results along Traverse D at GAEC's Site 1

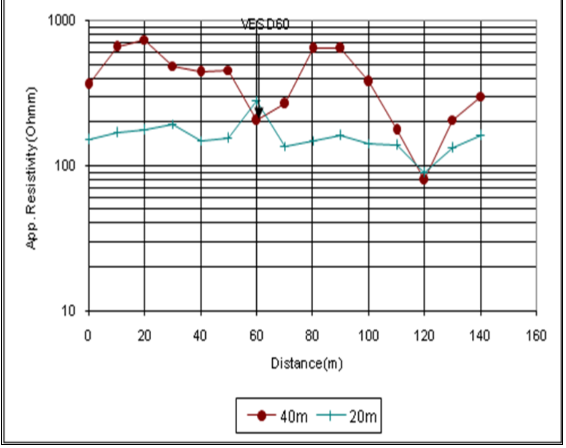


Fig. 6 Apparent Resistivity Profiling Results along Traverse E at GAEC's Site 1.

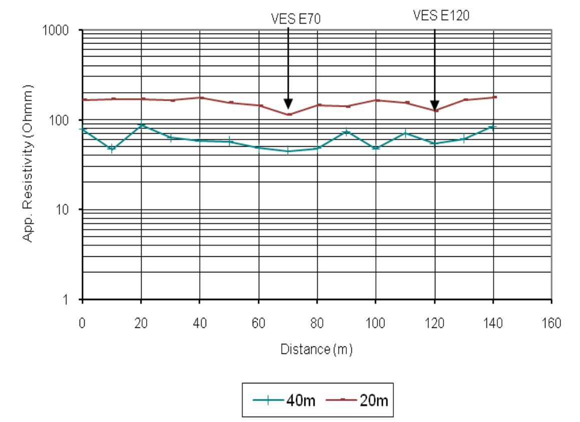


Fig. 7 Apparent Resistivity Profiling Results along Traverse F at GAEC's Site 1.

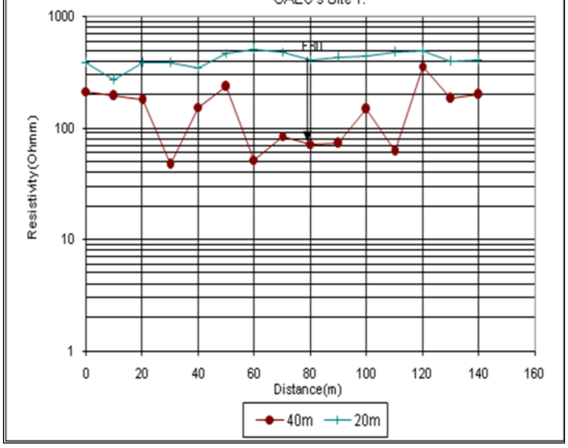


Fig. 8 Apparent Resistivity Profiling Results along Traverse G at GAEC's Site 1.

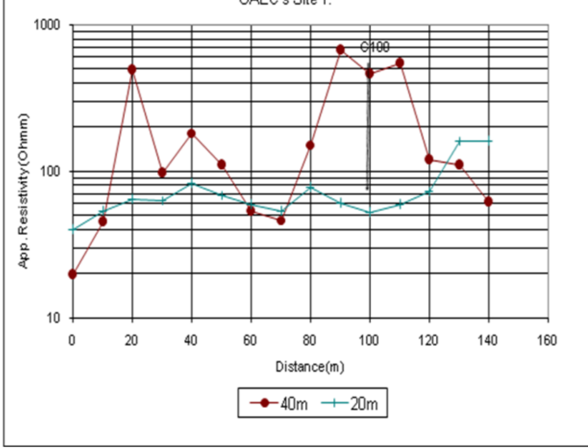
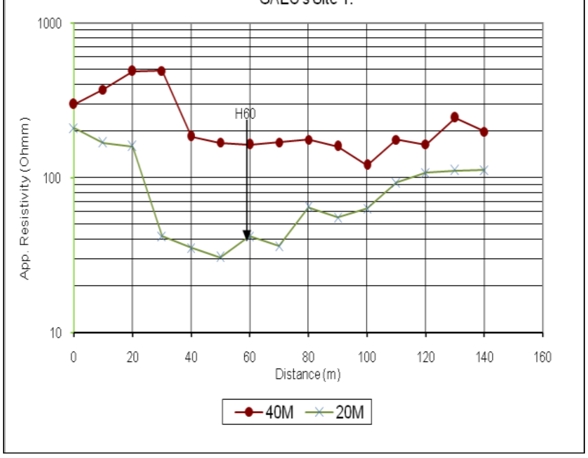
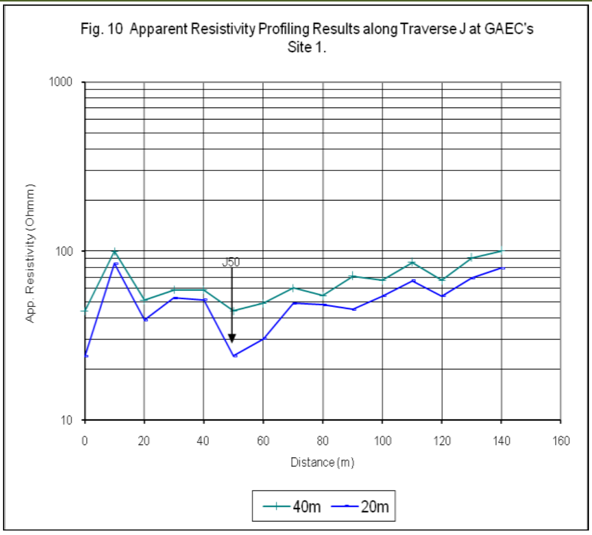
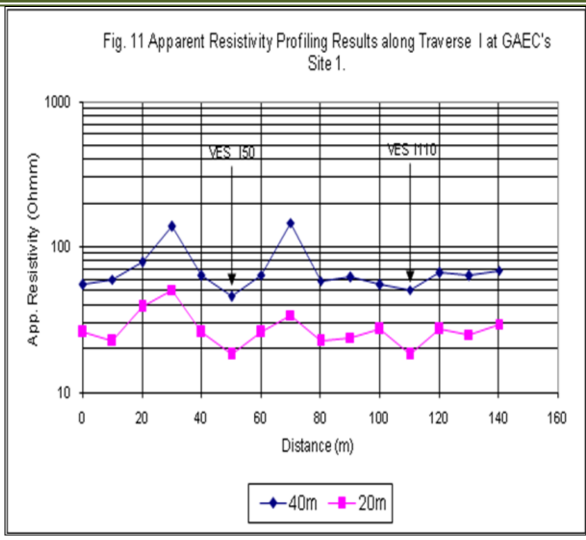


Fig. 9 Apparent Resistivity Profiling Results along Traverse H at GAEC's Site 1.







4.2. VES Survey

To determine the possible variations in resistivity of the underlying geological formation with depth, the VES survey was carried out based on the anomalous points identified during the HEP survey. This survey was performed to infer the possible subsurface layers from the geoelectrical resistivity values with depth variation for the geological formation investigated. A total of fourteen (14) VES points data was generated and modelled for their geoelectrical layer resistivities, depths and thicknesses of the investigated subsurface formation. The VES modelled data for the study area shows that the area is underlain by 3, 4 and 5-layers with the 3-layer being the dominant subsurface structure. The VES results showed that H, Q, A, HK, KH and HKH type resistivity curves exist in the area. The modelled curves A80, C122, E116, G100, H60, H120, I50 and I100 displayed H-type resistivity curves; B92 displayed A-type resistivity curve; point J50 displayed Q-type resistivity curve; D64 showed HK-type resistivity curves; E74 showed KH resistivity curve while B10 and F80 displayed HKH-type resistivity curve (Table 1). Dominant among the modelled VES curves for this study area is the H-type with about 57% occurrence, shown in Fig. 26. To illustrate the geoelectrical layers modelled, the following VES curves for A80, B10, B92, C122, D64, E74, E116, F80, G100, H60, H120, I50, I100 and J50 are shown (Figs. 12 to 25). The geoelectrical resistivity values for the first layer ranges from 6.1 to 2231.8 Ωm and corresponding thickness between 0.7 m and 5.3 m. This top layer of the area is mostly and presumably gravelly sand. The intermediate layers have resistivity values ranging from 3.9 to 2317.4 Ωm which shows moderately to highly weathered zones. The thicknesses of these intermediate layers are between 1.7 m to 36.6 m. The bedrock was encountered at resistivity values between 114.2 Ωm and 898.4 Ωm. The overburden layer varied from 3.0 m to 38.6 m. This wide variation in the overburden thickness is indicative of the heterogeneous nature of the weathering affecting the underlying formation within the study area (Fig. 27). Also, the modelled curves with multiple layers exceeding three (3) (B10, D64, E74 and F80) are possible fracture system or contact zones in the northern part of the area. Generally, bedrock apparent resistivity values appeared to be lower at the northern section but comparatively higher at southern part of the same area, suggesting that there is more development of fractures within bedrock of the northern part. This observation may be due to the formation of a small hill at the northern part while the southern section forms a gently but long stretching valley. Horizontal compressive stresses acting from the valley in the southern part and valley beyond the northern section of the study area, acts in the opposite direction. These opposing forces could lead to greater development of fracture system within the bedrock at the anticline section, with less development of fracture system within the syncline section of the study area. It is expected that as these compressive stresses continue, more development of fracture system shall continue in the northern section while existing fracture system at the southern section shall gradually be sealed.

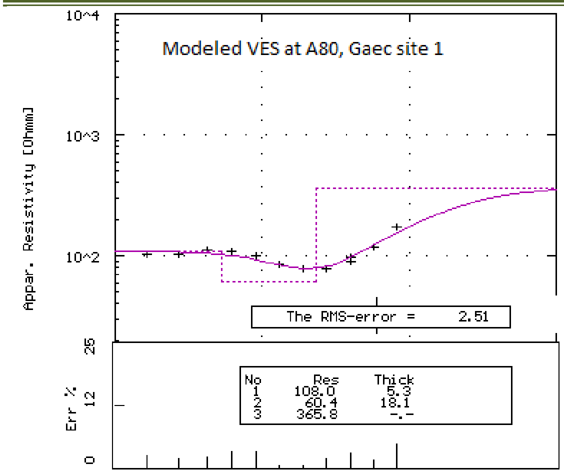


Fig. 12: VES curves at A80, GAEC Site 1

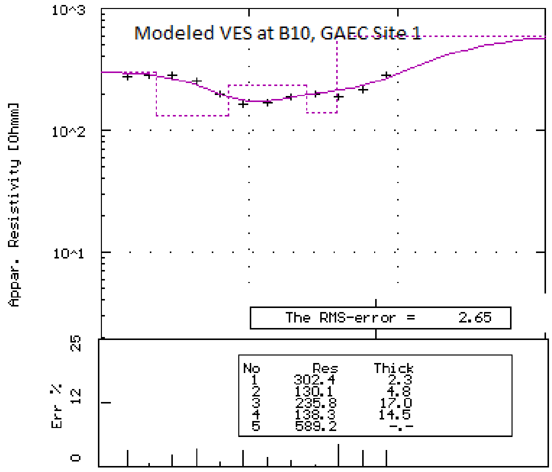


Fig. 13: VES curves at B10, GAEC Site 1

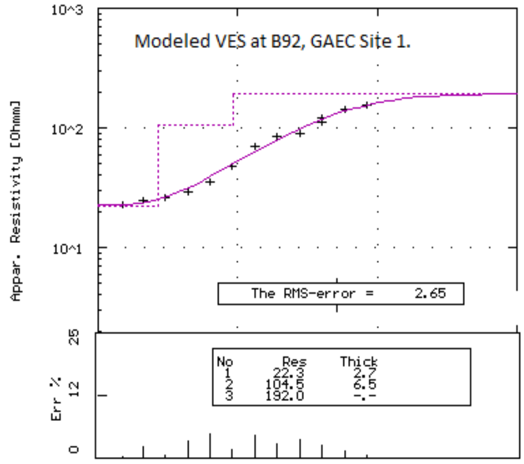


Fig. 14: VES curves at B92, GAEC Site 1

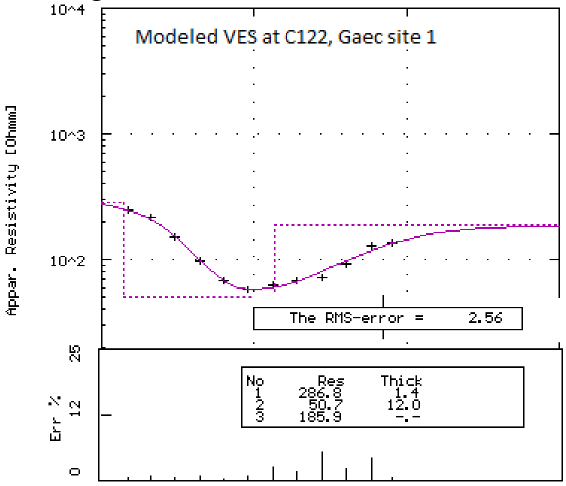


Fig. 15: VES curves at C122, GAEC Site 1

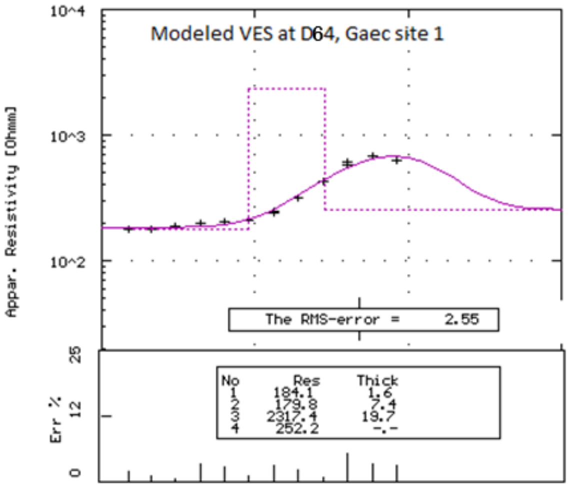


Fig. 16: VES curves at D64, GAEC Site 1

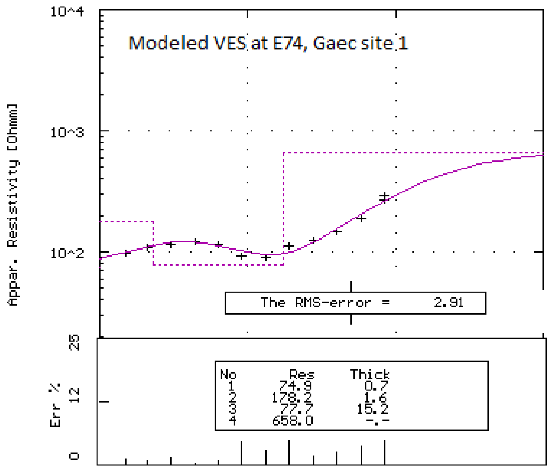


Fig. 17: VES curves at E74, GAEC Site 1

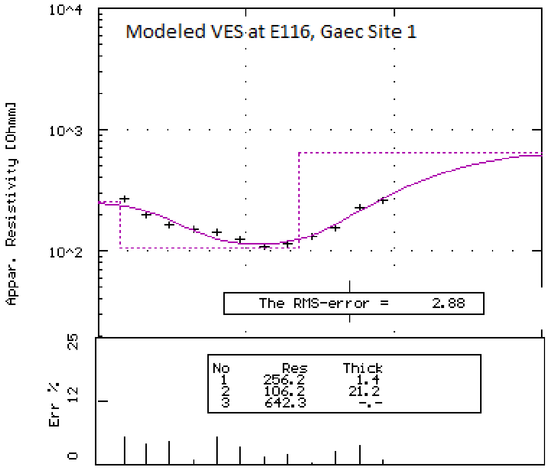


Fig. 18: VES curves at E116, GAEC Site 1

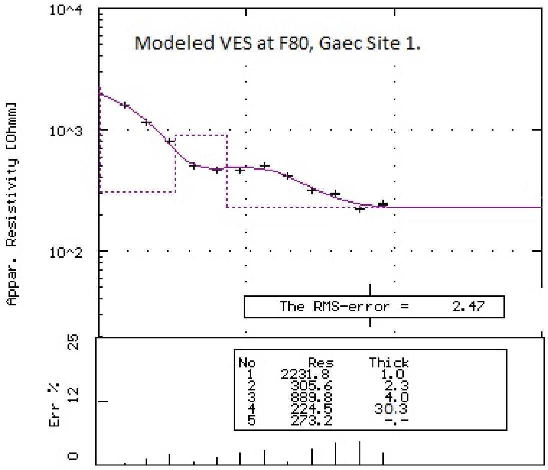


Fig. 19: VES curves at F80, GAEC Site 1

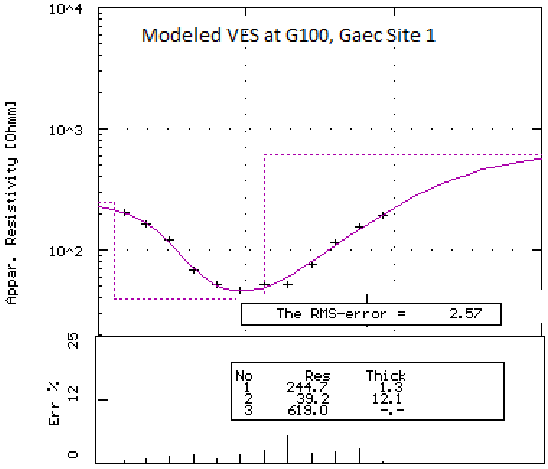


Fig. 20: VES curves at G100, GAEC Site 1

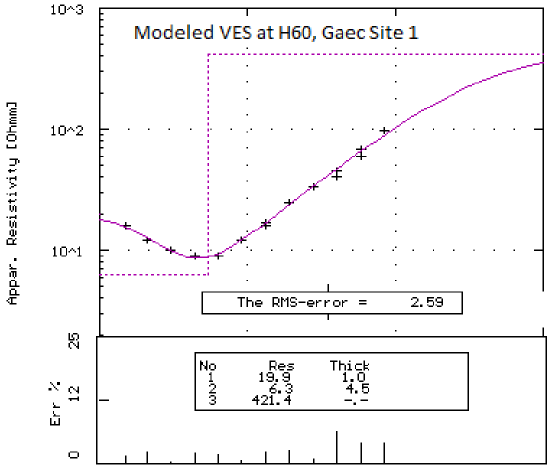


Fig. 2: VES curves at H60, GAEC Site 1

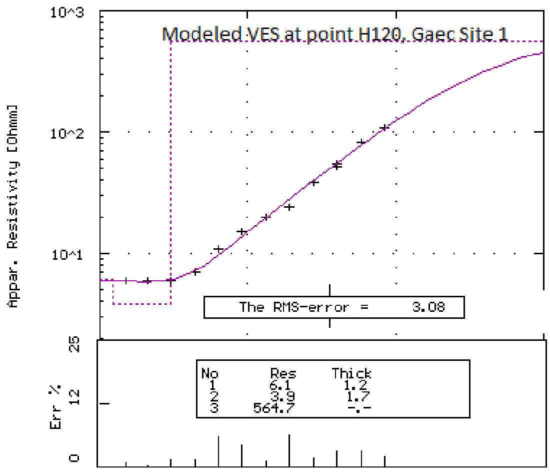


Fig .22: VES curves at H120, GAEC Site 1

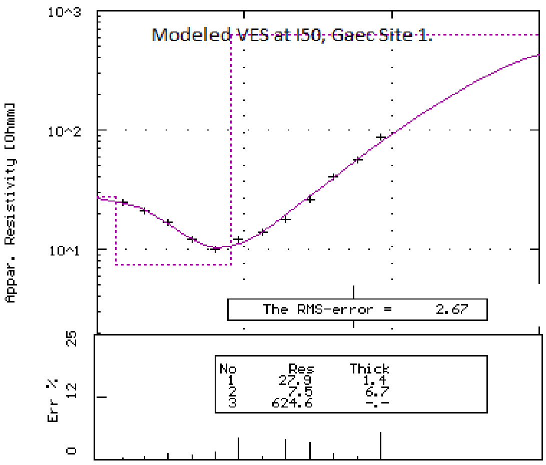


Fig. 23: VES curves at I50, GAEC Site 1

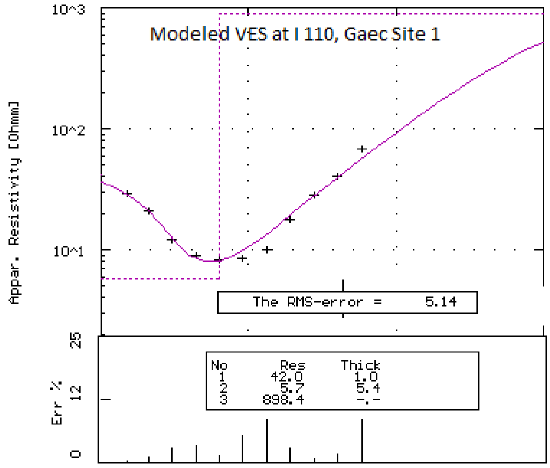


Fig. 24: VES curves at I110, GAEC Site 1

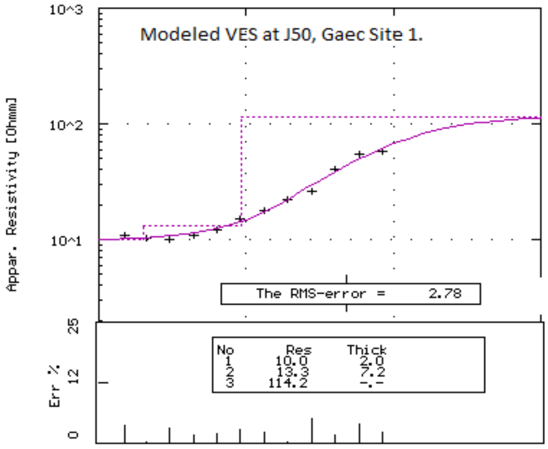


Fig. 25: VES curves at J50, GAEC Site 1

Table 1 VES curve types exhibited at the GAEC Site in this study

VES #	VES curve type	Frequency	Percentage
A80, C122, E116, G100, H60, H120, I50, I100	H	8	57.14%
J50	Q	1	7.14%
B92	A	1	7.14%
D64	HK	1	7.14%
E74	KH	1	7.14%
B10, F80	HKH	2	14.29%
Total		*14*	*100%*

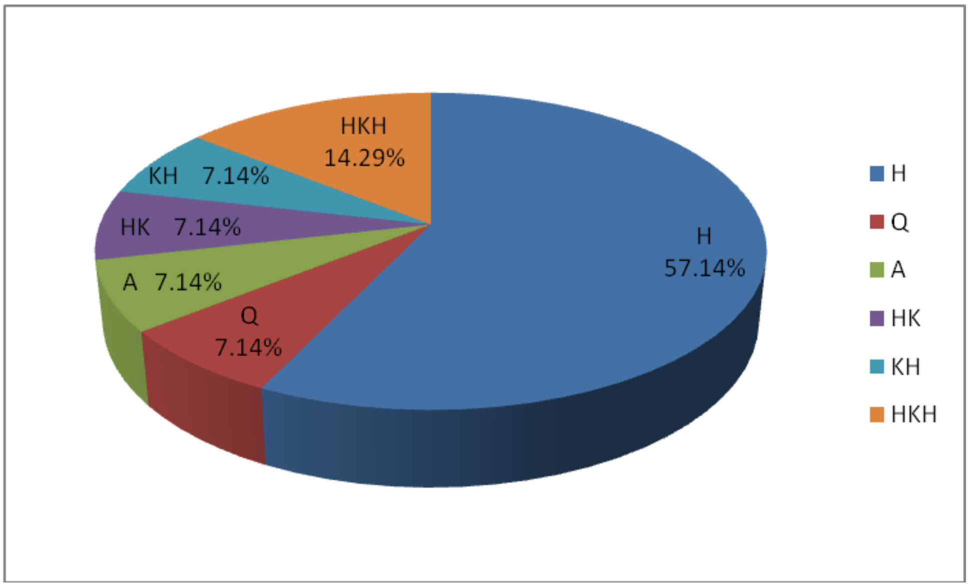


Fig. 26: Pie chart summarizing the VES curve types exhibited at the GAEC Site

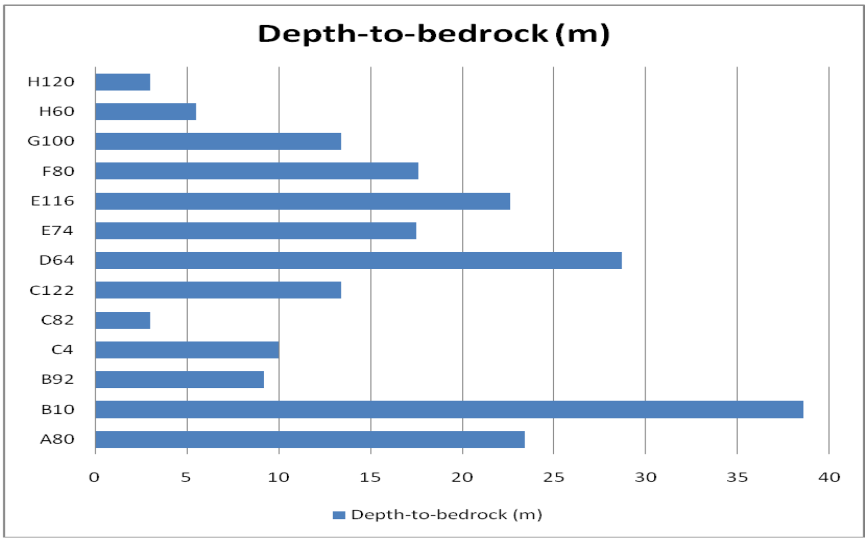


Fig. 27: Shows variation in depth-to-bedrock of the investigated area based on the geoelectrical resistivity data

5. Conclusion

An investigation to study the subsurface structures on portion of GAEC site applying geoelectrical resistivity technique was performed. HEP and VES surveys were conducted using Schlumberger electrode configuration to identify and delineate possible locations of lineament, fracture system, contact zones or weathered zones within the area. From the study there exist a wide variation in the depth-to-bed rock (2.9 m to 38.6 m). The bedrock apparent resistivities, mostly appeared to be lower at the northern part but relatively higher at the southern part of the same area, implying that there is more development of fractures within bedrock of the northern part. As a result, part of the study area with shallow overburden may require shallow foundation, whiles portions with intermediate overburden thickness may require deep foundations as well as portions with high overburden thickness may require the installation of piles for the construction of high rise superstructures. The observed multiple layers and the inferred fracture system in the northern section of the area shall require engineering ground improvement to withstand the load of any high rise building.

Acknowledgements

Our sincere appreciation goes to the following National Service Personnel Philip Boahene, Ahmed Amponsah, Yvonne Ntow and Jerry John Amoah for their immense assistance during the field work. We also acknowledge the management of NNRI and NDC-GH for their support. Thanks to the staff of GAEC who drive along the stretch of the study area for their cooperation during the field activities.

References

[1]. Senthil Kumar G.R. and Uwamungu Placide S. Electrical Resistivity Data Interpretation for Groundwater Detection in Tittagudi Taluk of Cuddalore District, Tamil Nadu, India,. International Journal of Research in Engineering and Technology. 2015;4(10).

[2]. Muchingami I, Hlatywayo DJ, Nel JM, Chuma C. Electrical resistivity survey for groundwater investigations and shallow subsurface evaluation of the basaltic-greenstone formation of the urban Bulawayo aquifer. Physics and Chemistry of the Earth, Parts A/B/C. 2012;50–52:44–51.

[3]. Jaroslav Vrba, Balthazar Th Verhagen. Groundwater for emergency situations□ : a methodological guide. Paris: Unesco; 2011; 87 -91.

[4]. Noye, R. M., Fofie, F. B., Nartey, S. T., & Mensah, E. K. (2017). Locating Aquifers in Crystalline Granitic Rock Using Electrical Resistivity Technique in the Sissala East District of Ghana. Journal of African Earth Sciences, 7, 68-78.

[5]. Asare Van - Dycke Sarpong and Menyeh Aboagye. Geo-Electrical Investigation Of Groundwater Resources And Aquifer Characteristics In Some Small Communities In The Gushiegu And Karaga Districts Of Northern Ghana. International Journal of Scientific & Technology Research. 2013;2(3).

[6]. Majumdar RK, Majumdar N, Mukherjee AL. Geoelectric investigations in Bakreswar geothermal area, West Bengal, India. Journal of Applied Geophysics. 2000 Oct;45(3):187–202.

[7]. Selvam S, Sivasubramanian P. Groundwater potential zone identification using geoelectrical survey: a case study from Medak district, Andhra Pradesh, India. Internat Jour Geomatics Geosci. 2012;3(1):55-62.

[8]. Zohdy AAR. A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. GEOPHYSICS. 1989;54(2):245–253.

[9]. Aning A, Sikah J, Danuor S, Manu E, Okrah C. Journal of Environment and Earth Science. Journal of Environment and Earth Science Vol6, No7,. 2016;6(7).

[10]. Danuor SK, Andrews ND, Aning AA, Noye RM. Geophysical investigations at the proposed site of the KNUST teaching Hospital building using the 2D and 3D resistivity imaging techniques. International Research Journal of Geology and Mining. 2013;3(3): 113-123.

[11]. Amartey EO, Akiti TT, Armah T, Osae S, Agyekum WA. Integrating gamma log and conventional electrical logs to improve identification of fracture zones in hard rocks for hydrofracturing: a case study from Ghana. Applied Water Science. 2016;7(3): 1091–1098.

[12]. Mohamed A. S. Vertical electrical resistivity soundings to locate ground water resources: a feasibility study, VPI-WRRC-BULL 73. 1975

[13]. Soupios PM, Georgakopoulos P, Papadopoulos N, Saltas V, Andreadakis A, Vallianatos F, et al. Use of engineering geophysics to investigate a site for a building foundation. Journal of Geophysics and Engineering. 2007;4(1): 94–103.

[14]. Ghana Geological Survey Department (GGSA). A New Geological map of Ghana. Accra. 2009.

[15]. Kesse GO. The mineral and rock resources of Ghana. Rotterdam□ ;Boston: A.A. Balkema□ ; Accord, Ma; 1985.

[16]. Junner N, Bates D. Reports on the geology and hydrology of the coastal area east of Akwapim range Accra, Geological Survey Memoir No. 7, Ghana. 1945.

[17]. Society of Exploration Geophysicists (SEG). Electric resistivity methods. [accessed 26 March 2020]. https://wiki.seg.org/wiki/Electric_resistivity_methods. 2018.

[18]. Mansour A Al-Garni. Geophysical Investigations for Groundwater in a Complex Subsurface Terrain, Wadi Fatima, KSA: A Case History. Jordan Journal of Civil Engineering. 2009;3(2).

[19]. Lowrie W. Fundamentals of Geophysics. Cambridge University Press; 2007.

[20]. Griffiths Donald H, King Roy F. Applied geophysics for geologists and engineers. 2. ed. Frankfurt: Pergamon Press; 1981

[21]. Telford WM, Geldart LP, Sheriff RE. Applied geophysics. Cambridge: Cambridge University Press; 1990.

[22]. Anomohanran O. Hydrogeophysical and hydrogeological investigations of groundwater resources in Delta Central, Nigeria. Journal of Taibah University for Science. 2015 Jan;9(1):57–68.

[23]. Vander Velpen BPA, Sporry RJ. RESIST. A computer program to process resistivity sounding data on pc compatibles. Computers & Geosciences. 1993 May;19(5): 691–703.

[24]. Loke MH. Electrical Resistivity Surveys and Data Interpretation. Encyclopedia of Solid Earth Geophysics. 2011;276–283

[25]. UKEssays. Application of electrical resistivity. [accessed 10 August 2020]. https://www.ukessays.com/essays/education/application-of-electrical-resistivity.php?vref=1

