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Delineation of the Geotechnical Parameters Within the Kaduna Refining and Petrochemical Corporation Layout

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Abstract: Direct Current Resistivity investigation for engineering studies was carried out around the Kaduna Refining and Petrochemical Corporation Industrial Layout within the Basement Complex of Central Nigeria. The study aimed at evaluating the competence of the near surface formation meant to aid in foundation design and other related engineering structures, and to unravel the subsurface profile which in turn determines if there would be any subsurface geotechnical parameters and lithological variation(s) that might lead to structures failure within the site. A total of twenty-two (22) VES statins were established. The data obtained were subjected to 1-D inversion algorithm to determine the layer parameters. The geo-electric section revealed three to five lithological units defined by the lateritic topsoil, silty/sandy/clayey, the weathered basement as well as the fresh basement. The resistivities and thicknesses of the topsoil range from 100 Ωm – 2668 Ωm and 0.3 m – 6.4 m respectively. The last layer considered as the fresh basement and in some cases the fractured basement has an infinite thickness with resistivity ranging from 610 Ωm – 79674 Ωm and the established average overburden thickness of the study area was found to be 23 m. A broad portion of the area was found to be competent for civil works except at VES stations C6 and D4 with relatively low topsoil resistivity. The competent regions have been recommended for major construction works such as high rise buildings, bridges and roads.

Keywords: Geotechnical, Competent Zone, Structure Failure, Lateritic Topsoil, Resistivity

1. Introduction

A country like Nigeria where industrialization is on the increase, the need to explore for suitable zones for engineering structures such as high rising buildings, tarred road, and bridges cannot be overemphasized. The area under study, Southern part of the Kaduna town is undoubtedly one of the industrial nerve centre of the Kaduna city in which most industrial activities revolve. The statistic of structural failures such as buildings, tarred roads and bridges throughout the nation is at alarming rate. According to [1], 57 people were killed as a result of building collapse in Ebute Meta, Lagos on 18th July, 2006; another four-storey residential building caved-in suddenly in July, 2006 killing 37 people and leaving 50 survivors to be pulled out of the rubble in Lagos. Nigerian Institute of Building estimation shows that 84 buildings had collapsed in the past 20 years in Nigeria, claiming more than 400 lives [1]. The cases of building collapse in Nigeria has reached a worrisome level in view of its alarming loses. It has been the concern of numerous authors to search for the causes, in order to proffer adequate solution of prevention, or preparedness against future occurrence. [2], noted that the rampant failure of building foundation is not unconnected to the subsurface movement resulting into crack or structural differential settlement. [3], identified lack of soil investigation and improper interpretation of site conditions among others as the main causes of structural collapse and failures in Nigeria. Electrical resistivity surveys have been used for many decades in hydro geological, mining and geotechnical investigations. More recently, it has been used for environmental surveys [4]. Subsurface geological features such as fractures, voids or cavities, shallow depth to the bedrock, near surface depth to the water table are among other common constraints to the building construction, especially to their foundation [5]. [6], observed that structures failure is not primarily due to usage of design/construction problems alone but can equally arise from inadequate knowledge of the characteristics and behaviour of residual soil which the structures are built and non-recognition of the influence of geology and geomorphology during the design and construction phases. The geological factors influencing structures include the nature of soils (laterite) and the near-surface geological sequence, existence of geological structures such as fractures and faults, presence of cavities, existence of ancient stream channel and shear zones [6]. This evaluation of geotechnical parameters is therefore a crucial requirement in the building and other civil structural development plans.

The study area is around the Kaduna refining, and within Kaduna town. In order to accommodate this expected industrial expansion, a proper geophysical investigation is necessary in order to consider the nature and feasibility of the subsurface material underlain in the area before any serious civil engineering structures are developed on it in order to avert likely future disaster occurrence.

2. The Geology and Description of the Study Area

The relief of the terrane under study is characterized by undulating plain, gentle slopes, and consists of peneplains with eroded flat tops (Figure. 1); often capped by layers of indurated laterites. The study area lies within the geographical coordinates of latitude and longitude of 10.4326 N to 10.4290 N and 007.4902 E to 007.4965 E respectively with an average height of 615 m above the sea level. According to [7], the superficial deposits, which overlie the basement rocks, act as recharge materials, especially where they are underlain by weathered basement. The study noted that the main aquifer components of the basement complex of Nigeria are weathered and fractured basement and water yielding capacities of wells drilled to these components always vary. The rocks of the area are capped by laterites; the laterites are sometimes highly consolidated especially at the surface and weathered into lateritic nodules mixed with silty and sandy clays [8]. The general geology of Nigeria consists of two main lithological units (Figure 1). These are the Precambrian Crystalline Basement and Cretaceous-Tertiary sedimentary rocks [9]. The Deep chemical weathering and fluvial erosion, influenced by the bioclimatic nature of the environment have developed the characteristics high undulating plains with subdued interfluves [10]. The crystalline basement complex composes mainly of metamorphic rocks [9].

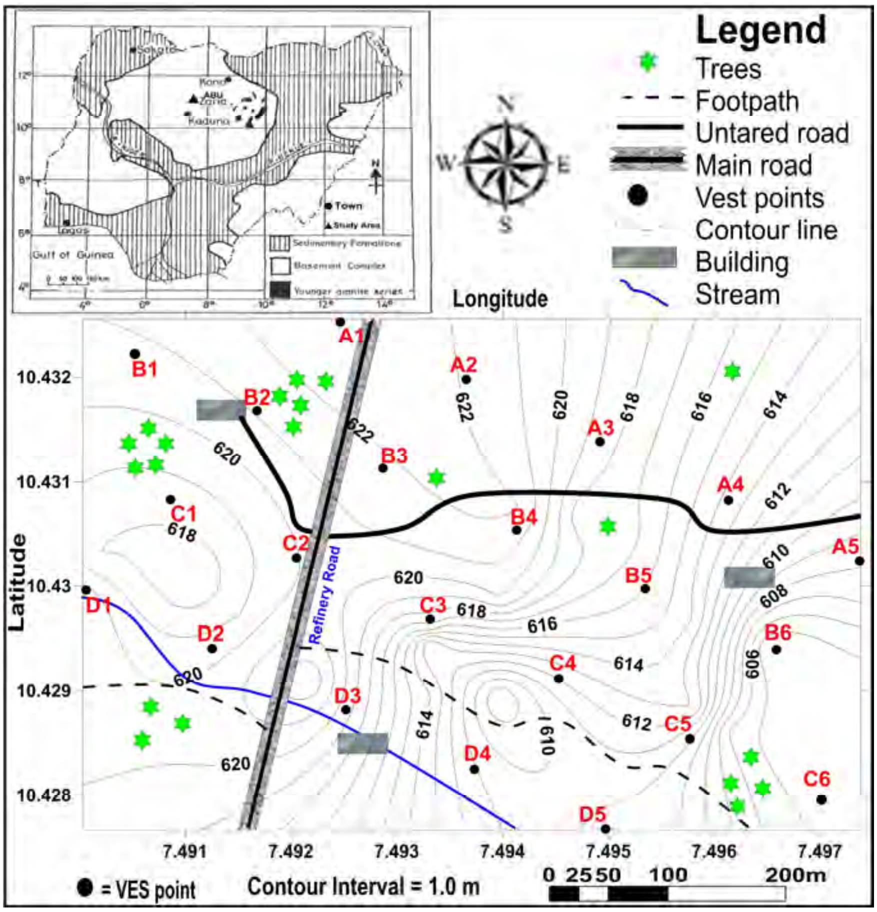

Figure 1. Elevation map of the study area showing VES points.

3. Theory of the Method Employed and Data Acquisition

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material and is based on the response of the subsurface material to the current flow through electrodes to the ground [4]. A total of twenty-four (24) Vertical Electrical Sounding (VES) points were digitized with maximum spread of 100 meters with an Omega Resistivity Meter using the Schlumberger configuration. For a single point source of current within the subsurface, which assumes homogeneous and isotropic conditions, the potential can be derived from two basic equations.

$$\vec{E} = \rho J \quad (1)$$

Where $\vec{E}$ = electric field intensity, J = current density and ρ = the resistivity of the material. The Divergence condition gives

$$\nabla . J = 0 \quad (2)$$

Combining equations (1) and (2), the Laplace's equation is obtained i.e.

$$\nabla . J = \frac{1}{\rho} \nabla . \vec{E} = 0 \quad (3)$$

but

$$\vec{E} = -\nabla V \quad (4)$$

Where v = scalar potential

$$\text{Hence } J = -\frac{1}{\rho} \nabla . V \quad (5)$$

Put equation (5) into (3), get

$$\nabla . J = \frac{1}{\rho} \nabla^2 V \quad (6)$$

The Laplacian equation in spherical polar coordinates when applied to equation (6) gives

$$\nabla^2 V = \frac{1}{r2}\frac{\partial}{\partial r}(r^2 \frac{\partial V}{\partial r}) + \frac{1}{r2 \sin\theta}\frac{\partial}{\partial \theta}(\sin\theta \frac{\partial V}{\partial \theta}) + \frac{1}{r2 Sin^2\theta}\frac{\partial^2 V}{\partial \Phi^2} = 0 \quad (7)$$

There is complete symmetry of current flowing through θ and Φ directions. If a single source of current I is introduced into an infinite homogeneous medium, the potential at a distance r will only be a function of r, then equation (7) transforms to

$$\frac{d^2V}{dr^2} + \frac{2}{r}\frac{dv}{dr} = 0 \quad (8)$$

(since $r \neq 0$)

Or $\frac{1}{r2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right) = 0$ *then* $r^2 \frac{dv}{dr} = a$ and $v = -\frac{a}{r} + b$; where *a* and *b* are constants and r is the distance from the current electrodes.

Since v = 0 when I→ ∞ , then b = 0

$$\text{Therefore } v = -\frac{a}{r} \quad (9)$$

The current flows radially through a hemispherical surface in the lower medium becomes

$I = 2\pi r^2 J$, but $J = -\frac{1}{\rho}\nabla . V = -\frac{1}{\rho}\frac{dv}{dr}$; hence $I = -2\pi r^2 . \frac{1}{\rho}\frac{dv}{dr} = -2\frac{\pi}{\rho} r^2 \frac{dv}{dr} = -2\frac{\pi}{\rho} a$

$$\text{this shows that } a = -I\frac{\rho}{2\pi} \quad (10).$$

put equation (10) into (9),

$$v = \frac{I\rho}{2\pi r} \quad (11)$$

If a solid material with constant resistivity is assumed, the current *I* is introduced through electrodes say, A and B respectively, on its surface the potential will be measured across the potential electrodes say, M and N at distances r_1, r_2, R_1 and R_2 which are the appropriate distances between both the potential and current electrode spreads respectively. Thus the potential difference between the potential electrodes invariably becomes

$$\Delta V = V_m - V_n = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1} + \frac{1}{r_2}\right) - \left(\frac{1}{R_1} + \frac{1}{R_2}\right)\right\} \quad (12)$$

The apparent resistivity is evaluated as

$$\rho_a = \frac{2\pi\Delta V}{I}\left(\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{R_1} - \frac{1}{R_2}}\right)$$

$$\rho_a = \frac{\Delta V}{I}\left\{2\pi\left(\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{R_1} - \frac{1}{R_2}}\right)\right\} \quad (13)$$

let k, represent the bracket terms, the geometric factor; which depends on the electrode configuration used during the field measurement [4]. Thus,

$$\rho_a = \frac{\Delta V}{I} k \quad (14)$$

The data collected was computed and processed by means of the Res ID version 1.00.07 Beta modeling software in order to perform resistivity curve inversion with its quality fitness expressed in terms of the RMS error [4]. The final model geoelectric parameters were used for surface contouring to reveal the variation in resistivity, depth to the basement (overburden thickness) and thickness underlain layer by the study area. Figure 2 shows a typical resistivity curve and the model parameters after quantitative interpretation for VES point B6 along profile B.

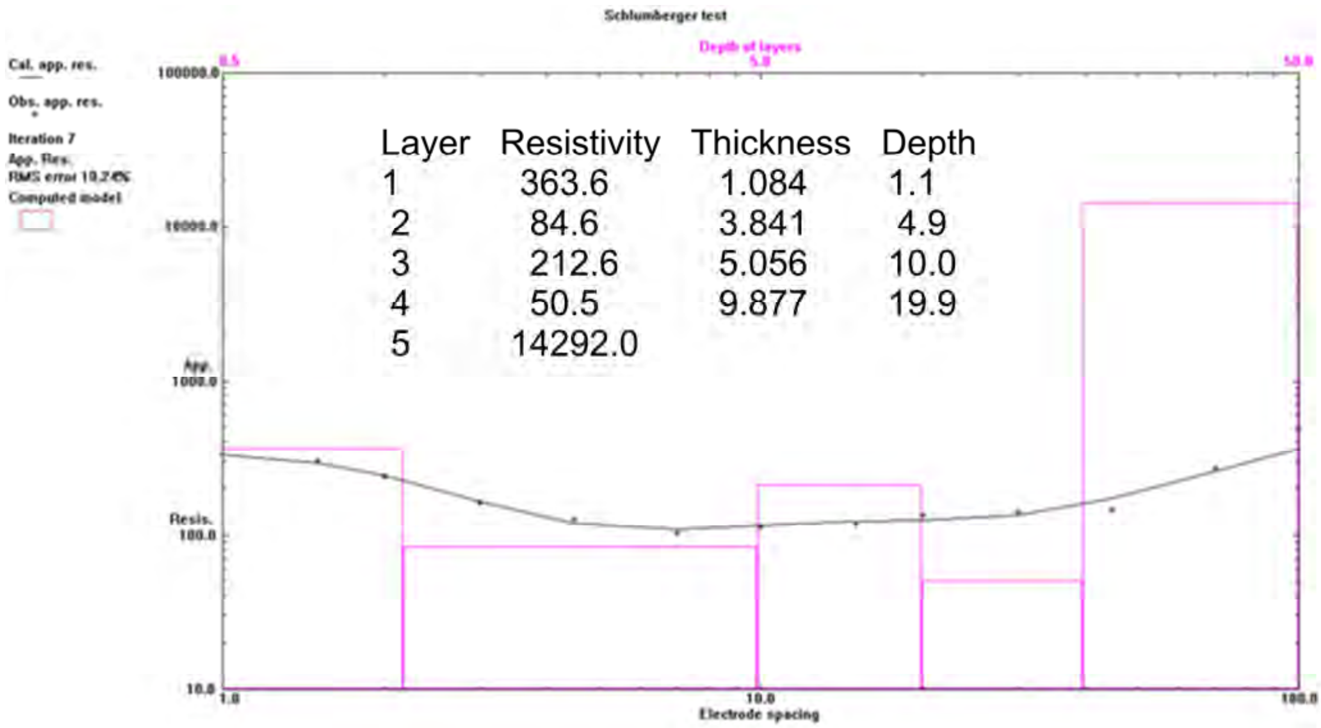

Figure 2. *Typical resistivity curve VES B6.*

4. Results and Discussion

The final model geoelectric parameters along six VES stations were used for the preparation of the geoelectric/geologic sections for one of the Profiles (Figure 3). The figure 3 shows the geoelectric/geologic section underlain by three to five layers. The first layer is highly varying in resistivity () with its thickness varying from 1.0 m – 4.5 m across the study area which is indicating of the variations of features from deposited silt along the stream and laterite/indurated laterite on other areas of the surface layer. The top layer parameters for all the five profiles is summarized in isopach and iso-resistivity maps (Figures. 4 and 5). The topsoil layer can be referred to as the engineering layer.

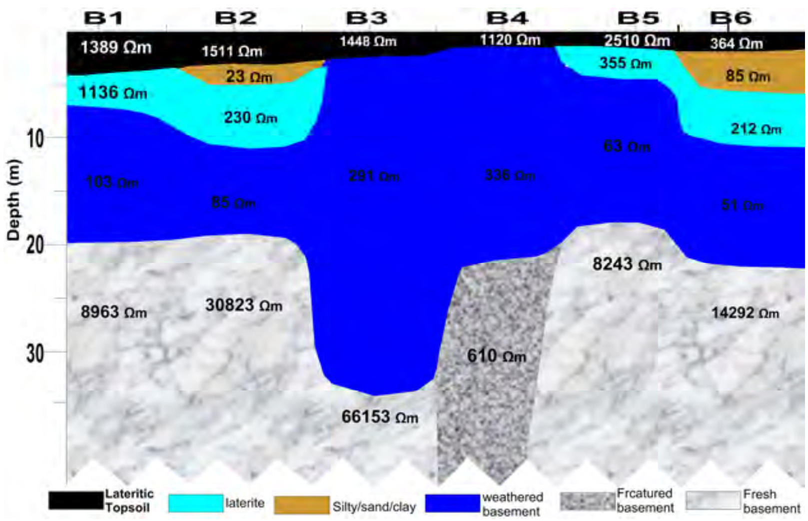

Figure 1. *Geoelectric/geologic section of profile B.*

Figure 4 shows the isopach map of the surface layer in the study area. The map was produced by contouring the first layer thickness of the study area. The thickness distribution of the topsoil varies from 0.3 m to 6.4 m. Thickness range between 1.2 and 2.7 m dominates the area. The Northwestern part of the area (VES stations A1, A2, B1, B2, C1 and D1) is characterized by thicknesses between 2.7 and 5.2 m. These are important data required for taking technical decisions before siting key structures.

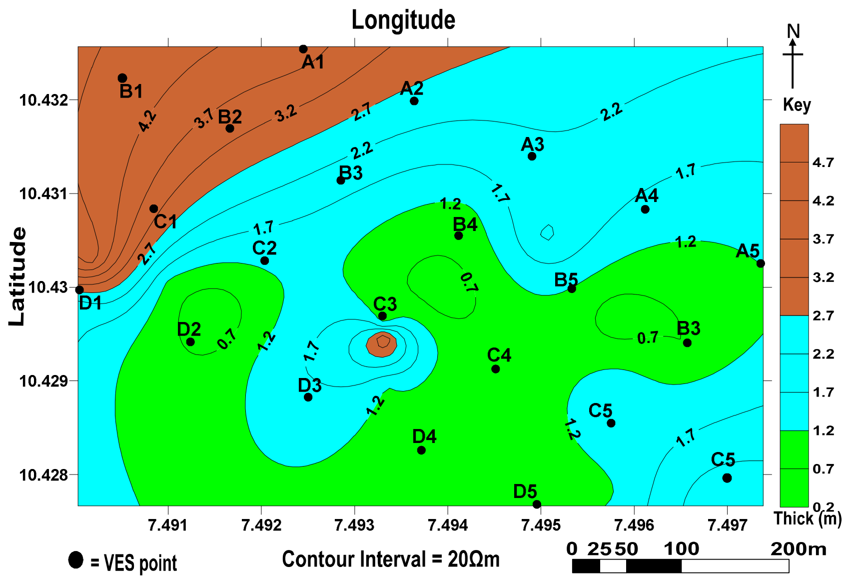

Figure 4. *Isopach map of the topsoil.*

Figure 5 shows the iso-resistivity of the topsoil of the area. The map shows that the topsoil is highly resistive across the area except in the Southeastern part of the study area at (VES D1, D2 and D4) and Some part of Southwest at (VES C5). [11], noted that the engineering competence of the subsurface can be qualitatively evaluated from the layer resistivity. The higher the layer resistivity value, the higher the competence of a layer; hence from the point of view of the resistivity value therefore, lateritic soil is the most competent of the delineated topsoil, followed by clayey sand and sandy clay being the least competent (Figure 5). The values vary from 100 Ωm to 2688 Ωm affected mostly by geologic surface feature such as clayey, loamy silt along the stream and consolidated laterite at the topsoil in the area. [6], observed the structural failure arising from his area of study was characterized by relatively low resistivity (mostly) with the stable zones typically resistive (). The study also identified the presence of intercept clayey sapolite with high moisture content in the failed zones. However, the presence of laterite in the study area beneath the clayey topsoil which extends beyond 3.0 m could reduce the danger posed by clay formation to large buildings. [6] and [12], both held that the area with topsoil resistivity between 300 – 1000 Ωm and >1000 Ωm could be considered moderately and highly competent zone. This zone is considered good enough for any massive engineering structures. The resistive zones (>1000 Ωm) was observed to dominate most part of the area. The observed relatively low resistivity (<300Ωm) at topsoil in some parts of Southwest (at VES stations D1, D2, and D4) and Southeast (at VES station C5) may not be unconnected with the nature of the topsoil and the adjacent stream in the study area.

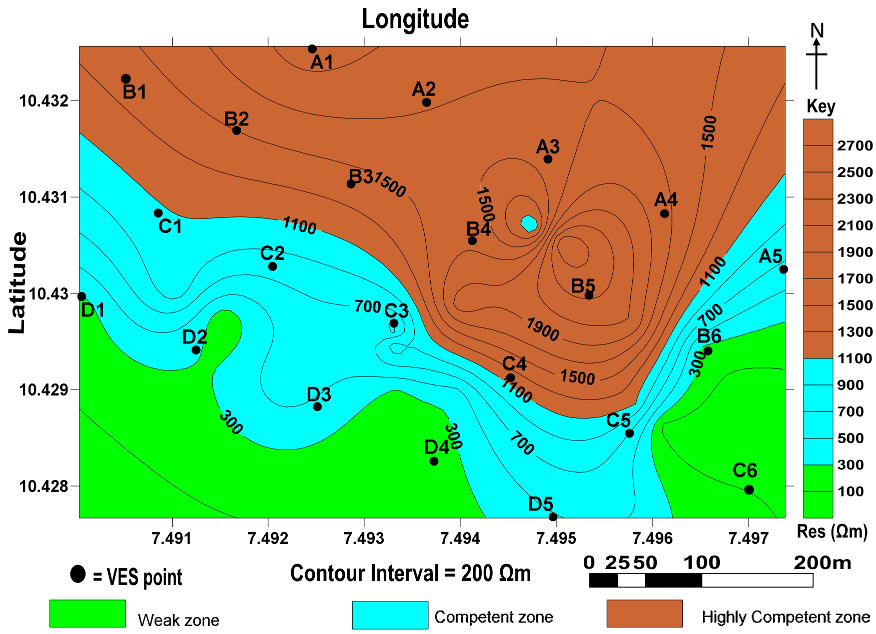

Figure 5. *Iso-resistivity map of topsoil.*

Figure 6 shows the iso-resistivity mapof the fresh basement. The map reveals the distribution of bed rock resistivity in order to indicate the nature, strength or competence and the degree of the weathering of the basement of rocks of the area. The figure 6 shows that the basement rock is highly resistive and it is believed to be fresh granite. [13] and [14] held that the resistivity of the basement is a function of their degree of weathering and hence its strength. The rocks in these regions are believed to be crystalline and hence highly competent. The zones depicted with blue colour could suggest to be less competent and according to [2], the rocks have probably undergone certain low degree of fracturing, faulting or are heavily weathered. This information is very important when taking geotechnical decisions.

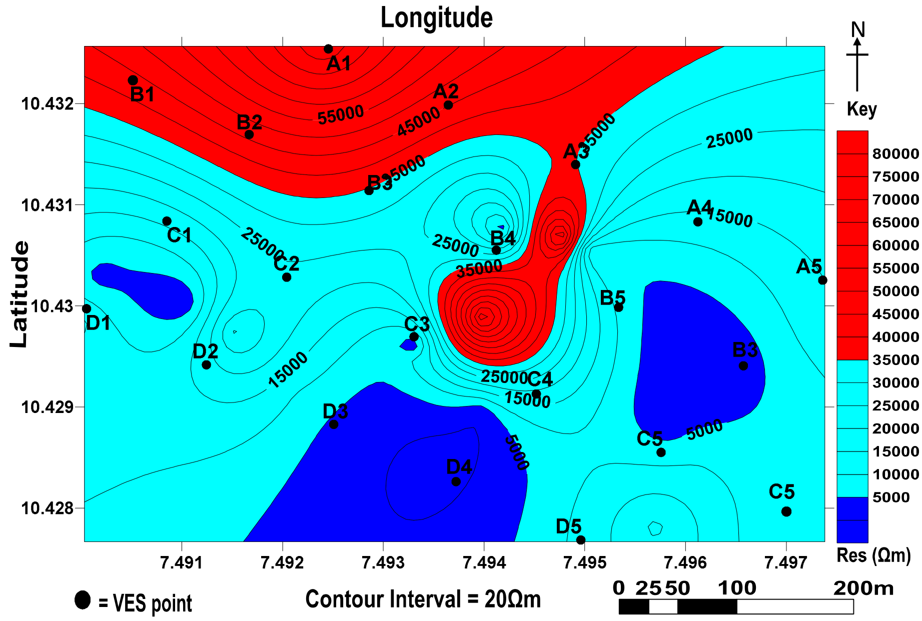

Figure 6. *Iso-resistivity of Basement rocks.*

5. Conclusion

The investigation shows the geo-electric and geologic sections derived from the study area which has revealed three to five subsurface layers, namely: lateritic topsoil followed by clayey/sandy/silty, layer, weathered basement and fractured/fresh basement rocks. A broad section of the area was classified as competent for civil works. There are no indications of any major linear structure such as fracture, faults or voids that could aid building subsidence in the study area.

However, the seasonal variation in the saturation of clay which causes ground movement could cause havoc in building construction due to the sensitiveness of soils to moisture loss or gain (swells and shrinkages). Considering the presence of consolidated laterite which extends beyond 3.0 m could reduce the danger posed by clay formation to large buildings as well as tarred roads. In summary, the interpreted data shows that there are no indications of any major trend such as fracture, cavities, voids or faults that could aid building subsidence in the area identified as competent zones. Other probable factors such tree roots, organic deposits, superficial cover that could cause foundation defects can therefore be eliminated by total evacuation of the topsoil.

References

[1] Adeniran A. J. (2013): Environmental Disasters and Management: Case Study of Building Collapse in Nigeria. Int J of Construction Engineering & Management 2(3), 39-45.

[2] Aboh, H. O. (2002). Geotechnical Characterization of Surface Materials in Kaduna Area, Kaduna State. Zuma J of Pure & Applied Science, 4(2): 23-33.

[3] Adebajo, K. (2005): A position paper by the Nigerian Institute of Structural Engineers a division of the Nigerian Society of Engineers (NSE) on Recent Structural Collapses in Nigeria and the Prevention of Future Incidences.

[4] Loke, M. H. (1999). Electrical Imaging Surveys for Environmental and Engineering Studies. A practical guide to 2-D and 3-D surveys. Malaysia.

[5] Opara, P. (2006). Building Collapse in Lagos State: Causes and Recommendations. Journal of Technology and Education in Nigeria 11 (1), 58-65.

[6] Michael, I. O.; Martins, O. O. and John, S. O. (2008): Geophysical Investigation of Road Failure in the Basement Complex Area of Southwestern Nigeria. Research Journal of Applied Sciences 3 (2): 103-112.

[7] Dogara, M. D., Aboh H. O. and Kogi K. A. (2016): D. C. Resistivity Investigation Of Subsurface Layering For Geotechnical Application In Millennium City, Kaduna, Kaduna State. Science World Journal Vol 11 (No 2), 30-34.

[8] Isaac, O. O., Jonah, C. A., and Joel, O. A. (2013): Assessment of Aquifer Characteristics in Relation to Rural Water Supply in Part of Northern Nigeria. Research 2(3) 22 – 27.

[9] Oyawoye, M. O. (1970): The Basement Complex of Nigeria, In: Dessauvagie, TFJ and Whiteman, A. J (Eds) African Geology. Ibadan: University Press, Ibadan Nigeria.

[10] Mortimore, M. J. (1970). Settlement Evolution and land" (Mortimore M. J. (ed) Zaria and its Region) Occasional paper 4. Department of Geography A. B. U. Zaria 102 – 122. Opara, P. (2006). Building Collapse in Lagos State: Causes and Recommendations. J of Technology and Education in Nigeria 11 (1), 58-65.

[11] Fadele, S. I., Jatua, S. B., and Patrick, N. O. (2012): Geophysical Engineering Investigation Around Makiyaye Village, Shika Area Within The Basement Complex Of North-Western Nigeria. Int J of Engineering Research and Applications, 11 43-1153.

[12] Bayowa, O. G., & Olayiwola, N. S. (2015). Electrical Resistivity Investigation for Topsoil Thickness, Competence and Corrosivity Evaluation: A Case Study from Ladoke Akintola. International Conference on Geological and Civil Engineering. V80. 11 [53-56].

[13] Aboh, H. O. and Osazuwa, I. B. (2000): Lithological Deductions from Regional Geoelectric Investigation in Kaduna Area, Kaduna State. Nig. J of Phys Vol. 12, 1-2.

[14] Abdullahi, N. K, and Udensi, E. E. (2008): Vertical Electrical Sounding Applied to Hydrogeologic and Engineering Investigations: A Case Study of Kaduna Polytechnic Staff Quarters, Nigeria. Nig. J of Phys, 20 (1), 175-188.