IJAAR PUBLISHING®

Engineering Research Journal | ISSN: **2782-8212**
Vol. 3, Issue 5 (May, 2023) | www.ijaar.org/erj

Soil Electrical and Geotechnical Property Measurements: a Case Study of Oleh, Delta State, Nigeria

Ebisine E. E. & *Okieke U.J.
Department of Electrical/Electronics Engineering, Delta State University, Oleh Campus, Delta State, Nigeria
*corresponding author: okiekeufuoma@gmail.com

Abstract
Adequate knowledge of the soil's engineering properties is a crucial factor to be considered during the design and development of engineering structures. Some geotechnical and electrical properties (particle size gradation, and soil electrical resistance and resistivity) of an undisturbed superficial soil deposit, within an undeveloped area of Isoko region of Nigeria were measured in accordance with standard procedures. The soil's sieve analysis results depicted that the soil contains moderate amount of fines, which range from 13.0 % - 20.1%. It was also noted that the soil's electrical resistance at Locations A, B, C, D and E declined from 19.82 Ω *- 7.23* Ω*, 13.23* Ω *- 5.38* Ω*, 9.2* Ω *- 4.04* Ω*, 7.21* Ω *- 3.92* Ω*, and 5.93* Ω *- 2.98* Ω *respectively, as the probe distance increased from 3 m to 15 m laterally. Additionally, the electrical resistivity result indicated that at Locations A, B, C, D and E, the resistivity inclined from 622.74 - 908.67* Ω*m, 415.69 - 676.16* Ω*m, 290.01 - 505.75* Ω*m, 226.54 - 492.67* Ω*m, and 186.32 - 374.53* Ω*m, as the probes' lateral distance increased from 3 m to 15 m. Spatially, it was observed that the centre part of the studied area had the lowest resistivity, but the highest amount of fine-grained soil particles. Results acquired from this study will be useful during the design of electrical earthing system for structures to be built within the area.*

Keywords: Earthing system, soil particle size, soil resistivity, spatial distribution.

Published *19/05/2023*
Ebisine E. E., Odoh, F.E. & *Okieke U.J. (2023). Soil Electrical and Geotechnical Property Measurements: a Case Study of Oleh, Delta State, Nigeria. Engineering Research Journal, 3(5), 27-36.

1. INTRODUCTION

Soil electrical properties provide information on the current status of the soil's moisture condition, aid the design of corrosion inhibition systems, enhance the design of electrical grounding (earthing) systems, and facilitate the evaluating of the underground hydrological properties (Sherrod *et al.*, 2011; Munk *et al*., 2017). Anthropogenic (human-induced) activities are some of the major factors that affect the performance of electrical properties of in-situ soils. Hence, human activities suspected of tempering with the electrical properties of soils around electrical installations should be minimized especially if such actions have negative consequences on the performance of the electrical installation. Odoh *et al.* (2023) reported that oil spills have adverse effects on in-situ soil's electrical resistance and dielectric properties; while Obukoeroro and Uguru (2021) stated that inducing such soils with humus materials or inorganic salts tend to improve (increase) the soil's electrical conductivity and reduce the soil's ambient resistance level.

Apart from human-induced actions, soil electrical properties are also highly influenced by the native physiochemical and mechanical properties of the soil. It was observed that poorly graded soils with high fines content developed lower soil resistance, when compared to well-graded soil with low volumes of fine grained particles. This was attributed to the higher moisture content of the soils with higher proportion of fine grained particles. According to Akpokodje *et al.* (2020), the moisture content of a soil mass is directly proportional the amount of the fines the soil contains; hence, soils with high quantity of fines possess higher water retention capability. From reports of investigations carried out by Igbologe and Okieke (2022), soils with higher water content and porosity will inevitably develop higher electrical conductivity, but lower current resistance levels. According to Oyeleye and Makanju (2020), heavily compacted soils tends to conducts lower amounts of electrical charges, when compared to loosely compacted soils, because compaction lowers water (which is considered as electrolyte) availability in the soil.

Soil electrical properties are important factors to be considered during the design of a building's earthing system, the determination of the groundwater status and the exploration underground minerals, including petroleum. Abbey and Digbani (2019) determined aquifer depths and its water volume by analyzing the electrical resistivity of the various strata in the soil profile. Akhtar et al. (2018) reported that the electrical resistivity method is one of the best non-destructive preliminary methods, for detecting the presence of water and other liquid minerals beneath the earth surface. Each mineral has its own electric resistivity threshold, while water's electrical resistance is a factor of its dissolved salt content; thus the water quality can be analyzed through its resistivity.

According to Institute of Electrical and Electronics Engineers (IEEE), the soil's electrical resistance is an essential factor to be considered in evaluating the efficacy of an electrical grounding system (IEEE, 2012). A good earthing system should be able to collect and dissipate the excessive currents into the earth's reservoir, as fast as possible, in order to reduce the occurrence of electrical hazards. Condition(s) of the soil adjacent to the earth rod, play a vital role during the configuration of the earthing systems; hence, detailed investigation into the geotechnical properties of the soil is indispensable, regardless of the earthing system to be adopted (Vasilios *et al*., 2020). According to Salam *et al.* (2017) and Uguru and Obukoeroro (2020), a good earthing system design must take into cognizance of the following; prevailing climatic conditions, soil's physical and mechanical properties, anticipated anthropogenic activities, earth rods (electrodes) arrangement and the total electrical load expected.

Isoko is a major region of Nigeria, and it is presently experiencing rapid urbanization and industrialization. Although several investigations had been done of electrical and mechanical properties of soil samples generally, review of related literature reviewed revealed that, very little is known with respect to areas of the Isoko region; hence, evaluating the engineering parameters of the undeveloped areas of this has become necessary, in order to reduce the occurrence of possible electrical failures. Therefore, this research was aimed at investigating the electrical and geotechnical behaviors of soils located in an undeveloped area of Isoko South Local Government Area of Delta State (LGA), Nigeria.

2. MATERIALS AND METHODS

2.1 Description of the study area

This research was carried out in an undeveloped area of Oleh community in Isoko south (LGA). The studied area lies between latitude 5.4401^{o}N - 5.4487^{o}N, and longitude 6.1977^{o}E – 6.2021^{o}E; the eastern and southern parts of the studied region shared common boundary with major highways. The region is situated with the tropical rain forest; with mean annual rainfall of approximately 1800 mm (Uguru *et al.*, 2021). The delineated area was covered with thick natural vegetation, with little cropping activities. The research was done in April, 2022, within the early months of the rainy season in the region; the soil was not saturated with water. All the ex-situ soil tests were done in one day.

2.2 Soil resistance determination

The soil electrical resistance was determined in accordance with IEEE standard, by adopting the Wenner four-electrode procedures (IEEE, 2012). During the resistance determination, four (4) probes were inserted into the undisturbed soil, to a predefined depth and equidistance spacing. For the purpose of this study, one probe depth (1 m) and four probe distances 6 m, 9 m, 12 m and 15 m) were used. The 1 m probe depth was taken because it was within the IEEE approved burial depth for earthing electrode (IEEE, 2000). At each testing location, soil samples were collected at the depth of 0.5 m to 1.0 m for geotechnical properties analysis.

The Schematic diagram of the experimental setup is shown in Figure 1. After the connections were secured at the terminals, and apparatus was switched on, the soil's resistance can be read from the earth resistivity meter screen. Thereafter the soil resistivity was calculated by using Equation 1.

$$\rho = 2\pi aR \qquad (1)$$

Where: ρ = Resistivity (Ωm), a = Probe spacing (m), and R = Measured resistance (Ω)

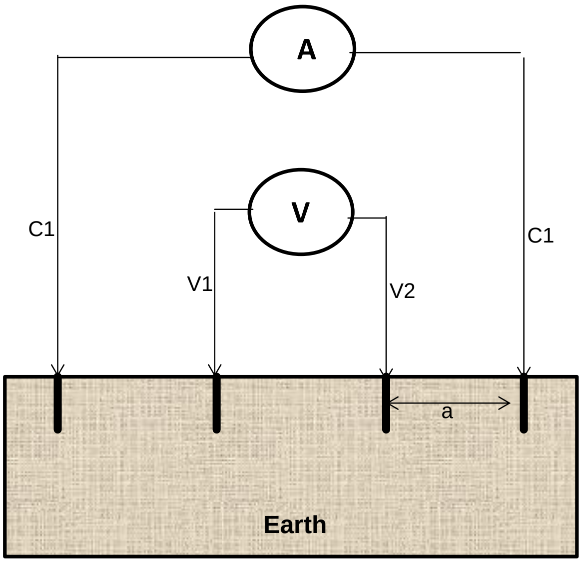


Figure 1: The in-situ earth resistance measurement experimental setup

2.3 Particle size grading

The particle size grading (sieve analysis) of the soil was done in accordance with BS 1377 guidelines. Then the volume of fines in the soil sample was calculated through Equations 2 and 3 (Akpokodje and Uguru, 2019).

$$\%\, weight\ retained = \frac{weight\ retained}{Initial\ \ weight} \times 100 \qquad 2$$

$$\%\, passing = 100 - \ \%\, weight\ retained \qquad 3$$

2.4 Data evaluation

The raw data obtained from the field work were analyzed through the use of charts and "means". Thereafter, ArcGIS geostatistical tool was used to determine the spatial variation of the soil resistivity within the studied area.

3. RESULTS AND DISCUSSION

3.1 Geotechnical properties

Soil particle size grading

The result of the sieve analysis is presented in Figure 2. Using the Unified Soil Classification System (USCS) guideline, the soil fine grained particles were found to range between 13.0 % and 20.1%. It can be deduced from the chat that the soil contained appreciable amounts of fine grained particles, mostly at Locations 4(D) and 5(E). This is an indication that the Locations 4(D) and 5(E) soils will have higher natural moisture contents, when compared to Locations I(A) and 2(B). According to Agbi and Uguru (2021), fine-grained particle size soils have higher water retaining capacity, when compared to coarse-grained particle size soils, in the absence of stabilization agents. Remarkably, the reasonable fines proportion (>5%) of the soils makes the soil samples (irrespective of the sampling station) poorly graded – using the USCS guideline; thus, they are not suitable for concrete production. Akpokodje et al. (2021) reported that soils appropriate soil for high quality concrete production must possess lower fines volume (fines ≤3) and coefficient of uniformity greater than six.

The fines content of the studied region's soil was higher than the results obtained by Agbi *et al*. (2020) for soil samples collected from other districts in within the Isoko region. The differences in the soils' fines content, despite been collected from the same geographical regions could be attributed to these factors - depth of sample collection and anthropogenic actions – as explained by Akpokodje *et al*. (2022) and Liu *et al*. (2022). Interestingly, the fairly high fines volume recorded in most of the soil samples (Locations C, D and E), may be an added advantage to the soil's electrical behaviors. Obukoeroro and Uguru (2021) stated that fine grained particle soils tends to have higher electrical conductivity, when compared to coarse grained particle soils, possibly due to their higher water retaining ability.

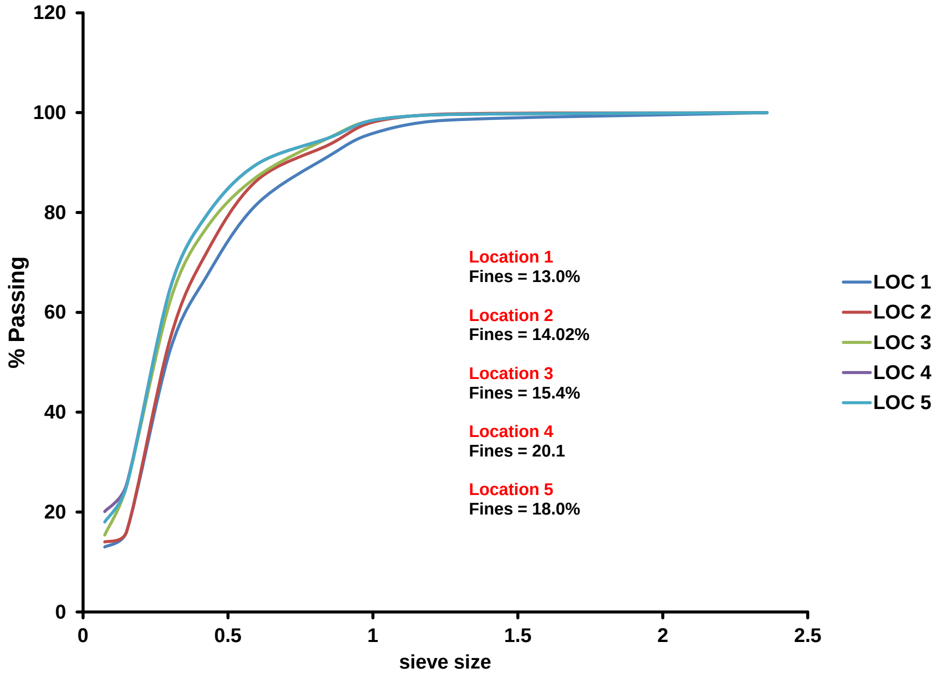


Figure 2: Particle grading result

3.2 Soil electrical properties

Soil electrical resistance

The results of the measured resistance are presented in Figure 3. As shown in Figure 3, the soil resistance varied unevenly across the studied region. It was noted that regardless of the probe distance, Location A generally had the highest resistance, while Location E had the lowest resistance. At Location A, the soil resistance decreased from 19.82Ω - 7.23Ω, as "a" increased from 3 m to 15 m; in Location B and C, it was noted that R declined from13.23Ω to 5.38Ω, and 9.2 Ω and 4.04Ω respectively, as the "a" increased from 3 m to 15. Likewise, at Locations D and E, the soil R decreased from 7.21 Ω to 3.92Ω, and 5.93Ω and 2.98Ω respectively. This is an indication that probe distance significantly affects the soil resistance to current flow; which is in conformity with observations of Salam *et al*. (2017).

Soil resistance is influenced by several factors such as; soil conduction, soil particle grading and the vegetative cover. According to Igbologe and Okieke (2022), vegetation helps to lower the soil temperature and improves the soil's water holding capacity (moisture content), and these factors decrease the electrical resistivity of the soil; thus increasing the electrical conductivity of the soil in the process. Though the soil resistance was quite low (R ≤20Ω), it was higher than the recommended limit of 2.0 Ω approved by the Nigerian Electricity

Management Services Agency (NEMSA) and 5.0 Ω approved by IEEE (Omorogiuwa and Fayose, 2018).

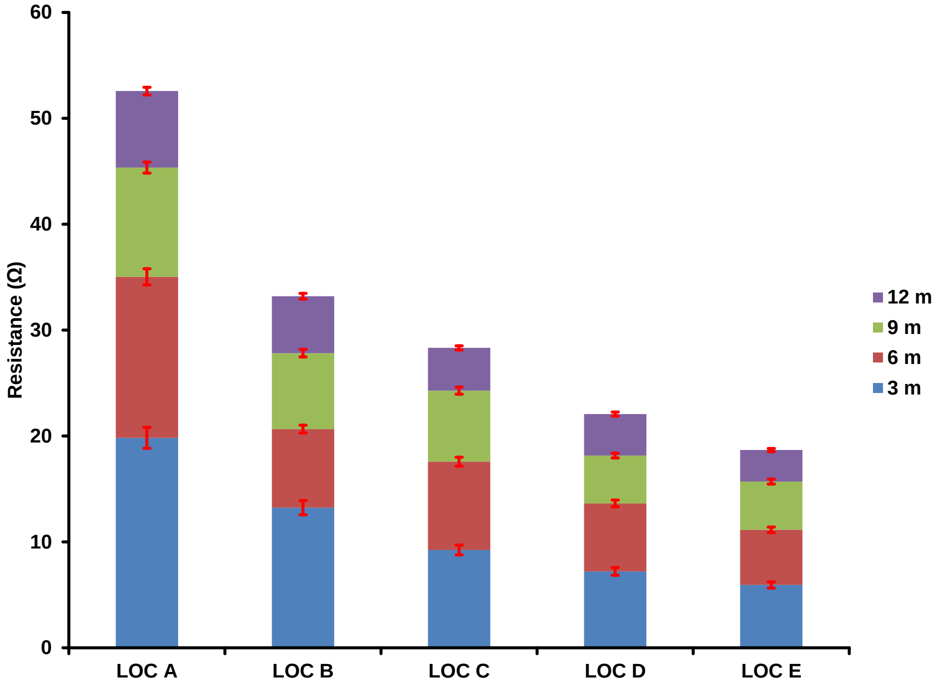


Figure 3: Soil resistance

Soil resistivity

The results of the soil resistivity are plotted in Figure 3. Figure 3 revealed that ρ is a factor of the probe distance, which is similar to the findings of Munk *et al*. (2017). It was also observed that the soil's ρ at Locations A, B, C, D and E inclined from 622.74 - 908.67 Ωm, 415.69 - 676.16 Ωm, 290.01 - 505.75 Ωm, 226.54 - 492.67 Ωm, and 186.32 - 374.53 Ωm, as the probe distance increased from 3 m to 15 m. Generally, the soil with the highest resistivity was situated at Location A, while Location E soil had the lowest resistivity. Spatially, the soil electrical resistivity followed this hierarchy; Point A > Point B > Point C > Point D > Point E. The trend (floatation) observed in the ρ values as the probe distance increased from 3 m to 15 m, may be attributed to the condition of the soil at the probe position, and other anthropogenic impacts. Similar discrepancies in the soil ρ with increase in probe distance were recorded by Obukoeroro and Uguru (2021). The variations in the soil ρ recorded in this study's findings, when compared to other related reports, can be linked to variations in the soil's geotechnical properties, soil temperature, probe depth, and soil biochemical conditions (Berlijn *et al*., 2007).

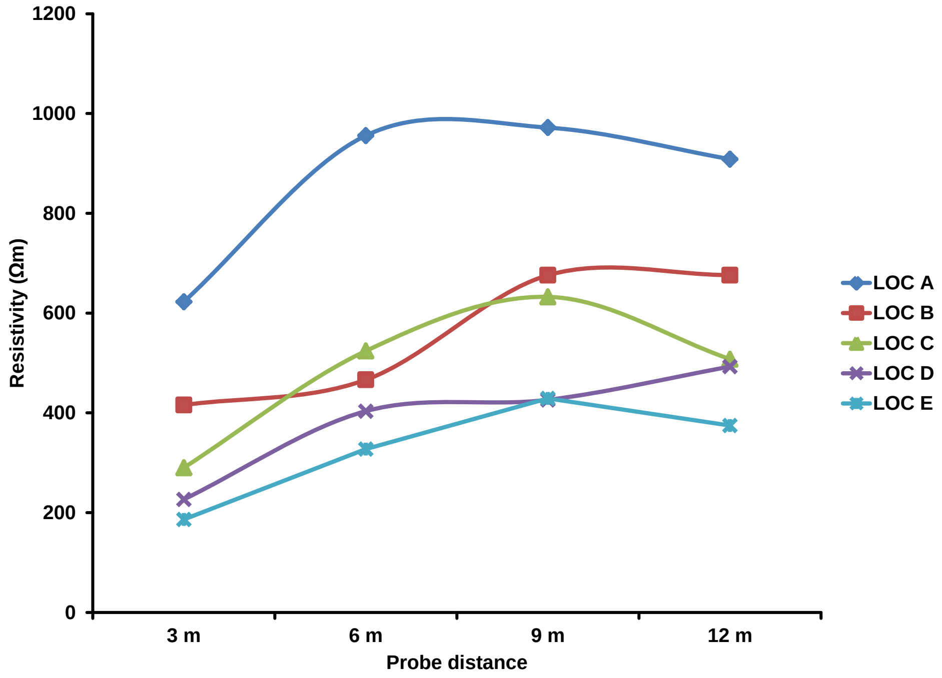


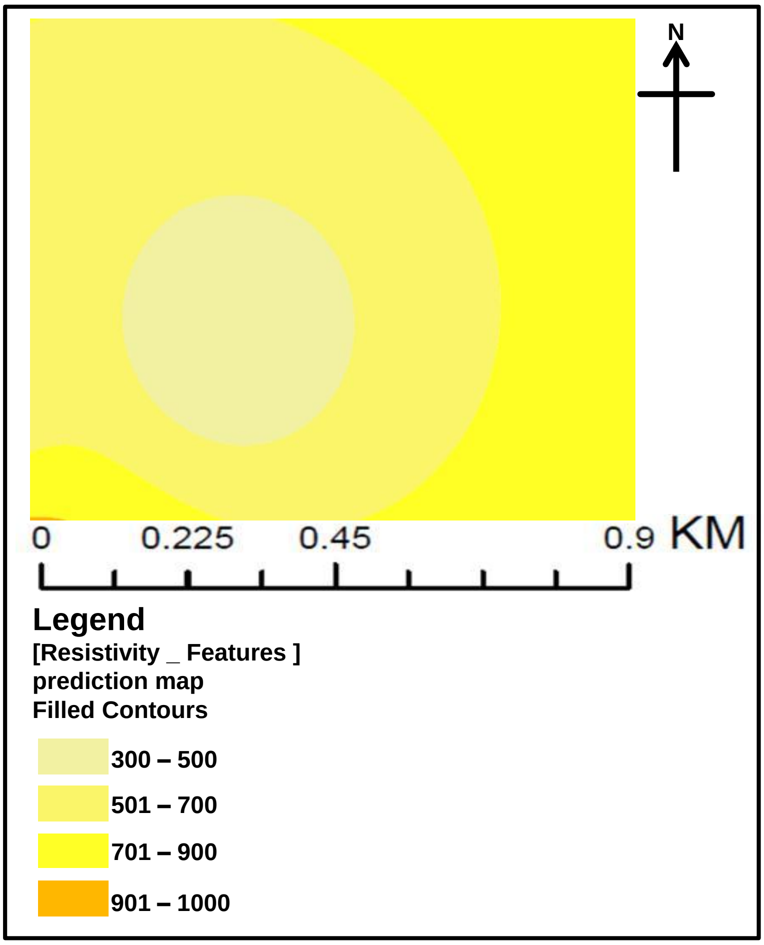
Figure 4: Soil resistivity

Soil regions with low soil resistance are recommended for earthing systems in all electric facilities, in order to achieve good ground potential rise (IEEE, 2013). Soils with high ρ values are not suitable for grounding system, as they did not cause electrocution, but are directly linked to instrumentation blunders, besides causing harmonic distortions in electrical system (Salam *et al.*, 2017).

3.3 Spatial distribution of the soil resistivity

The spatial distribution of the soil resistivity shown in Figure 4 showed that the ρ spreads un-uniformly from the center of the region to the edges. This indicates that the central part of the studied area had the lowest soil resistivity, while the soils at the eastern part of the area had the highest resistivity. The high ρ recorded at the eastern part of area could be possibly caused by the soil compaction and influences of the structures found along the major roads. Additionally, the presence of the higher percentage of coarse soil particles in the eastern region could also contributes to the higher resistance developed by the eastern parts of the soil to electrons flow. Obukoeroro and Uguru (2021) stated that coarse grained soil trends to have higher resistivity, when compared to fine-grained soil.

Furthermore, the lower resistivity recorded at the centre of the studied region, can be attributed to the presence of organic materials and the higher fine content of the soil. According to Oyeleye and Makanju (2020), clayey soil that has high percentage of fines, tends to have lower resistivity than sandy soil that contain lower volume of fines in the soil mass. As seen in Figure 2, the volume of fines at the region’s center (at soil depths of 1 m) is higher than the volume recorded at the eastern and western parts of the region. The higher vegetative cover found in the region’s center could be another factor that lowered the soil’s resistivity. Similar wide variation in the electrical resistivity of an undeveloped area was reported by Igbologe and Okieke (2022). Based on the spatial distribution map, the eastern part of the studied area required higher soil stabilization, before installation of electrical grounding systems; because, it has been proven (Gabriel and Kehinde, 2011) that soil with high resistivity lowers the efficiency of the grounding system.



4. CONCLUSIONS

This research was done to evaluate some engineering properties of soil samples within the Isoko region of Nigeria. Soil samples were taken from six stations with an area of 0.9 km2, and their geotechnical and electrical properties was determined in accordance with ASTM and IEEE recommended guidelines. The geotechnical analysis findings revealed that the soils contains fines that ranged from 13% - 20.1%, making the soils poorly graded, thus lowering their suitability in the concrete industry. It was noted that the electrical resistance of the soils declined non-linearly, with a linear increment in probe distance. The soil resistance varied from 2.98 Ω - 19.82 Ω, uniformly spread across the studied area. Furthermore more the soil resistivity ranged between 186.32 Ωm and 908.67 Ωm, and the spatial distribution map revealed that the center of the studied area had the lowest soil resistivity. The study’s findings revealed that the soil in studied area is not appropriate for concrete production, but have appreciable soil resistance quality for the installation of electrical systems.

REFERENCES

Abbey, M.E. and Digbani, T. (2019).Determination of ground water potential using electrical resistivity method.*International Journal of Science and Research.* 9(4): 878 – 882

Agbi, G.G., Akpokodje, O.I and Uguru, H. (2020). Compressive strength of commercially produced sandcrete blocks within Isoko Metropolis of Delta State, Nigeria. *Turkish Journal of Agricultural Engineering Research*, 1(1): 91-103.

Agbi, G.G. and Uguru, H. (2021). Assessing the impact of cassava starch on the structural properties of sandcete blocks produced from recycled paper. *Saudi J Eng Technol*, 6(5): 99-103.

Akhtar I.R, Mohd, A. A. M., and Mohd, H.Z.A. (2018). Application of Electrical Resistivity Method (ERM) in Groundwater Exploration.*IOP Conf. Series: Journal of Physics: Conf. Series* 995: 12094 – 12106

Akpokodje, O.I. and Uguru, H. (2019).Effect of fermented cassava waste water as admixture on some physic-mechanical properties of solid sandcrete blocks. *International Journal of Engineering Trends and Technology*, 67(10): 216 – 222

Akpokodje, O.I., Agbi, G.G. and Uguru, H. (2020).Evaluation of Cassava Effluent as Organic Admixture in Concrete Production for Farm Structures. *Turkish Journal of Agricultural Engineering Research*, 1(2):271-282.

Akpokodje, O. I. Agbi, G. G., Uguru, H. and Nyorere, O. (2021). Evaluation of the compressive strength of commercial sandcrete blocks produced in two metropolises of Delta State, Nigeria. *Applied Journal of Physical Science*. 3(2): 61-71

Akpokodje, O. I., Juwah, H. O. and Uguru, H. (2022). Impacts of petroleum spills on geotechnical properties of soils: A review. *Journal of Engineering Innovations and Applications*. 1(1): 1-6

Berlijn, S., Halsan, K. and Gärtner, T. (2007).The measurement uncertainty in and practicality of measurement of soil resistivity and grounding resistance. In Proceedings of the 15th International Symposium on High Voltage Engineering (ISH 2007), Ljubljana, Slovenia.

Gabriel, A. and Kehinde, O. (2011). Assessment of soil resistivity on grounding of electrical systems a case study of north east zone, Nigeria. *J. Acad. Appl. Stud*. 28- 38.

Idoniboyeobu, D.C., Bala, T.K. and Okekem, E. (2018). Assessment and evaluation of soil effect on electrical earth resistance: A case study of Woji area, Port-Harcourt, Nigeria. *International Journal of Engineering and Technical Research*. 8(6): 83-94.

Igbologe, O. and Okieke, U. (2022). Evaluation of the earth's electrical properties of the undeveloped area at the Delta State University of Science and Technology, Ozoro, Nigeria. *Advances in Research*, 23(2): 1-10

IEEE (2012). IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System. IEEE Stand. 81-2012; IEEE: New York, NY, USA.

IEEE (2013). IEEE Guide for Safety in AC Substation Grounding. IEEE Stand. 80-2013, 1; IEEE: New York, NY, USA

IEEE Std 80-2000 (2000). IEEE guide for safety in AC substation grounding

Liu, Y., Wu, X., Wu, T., Zhao, L., Li, R., Li, W., Hu, G., Zou, D., Ni, J., Du, Y., Wang, M. and Li, S. (2022). Soil texture and its relationship with environmental factors on the Qinghai–Tibet Plateau. *Remote Sensing*, 14: 3797- 3810.

Munk, J., Petersen, T., Cullin, M. and Schnabel, W. (2017) Analysis of a Simple Probe for In-Situ Resistivity Measurements. *Journal of Water Resource and Protection*, 9: 1-10.

Obukoeroro, J. and Uguru. H. (2021). Evaluating the geotechnical and electrical properties of soil samples around Delta State Polytechnic, Ozoro, Nigeria. Applied Journal of Physical Science. 3(1):21-27.

Odoh, F.E., Asibeluo, U.N. and Akpokodje, O.I. (2023). Electrical and geotechnical properties of soils around electrical power transformers. *International Journal of Advanced Academic Research*. 9(4): 1-13

Omorogiuwa, O.S. and Fayose, O. (2018). Performance evaluation of the earthing system in Ambrose Alli University, Ekpoma, Nigeria. *Advances in Electrical and Telecommunication Engineering*, 1(2):93-98.

Oyeleye, M.O. and Makanju, T.D. (2020). Soil resistivity adequacy assessments: Case study of proposed school of environmental technology building federal university of technology, Akure. *European Journal of Engineering Research and Science*.4(2):1-6.

Salam, M., Rahman, Q.M., Ang, S.P. and Wen, F. (2017).Soil resistivity and ground resistance for dry and wet soil.*J. Mod. Power Syst. Clean Energy*. 5(2):290–297

Sherrod, L., Sauck, W. and Werkema Jr., D.D. (2011) A Low-Cost, In Situ Resistivity and Temperature Monitoring System. *Ground Water Monitoring and Remediation*, 32: 31-39.

Uguru, H. and Obukoeroro J. (2020). A survey of residential and mini-industrial wiring systems in Nigeria: A case study of Bayelsa State, Southern Nigeria. *Journal of Engineering and Information Technology*. 7(7):148-154

Uguru, H., Akpokodje, O.I. and Agbi, G.G. (2021). Assessment of spatial variability of heavy metals (Pb and Al) in alluvial soil around Delta State University of Science and Technology, Ozoro, Southern Nigeria. *Turkish Journal of Agricultural Engineering Research*, 2(2): 450-459.

Vasilios, P.A., Katerina, D.D., Christos, A.C. and Ioannis, F.G. (2020).Effect of Soil Resistivity Measurement on the Safe Design of Grounding Systems. *Energies*, 13, 3170 – 3183