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Relationship between Geoelectrical and Geotechnical Index Properties of Soils

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Abstract: This research evaluates how well the resistivity survey approach works to estimate certain geotechnical index parameters. Soil samples were collected from freshly drilled boreholes and subjected to relevant laboratory analysis, while vertical electrical soundings were conducted in the vicinity of the boreholes. The research area's resistivity values were plotted against the moisture content and plasticity index of each soil layer and sample to investigate the correlation between the engineering properties and the processed geoelectric parameters. The results indicate that the link between electrical resistivity values and soil moisture content is inverse and non-linear. Analysis of the data futher shows that lower resistivity values were recorded for sediments with more water content, whereas higher resistivity values were recorded for sediments with less moisture content. The analysis also reveals that cohesive soils had a higher plasticity index and typically have higher liquid limit values relative to cohesionless soils. As per the grain size distribution of the soils and USCS classification, the results are such that the CH and CL soil types, had an average resistivity of 88.7 Ωm, clayey sand (SC) sediments recorded a mean resistivity value of 157.2 Ωm, and silty sand (SC) and poorly sorted sand (SP), respectively, had average resistivity values of 307.3 Ωm and 638.8 Ωm. This implies that, with other factors kept constant, soil resistivity values generally increase with increase in soil grain sizes.

1. Introduction

A geotechnical assessment typically comes before construction of high rise buildings, bridges, and roads. Such an assessment should accurately assess the geotechnical characteristics of the soil and the overall state of the subsurface, which will ultimately affect how well a particular civil engineering project will perform.

The usual method to determine a soil's geotechnical properties is to conduct a soil boring, collect samples, and analyze them in a laboratory. Although this method is still highly recommended in the field of soil investigations, there are some disadvantages. [1] and [2], among others, have identified the use of an invasive procedure to obtain samples, a very long operational time, and the high cost of equipment and personnel as some of the disadvantages.

The introduction of a supplemental technique known as the geoelctric method can address the aforementioned drawbacks of the conventional approach. To ascertain the subsurface resistivity variation in earth materials within a specified area of investigation, geoelectric surveys are conducted. The geoelectric method involves introducing artificially produced electric currents to the ground and measuring the resulting potential differences. Information of the subsurface heterogeneities and their electrical characteristics can be learned from analysis of the pattern of potential differences. According to studies, specific intrinsic characteristics of soil, such as porosity, grain size distribution, matrix mineralogy, and moisture content, have a significant impact on the soil's resistivity and can be meaningfully correlated [3, 4].

Soil categorization schemes based on Atterberg limits and grain size distribution are widely used by geotechnical engineers. [5] Stated that resistivity is significantly influenced by a geological material's lithology, porosity, water content, and salt concentration. The No. 200 (75 um) sieve is used as the dividing line between coarse-grained (sands and gravels) and fine-grained (silts and clays) soil textures. According to [6], clay is a substance that is both plastic and compressible. It is made up of tiny, flat particles of minerals. The electrical resistivity approach may be used to map various soil types, which will help the geotechnical engineer identify the soil.

This research attempts to establish a link between recorded geophysical characteristics of soils and their geotechnical index features by analyzing the influence of soil particle sizes and plasticity index on resistivity values. This nexus, which also provides a volumetric rather than a point evaluation of the subsurface, will be an asset to a well-thought-out, economically viable drilling and testing program.

Yenagoa is the location of the research area. It is situated between longitudes 6^0 10'E and 6^0 25'E and latitudes 4^0 55'N and 5^0 51'N (Figure 1). The study sites are connected by a network of motorable roadways. “The research area is underlain by 40–150 m thick Quaternary deposits, which are typically composed of quickly alternating phases of silty clay and sand, with the clays becoming more noticeable towards the sea” [7]. Strata logs have generally been used to identify multi-aquifer systems in the Delta [8]. "Generally, the region slopes southward and the geomorphology of the area is monotonously flat" [9].

2. Materials and Method

Soil boring, laboratory analysis, and field geoelectric surveys were the investigation methodologies used in this study.

2.1. Geoelctrical survey

Measurements were taken and vertical electrical sounding (VES) was performed using the ABEM SAS 1000 Terrameter. The Schlumberger array was used for the data acquisition. Following the collection of data and the manual calculation of apparent resistivities and geometric factors, the field data was transferred to a computer system and processed using the IP2WIN 1-D inversion program.

2.2. Soil sampling

For the purpose of soil boring, a hand auger and manual percussion rig were used. In four areas, auger boring was carried out to a maximum depth of around 6 meters, while percussion drilling was carried out to a maximum depth of 30 meters in four additional locations. For testing and analysis at the laboratory, the soil samples were brought to the location in waterproof bags. The samples were evaluated for moisture content, liquid limit, plastic limit, and grain size distribution using ASTM standard procedures [10, 11]. The Unified Soil Classification System (USCS) was then used to classify the samples based on the analytical results.

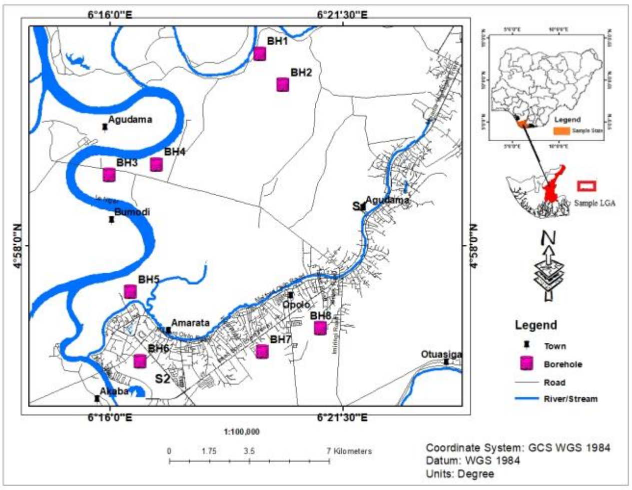


Figure 1: The study area

3. Results and Discussion

3.1. Geoelectric Results

The vertical electrical soundings were performed with the electrode array centered near the borehole locations. Figure 2 is a presentation of the modelled geoelectric curves showing the true resistivity and depth of soil layers for some selected investigation sites.

3.2. Relationship between Resistivity, Moisture content and Atterberg limits

Following the assessment of the soils' geotechnical index characteristics, the samples were split into three groups, designated S1, S2, and S3. The link between the moisture content, plasticity index, and resistivity values was then investigated. The determination of the categories was based on the USCS categorization of the samples. Group S1 was made up of fine-grained soil sediments that basically plotted on the Cassagrande plasticity chart's CH, MH, and CL sections. Samples categorized as SC, SM, SC-SM, and SP-SM comprised Group S2, whereas Group S3 was composed of badly graded sands (SP). The average moisture content of each soil type recovered from the boreholes is shown in Figure 3.

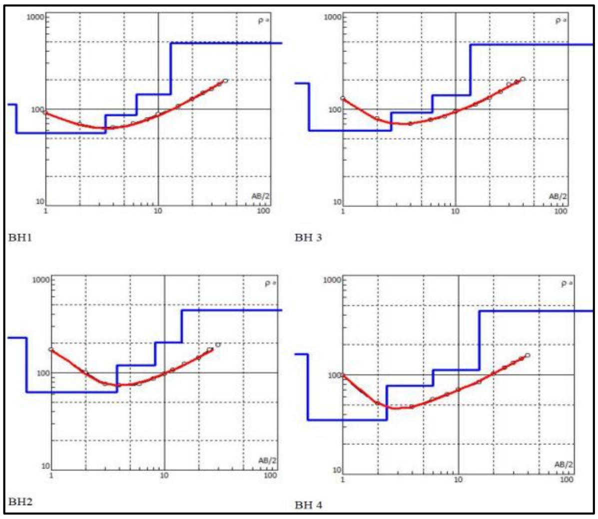


Figure 2: Computer modelled geoelctric curves for VES1 - VES4 locations

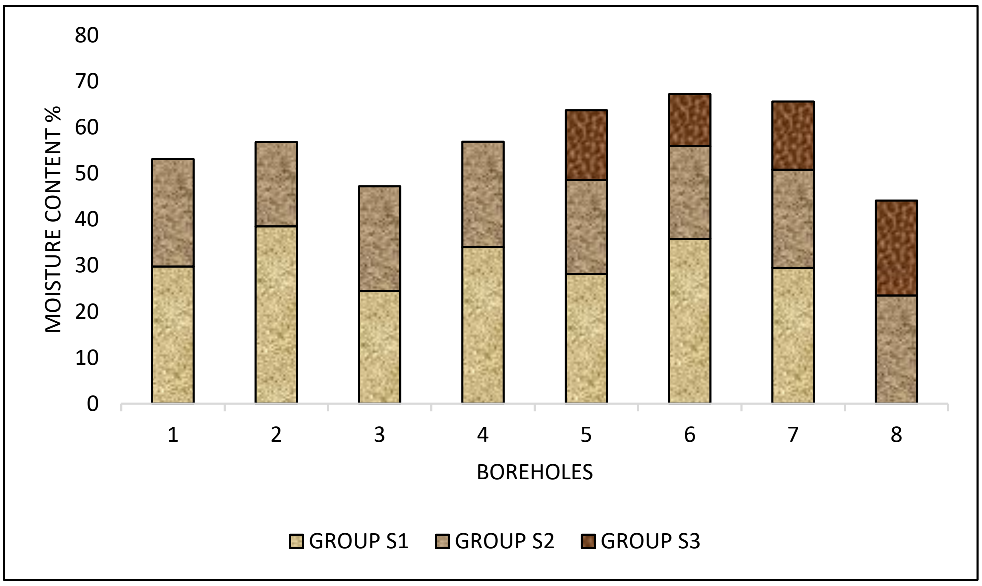
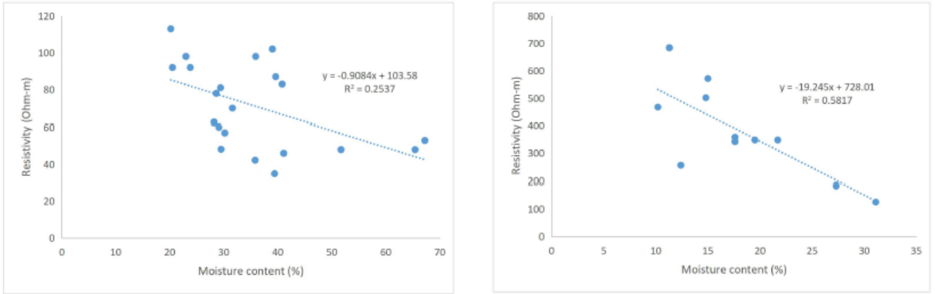


Figure 3: Stacked average moisture content across boreholes

The graphical plots of the relationship between the soil resistivity, moisture content and plasticity index of the cohesive and fine-grained sediments are shown in Figure 4.

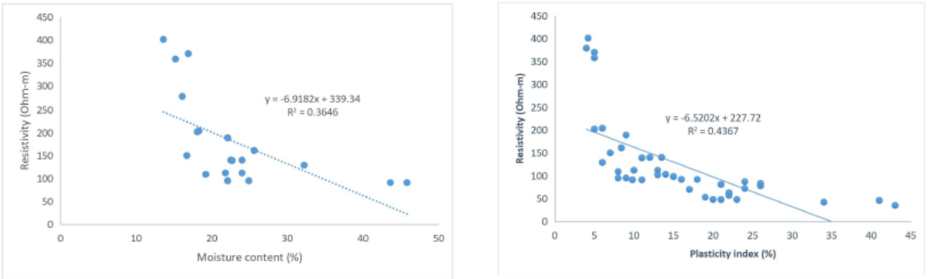
3.3. Resistivity and Moisture Content

The soil moisture content and the field-measured electrical resistivity values show a non-linear, inverse trend. The observed relationship between the moisture content and electrical resistivity was variable with respect to location and soil sample category. In general, electrical resistivity in soils rises as the water content decreases. In comparison to clay soil samples, sandy soil samples have lower moisture contents. According to [12], resistivity is significantly impacted by pore water content at lower percentages and exhibits a positive correlation with it, whereas resistivity is less affected by moisture content at greater moisture content.



Relationship between resistivity and moisture content for Group S1 samples

Relationship between resistivity and moisture content for Group S3 samples



Relationship between resistivity and moisture content for Group S2 samples

Relationship between resistivity and plasticity index for Group A1 and A2 samples

Figure 4: Relationship between resistivity and index properties

3.4. Resistivity and Plasticity Limit

For the clayey-silty soil samples from Group S1 and those from Group S2 (clayey-silty sands), the plots of the soil resistivity against plasticity index (Figures. 9 and 10) show a fair to moderate correlation respectively. Groups S1 and S2 have correlation coefficients of R^2 = 0.4513 and R^2 = 0.5182, respectively. Since the poorly sorted sand (Group S3) samples are essentially non-plastic soils, no correlation was seen. It is evident that soils with high plasticity indices are more likely to be clay-based and typically have greater liquid limit and natural moisture content values. Since the plasticity index depends on both clay and water content, the lower R2 value for group S1 compared to group S2 is attributed to the nonlinear relationship between resistivity and water content beyond around 25%.

3.5. Resistivity and Grain size distribution

Based on the results of laboratory tests performed, 4 soil types namely A1, A2, A3 and A4 in order of increasing grain size were identified and the average measured resistivity values for each soil type recorded. The group A1 were the finest in terms of grain size and comprised fat clay (CH) and lean clay (CL) class sediments, whereas the poorly sorted clean sands (SP) that made up group A4 sediments were comparatively the coarsest. Goup A2 samples were predominantly composed of clayey sands (SC), while group A3 samples were made up of silty sands (SM) and poorly graded sand with silt (SP-SM).

Figure 5 presents the average grain size distribution for the group A2, A3, and A4 samples. From the results, group A4 had the highest average soil resistivity value (628.8 m), followed by group A3 (307.3 m), and group A2 (157.2 m). The group A1 samples had the lowest average resistivity (88.7 m) of all the soil samples.

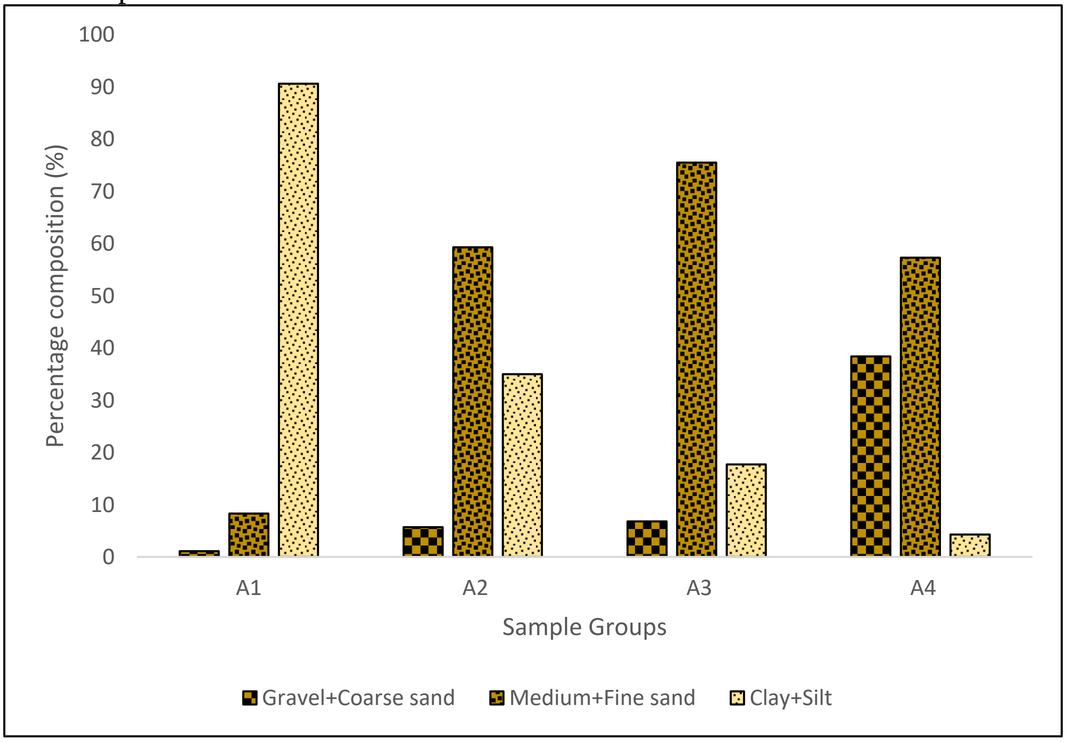


Figure 5: Percentage composition of grain type in soil samples

The grain size distribution results show that the average composition of gravel and coarse sand was highest in group A4 (38.4%) compared to groups A3 (6.8%), A2 (5.7%), and A1 (1.1%). The amount of silt and clay sediments was found to be highest in group A1 (90.6%), followed by 35.0% in A2, 17.7% in group A3, and 4.3% in group A4. The mean distribution of medium and fine sand was as follows: group A4 had 57.3%, group A3 had 75.5%, group A2 had 23.0%, and group A1 had 8.3%. According to each group's composition, a relationship between the resistivity values and the soil samples (Figure 6) reveals that fine grain sediments, such as silts and clays record the lowest resistivity values while the coarser sediments such as coarse sand and gravel have the highest resistivity values with respect to soils analysed.

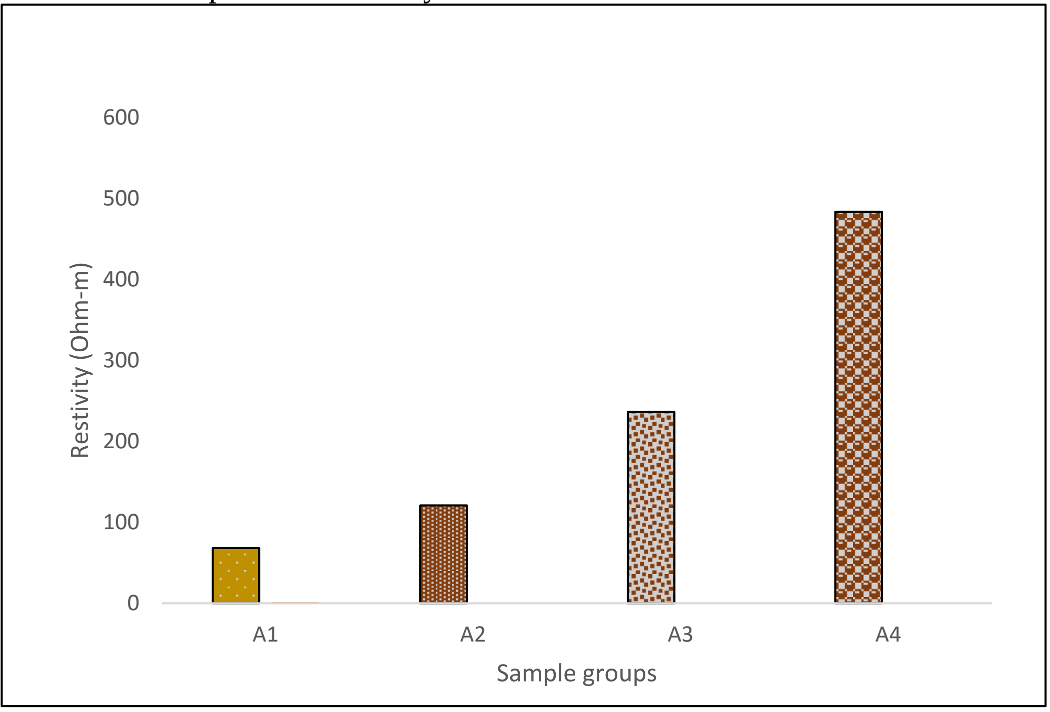


Figure 6: Average resistivity of soil samples

4. Summary and Conclusion

The study analyses the relationship between moisture content, plasticity index and grain size distribution on the value of electrical resistivity of soils. Laboratory testing of soil samples for moisture content and plasticity index reveals 3 subsoil categories namely S1 (clayey-silty sediments), S2 (clayey-silty sands) and S3 (poorly graded sands), while 4 soil groups designated A1, A2, A3 and A4 in order of increasing grain sizes were identified. Subsequently, the average measured resistivity values for each soil group were processed using the IP2WIN software and recorded.

Through the charting of resistivity values against the moisture content and plasticity index derived for each soil sample at all drilling sites, the link between the geotechnical qualities and geoelctric parameters was investigated. The findings indicate that the values of soil electrical resistivity and soil moisture content follow an inverse, nonlinear pattern. It was also noted that the poorly graded sands had a higher correlation while the clay and silt group had the lowest correlation. Comparably, graphical plots of the soil resistivity and plasticity index for the clayey-silty soil samples and the clayey-silty sands demonstrate medium to moderate association, respectively, with no correlation seen for the sands since they are essentially non-plastic.

The study's findings also show that the grain size of the geomaterials has a major impact on resistivity levels. Higher resistivity readings are produced by soils made up of relatively coarser grains, such as sand and gravel, while soils with larger proportions of silt and clay, typically have lower resistivity values.

Thus, geoelectric sounding measurements may be constrained by the known quantitative connection between resistivity and soil moisture content, plasticity index, and particle size distribution. This strategy will guarantee that the resistivity data are trustworthy sources that support suburface geotechnical data for site analysis and geotechnical evaluation of the appropriateness of the soil before building in the study area.

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