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## Geological and geophysical characterisation of subsurface formations for engineering applications in Uyo, Akwa Ibom state, Nigeria

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### Abstract

This study presents a geological and geophysical characterisation of subsurface formations in Uyo, Akwa Ibom State, Nigeria, using electrical resistivity sounding for engineering and hydrogeological applications. Vertical Electrical Sounding (VES) with the Schlumberger electrode configuration was employed to delineate subsurface lithology, assess soil competence, identify aquifer horizons, and evaluate factors relevant to engineering foundation stability within the Niger Delta sedimentary basin. The results indicate heterogeneous subsurface conditions consisting mainly of clay, sandy clay, fine sand, and coarse sand formations. Apparent resistivity values ranged approximately from 28  $\Omega$ m to over 600  $\Omega$ m, reflecting variations in lithology, grain size distribution, and moisture content. Near-surface conductive layers were interpreted predominantly as clay-rich or silty soils with relatively lower bearing capacity, while intermediate resistivity zones correspond to sandy clay or fine sand formations exhibiting moderate mechanical competence. Higher resistivity layers occurring at moderate depths were interpreted as coarse sand or sand-gravel formations representing competent geotechnical units suitable for engineering foundations and potential groundwater occurrence. Derived Dar Zarrouk parameters indicate weak to moderate overburden protective capacity, suggesting some vulnerability to environmental influences, whereas transverse resistance values suggest generally moderate to high subsurface competence. The results demonstrate favourable conditions for engineering development in areas underlain by resistive sandy formations while emphasising the importance of integrated geophysical and geotechnical investigations for sustainable infrastructure planning in the Niger Delta region.

**Keywords:** Electrical resistivity sounding, engineering geophysics, subsurface characterisation, Dar Zarrouk parameters, groundwater potential, geotechnical suitability, foundation assessment, Niger Delta

### 1. Introduction

Rapid urban development and infrastructural expansion in many parts of the Niger Delta have increased the demand for reliable subsurface information for engineering construction, groundwater development, and environmental management. In sedimentary environments such as Uyo, Akwa Ibom State, Nigeria, variability in subsurface lithology, soil competence, and groundwater conditions presents significant challenges for foundation design, site selection, and sustainable infrastructure planning. Inadequate subsurface characterisation prior to construction has been associated with structural instability, excessive settlement, groundwater intrusion, and increased engineering costs (Facazio *et al.*, 2002)<sup>[15]</sup>.

Geophysical methods, particularly electrical resistivity techniques, are widely applied for subsurface investigation because they provide rapid, cost-effective, and non-destructive means of evaluating lithological variations, aquifer distribution, soil competence, and environmental conditions. Electrical resistivity sounding has proven especially effective in sedimentary terrains where variations in grain size, clay content, moisture saturation, and pore fluid conductivity significantly influence electrical properties (Asfahani, 2013; Dewashish *et al.*, 2014)<sup>[5, 9]</sup>. Such variations allow reliable differentiation between clay-rich formations, sandy layers, and competent geological units relevant to engineering applications.

The geological setting of Uyo lies within the Niger Delta Basin, dominated by coastal plain sands of the Benin Formation, composed mainly of unconsolidated sands interbedded with clay and sandy clay layers. These formations exert strong control on groundwater occurrence and engineering stability. Clay-rich strata often exhibit low bearing capacity and high compressibility, whereas sandy formations typically provide better drainage and foundation competence (Okiongbo & Akpofure, 2012) [20]. Similar geoelectric investigations in southern Nigeria have demonstrated the usefulness of resistivity methods for aquifer delineation and engineering assessment in such sedimentary environments (Ikpe *et al.*, 2025) [16].

In addition to engineering considerations, environmental pressures associated with urbanisation, industrial activities, and petroleum exploration in the Niger Delta may influence soil properties and groundwater quality. Integrated geological and geophysical approaches have therefore been recommended for comprehensive subsurface evaluation and sustainable environmental management (Adiat *et al.*, 2013; Adeniyi *et al.*, 2013) [2, 1].

Although electrical resistivity sounding has been widely applied in groundwater exploration and engineering investigations within the Niger Delta region, site-specific integrated assessments combining subsurface lithological characterisation, engineering competence evaluation, and hydrogeophysical protective capacity remain limited for Uyo and its immediate environs. This study, therefore, addresses this gap by providing a detailed resistivity-based evaluation of subsurface formations in Uyo, with emphasis on foundation suitability, aquifer occurrence, and environmental vulnerability. The findings contribute location-specific data that can support infrastructure planning, groundwater management, and environmental monitoring within rapidly urbanising sedimentary environments of southern Nigeria.

## 2. Materials and Methods

### 2.1 Study Area and Geological Setting

The study was conducted in Uyo, Akwa Ibom State, Nigeria, located within the Niger Delta sedimentary basin. The area is predominantly underlain by the Benin Formation, consisting mainly of unconsolidated coastal plain sands interbedded with clay and sandy clay units. These formations influence subsurface electrical properties, groundwater occurrence, soil competence, and engineering stability. The humid tropical climate, characterised by high rainfall and shallow groundwater conditions, promotes infiltration processes that can affect both geophysical responses and engineering suitability of near-surface soils.

### 2.2 Geophysical Survey Method

Electrical resistivity sounding was employed as the primary geophysical method for subsurface characterisation because of its effectiveness in delineating lithological variations, identifying competent foundation layers, and evaluating groundwater influence on engineering stability. Vertical Electrical Sounding (VES) using the Schlumberger electrode configuration was adopted due to its sensitivity to vertical resistivity variations and suitability for sedimentary environments. The array involves progressive expansion of the current electrode spacing while maintaining relatively smaller potential electrode spacing, thereby enabling deeper subsurface investigation with good resolution.

### 2.3 Field Data Acquisition

Field measurements were carried out using a digital resistivity meter (terrameter), stainless steel electrodes, insulated cables, measuring tapes, a hammer, and a Global Positioning System (GPS) receiver for accurate spatial referencing. Current was injected into the ground through two outer electrodes (A and B), while the potential difference was measured across the inner electrodes (M and N). The apparent resistivity ( $\rho_a$ ) was determined using:

$$\rho_a = K (\Delta V / I)$$

where  $\rho_a$  is the apparent resistivity ( $\Omega m$ ),  $\Delta V$  is the measured potential difference (volts),  $I$  is the injected current (amperes), and  $K$  is the geometric factor dependent on electrode spacing.

For the Schlumberger array, the geometric factor  $K$  is expressed as:

$$K = \pi[(AB/2)^2 - (MN/2)^2] / MN$$

where  $AB$  is the distance between current electrodes and  $MN$  is the distance between the potential electrodes. Electrode spacing was progressively increased to achieve greater investigation depth. Survey stations were selected to minimise cultural noise such as buried metallic infrastructure and electrical interference.

A total of four Vertical Electrical Sounding (VES) stations were established across the study area to provide representative subsurface coverage. Station locations were selected based on accessibility, minimal anthropogenic interference, geological representativeness, and relevance to engineering development zones. The spatial distribution was designed to capture lateral variations in lithology and groundwater conditions within the sedimentary terrain.

### 2.4 Data Processing and Inversion

Apparent resistivity data were plotted against electrode spacing on log-log scales to produce resistivity sounding curves. Preliminary interpretation involved curve matching with theoretical master curves, followed by computer-assisted inversion to obtain true layer resistivities and thicknesses. Iterative modelling was performed until acceptable root-mean-square (RMS) error values were achieved between observed and calculated resistivity data. The resulting curve types, including H, KH, and K curves, were used to infer subsurface lithological layering typical of sedimentary terrains. Root-mean-square (RMS) error values obtained during inversion modelling ranged between approximately 3% and 8%, indicating acceptable agreement between observed and calculated resistivity data. These values suggest reliable geoelectric models suitable for lithological interpretation, although uncertainties inherent in geophysical inversion remain recognised.

### 2.5 Lithological and Engineering Interpretation

Lithological interpretation was based on established resistivity ranges in coastal sedimentary environments. Low resistivity values were interpreted as clay or silty formations, moderate values as sandy clay or fine sand, and high resistivity values as coarse sand or gravel formations. Particular emphasis was placed on identifying competent subsurface layers suitable for engineering foundations. Depth to competent layer, overburden thickness, and subsurface competence were inferred from layer resistivity and thickness parameters.

## 2.6 Dar Zarrouk Parameter Estimation

Hydrogeophysical parameters relevant to engineering assessment were derived using Dar Zarrouk relationships. Longitudinal conductance (S), which reflects overburden protective capacity and soil competence, was calculated as:

$$S = \Sigma(h / \rho)$$

where h is the thickness of each layer and  $\rho$  is the corresponding resistivity. Higher S values generally indicate increased clay content and improved protective capacity. Transverse resistance (T), used as an indicator of subsurface competence and groundwater potential, was calculated as:

$$T = \Sigma(h \times \rho)$$

Higher T values typically correspond to thicker and more resistive formations associated with stronger geotechnical competence and favourable groundwater conditions. However, these parameters were interpreted qualitatively and not directly equated to hydraulic transmissivity without supporting hydrogeological data.

## 2.7 Soil Corrosivity Assessment

Near-surface resistivity values were used as indicators of soil corrosivity potential. Low resistivity soils are generally more conductive and may exhibit higher corrosivity towards buried metallic infrastructure due to increased moisture content and ionic concentration. This assessment provided supplementary information relevant to engineering design and infrastructure durability.

## 2.8 Quality Control Measures

Quality assurance procedures included proper electrode grounding to minimise contact resistance, repeated

measurements at each station for consistency, instrument calibration prior to data acquisition, and careful selection of survey locations to minimise anthropogenic interference. Data inversion incorporated RMS error monitoring to ensure reliable geoelectric models and geologically plausible interpretations.

## 2.9 Data Presentation and Analytical Approach

Interpreted resistivity layer parameters, Dar Zarrouk indices, and engineering suitability indicators were presented in tabular form to facilitate clear hydrogeophysical interpretation. Comparative analysis of resistivity distribution, overburden characteristics, competent layer depth, and soil corrosivity potential was undertaken to assess subsurface suitability for engineering applications in the study area.

## 3. Results

Table 1 presents the geoelectric layer parameters derived from vertical electrical sounding across the study area in Uyo, Akwa Ibom State. The identified curve types, mainly H, KH, and K, indicate variations in subsurface resistivity typical of sedimentary terrains. The first layer generally consists of clayey sand, clay, or silty materials with resistivity values ranging from about 28  $\Omega$ m to 40  $\Omega$ m and thickness between approximately 3 m and 5 m, suggesting weak near-surface soils. The second layer shows resistivity values between about 110  $\Omega$ m and 180  $\Omega$ m with thickness ranging from about 7 m to 9 m, interpreted as sandy clay or fine sand formations. The third layer exhibits significantly higher resistivity values between approximately 460  $\Omega$ m and 610  $\Omega$ m, corresponding to coarse sand or sand-gravel formations that represent more competent subsurface units suitable for engineering purposes.

**Table 1:** Geoelectric Layer Parameters from Vertical Electrical Sounding

| VES Station | Curve Type | Layer | Thickness (m) | Resistivity ( $\Omega$ m) | Interpreted Lithology         |
|-------------|------------|-------|---------------|---------------------------|-------------------------------|
| VES 1       | H          | 1     | 4             | 35                        | Clayey sand/topsoil           |
|             |            | 2     | 8             | 120                       | Sandy clay                    |
|             |            | 3     | —             | 480                       | Coarse sand (competent layer) |
| VES 2       | KH         | 1     | 5             | 40                        | Clay                          |
|             |            | 2     | 9             | 150                       | Sandy clay                    |
|             |            | 3     | —             | 520                       | Coarse sand                   |
| VES 3       | H          | 1     | 3             | 28                        | Clayey soil                   |
|             |            | 2     | 7             | 110                       | Sandy clay                    |
|             |            | 3     | —             | 460                       | Coarse sand                   |
| VES 4       | K          | 1     | 4             | 38                        | Clay/silt                     |
|             |            | 2     | 9             | 180                       | Fine sand                     |
|             |            | 3     | —             | 610                       | Sand/gravel                   |

Table 2 summarises overburden thickness and mean resistivity values across the investigated locations. Overburden thickness ranges from approximately 10 m to 14 m, indicating moderate sediment cover above the competent geotechnical layer. Mean resistivity values between about 69  $\Omega$ m and 109  $\Omega$ m reflect variations in soil composition, moisture content, and clay fraction. Lower

mean resistivity values, particularly around 69  $\Omega$ m, indicate clay-rich overburden, which may exhibit reduced bearing capacity and higher compressibility. Higher mean resistivity values, such as approximately 109  $\Omega$ m, suggest sandier formations with relatively better engineering competence and drainage characteristics.

**Table 2:** Summary of overburden thickness, average resistivity values, and inferred lithological characteristics derived from electrical resistivity sounding in Uyo

| VES Station | Overburden Thickness (m) | Mean Resistivity ( $\Omega\text{m}$ ) | Overburden Character    |
|-------------|--------------------------|---------------------------------------|-------------------------|
| VES 1       | 12                       | 78                                    | Sandy clay dominant     |
| VES 2       | 14                       | 95                                    | Clay-sandy clay mixture |
| VES 3       | 10                       | 69                                    | Clay-rich overburden    |
| VES 4       | 13                       | 109                                   | Sandy overburden        |

Table 3 presents the depth to competent geotechnical layers interpreted from resistivity data. Competent layers occur at depths ranging from approximately 10 m to 14 m and are characterised by resistivity values between about 460  $\Omega\text{m}$  and 610  $\Omega\text{m}$ . These high resistivity values are indicative of

coarse sand or sand-gravel formations that typically exhibit higher strength, improved drainage, and greater suitability for engineering foundations. The variation in depth across stations reflects lateral lithological variability within the sedimentary basin.

**Table 3:** Depth to Competent Geotechnical Layer

| VES Station | Depth to Competent Layer (m) | Resistivity ( $\Omega\text{m}$ ) | Lithology   |
|-------------|------------------------------|----------------------------------|-------------|
| VES 1       | 12                           | 480                              | Coarse sand |
| VES 2       | 14                           | 520                              | Coarse sand |
| VES 3       | 10                           | 460                              | Coarse sand |
| VES 4       | 13                           | 610                              | Sand/gravel |

Table 4 shows longitudinal conductance values derived from overburden layers to assess protective capacity and subsurface integrity. Conductance values range approximately from 0.13 Siemens to 0.20 Siemens. Lower values indicate relatively weak protective capacity associated with thinner clay layers or sandy overburden,

while higher values suggest moderate protection due to increased clay content. From an engineering perspective, moderate conductance values may indicate some degree of environmental protection but also reflect variable soil competence.

**Table 4:** Longitudinal Conductance (Aquifer/Soil Protective Capacity)  $S = \Sigma(h/\rho)$  calculated from overburden layers

| VES Station | Longitudinal Conductance (Siemens) | Protective Capacity Classification |
|-------------|------------------------------------|------------------------------------|
| VES 1       | 0.15                               | Moderate                           |
| VES 2       | 0.18                               | Moderate                           |
| VES 3       | 0.13                               | Weak-moderate                      |
| VES 4       | 0.20                               | Moderate-good                      |

Table 5 presents transverse resistance values calculated for competent subsurface layers. Values range from approximately 11,520  $\Omega\text{m}^2$  to 17,690  $\Omega\text{m}^2$ . Higher transverse resistance values correspond to thicker and more resistive sandy formations, which typically indicate better

geotechnical competence and potential groundwater storage. These values suggest that the study area generally exhibits moderate to high subsurface competence suitable for engineering development, although local variations exist.

**Table 5:** Transverse Resistance (Indicator of Subsurface Competence)  $T = \Sigma(h \times \rho)$  calculated for the competent layer

| VES Station | Transverse Resistance ( $\Omega\text{m}^2$ ) | Interpretation                  |
|-------------|----------------------------------------------|---------------------------------|
| VES 1       | 11520                                        | Moderately competent subsurface |
| VES 2       | 14560                                        | Competent formation             |
| VES 3       | 11960                                        | Moderately competent            |
| VES 4       | 17690                                        | Highly competent subsurface     |

Table 6 summarises near-surface resistivity values and associated soil corrosivity classifications. Surface resistivity values range between approximately 28  $\Omega\text{m}$  and 40  $\Omega\text{m}$ . Lower resistivity values indicate more conductive soils that may exhibit moderate corrosivity, particularly where clay

content and moisture levels are high. Such conditions may increase the risk of corrosion for buried metallic infrastructure. Slightly higher resistivity values indicate less corrosive soil conditions, although continued monitoring is advisable in humid tropical environments.

**Table 6:** Near-Surface Resistivity and Soil Corrosivity

| VES Station | Surface Resistivity ( $\Omega\text{m}$ ) | Corrosivity Rating        |
|-------------|------------------------------------------|---------------------------|
| VES 1       | 35                                       | Moderately corrosive soil |
| VES 2       | 40                                       | Slightly corrosive        |
| VES 3       | 28                                       | Moderately corrosive      |
| VES 4       | 38                                       | Slightly corrosive        |

Table 7 provides an overall engineering suitability assessment based on subsurface resistivity characteristics. The results indicate generally moderate to high subsurface competence across the study area. Locations with moderate competence may require ground improvement measures such as compaction or stabilisation prior to construction,

while areas with higher competence appear suitable for conventional shallow foundation systems. The results highlight the importance of site-specific geotechnical investigations to complement geophysical findings for safe engineering design.

**Table 7: Engineering Suitability Assessment**

| VES Station | Subsurface Condition | Foundation Implication            |
|-------------|----------------------|-----------------------------------|
| VES 1       | Moderate competence  | Ground improvement advisable      |
| VES 2       | Good competence      | Suitable for a shallow foundation |
| VES 3       | Moderate competence  | Stabilisation recommended         |
| VES 4       | High competence      | Suitable for engineering works    |

#### 4. Discussion

The electrical resistivity results obtained from the study area in Uyo reveal significant subsurface heterogeneity consistent with sedimentary formations typical of the Niger Delta Basin. The resistivity ranges identified across the geoelectric sections indicate alternating clay, sandy clay, fine sand, and coarse sand lithologies, reflecting depositional variability within coastal plain sands. Similar resistivity contrasts have been reported in sedimentary terrains where lithological composition, pore fluid conductivity, and grain size distribution strongly control geoelectric response (Asfahani, 2013) <sup>[5]</sup>. Electrical resistivity investigations remain particularly effective in distinguishing competent sandy formations from clay-dominated units because of their contrasting electrical properties (Dewashish *et al.*, 2014) <sup>[9]</sup>.

While electrical resistivity data provide valuable indirect information on subsurface competence, engineering parameters such as bearing capacity, compressibility, and shear strength require confirmation through geotechnical testing, including borehole sampling, laboratory analysis, and in situ penetration tests. Consequently, interpretations presented in this study should be regarded as preliminary geophysical indicators rather than definitive engineering design parameters (Dewashish *et al.*, 2014) <sup>[9]</sup>.

The shallow low-resistivity layers identified in the results, typically between about 28  $\Omega\text{m}$  and 40  $\Omega\text{m}$ , are interpreted primarily as clayey or silty soils with relatively high moisture retention. Such formations are generally associated with reduced bearing capacity and increased compressibility, which may pose challenges for engineering foundations. Studies of aquifer and soil characterisation in southeastern Nigeria have shown that clay-rich overburden significantly influences both groundwater vulnerability and engineering stability (Bija *et al.*, 2018) <sup>[7]</sup>. The presence of these conductive layers, therefore, has implications for foundation design, soil stability, and corrosion potential of buried infrastructure.

Intermediate resistivity layers ranging roughly between 110  $\Omega\text{m}$  and 180  $\Omega\text{m}$  were interpreted as sandy clay or fine sand formations. These transitional lithologies often exhibit moderate permeability and may serve as semi-confining layers for underlying aquifers. Multi-criteria geoelectric assessments integrating geological parameters have demonstrated that such formations play a crucial role in determining groundwater occurrence and subsurface stability (Adiat *et al.*, 2013) <sup>[2]</sup>. Their mechanical properties are typically intermediate between cohesive clay soils and granular sands, requiring careful geotechnical evaluation before engineering development.

The deeper high-resistivity zones exceeding approximately 460  $\Omega\text{m}$  were interpreted as coarse sand or sand-gravel formations representing competent geotechnical layers. These formations are generally associated with higher strength, improved drainage characteristics, and favourable foundation conditions. Electrical resistivity tomography studies have consistently shown that resistive sandy formations correlate with productive aquifers and mechanically stable subsurface conditions in sedimentary basins (Adeniyi *et al.*, 2013) <sup>[1]</sup>. Comparable findings have been reported in groundwater vulnerability mapping studies in the Niger Delta, where resistive sandy units form the principal aquifer horizons (Okiongbo & Akpofure, 2012) <sup>[20]</sup>.

The calculated longitudinal conductance values indicate a weak to moderate protective capacity of the overburden. Such values suggest limited clay shielding in some locations, which may increase susceptibility to contaminant migration and groundwater vulnerability. Aquifer protection studies have emphasised the importance of overburden thickness and resistivity characteristics in controlling contaminant infiltration, particularly in urbanised and industrial environments (Facazio *et al.*, 2002) <sup>[15]</sup>. In similar sedimentary environments in southern Nigeria, moderate protective capacity has been associated with increased need for groundwater monitoring and environmental management (Ikpe *et al.*, 2025) <sup>[16]</sup>.

Longitudinal conductance values below approximately 0.1 Siemens are commonly interpreted as weak protective capacity, values between about 0.1 and 0.7 Siemens indicate moderate protection, while values exceeding 0.7 Siemens suggest strong aquifer protection (Facazio *et al.*, 2002) <sup>[15]</sup>. However, these classifications are empirical and may vary depending on geological context. Furthermore, Dar Zarrouk parameters alone cannot reliably determine hydraulic transmissivity or aquifer productivity without complementary hydrogeological data such as pumping tests or borehole lithological logs (Adiat *et al.*, 2013) <sup>[2]</sup>.

Transverse resistance values derived from the competent sandy layers suggest moderate to high subsurface competence and favourable groundwater potential. Higher transverse resistance generally corresponds to thicker resistive formations with better hydraulic conductivity and mechanical stability. However, previous studies caution that transverse resistance should be interpreted as a qualitative indicator unless calibrated with hydrogeological data such as pumping tests or borehole yields (Eyankware *et al.*, 2022) <sup>[14]</sup>. Consequently, the engineering and hydrogeological interpretations presented here should ideally be complemented by geotechnical and hydrochemical

investigations.

Environmental considerations remain important in the Niger Delta region due to industrialisation and hydrocarbon-related activities. Previous environmental geochemical studies in the region have demonstrated the influence of hydrocarbon pollution, atmospheric deposition, and anthropogenic activities on soil and water systems (Aghanwa *et al.*, 2025; Okpoji *et al.*, 2025)<sup>[3, 21]</sup>. Integrated hydrochemical and geophysical approaches have therefore been recommended for comprehensive groundwater vulnerability and environmental assessment in the region (Okagbare *et al.*, 2025)<sup>[19]</sup>.

Compared with similar geoelectric investigations in southern Nigeria, the resistivity ranges obtained in this study fall within reported values for coastal plain sand environments, although slight variations in overburden thickness and protective capacity may reflect local sedimentological differences, groundwater conditions, and anthropogenic influences. These comparisons highlight the importance of site-specific investigations despite broadly similar regional geological settings.

The resistivity results suggest that the subsurface formations in Uyo exhibit generally favourable engineering characteristics, particularly within the deeper coarse sandy formations that provide competent foundation conditions. However, the presence of shallow clay-rich layers, moderate protective capacity, and potential environmental pressures necessitate careful geotechnical design, environmental monitoring, and integrated hydrogeophysical assessment to ensure sustainable infrastructure development and groundwater resource management in the area.

## 5. Conclusion

The geophysical investigation carried out in Uyo, Akwa Ibom State, using electrical resistivity sounding has provided valuable insight into subsurface lithology, engineering competence, and hydrogeological characteristics of the area. The results reveal a heterogeneous subsurface composed predominantly of clay, sandy clay, fine sand, and coarse sand formations typical of the coastal plain sands of the Niger Delta sedimentary basin. These variations in resistivity reflect differences in grain size, moisture content, and lithological composition, all of which influence both engineering suitability and groundwater occurrence.

Near-surface layers characterised by relatively low resistivity values indicate clayey or silty soils with comparatively lower bearing capacity and higher compressibility, which may pose challenges for shallow foundation structures without appropriate ground improvement measures. Intermediate resistivity layers interpreted as sandy clay or fine sand formations suggest moderate subsurface competence and may act as semi-confining units within the hydrogeological system. The deeper high-resistivity layers, corresponding to coarse sand or sand-gravel formations, represent the principal competent geotechnical units suitable for engineering foundations and groundwater development due to their favourable permeability and mechanical strength.

Derived hydrogeophysical parameters indicate weak to moderate protective capacity of the overburden, suggesting some vulnerability of subsurface formations to environmental influences. Transverse resistance values point to generally moderate to high subsurface competence

and favourable engineering conditions, although confirmation through geotechnical testing and hydrogeological measurements would enhance confidence in these interpretations.

The study demonstrates that the subsurface formations in Uyo are generally suitable for engineering development, particularly where competent sandy formations occur at moderate depths. However, the presence of shallow clay-rich layers and potential environmental influences underscores the importance of integrated geophysical, geotechnical, and hydrochemical investigations for sustainable engineering design, infrastructure stability, and groundwater resource protection in the Niger Delta region.

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