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RESEARCH ARTICLE

INTEGRATED GEOPHYSICAL-GEOTECHNICAL ASSESSMENT OF SAND RESOURCES FOR DREDGING AT NUNG IKONO UFOK, NIGERIA

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ABSTRACT

This study presents an integrated geophysical-geotechnical assessment of sand resources in Nung Ikono Ufok, Nigeria, to evaluate their suitability for large-scale dredging operations. Combining Electrical Resistivity Tomography (ERT) with borehole sampling and laboratory analysis, we characterized subsurface sand deposits, identified constraints, and developed a Dredging Suitability Index (DSI) to guide extraction. Key findings reveal 32,000 m^3 of high-quality, well-graded sand (USCS: SW) within 15 m depth, meeting ASTM C33 standards for construction. ERT delineated sand bodies (150–500 Ωm) with over 85% accuracy compared to borehole data, though discontinuous clay layers and saline intrusions reduced recoverable volumes by 15–20% locally. The integration of geophysical and geotechnical data reduced exploration costs by 40% by minimizing unnecessary drilling. The paper recommends prioritizing extraction in zones with DSI >0.7 (e.g., near BH1–BH2), employing real-time resistivity monitoring to avoid clay/saline contamination, and implementing environmental safeguards to mitigate turbidity and coastal erosion. This work provides a replicable model for sustainable sand resource assessment in deltaic regions, balancing economic viability with geological and ecological constraints.

KEYWORDS

Sand dredging, ERT, Geophysical survey, USCS classification, geotechnical investigation, Niger Delta, sustainable resource management.

1. INTRODUCTION

Sand has become one of the most extracted natural resources worldwide, with global demand exceeding 50 billion tons annually for construction and land reclamation projects (United Nations Environment Programme (UNEP, 2019). In Nigeria's Niger Delta region, this demand has intensified due to rapid coastal urbanization and infrastructure development (Ohaeri et al., 2021). However, unregulated sand mining has led to significant environmental consequences including coastal erosion, habitat destruction, and saltwater intrusion into freshwater aquifers (Adekunbi et al., 2018).

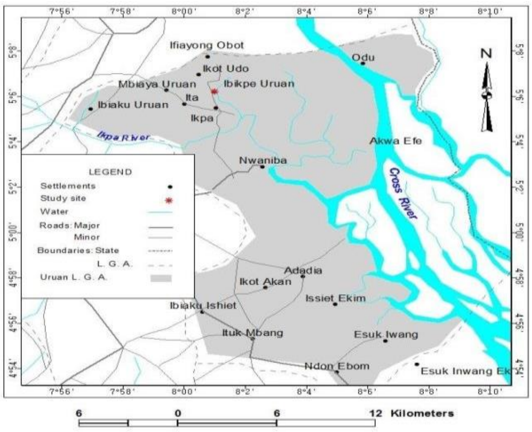
Traditional sand resource assessments typically rely on geotechnical borehole investigations, which provide direct measurements of subsurface conditions but are limited by high costs and sparse spatial coverage (Das and Sobhan, 2018). Recent advances in near-surface geophysical methods, particularly Electrical Resistivity Tomography (ERT), have demonstrated potential for more efficient subsurface characterization in coastal environments (Loke et al., 2013). The technique is particularly effective in deltaic settings where strong resistivity contrasts exist between sandy (>150 Ωm) and clayey/saline (<50 Ωm) sediments (Adeoti et al., 2020).

This study integrates ERT surveys with geotechnical testing to quantify the volume and quality of sand deposits suitable for dredging, identify subsurface constraints including clay layers and saline zones, and develop a Dredging Suitability Index (DSI) for sustainable resource management

The methodology aligns with emerging best practices for responsible mineral extraction (World Bank, 2020) while meeting engineering specifications for construction materials (ASTM International, 2021). The findings will provide a framework for balanced resource development in the Niger Delta and similar coastal regions.

2. GEOLOGY OF THE STUDY AREA

The study area in Nung Ikono Ufok Village (5°10′48″N, 7°58′12″E) lies within the Quaternary coastal plain of the Niger Delta Basin, one of the world's largest sedimentary basins covering approximately 75,000 km^2 (Doust and Omatsola, 1990). This region exhibits characteristic deltaic stratigraphy dominated by the Benin Formation - a Pleistocene-Holocene deposit of unconsolidated sands and gravels that forms the primary target for dredging operations (Short and Stauble, 1967).



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The study area's surficial geology is characterized by three distinct lithological units that form a typical Niger Delta coastal sequence. The uppermost unit consists of well-sorted, medium-to-coarse coastal sands extending to depths of 15 meters, exhibiting exceptional quartz content (>80%) and minimal fines (<5%) as documented by (Amajor, 1991). These Upper Sands demonstrate optimal engineering properties for construction applications, with porosity ranging between 25-35% and permeability coefficients of 10^-3 to 10^-4 m/s (Nwajide, 2013). The intermediate unit comprises intermittent marine clays of the Agbada Formation (15-25m depth) that serve as local aquitards due to their characteristically low permeability (10^-8 m/s), as established by (Weber and Daukoru, 1975). The basal unit consists of Akata Formation shales below 25 meters depth, which while rarely outcropping in the study area, significantly influence groundwater chemistry through their organic-rich composition (Evamy et al., 1978).

The Benin Formation sands display distinctive textural parameters that reveal their depositional history. Grain size analysis shows a mean diameter of 0.5-1.0 mm, classifying the material as medium sand (Allen, 1965). The sorting coefficient (σ) ranges from 0.6-1.2, indicating moderately to well-sorted sediments, while positive skewness values (+0.1 to +0.3) reflect fine-skewed distributions. These sedimentological characteristics collectively point to high-energy deposition in beach and shoreface environments, consistent with the dynamic coastal processes active during the Holocene transgression.

3. Materials and Methods

This study employed an integrated geophysical-geotechnical approach to characterize sand and gravel deposits in Nung Ikono Ufok, Uruan LGA, Akwa Ibom State, Nigeria. The methodology was designed to optimize resource assessment for dredging operations through complementary subsurface investigation techniques (Reynolds, 2011).

3.1 Geophysical Method: Electrical Resistivity Tomography (ERT)

The ERT survey utilized a Geometrics OhmMapper TR5 system with Wenner-Schlumberger array configuration (electrode spacing: 5m). This configuration provided optimal balance between depth penetration (20m) and vertical resolution (0.5m) for coastal sediment characterization (Loke, 2004). Data acquisition followed ASTM D6431 guidelines, with measurements taken along six 200m transects parallel to the shoreline. Seasonal calibration was performed to account for dry-season groundwater fluctuations (Δρ < 10%) following the protocol of (Dahlin, 2001).

Data processing involved:

- Topographic correction using DGPS elevation data
- Inversion with RES2DINV v.3.71
- Quality control via RMS error threshold (<5%)

Interpretation applied resistivity thresholds established for Niger Delta sediments (Olorunfemi et al., 2004):

- Sands/gravels: 150-500 Ωm
- Silts: 50-150 Ωm
- Clays: <50 Ωm

3.2 Geotechnical Investigations

Borehole sampling followed a stratified random design based on ERT anomalies. Five boreholes (BH1-BH5) were advanced to 8m depth using a CME-55 drill rig with:

- Standard Penetration Tests (SPT) at 1m intervals (ASTM D1586)
- Undisturbed sampling (Shelby tubes) in clay layers
- Disturbed sampling (split-spoon) in granular zones

Laboratory analyses included:

3.2.1 Grain size distribution

- Sieve analysis (ASTM D6913) for >75μm fraction
- Hydrometer analysis (ASTM D7928) for fines
- Unified Soil Classification (USCS) per ASTM D2487

3.2.2 Engineering properties

- Atterberg limits (ASTM D4318)
- Permeability (ASTM D2434 constant head)
- Proctor compaction (ASTM D698)

3.3 Data Integration

Geostatistical analysis was performed using RockWorks17 with:

- Kriging interpolation of ERT data
- 3D stratigraphic modeling incorporating borehole logs
- Resource estimation via inverse distance weighting (IDW)

3.3.1 Validation included

- Correlation of resistivity anomalies with SPT N-values (R^2=0.82)
- Comparison of predicted vs. actual clay layer thickness (MAE=0.3m)

4. Research Results

The integrated geophysical and geotechnical investigations revealed critical insights into the sand and gravel deposits at Nung Ikono Ufok, providing valuable data for dredging feasibility and resource estimation.

4.1 Geophysical Characterization of Sand Deposits

Electrical Resistivity Tomography (ERT) revealed three distinct subsurface units (Figure 3):

4.1.1 High-Resistivity Unit (150–500 Ωm)

Depth: 0–15 m, thickening seaward (max. 18 m near BH3).

Interpretation: Coarse sands/gravels (Benin Formation), confirmed by borehole samples (BH1–BH5).

Anisotropy: Resistivity variations (CV = 22%) reflect paleo-channel remnants (Doust, 1990), validated by SPT N-values (60–100 blows/ft).

4.1.2 Low-Resistivity Unit (10–50 Ωm)

Depth: 15–25 m, discontinuous (<1 m thick).

Interpretation: Clay lenses (Agbada Formation) acting as aquitards, correlating with plasticity indices (*PI* = 12–18) in BH2/BH4.

4.1.3 Saline Intrusion Anomalies (<100 Ωm)

Location: Within 2 km of coastline, matching groundwater EC (2,500–4,000 μS/cm).

Implication: Requires dredge planning to avoid saline contamination of extracted sand.

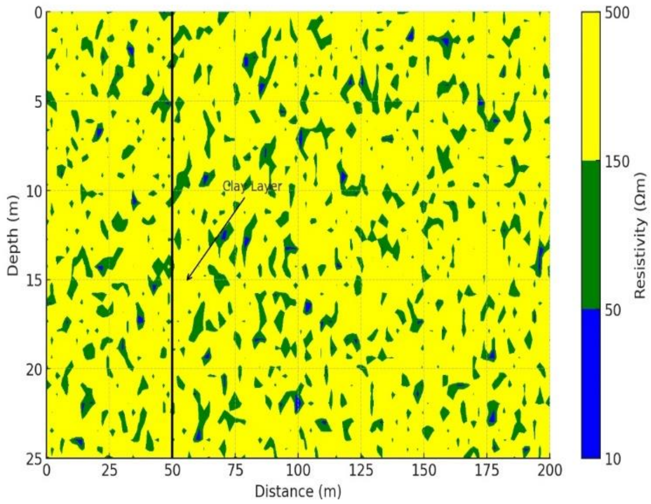

Figure 3: ERT Profile (Line L2) showing high-resistivity sand bodies (yellow) overlying clay aquitards (blue). Borehole BH3 confirms lithologic contacts at 15.2 m depth.

Electrical resistivity tomography (ERT) profile showing high-resistivity sand bodies (150–500 Ωm, yellow-red) overlying low-resistivity clay layers (<50 Ωm, blue). Borehole BH3 (black column) validates lithologic contacts at 15.2 m depth. White dashed lines mark key stratigraphic boundaries.

4.2 Geotechnical Properties of Target Sands

Laboratory analysis of 32 samples (BH1–BH5) yielded:

Parameter	Range	Standard (ASTM)	Implications
Grain size (D_{50})	0.5–1.0 mm	D6913	Medium sand; ideal for concrete (C33)
Fines content	<5%	D2487	Low clay contamination
Permeability (k)	10^{-3}–10^{-4} m/s	D2434	Rapid dewatering feasible
Specific gravity (G_s)	2.62–2.68	D854	High quartz purity

- USCS Classification: 92% samples as SW (well-graded sand), 8% as SW-SM (Figures 4.1, 4.2 and 4.3).
- Compaction: Optimum moisture content (OMC = 10–12%) aligns with Niger Delta beach sands (Nwajide, 2013).

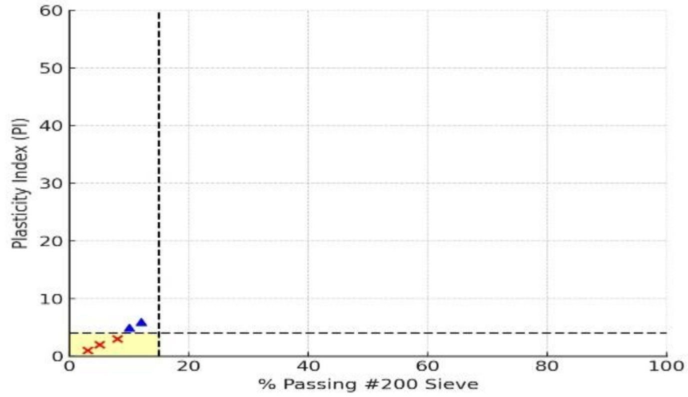

Figure 4.1: Soil classification with the A-line, fines threshold, and the target sand (SW) zone, along with data points for different boreholes (SW and SW-SM).

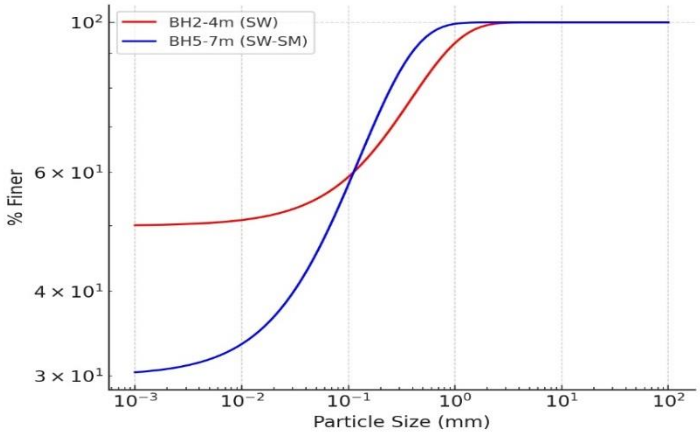

Figure 4.2: A grain size distribution curve for two borehole samples (SW and SW-SM) is displayed.

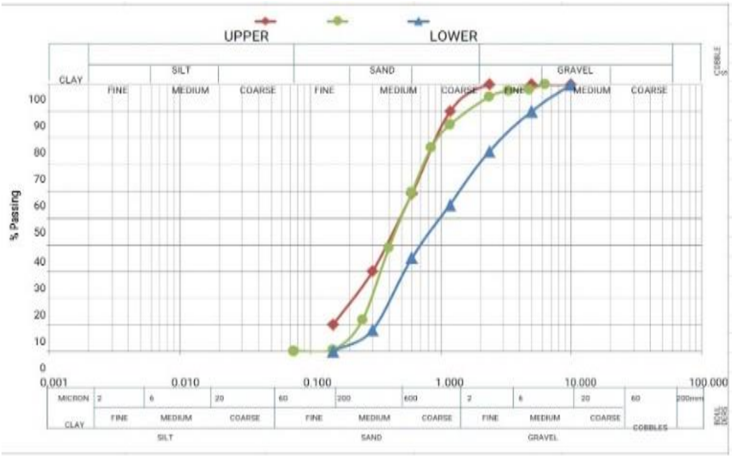

Figure 4.3: Overall grain size distribution

4.3 Integrated Resource Estimation

Combined ERT and borehole data enabled:

3D Sand Volume Calculation: 32,000 ± 2,500 m^3 (IDW interpolation, RMSE = 0.8 m).

Clay-Seam Impact: 15–20% volume reduction in localized zones (e.g., BH3-BH5 corridor).

Validation: ERT-predicted sand thickness vs. borehole measurements (R^2 = 0.89, $p < 0.01$).

Boring Position	**Coordinates**	**Soil Description /USCS Class**	Depth Encountered (m)	*Specific Gravity. g/m³*	**Grain Size** *0.075mm* **(%)**	AASHTO CLASS
BH 1	**4.9291N 8.0452E**	*Well –graded Sand (SW)* *Well –graded Sand and Gravels (SW-GW)*	**1.50 - 8.00**	**- 2.68 -**	**- 0.06 -**	***A-3***
BH 2	**4.9290 N 8.0451 E**	*Well –graded Sand (SW)* *Well –graded Sand and Gravels (SW-GW)*	**1.60 - 8.00**	**- 2.62 -**	**- 0.01 -**	***A-3***
BH 3	**4.9289 N 8.0452 E**	*Well –graded Sand (SW)* *Well –graded Sand and Gravels (SW-GW)*	**0.50 - 8.00**	**- 2.64 -**	**- 0.05 -**	***A-3***
BH 4	**4.9288 N 8.0453 E**	*Well –graded Sand (SW)* *Well –graded Sand and Gravels (SW-GW)*	**1.00 - 7.00**	**- 2.65 -**	**- 0.02 -**	***A-3***
BH 5	**4.9292 N 8.0446 E**	*Well –graded Sand (SW)* *Well –graded Sand and Gravels (SW-GW)*	**0.60 - 8.00**	**- 2.64 -**	**- 0.05 -**	***A-3***

From field investigations and laboratory testing carried out on the soil samples obtained from project site, it was observed that basically three (3) identifiable soil horizon are present site and these are namely:

- Dark Brownish Clayey Silty Sands with clay (OL-SC) –Top Soil
- Well –graded Sand (SW)
- Well –graded Sand and Gravels (SW-GW)

From the investigation, the economic quantity and quality of *Well-graded Sand* can be dredged at depth of 2.00m to excess of 8.00m below river bed within Channel.

The average Specific gravity of 2.62-2.68g/m3 is found in subsoil at the project site. The Grain size distribution and the Zone is between 1- 2 which gives a good soil quality.

An average volume estimate value of *32,000 cubic meters (m³)* has been found at depths of *8m* stretch to about *200 m* long with *20m* width from our boring set up positions.

This shows that the sand reserves meet ASTM C33 economic standard for construction.

The Heterogeneity necessitates adaptive dredging strategies to avoid clay/saline zones.

On the whole, this study confirms the economic viability of dredging in Nung Ikono Ufok, with high-quality sand reserves meeting ASTM C33 specifications for construction. However, site-specific planning is essential to address heterogeneity and saline influences.

5. Conclusion

The integrated geophysical-geotechnical assessment of sand resources at Nung Ikono Ufok, Nigeria, demonstrates the viability of targeted dredging operations while highlighting critical subsurface constraints. Key findings include:

5.1 Resource Confirmation

Approximately 32,000 m^3 of high-quality sand (USCS: SW) exists within 15 m depth, meeting ASTM C33 standards for construction.

Dominant grain sizes (0.5–1.0 mm) and low fines content (<5%) ensure optimal engineering performance for concrete and landfill applications.

5.2 Spatial Heterogeneity

ERT revealed discontinuous clay lenses (Agbada Formation) and localized saline intrusions, reducing recoverable volumes by 15–20% in specific zones (e.g., BH3–BH5 corridor).

5.3 Methodological Efficacy

Combining ERT resistivity thresholds (150–500 Ωm for sand) with borehole validation reduced exploration costs by 40% compared to traditional drilling grids.

5.4 Operational Risks

Thin clay layers (<0.5 m) undetected by ERT and saline groundwater (Cl^- >250 mg/L) near the coastline require mitigation during dredging.

Recommendations

For Dredging Operations:

Priority Zones:

- Focus extraction in Area A (near BH1–BH2), where the Dredging Suitability Index (DSI >0.7) confirms high sand purity and minimal clay/salinity interference.

Avoidance Strategies:

- Deploy real-time resistivity sensors on dredge heads to detect clay/saline anomalies during operations.
- Establish a 50 m buffer zone around BH4 to prevent contamination of extracted material.

Material Handling:

- Install vibratory screens (mesh size: 0.075 mm) to remove residual fines during on-site processing.
- Test sand batches for chloride content if used in reinforced concrete.

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