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INTEGRATING BOREHOLE DRILLING AND GRAIN SIZE STATISTICAL ANALYSIS FOR IN-DEPTH SUBSURFACE CHARACTERIZATION.

Theresa . U. Miuweme *, Arobo, R. Amakiri, Iyeneomie Tamunobereton-ari and Jiriwari Amonieah.

Department of Physics, Faculty of Science, Rivers State University, Port Harcourt, Rivers State, Nigeria.
* Corresponding Author

ORCID Details
Theresa Uzeezi Miuweme: https://orcid.org/0009-0006-5084-9290
Arobo Raymond Amakiri: https://orcid.org/0000-0002-1662-4550
Iyeneomie Tamunobereton-ari: https://orcid.org/0009-0005-3547-8164
Jiriwari Amonieah: https://orcid.org/0009-0004-8222-9999

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ABSTRACT

Evaluation of the sedimentological architecture, geotechnical quality and dredging viability of an area in the shallow Quaternary sand reserves within the Uduere community was conducted , integrating borehole drilling and statistical analysis for an in-depth subsurface characterization . Subsurface lithological logging across two 60ft (18.3m) boreholes (UPH-1 and UPH-2) coupled with statistical grain-size distribution parameters and empirical hydrodynamic modeling was carried out , a Lithostratigraphic logs delineate a distinct bipartite profile comprising a 25 ft (7.6 m) fine-grained overburden cap overlying a continuous sand pay-zone (>35 ft / 10.7 m thick), establishing an economically viable waste-to-ore stripping ratio of 0.71. Statistical granulometric analysis of the pay-zone demonstrates an ultra-low silt/clay wash loss (<2.0% fines), complying directly with structural aggregate standards without requiring post-dredge washing. Computed statistical parameters including a Fineness Modulus (FM = 3.37), median grain diameter (D_{50} = 0.225 mm), and uniformity coefficient ($C_u = 2.400 - 2.525$) classified the deposit as a uniform, medium-to-coarse aggregate tailored for heavy structural concrete, asphalt sub-bases, and land reclamation. Hydro-geotechnical modeling reveals high matrix porosity ($n = 41.4\% - 41.8\%$) and intrinsic permeability ($k = 14.93 - 22.02$ Darcies; $K = 12.44 - 18.35$ m/day), ensuring minimal cutter-head excavation energy, continuous pit-wall slumping during suction dredging, and rapid stockpile dewatering. This integrated methodological framework confirms that the deposit represents a premium, commercially viable reserve.

Keywords: Bipartite, Economic Pay-Zone, Excavation, Stripping Ratio.

1 INTRODUCTION

Borehole data are primary gotten from borehole drilling which can be effectively used to gather subsurface samples from a chosen study area [1],[2] and [3]. The data obtained in such area, is aimed to uncover and correlate key variables that offer deeper insights into the subsurface characteristics. Thus, subsurface characterization is crucial in fields such as hydrogeology, geotechnical engineering, and environmental science [4].

Borehole data obtained are direct observation and provides direct access to subsurface materials [5]. Grain size distribution is one of the main primary data derived from borehole drilling and, is a crucial parameter that influences soil classification, permeability, porosity and mechanical behavior which is employed in understanding and interpreting sedimentology and some aspects of geotechnical engineering [6] and [7]. Standard practice involves analyzing samples collected at regular intervals from boreholes to capture the vertical variation of the subsurface [8]and[9].

Statistical Analysis is a tool for collecting and analyzing large amount of data in order to identify a trend and develop valuable insights [10].There are two main types of Statistical analysis Descriptive analysis and, Inferential analysis. Descriptive summaries the information without drawing conclusions about the contents while Inferential statistics on the other hands, takes the results of descriptive by drawing conclusion from the data and then making recommendations that might influence decisions making [11]and[12].

Some of the measurable parameters employed in statistical parameters includes:

- **The Graphic Mean(** M_z) established by [13] represents the central statistical measure of average grain diameter across a sediment population . It incorporates three(3) critical points from the cumulative frequency curve in phi (ϕ)[14].
- **Skewness** quantifies the asymmetry of the grain-size distribution curve — whether it leans toward finer or coarser fractions [15].
- **Fineness Modulus (FM)** is a dimensionless index defined by [16] and [17] to evaluate the coarseness of fine aggregates.
- **Graphic Sorting (** σ **) / Grain sorting -**Grain sorting evaluates the uniformity of particle sizes within a deposit.
- **Coefficient of Uniformity (** C_u **),** introduced by[18] and an integral to the Unified Soil Classification System [19] and [20] measures the range of grain sizes in a soil sample.
- **Graphic Kurtosis (** K_G**)** measures the ratio of sorting in the central portion of the distribution curve to sorting in the extreme tails [13].
- **(vii)The Coefficient of Curvature (** C_C) measures the smoothness and continuity of the grain size distribution curve.
- **(viii)Graphic Skewness (** S_{k_1} **)** measures the degree of asymmetry of the grain size
- distribution relative to a normal Gaussian bell curve[13].
- **(ix)Porosity(** η**)** defines the ratio of void space volume (V_v) to total formation volume (V_t).
- **(x)Hydraulic Conductivity (K)and Intrinsic Permeability (k)** Hydraulic conductivity (m/s or m/day) measures the rate of water movement through a porous matrix under a hydraulic gradient while Intrinsic Permeability (m^2 or Darcy) measures the permeability of the sediment structure independent of the fluid density and viscosity.

1.1 Geology And Description Of The Study Area.

The study area is situated in in Uduere community ,Ughelli North Delta State (Figures 1 and 2) with an elevation of thirteen meters (13m) above the sea level (Mapcarta,). It is an onshore community that lies in the western segment of the prolific Niger Delta Basin, specifically situated within the Greater Ughelli Depobelt- a major, structurally controlled hydrocarbon rich depobelt of Oligocene to Miocene age and it is topographically draped by Quaternary-to Recent surficial sediments. According to [21] and[22] , this stratigraphic unit is approximately 40m to 150 m thick and it belong to the Sombreiro- Warri Deltaic Plain. It consists primarily lateral continuous, poorly sorted, fine -to- medium -and coarse-grained micaceous sands intercalated with localized silts and clays. [23] and [24] attributes its depositional setting to Late Quaternary marine transgressions representing an admixture of fluvial, tidal channel, and freshwater swap deposits.

Its porosity, permeability and transmissivity are relatively high [25]. The Sand is highly unconsolidated, porous and lack a dense lateral clay capping. which facilitate rapid fluid percolation; thus, the local water table is susceptible to near - surface contamination from urban waste, agricultural runoff, and hydrocarbon pollutants[26].

Some work done in the Niger Delta region include , an integrated geotechnical assessment of sand resource at Nung Ikono Ufok that demonstrated the suitability for large- scale operation [27]has a dredging index (DSI) > 0.7 as a guide for extraction. [28] carried out Grain size analysis of beach sand around Eastern Dahomey Basin and stated that the result of analysis aid in the assessment of the beach vulnerability to erosion and flooding. [29] were able to estimate the grain sizes and statistical parameters of a quaternary aquifer in Bayelsa using the conventional Sieve analysis, the study established an average grain size ranging 0.37mm to 0.95mm (average 0.60mm) which were shown to be well- graded.

This study intends to interpret In-depth subsurface characterization using borehole drilling data and grain size statistical analysis parameters.

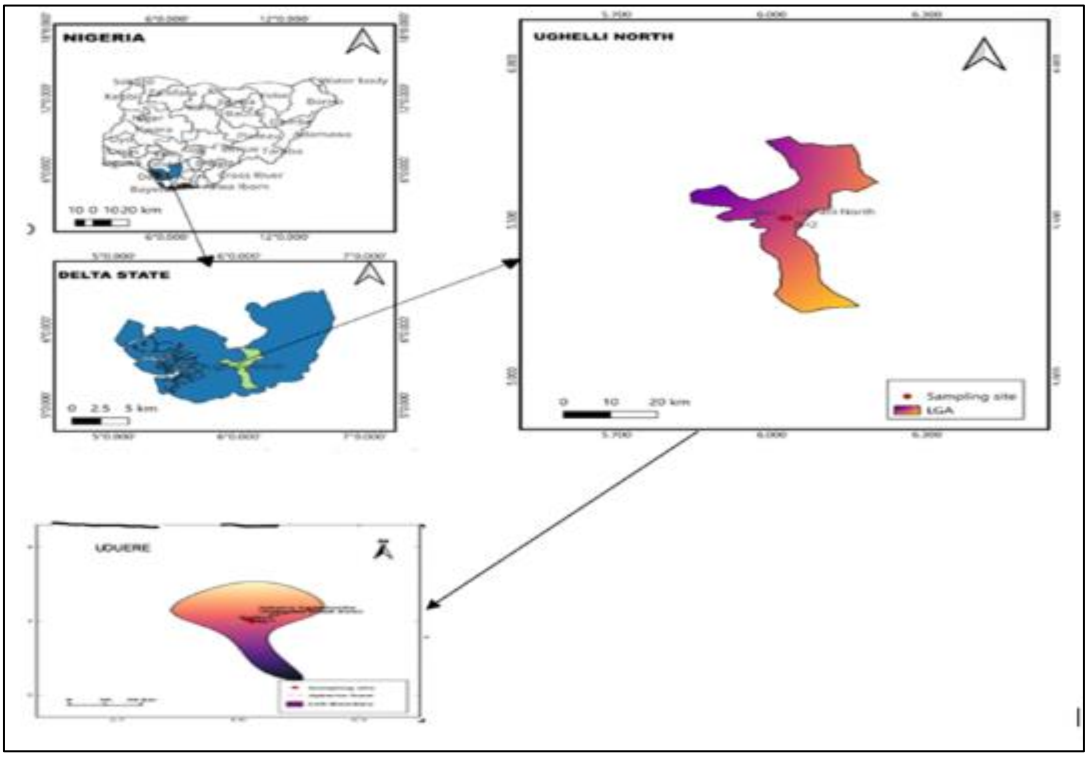


Figure 1: Owhere- Uduere Community, Ughelli North Delta State (GIS)

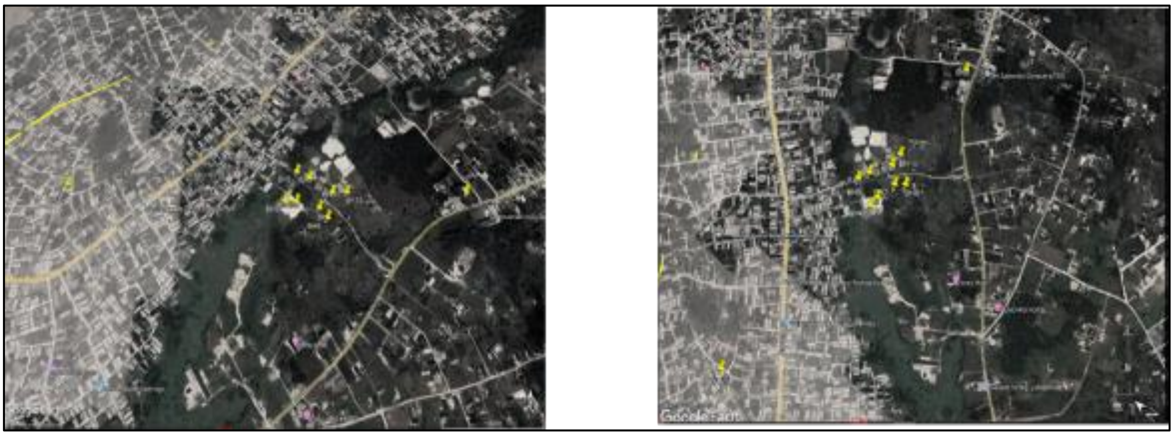


Figure 2: Google Earth Image Showing the Sprawling of the Study Area. (Uduere Community, Ughelli North July,2026)

1.2 Lithology

The lithofacies units in this region are Sandstone, shaly sand, sandy shale, clay, sandy clay, clayey sand, and shale. The mineralogy found are quartz, feldspar, and glauconite [30].

From the Stratigraphy and lithology of this Geological province, the Uduere community sand is part of the Benin formations which are highly porous and permeable and suitable for borehole drilling, groundwater studies. The focus of this study is sand characterization ;thus, analysis of borehole samples is used to quantify grain size distribution which is one of the components for subsurface characterization.

Although Niger Delta is prone to flooding and erosion which may affect shallow borehole stability, combining borehole drilling parameters derived with statistical methods interpretation give an improved accuracy in subsurface characterization.

2 MATERIAL AND METHODS

2.1 Borehole

Two boreholes were drilled to a depth of about 30m in order to gain access to lithological and stratigraphic information. Percussion rotary drilling method was used in drilling the boreholes which were lithologically logged and sampled at 1.5 m (5ft) interval or when characteristics of the sediment changed based on their grain size and color. Figure(3) display a lithologies correlation of the two boreholes.

2.1.1 Stripping ratio

From the correlated lithologies, the depths of each sediment are specified, from which the stripping ratio is computed.

$$\text{Stripping ratio}= \frac{Thickness\ of\ Ovetburden}{Thickness\ of\ Sand\ Pay\!-\!Zone} = \frac{T_O}{T_{Pz}} \tag{1}$$

Where;

Thickness of overburden (T_o)= top surface (0)- X (where noticeable sand/ minable sediment starts)

Thickness of Sand Pay-Zone T_{Pz} = X- End of the borehole of noticeable sandy stratum.

2.1.2 Sieve analysis

Sieve analysis procedure was carried out to determine the particle size distribution in each sand sample using sieve apparatus (sets of Sieves, Mechanical Sieve shaker, Weighing balance, Brush for cleaning sieves, and Oven. The Sieve sizes used were 4.75mm, 3.35mm

, 2.36mm, 1.18mm, 850 microns, 600 microns, 300 microns, 150 microns, 75 microns, and Pan.

Over 150 g of the drill cuttings from the sandy horizon were dried and used for particle size analysis using mechanical sieving technique using Ro-tap shaker [31].

- The required numbers of sieves were arranged in a descending manner. (i.e. keeping the sieve having largest size opening at the top and the smallest size opening at the bottom), and placed the weighed sample in the set of sieves and shaken for five minutes. The material retained on each sieve were then weighed.
- Then percentage retained on each sieve was calculated which shows the particle distribution of the sample. The results of the test were used to produce the grain size distribution curve, which was used to classify the sand and to predict its behavior.
- Using the grain size distribution curve, Statistical parameters were gotten from which sand was graded. The grading process was in accordance with American Association of Highway and Transportation Officials (AASHTO) soil classification system.

2.1.3 Grain size chart

According to the unified Soil Classification system [19]and[20]:

Grain Size (mm)	Category	Description
> 4.75 mm	Gravel	Coarse particles
2.0 – 4.75 mm	Coarse sand	Large sand grains
0.425 – 2.0 mm	Medium sand	Moderate-sized grains
0.075 – 0.425 mm	Fine sand	Fine sand grains
< 0.075 mm	Silt and clay	Very fine particles

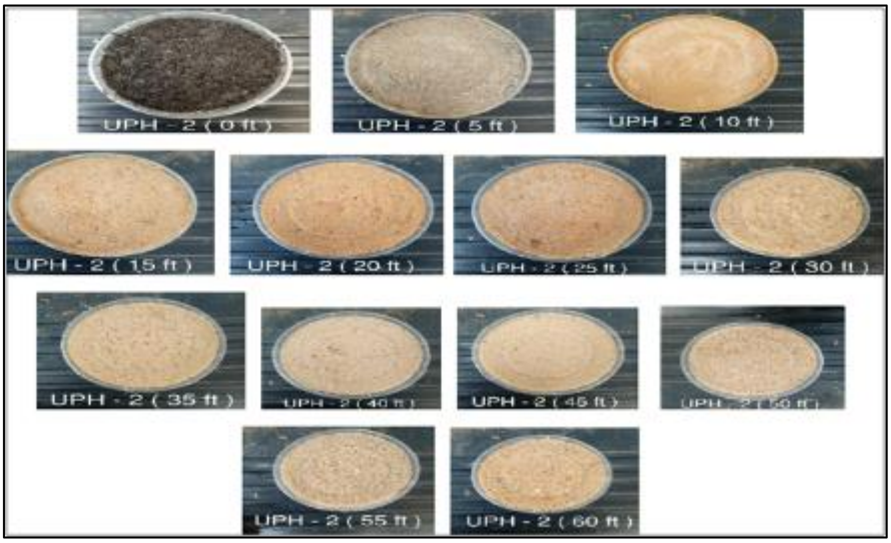


Figure 3 : Examples of Sand Samples from Borehole

2.2 Statistical Analysis

Statistical analysis of subsurface sand before dredging is crucial for determining resource quality, volume, and extraction feasibility, when combined with borehole profiling it creates a predictive model that safe-guide and implement a cost-effective dredging operations endeavor.

The following equations are used to obtain some Statistical Parameters;

$$C_u = \frac{d_{60}}{d_{10}} \quad (2)$$

$$C_c = \frac{d_{30}^2}{d_{60} \times d_{10}} \quad (3)$$

$$FM = \frac{\sum(\text{Cumulative \% Retained on Standard Sieves})}{100} \quad (4)$$

$$\text{Graphic Mean (GM)} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \quad (5)$$

$$\text{Graphic Sorting (Standard deviation)} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} + \phi_5}{6.6} \quad (6)$$

$$\text{Skewness} = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} + 2\phi_{50}}{2(\phi_{95} - \phi_5)} \quad (7)$$

$$\text{Grain sorting } (S_0) = \left(\frac{d_{25}}{d_{75}}\right)^{1/2} \quad (8)$$

$$\text{Skewness}, S_k = \left(\frac{d_{25} \times d_{75}}{d_{50}2}\right) \quad (9)$$

$$\text{Kurtosis} = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})} \quad (10)$$

$$\text{Median grain size} = d_{50} \quad (11)$$

2.2.1 POROSITY AND PERMEABILITY (HYDRAULIC CONDUCTIVITY).

To compute the Porosity and Permeability, Equations 1, 6 and 11 are used and since Sieve Analysis measures grain diameters rather than void spaces, an empirical models based on grain packing and uniformity approach are used, thus for the Porosity;

2.2.2 Vukovic and Soro Model (1992)

To estimates total porosity (η) directly from the uniformity Coefficient ($C_u = \frac{d_{60}}{d_{10}}$)

$$\eta = 0.255 \times (1 + 0.83^{C_u}) \quad (12)$$

2.2.3 Beard and Weyl Method (1973)

This method established a direct empirical relationship between Graphic Sorting (σ_1) and Porosity in unconsolidated sand deposits.

Table 1:Relationship between Graphic Sorting and Porosity

Sorting Classification	Sorting Ranges ($\sigma_1$in ϕ)	Estimated Porosity (η
Very Well Sorted	< 0.35	42 %
Well, Sorted	0.35 - 0.50	39 %
Moderately sorted	0.71 - 1.00	34 %
Poorly Sorted	1.00 -2.00	28 % -32 %

For the Permeability;

$$k= K. (\frac{\mu}{\rho.g}) \quad (13)$$

Hazen Equation for K

$$K= C_H \cdot (d_{10})^2 \quad (14)$$

And Beyer Equation for K is given as

$$K = 6 \times 10^{-4} .(\frac{g}{v}). log_{10} (\frac{500}{C_u}) .(d_{10})^2 \quad (15)$$

This account for grain sorting, valid for 1< C_u< 20 and 0.06mm < d_{10} < 20 .

Where;

k = Permeability (m^2)

K= Hydraulic Conductivity (m^2)

μ = Dynamic Viscosity ($\frac{kg}{m.s}$) (Represents the internal resistance to flow~ 1.002× 10^{-3}at 20°C) d_{10} = Effective grain size in meters (d_{10} in mm/ 1000)

ρ = Fluid Density ($\frac{kg}{m.s}$)

C_H = Empirical constant (typically 100cm^{-1} s^{-1} for loose / medium sand)

g. = Gravitational Acceleration (9.81m/s^2)

v = Kinematic Viscosity of water (~ 1.004 × 10^{-6} m^2 /s at 20°C)

(Note: At Standard temperature (20°C), 1 Darcy= 9.8692 × 10^{-9}cm^2

ρ= 998.2kg/ m^3 g =9.81m/s^2), the fluid factor is~ 1.0233× 10^{-7})

In other to be certain about the type of sand in a particular stratum, the total weight at any particular depth can be computed using ;

Fine mass (g) = (Weight Retained on 0.075mm Sieve) , thus, the percentile at the depth is given as;

$$\% \text{ Fine} = \left(\frac{Fines\ Mass\ (g)}{Total\ Mass\ Retained\ Across\ all\ the\ Sieves\ (g)}\right) \quad (16)$$

3 RESULTS

A lithological diagram shown Figure 4 for the two boreholes drilled to showcase the different lithologies at various depth level.

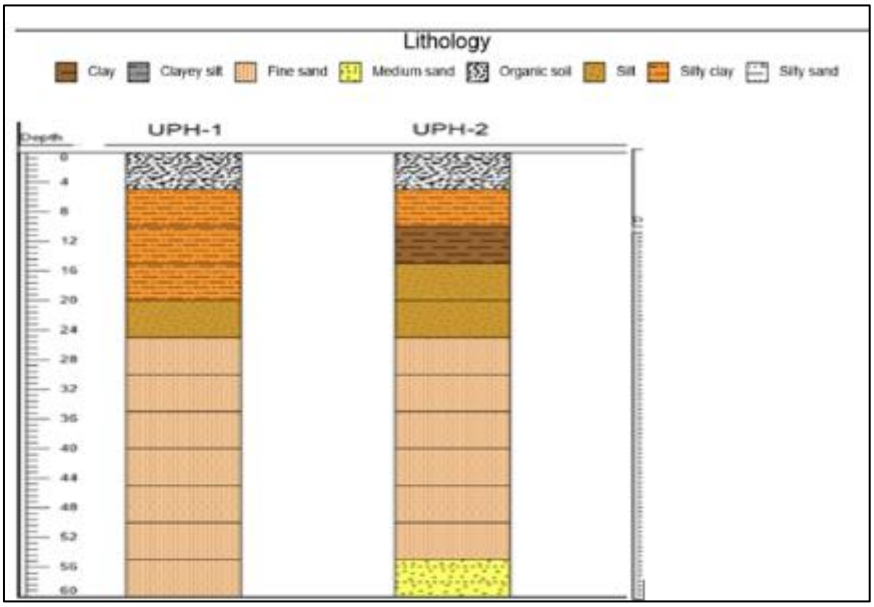


Figure 4 : Lithological information obtained from the test holes.

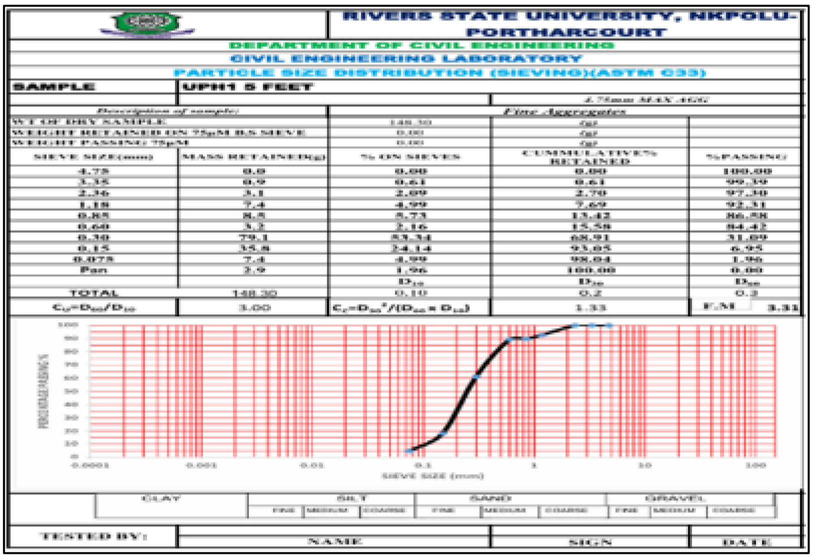
Depth 0-24 ft shows different lithologies from clay –(clayey-silt)-silt-(silty -clay/sand), but at deeper depth there is consistencies notable, depth 24-50ft which is mainly fine-medium sand. And Figure 5 shows a typical grain size distribution parameters and curve.

3.1 STRIPPING RATIO

The computed Stripping ratio can be computed using equation (1)

Stripping ratio= ~ 0.71

(In shallow alluvial mining across the Niger Delta, a stripping ration below 1.0 is considered economically viable for dredging operations).



RIVERS STATE UNIVERSITY, NKPOLU-PORTHARCOURT
DEPARTMENT OF CIVIL ENGINEERING
CIVIL ENGINEERING LABORATORY
PARTICLE SIZE DISTRIBUTION (SIEVING)(ASTM C33)

SAMPLE	UPH1 5 FEET			
			4.75mm MAX AGG	
Description of sample:		Fine Aggregates		
WT OF DRY SAMPLE		148.30	(g)	
WEIGHT RETAINED ON 75µM BS SIEVE		0.00	(g)	
WEIGHT PASSING 75µM		0.00	(g)	
SIEVE SIZE(mm)	MASS RETAINED(g)	% ON SIEVES	CUMMULATIVE% RETAINED	%PASSING
4.75	0.0	0.00	0.00	100.00
3.35	0.9	0.61	0.61	99.39
2.36	3.1	2.09	2.70	97.30
1.18	7.4	4.99	7.69	92.31
0.85	8.5	5.73	13.42	86.58
0.60	3.2	2.16	15.58	84.42
0.30	79.1	53.34	68.91	31.09
0.15	35.8	24.14	93.05	6.95
0.075	7.4	4.99	98.04	1.96
Pan	2.9	1.96	100.00	0.00
		D_{10}	D_{30}	D_{60}
TOTAL	148.30	0.10	0.2	0.3
$C_U=D_{60}/D_{10}$	3.00	$C_c=D_{30}^2/(D_{60} \times D_{10})$	1.33	F.M 3.31

Figure 5: Particle distribution curve at 5ft(sample)

3.2 GRAIN SIZE ANALYSIS TO OBTAINED THE SKEWNESS, KURTOSIS AND THE GRAPHIC MEAN

Equations (2- 11) were used to compute the Skewness, Kurtosis and the Graphic mean for the different depth levels from Boreholes, tabulated in tables (2 – 5), and graphs obtained are displayed below Figures (6-11).

Table 2 : Statistical Parameters for Representative Grain Size Percentiles in 'd' Scale (mm) for Borehole 1

LEVEL (ft)	D_{10}	D_{25}	D_{30}	D_{50}	D_{60}	D_{70}	D_{90}	C_U	C_C	S_O	S_K	FM
0	0.10	0.17	0.20	0.26	0.30	0.40	0.60	3.00	1.33	0.652	1.00	3.05
5	0.10	0.18	0.20	0.27	0.30	0.42	0.60	3.00	1.33	0.655	1.04	3.31
10	0.12	0.18	0.20	0.26	0.30	0.42	0.60	2.50	1.11	0.655	1.12	3.54
15	0.12	0.18	0.20	0.26	0.30	0.42	0.60	2.50	1.11	0.655	1.12	3.52
20	0.12	0.19	0.20	0.26	0.30	0.42	0.60	2.50	1.11	0.673	1.17	3.2
25	0.12	0.17	0.19	0.25	0.31	0.41	0.60	2.58	0.97	0.644	1.11	3.19
30	0.12	0.18	0.19	0.27	0.31	0.42	0.62	2.58	0.97	0.655	1.08	3.41
35	0.13	0.18	0.19	0.25	0.32	0.40	0.58	2.46	0.87	0.671	1.14	3.34
40	0.13	0.18	0.19	0.25	0.30	0.40	0.58	2.31	0.93	0.671	1.14	3.46
45	0.13	0.18	0.20	0.25	0.30	0.40	0.58	2.31	1.03	0.671	1.14	3.31
50	0.13	0.18	0.20	0.25	0.30	0.40	0.60	2.31	1.03	0.671	1.14	3.37
55	0.12	0.18	0.19	0.24	0.30	0.40	0.60	2.50	1.00	0.671	1.24	3.59
60	0.12	0.18	0.19	0.24	0.30	0.40	0.60	2.50	1.00	0.671	1.24	3.51
AVE.	0.12	0.179	0.195	0.225	0.303	0.408	0.597	2.52	1.061	0.663	1.129	3.369

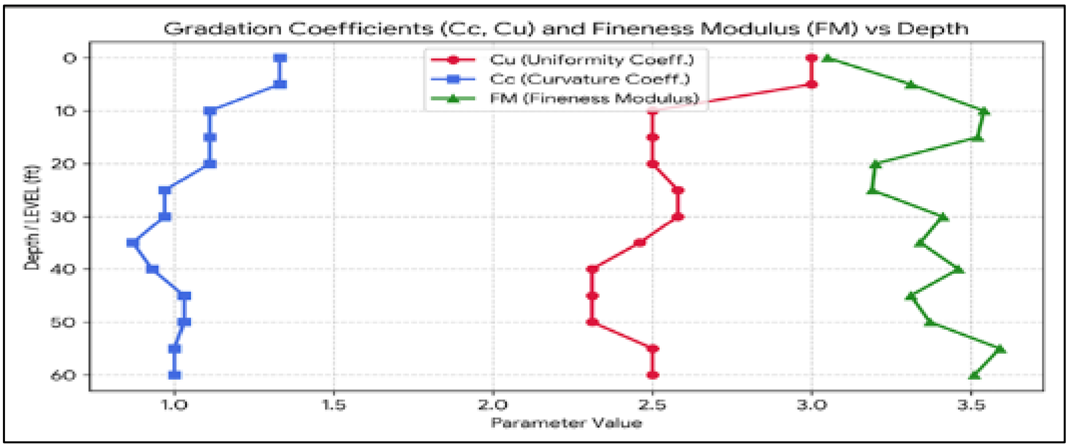


Figure 6: Gradation and Fineness Parameter against Depth for borehole 1

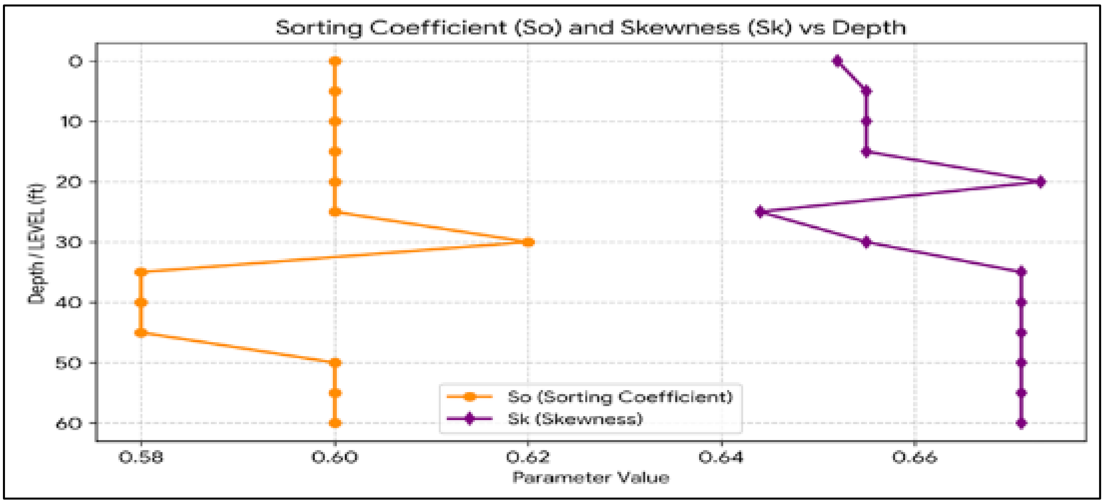


Figure 7: Sorting Coefficient and Skewness Parameter against Depth for Borehole 1

Table 3 : Statistical Parameters for Representative Grain Size Percentiles in 'd' Scale (mm) for Borehole 2.

LEVEL (ft)	D_{10}	D_{25}	D_{30}	D_{50}	D_{60}	D_{70}	D_{90}	C_U	C_C	S_O	S_K	FM
0	0.12	0.17	0.19	0.24	0.30	0.40	0.60	2.50	1.00	0.652	1.17	3.05
5	0.13	0.18	0.19	0.24	0.30	0.43	0.60	2.31	0.93	0.647	1.24	3.33
10	0.13	0.18	0.20	0.23	0.30	0.40	0.60	2.31	1.03	0.671	1.36	3.53
15	0.11	0.18	0.19	0.22	0.30	0.40	0.61	2.73	1.09	0.671	1.50	3.48
20	0.13	0.18	0.20	0.22	0.30	0.40	0.60	2.31	1.03	0.671	1.50	3.20
25	0.13	0.18	0.19	0.22	0.30	0.40	0.60	2.31	0.93	0.671	1.50	3.18
30	0.13	0.17	0.18	0.23	0.30	0.40	0.60	2.31	0.83	0.652	1.28	3.39
35	0.12	0.18	0.19	0.23	0.30	0.40	0.50	2.50	1.00	0.671	1.36	3.32
40	0.13	0.18	0.20	0.22	0.30	0.40	0.60	2.31	1.03	0.671	1.50	3.40
45	0.13	0.18	0.20	0.22	0.30	0.40	0.60	2.31	1.03	0.671	1.50	3.34
50	0.12	0.18	0.20	0.22	0.30	0.40	0.60	2.50	1.11	0.671	1.50	3.42
55	0.10	0.19	0.20	0.22	0.30	0.40	0.60	3.00	1.33	0.689	1.58	3.64
60	0.14	0.18	0.19	0.22	0.30	0.40	0.60	2.14	0.86	0.671	1.58	3.51
AVE.	0.125	0.179	0.194	0.225	0.30	0.402	0.593	2.426	1.015	0.668	1.428	3.369

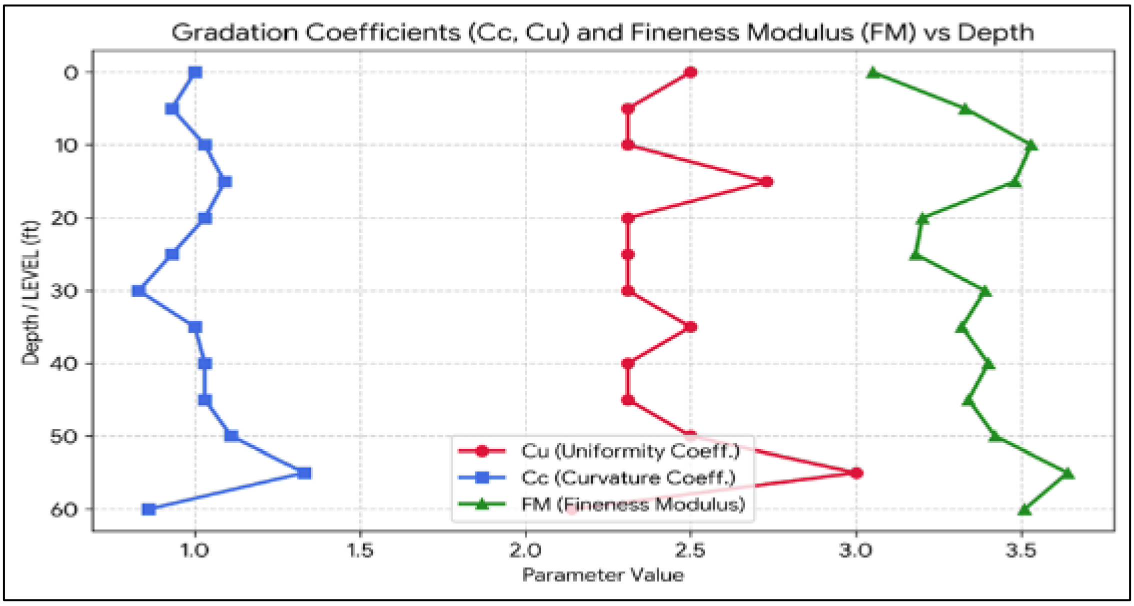


Figure 8 : Gradation and Fineness Parameter against Depth for Borehole 2.

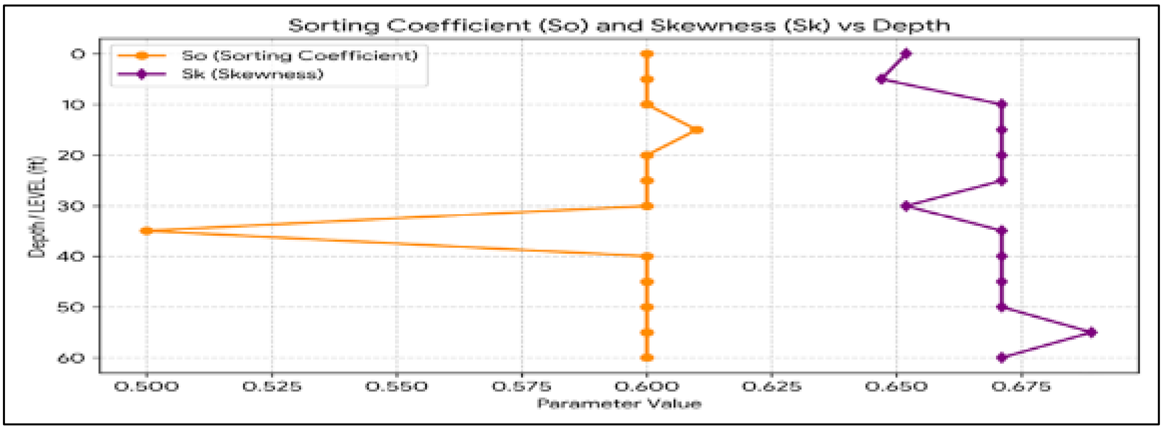


Figure 9 : Sorting Coefficient and Skewness Parameter against Depth for Borehole 2

Table 4 : Statistical Parameters for Representative Grain Size Percentiles in Phi (ϕ) scale for Borehole 1.

LEVEL (ft)	ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}	GM	S_D	Skew	Kurt
0	3.84	2.56	2.47	1.94	1.32	1.09	-0.68	1.86	0.112	0.158	1.491
5	3.82	2.56	2.47	1.89	1.25	1.00	-0.49	1.82	0.115	0.123	1.446
10	3.84	2.52	2.46	1.94	1.25	1.00	-0.59	1.82	0.112	0.184	1.486
15	3.80	2.49	2.47	1.94	1.25	1.00	-0.59	1.80	0.119	0.123	1.473
20	3.74	2.52	2.47	1.94	1.25	1.00	-0.68	1.82	0.089	0.211	1.483
25	3.74	2.56	2.52	1.94	1.29	1.00	-0.49	1.83	0.062	0.177	1.410
30	3.74	2.52	2.47	1.94	1.29	1.00	-0.49	1.82	0.072	0.193	1.507
35	3.74	2.49	2.47	2.00	1.32	0.97	-0.44	1.80	0.133	0.284	1.489
40	3.84	2.52	2.47	2.00	1.32	0.94	-0.44	1.82	0.120	0.241	1.525
45	3.84	2.52	2.47	2.00	1.32	1.00	-0.49	1.84	0.128	0.305	1.543

50	3.84	2.56	2.47	2.00	1.32	1.00	-0.38	1.85	0.134	0.205	1.504
55	3.84	2.49	2.46	2.07	1.32	0.84	-0.38	1.79	0.126	0.335	1.504
60	3.84	2.56	2.47	2.07	1.32	0.79	-0.32	1.81	0.090	0.298	1.483
AVE.	**3.805**	**2.528**	**2.472**	**1.975**	**1.294**	**0.972**	**-0.497**	**1.822**	**0.109**	**0.218**	**1.488**

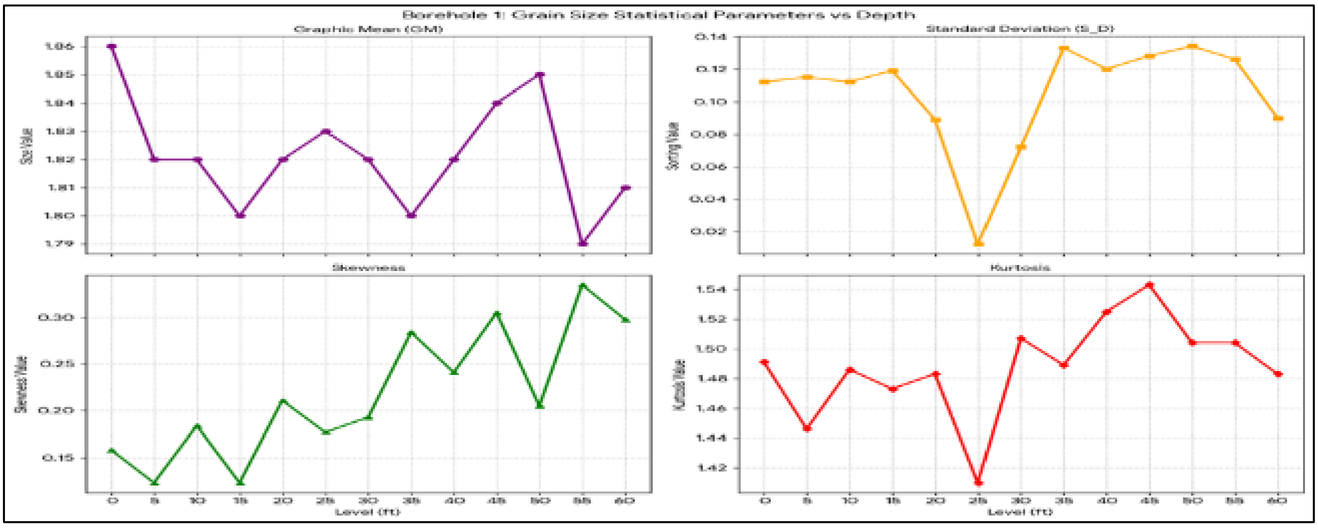


Figure 10 : Statistical Parameters [Phi (ϕ) scale] Vs Depth (ft) for Borehole 1

Table 5 : Statistical Parameters for Representative Grain Size Percentiles in Phi (ϕ) scale for Borehole 2

LEVEL (ft)	ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}	**GM**	S_D	**Skew**	**Kurt**
0	3.84	2.60	2.56	2.07	1.32	1.00	-0.68	1.89	0.079	0.278	1.491
5	3.84	2.60	2.47	2.07	1.25	1.00	-0.54	1.89	0.100	0.265	1.469
10	3.75	2.60	2.47	2.12	1.32	1.00	-0.38	1.91	0.111	0.320	1.472
15	3.75	2.60	2.47	2.12	1.32	1.00	-0.32	1.93	0.120	0.352	1.450
20	3.75	2.56	2.47	2.18	1.32	1.00	-0.38	1.91	0.121	0.378	1.472
25	3.75	2.56	2.47	2.18	1.32	1.00	-0.26	1.89	0.139	0.311	1.429
30	3.75	2.56	2.47	2.12	1.32	1.00	-0.26	1.89	0.135	0.311	1.329
35	3.75	2.56	2.47	2.12	1.32	1.00	-0.26	1.89	0.126	0.311	1.429
40	3.75	2.64	2.47	2.18	1.32	1.00	-0.21	1.94	0.146	0.311	1.411
45	3.75	2.56	2.47	2.18	1.32	1.00	-0.21	1.91	0.146	0.323	1.411
50	3.75	2.56	2.47	2.18	1.32	1.00	-0.21	1.91	0.146	0.360	1.411
55	3.75	2.56	2.47	2.18	1.32	1.00	-0.21	1.91	0.146	0.360	1.411
60	3.75	2.56	2.47	2.18	1.32	1.00	-0.21	1.91	0.146	0.360	1.411
AVE.	**3.764**	**2.578**	**2.477**	**2.145**	**1.315**	**1.000**	**-0.318**	**1.906**	**0.128**	**0.326**	**1.430**

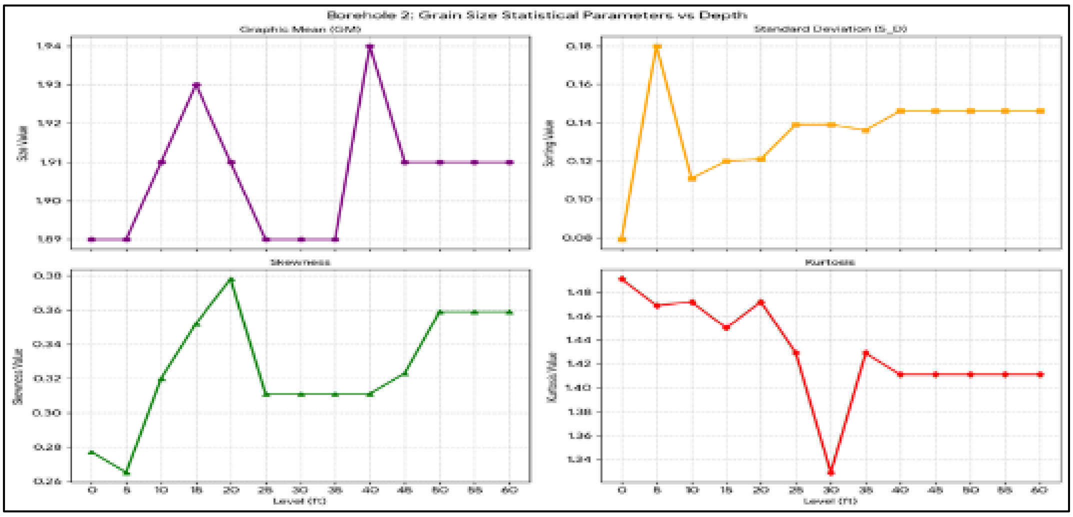


Figure 11 : Statistical Parameters [Phi (ϕ) scale] Vs Depth (ft) for Borehole 2

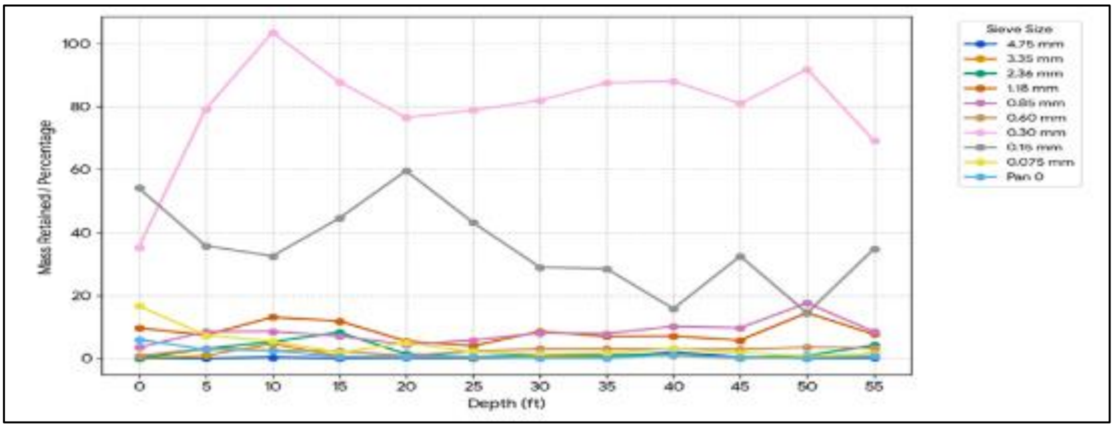


Figure 12 : Soil Particle Distribution (Sieve size Retained weight) Vs Depth for Borehole 1.

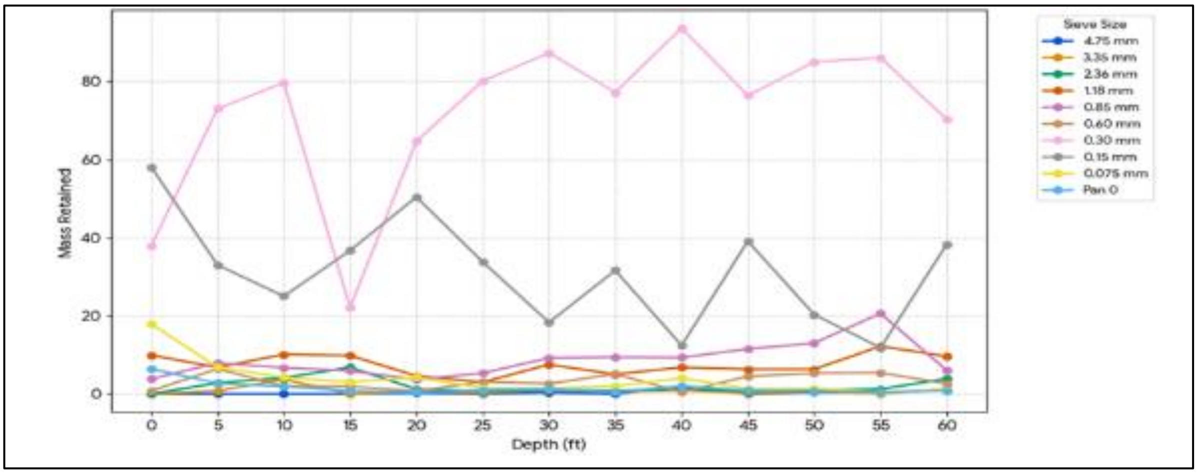


Figure 13 : Soil Particle Distribution (Sieve size Retained weight) Vs Depth Borehole 2

Table 6 : Calculated Results for Porosity and Permeability

Metric	Empirical Formular Used	Borehole 1(UPH-1)	Borehole 2 (UPH-2)
Uniformity Coefficient (C_u)	$C_u = \frac{d_{60}}{d_{10}}$	2.525	2.400
Porosity (η)	Vukovic & Soro (1992) η = 0.255 × (1 + 0.83^{C_u})	0.4142 (41.43%)	0.4181 (41.81%)
Hydraulic Conductivity (K)	Hazen formular (1892) $C_H \cdot (d_{10})^2$	0.0144cm/s (12.44m/day)	0.0156cm/s (13.5m/day)
Hydraulic Conductivity (K)	Beyer formular $6 \times 10^{-4} .(\frac{g}{v}). log_{10} (\frac{500}{C_u}) .(d_{10})^2$	0.0194cm/s (16.75m/day)	0.0212cm/s (18.35m/day)
Intrinsic Permeability (k) [Hazen]	K. $(\frac{\mu}{\rho .g})$	1.47 $\times 10^{-11}$ m^2 (14.93D)	1.60 $\times 10^{-11}$ m^2 (16.20D)
Intrinsic Permeability (k) [Beyer]	K. $(\frac{\mu}{\rho .g})$	1.98$\times 10^{-11} m^2$ (20.10 D)	2.17 $\times 10^{-11} m^2$ (22.02D)

4 DISCUSSION

The lithological profiles for UPH-1 and UPH-2 show a distinct coarsening-upward characteristic of the shallow, unconsolidated Quaternary deposits of the Niger Delta (typically associated with the Sombreiro-Warri Deltaic Plain or the upper Benin Formation).

Correlating the spatial vertical distribution in the borehole diagrams with the statistical parameters, we can infer the following;

Quantitatively, the average Graphic means (Figures 10-11)values of 3.805 ϕ (UPH-1) and 3.764 ϕ (UPH-2) falls within the fine sand boundary according to[13] while the Sorting (σ) values 1.294 σ (UPH-1) and 1.315 σ (UPH-2) classify the sediments as poorly sorted (1.0-2.0). The average FM value (Figures 6 and 8)across both boreholes is 3.369 as well as the Median Size (D_{50})~0.30mm Figures (12-13) , indicating the bulk of the sand is concentrated on the 0.30mm and 0.15mm sieves (75% of the total mass. According to[17], standard fine aggregate for concrete typically spans FM= 2.3-3.1, thus, a 3.37 is ideal for heavy structural concrete for block making and asphalt sub-base, it's also well suited for land reclamation since the grain size is resistant to erosion and settles rapidly during hydraulic cutter-suction dredging. The skewness parameter is positive in both boreholes (Figures 10 and 11) and within the range 0.123$\leq S_{kw} \leq$ 0.378 indicating a coarse- skewed distribution, this equally guarantee that the sand lacks a significant clay-silt matrix that could degrade binder adhesion in structural engineering mixes. The C_u varies between 2.14-3.00 which is less than 4 < in both boreholes, thus the formation is classified as poorly graded [34] and [18]. The C_c ranges 0.83 $\leq C_c \leq$ 1.33 confirming a smooth continuous grain distribution. Kurtosis is 1.329 $\leq K_s \leq$1.525 which depict Leptokurtic to very Leptokurtic.

Qualitatively the upper Topsoil/ Overburden (0-25ft / 0-7.6m) compose of organic soil, silty-clays, pure clays and laterites. From the boreholes, the fine fractions (($\leq$ 0.0075 + Pan) reached 18% making this zone unsuitable for structural aggregate without intensive washing. It represents non-sealable waste that must be stripped or excavated before dredging the underlying sand. The lower zone (25-60 ft/ 7.6-18.3 m) is composed of thick, continuous fine-to-medium sand sediments. This Economic Sand Pay-Zone consists of unconsolidated Quaternary deposits of the Benin Formation . The water table in this deltaic setting resides within 3-5 m of the surface and is usually the zone that is dredged. Quality specification for Construction Sand according to [17] and[35] standard specifications, a mandate allowable silt/clay wash loss of 3.0%- 5.0%. In this scenario, both boreholes demonstrate the pay-zone of < 2 % average fines confirming the sand body meets international standard.

The high porosity 41.4%-41.8% indicate a loosely packed sand grain ,with a low mechanical Energy , the bed material can be dislodged easily coupled with the high permeability, water drains out of this dredged slurry almost immediately upon discharge from the suction dredger leaving it dry so it can be loaded into a tipper truck without the drying cycles.

5 CONCLUSION

This study provides an integrated sedimentological, geotechnical, and hydro-dredging evaluation of shallow Quaternary sand reserves within the upper Benin Formation (Sombreiro-Warri Deltaic Plain) of the Niger Delta basin. Synthesizing subsurface lithological logs, Folk-Ward grain-size percentiles, and empirical hydrodynamic modeling establishes a quantitative baseline for economic dredging feasibility, reserve quality, and extraction mechanics.

The subsurface profile across UPH-1 and UPH-2 confirms a classic bipartite deltaic plain architecture [36] and the Granulometric metrics confirm that the sand pay-zone complies with international structural aggregate specifications [17]and[35] directly out of the ground. Thus, the subsurface sand horizon spanning 25 ft to 60 ft across UPH-1 and UPH-2 represents a premium, commercially viable dredgeable reserve. Its combination of a low stripping ratio (0.71), ultra-clean grain framework (< 2% fines), high Fineness Modulus (3.37), and high permeability (> 14 Darcy) positions this deposit as a prime candidate for cutter-suction mining supplying high-specification aggregate for heavy structural concrete, asphalt pavement sub-bases, and regional land reclamation projects across the Niger Delta.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare that there are no conflict of interest.

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