Estimation of grain size statistical parameters and Porosity of the Quaternary aquifers in part of Bayelsa State Nigeria

Amakiri, A. R. C.[1], Risi, I.[1], Amonieah[1], J., Okiongbo, K. S[2].

[1]Department of Physics, Rivers State University, Port Harcourt;
[2] Department of Physics, Niger Delta University, Wilberforce Island, Bayelsa State,
Corresponding author: Dr. A. R. C. Amakiri
amakiri.arobo@ust.edu.ng

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Abstract: An attempt has been made in this study to estimate the grain sizes and statistical parameters of aquifer sediments, in parts of Bayelsa State, South-South Nigeria. Precise measurement of statistical parameters of sediments is a vital and significant factor for the comparative evaluation of sedimentary depositional environment. Particle size analysis is a vital tool for the determination of the cost, quality and performance of aggregates for several economic purposes, such as in the construction, hospitality, agricultural industrial and of course in ground water resource management. Particle size distribution parameters were determined through conventional sieve analysis, the graphical method for obtaining statistical parameters was employed in this study. Sieve analysis is the process of measuring the particle size distribution of unbound sediments, it is a less costly and simple to access process. The resulting cumulative frequency distribution curves are continuous with only a single mode value, indicating that all the samples in the study are evidently homogeneous at their specific sites. The coefficient of uniformity (η) evaluated ranges from 2.81 to 5.6 for samples 1 and 3 respectively, while the porosity values estimated ranges from 0.34 (34%) to 0.43 (43%) for samples 2 and 4 respectively. The study indicated that the samples have average grain sizes ranging from 0.37 to 0.95 mm (average 0.60 mm), which were shown to be well graded. The inclusive graphic kurtosis of the sediment grains ranges from 0.12 – 1.5 (average 0.59), occupying sediments that are very platykurtic (very deficiently peaked) being less than 0.67 to mesokurtic and leptokurtic or excessively peaked (relatively better sorted in the central parts than in the tails).

Key terms: particle size, graded, sorted, platykurtic, mesokurtic, and kurtosis.

1. Introduction

Particle or grain size analysis is a very vital resource for the determination of the cost, quality and performance for the specification of aggregates, for several projects, including, Silica Sand used for the filtration of water, civil construction works, Agricultural projects, and ground water resources. The geologic significance of statistical parameters such as skewness and kurtosis in a localized environment has been sufficiently investigated and documented by Inman (1949), Folk and Ward (1957), Schon (2011) etc. precise estimation of the statistical parameters of sediments is significant for the comparative analysis of sedimentary environments. Sedimentary rocks. occupy over 50% of the earth's surface and are inferably fundamentally important to humans in various aspects (Schon, 2011).

The term 'lithology', is defined as; 'the physical character of a rock.' (The American Geological Institute Glossary of Geology). Lithology is used in addition to the mineral composition for geological characterization of rocks in general and for sedimentary rocks in particular. .

Sedimentary rocks are formed by a sequence of physical, chemical, and biological processes. Magmatic, sedimentary, and metamorphic source rocks are disaggregated by weathering to form; resistant residual particles (like silicate minerals or lithic fragments), secondary minerals (like clays), water soluble ions of calcium, sodium, potassium, silica or the like,

Weathered materials are transported through the means of, water, ice, or wind to other locations where they are deposited. Consequently, mineral grains are dropped to the depositional surface; dissolved matter are precipitated either through inorganic processes (where they are sufficiently concentrated), otherwise through organic processes; decaying plant and animal residues may also be introduced into the depositional environment.

Two major classes of sedimentary rocks are generally distinguishable as clastic (or siliciclastic) and carbonates (and evaporites). Siliciclastic rocks are composed of various silicate grains; carbonates consist mainly of only two minerals, dolomite and calcite. Clastic sediments are sediments that have been transported over long distances, whereas carbonates are formed on-site (mostly marine). Clastic sediments are relatively chemically stable; they form an inter granular pore space. Carbonates on the other hand are chemically unstable; their pore spaces are very complex in nature and are controlled by a variety of influences and pore space geometries.

Several empirical relations are available for the estimation of statistical parameters that give physical interpretation to the shape and structure of clastic grain properties e.g, Trask (1930), Krumbein (1938), Otto (1939), Inman (1952) and Folk and Ward (1957); Schon (2011) etc. These statistical parameters such as skewness and kurtosis reflect the normality of the grain distribution within the geological environment (Folk and Ward, 1957). Precise measures of average size, sorting and other frequency distribution properties of clastic materials are necessary and required indices for the quantitative comparison of sedimentary environments. These properties may either be determined mathematically by the method of moments or graphically by frequency cumulative curves, where percentiles are read off (Folk and Ward, 1957).

The aim of this study is to estimate the grain size parameters as well as the porosity of aquifers in the study area, and the specific objectives are, to carry out sieve analysis, estimate statistical grain size parameters and finally obtain porosity from the estimated grain size parameters.

1.1 The study area

The study area is part of Bayelsa State (Figure 1) in the South-South geopolitical zone of Nigeria which lies within the Niger Delta. The Niger Delta is located between latitudes 3° - 6°N and longitude 5° - 8°E (Figure 1).

From apex to coast the sub-aerial portion stretches more than 300km, covering an area of 75,000km^2. The Niger Delta is an active sedimentary basin at present and has since the Paleocene times prograded a distance of more than 250km from the Benin and Calabar flanks to the present delta front; the area is well linked with Rivers and tributaries as it lies along the coastal plains.

Stratigraphically, the Niger Delta is divided into Akata, Agbada and Benin Formations in order of decreasing age. These three

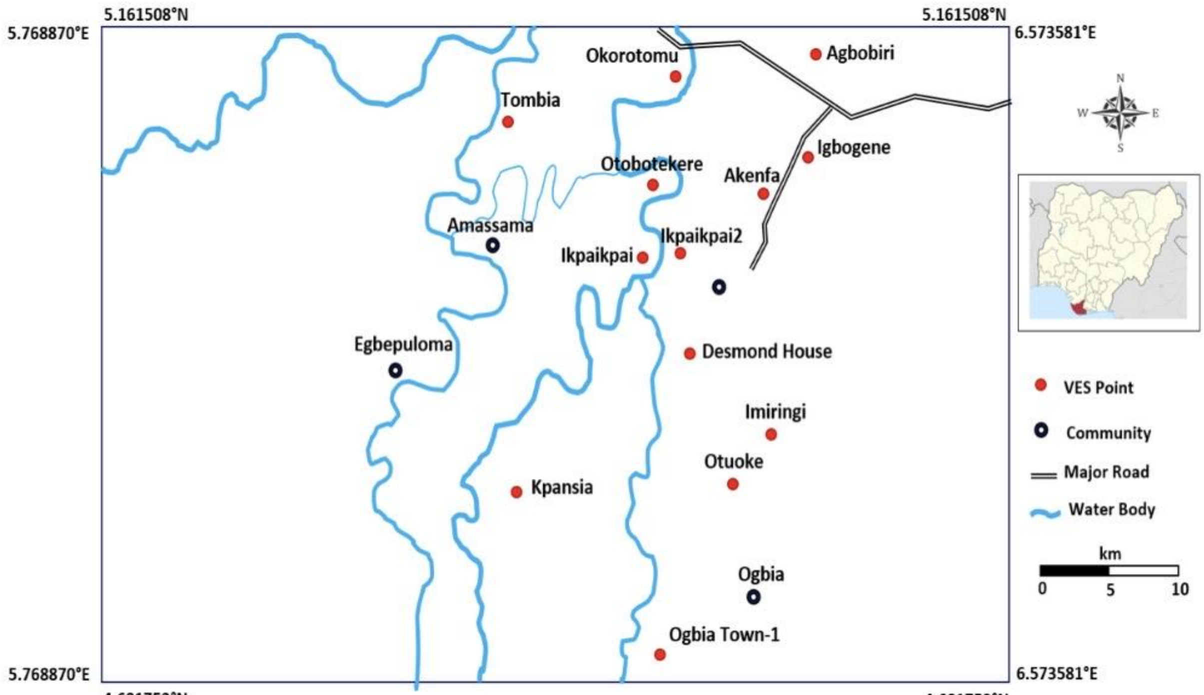

Fig 1.1: Map of Study Locations in Bayelsa State

lithostratigraphic units have been recognized in the subsurface of the Niger Delta, in the order of, from, the oldest to the youngest, follows from the Akata, to the Agbada and then to the Benin formation (Short and Stauble, 1967, Amakiri and Uko, 2002).

.2.0 **Methodology**

2.1 Sieve analysis

Particle-size distribution parameters were determined, in this study, through conventional sieve analysis procedures. Distribution of grain-sizes were determined by sieve analyses carried out at the Laboratory

of the Department of Civil Engineering, Rivers State University Port Harcourt.

Sieve analysis is the process of measuring the particle size distribution of unbound sediments. It is a less costly and simple to access process. Particle size is the major physical soil property, it is usually determined from particle or grain size distribution (PSD or GSD) of different particles in each sample of soil. Sand, Silt and Clay are texturally classified as soil particles whose diameters are smaller than 2.0 mm. The particle size properties that have the highest effect on soil retention are percentage of sand, silt, clay, fine sand, coarse sand, very coarse sand, and coarse fragments (particles with sizes > 0.2cm).

Usually grain classification is done according to the 'd' scale 'grading characteristics' (Hussain and Nabi, 2016). For instance, the d_{10} diameter represents the diameter for which 10 % of a sediment sample's mass is made up of smaller particles (i.e particles that passes through the corresponding-sized sieve).

Grain size classification can also be given in the Phi (ϕ) scale. The Phi (ϕ) – scale is an alternative description of grain size to the 'log normal' (d) distribution scale, and is given as (Krumbian, 1934, Amakiri, 2019),

$$\text{Phi } (\phi) = -\log_2(d) = -\frac{log_{10}d}{log_{10}2} \qquad 1$$

Using the aquifer sediment samples, grain size distribution was estimated using the standard sieving technique described in literature (Alyamani and Sen, 1993; Tanner and Balsillie,1995; ASTM, 1995; 2007). Grain size distribution of the collected sediment samples (after the samples had been previously dried) was carried out through the mechanical sieving technique using a Ro-tap shaker (Alyamani and Sen, 1993, Tanner and Balsillie, 1995). The Particle size parameters (for the Six sediment samples) are presented in Table 3 and the grain size distribution curves (for the six samples, 1, 2, 3, 4, 5 and 6) were obtained in the d scale (Figure 2) and the Phi (φ) scale (Figure 3). With the aid of the grain size distribution curves, the various mean representative grain diameters, $d_{5,}$ $d_{10,}$ d_{60} etc were determined for the sediment samples in the d scale and the Phi (φ) scale shown in Tables 4 and 5 respectively. .

Soil having sufficient dispersion of particle sizes (characterized by a concave smooth PSD) is classically designated "well graded", while soils consisting principally of a single particle size (with its PSD having a nearly vertical step) are designated "uniform". Soils containing mixed-sized particles (large and small), but few medium-sized particles (whose PSD has a horizontal step) are designated "gap-graded". (Powrie, W., 2004).

Sediment samples were classified according to particle sizes obtained from the grain-size distribution curves, using the Soil Classification System for clastic sediments in millimeter (Table 1) and in Phi (ϕ) scale (Table 2), which divides soils into basic soil type groups – according to soil size - which in turn is subdivided into coarse, medium and fine sand...

Table 1: Soil classification system for clastic sediments (from Schon, 2011)

Basic Soil Type	Sub-Type	Grain size range (mm)

	Fine Sand	0.063 – 0.2
Sandy	Medium Sand	0.2 – 0.63
	Coarse Sand	0.5 – 2.0

Table 2: Typical grain size ranges

	Phi (φ) range	
Sediment	From	To
Boulder	-12	- 8
Cobble	-8	- 6
Pebble	-6	-2
Granular	-2	-1
Very coarse grained	-1	0.0
Coarse grained	0.0	1.0
Medium grained	1.0	2.0
Fine grained	2.0	3.0
Very fine grained	3.0	4.0
Coarse silt	4.0	5.0
Medium silt	5.0	6.0
Fine silt	6.0	7.0
Very fine silt	7.0	8.0
Clay	8.0	Lesser

2.2 Grain size statistical parameters

Physical interpretation of the shape and structure of clastic grain properties, from estimated statistical parameters can be obtained from several empirical relations available in literature (Trask (1930), Krumbein (1938), Otto (1939), Inman (1952) and Folk and Ward (1957); Schon (2011) etc.). These statistical parameters such as skewness and kurtosis reflect the normality of the grain distribution within the geological environment (Folk and Ward, 1957). Precise measures of average size, sorting and other frequency distribution properties of clastic materials are necessary and required indices for the quantitative comparison of sedimentary environments.

In this study both the Folk and Ward (1957) and the Schon (2011) approaches were used to estimate the statistical parameters of the collected samples in the study area; Equations 2 to 7 are the Folk and Ward (1952) derived relations based on the Phi (ϕ) scale, while equations 8 and 9 are the Schon (2011) relations expressed in 'd' (mm) scale. These parameters may be determined mathematically by the method of moments or graphically by the frequency cumulative curves, where percentiles are read off (Folk and Ward, 1957).

In this study, the graphical method has been employed; furthermore, the Folk and Ward (1957) and the Schon (2011) approaches were employed to estimate the statistical parameters of the collected samples in the study area.

From the grain size distribution curves (Figs. 2 and 3), the various statistical parameters of the grain sizes for the six sample sediments were estimated and shown in Tables 4 and 5 in the d (mm) and Phi (φ) scales respectively.

Equations 4 to 8 are the Folk and Ward (1952) derived relations based on the Phi (ϕ) scale, while Equations 9 to 11 are the Schon (2011) relations expressed in **'d'** (mm) scale. The statistical parameters expressed in phi (ϕ) scale, used by Folk and Ward (1957) are alternatively expressed in the **'d'** (mm) scale used by Schon (2011) and the scales are related as in Equ. 1.

Graphic Mean (GM): the graphic mean is given as,

$$(GM) = \frac{\phi_{16} + \emptyset_{50} + \emptyset_{84}}{3} \qquad 2$$

Where, $\emptyset_{16}$ refers to the ø grain size at a cumulative weight per cent equivalent to 16.

The graphic mean is a measure of the overall representation of the true Phi (ϕ) (the optimal average value of the grain size).

The graphic mean gives insight to the grain size in accordance with the ranges shown in Tables 1 and 2.

$$\text{Median} = \phi_{50} \qquad 3$$

This is the fifty cumulative percentile, the value for which half the quantity of grains (in terms of mass) was lesser than this and half greater. The graphic median was not used in this study; since it can be very misleading as it is dependent only upon one point ($\emptyset_{50}$) on the cumulative curve (Folk and Ward, 1957).

2.3 Graphic Sorting (Standard deviation)

This statistical parameter was estimated using Equ. 6, thus,

$$GSTD = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} + \phi_{5}}{6.6} \qquad 4$$

The graphic sorting or inclusive standard deviation (GSTD) measures the grain sorting; according to Folk and Ward (1957) grains having GSTD values less than 0.35 are regarded as very well sorted, if GSTD lies between 0.35 and 0.50, they are well sorted, 0.5 - 1.0, moderately sorted, 1-2 poorly sorted and 2 - 4, extremely poorly sorted. The GSTD is an adequate measure of the dispersivity of grain sizes within the given sample; it signifies the range of grain size variability within the sample (Alyamani and Sen, 2000). The GSTD is a very important geologic parameter as it gives insight to the depositional sequence of the sedimentary environment (Folk and Ward, 1957),

Skewness (GSK): The skewness is a measure of how different (or skewed) the data are from a Gaussian distribution. The inclusive graphic skewness (GSK) obtained in this study is given as,

$$GSK = \frac{\phi_{16} + \phi_{84} - 2\emptyset_{50}}{2⟦\phi_{84} - \phi_{16})} + \frac{\phi_{5} + \phi_{95} - 2\emptyset_{50}}{2(\phi_{95} - \phi_{5})} \qquad 5$$

Perfectly symmetrical curves have a GSK of 0.00 however the ideal mathematical limits are between – 1.00 and + 1.00, but practically most curves will have their GSK between - 0.80 and + 0.80. Positive skewness is an indication that samples have a "tail" of fines while negative skewness indicates a tail of coarser grains. The next parameter is the Graphic Kurtosis (GK); it measures the ratio of the sorting in the extremes of the distribution compared with the sorting in the central of the distribution. This makes this parameter a sensitive and highly valuable indicator of the normality of a distribution. Using Equation 6, normal curves will have Gk = 1.00, a curve with GK =

2.00 is regarded as 'leptokurrtic' or excessively peaked (relatively better sorted in the central parts than in the tails). If GK = 0.70, it is said to be 'platykurtic' or deficiently peaked. Generally, limits of kurtosis are GK < 0.67 very platykurtic; GK between 0.67 and 0.90, platykurtic; GK between 0.9 and 1.11, mesokurtic; Gk between 1.11 and 1.50, leptokurtic; GK between 1.5 and 3.0, very leptokurtic; and GK over 3.0, extremely leptokurtic (Folk and Ward, 1957).

Kurtosis (K): this parameter is defined as a measure of how well the tails of the data fit a Gaussian distribution. It's expression is,

$$K = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})} \qquad 6$$

Kurtosis, mathematically is the standardizes 4th moment of a distribution; moments are a set of measurements that tell how shaped a distribution is (Turney, 2022). Kurtosis measures the tailedness of a distribution. Tailedness is how often outliers occur in a distribution. It can be leptokurtic, (from the Greek origin leptos implying narrow); where the distributions are more kurtotic than the normal distribution. Leptokurtic distributions are sometimes called positive kurtosis, since the excess kurtosis is positive. Kurtosis can also be said to be platy kurtosis (with the Greek origin platus meaning flat and implying tailedness and not necessarily peekedness). Platy kurtosis is sometimes called negative kurtosis, since the excess kurtosis is negative. Finally kurtosis can also be mesokurtic, in which case the tailedness is moderate, they have outliers which are neither highly frequent, nor highly infrequent. They are usually equivalent to the normal distribution (Turney, 2022).

Median grain size: the median grain size gives the midpoint of the curve at d_{50} (grain size in millimeters of the 50th percentile). It is given as,

$$\text{Median grain-size} = d_{50} \qquad 7$$

For the 'd' scale, the following statistical parameters were employed after Schon (2011).

2.4 Grain sorting (S_0): Grain sorting (So) describes how narrow the distribution is to a single grain size, where d_{25} is the grain size (mm) of the 25th percentile and d_{75} the grain size (mm) of the 75th percentile.

Skewness. It is given as,

$$S_0 = (d_{25}/d_{75})^{0.5} \qquad 8$$

Skewness (S_k): Skewness expresses the symmetry of distribution and it is given as, Schon (2011),

$$S_k = (d_{25} * d_{75})/d_{50}^2 \qquad 9$$

Grain shape (sphericity) describes how nearly a particular grain approaches the shape of a sphere. Grain roundness (angularity) measures the sharpness of edges and corners. Comparison charts are used for both properties. Grain packing is a measure of the density of the grain aggregates. In terms of physical properties, the spatial arrangement of the individual particles can be defined as internal Structure - it controls, for example, anisotropy properties (Schon, 2011).

2.5 Coefficient of uniformity (η)

The coefficient of uniformity (or uniformity coefficient) is appropriate to describe the uniformity of the gravel packing material (Awad and Al-Bassan, 2001). The coefficient of uniformity is an indicator of the effects of size, shape, distribution, packing, and sorting of grains (Chilingar et al., 1963; Salem, 1992). It is given as (Schon, 2011),

$$\eta = \frac{d_{90}}{d_{10}} \qquad 10$$

Where d_{90} is the grain diameter (mm) defined in such way that ninety per cent (90%) of the distribution is finer than this diameter and d_{10} is the grain diameter in (mm) such that ten per cent (10%) of the distribution is finer than this diameter (Lopez, et al., 2015). Hazen (1893) introduced the term 'uniformity coefficient' and it can also be defined as d_{60}/d_{10} or d_{40}/d_{10} (Awad and Al-Bassan, 2001). The uniformity coefficient varies inversely with the uniform grading of the materials of which the aquifers are constituted. In practice, the d_{60} size and the uniformity coefficient are essential elements of

the well design criteria. The size of the d_{60} determines the size of the aperture of the screen slot, especially when groundwater is not practically corrosive.

The coefficient of uniformity (η) is an indicator to the effects of grain size, shape, distribution, packing, and sorting of grains (Chilingar et al., 1963; Salem, 1992). The uniformity coefficient is suited to describing the uniformity of gravel pack material; the lower the value of the uniformity coefficient, the more uniform the grading of the aquifer material (Awad and Al-Bassam, 2001). The uniformity coefficient is related to the general shape and slope of the particle size distribution curve, the higher the uniformity coefficient the larger the range of particle size. Granular materials with uniformity coefficient (η) less than 10 may be regarded as uniformly graded, while granular materials with uniformity coefficient (η) more than 10 may be regarded as well-graded (Powrie, 2004).

2.6 Estimation of Porosity

Porosity (ϕ) is a vital hydraulic parameter which is necessary for estimating aquifer hydraulic conductivity (K) and other hydraulic parameters. In this study, porosity was estimated using both grain size analysis and VES data.

2.7 Porosity estimation using grain size data.

We then estimated porosity values from the empirical relation between porosity and coefficient of grain uniformity (η) following, Vukovic and Soro (1992),

$$\phi = 0.255(1 + 0.83^{\eta}) \qquad 11$$

Where η is the coefficient of grain uniformity given by Urish (1981) and Salem (2001) as in Equation 10.

3.0 Results and Discussion

3.1 Grain size distribution

The grain size distribution for the sediments in the six locations, in 'd' (mm) and Phi (ϕ) scales is shown in Table 3. The cumulative weight passing for grain sizes of 2 to 0.15 mm in the 'd' scale and -1 to 2.70 in the (ϕ) scale, is also highlighted in Table 3.

All the samples are evidently seen to be homogeneous at their specific sites, hence their cumulative frequency distribution curves are continuous with only a single mode value (Alyamani and Sen, 1993).

3.2 Statistical parameters and porosity estimated from grain size data.

The statistically derived parameters for the six sample locations in the 'd' and phi (φ) scales are shown in Tables 4 and 5 respectively. The grain size distribution curves obtained from Tables 4 and 5 are shown in Figures 2 and 3 for the 'd' and phi (ϕ) scales respectively. The median statistical parameter, $d_{50,}$ (Eq.3.8) was used to estimate the average grain sizes in the 'd' mm scale and, consequently, Table 4 shows that the samples have average grain sizes ranging from 0.37 to 0.95 mm (average 0.60 mm). Comparing these values with the standard classification of clastics (Schon, 2011), we observe that samples 1, 2, 3 and 5 are medium sand grains while samples 4 and 6 are coarse Sand grains. The grain sorting (S_o) for the six representative samples (Table 5) shows that samples 1, 3 and 4 have a value of 0.3 while samples 2, 5 and 6 have a value of 0.2 (average 0.3). These obtained values of S_o indicates that the sediments are very well sorted (Folk and Ward, 1957, Schon, 2011).

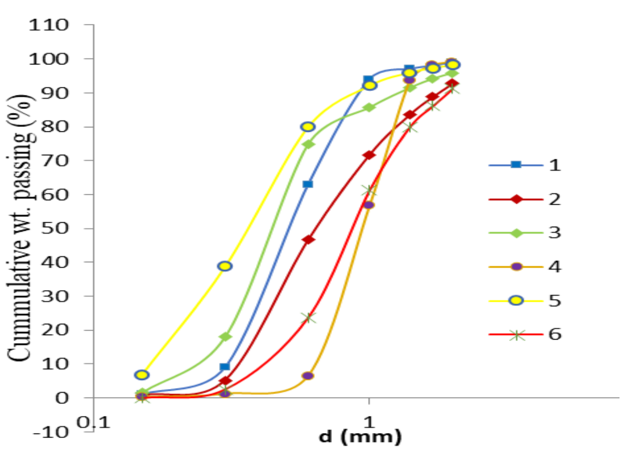

Fig. 2 : Cummulative grain size (mm) curve (in d scale) for the Six samples

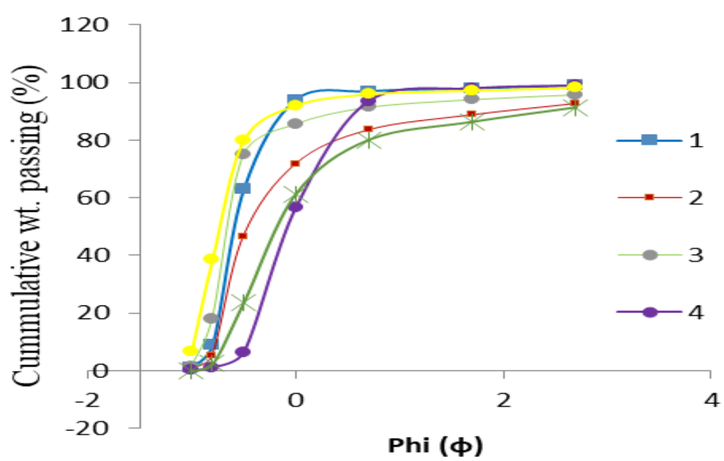

Fig. 3: Cummulative grain size curve (in ϕ scale) for six samples

Table 3: Grain size distribution of sediments (in 'd' and φ scales)

Grain size (mm)	2.00	1.70	1.40	1.00	0.60	0.30	0.15

Grain size (ϕ)	-1.00	-0.80	-0.50	0.00	0.70	1.70	2.70
Cumulative weight passing (%)							
Sample 1	99.00	98.00	97.00	94.00	63.00	9.00	1.00
Sample 2	92.77	88.87	83.61	71.75	46.7	5.21	0.75
Sample 3	95.87	94.18	91.49	85.67	74.88	18.02	1.58
Sample 4	99.03	98.11	93.6	56.69	6.53	1.23	0.24
Sample 5	98.30	97.30	96.00	92.10	80.00	38.80	6.90
Sample 6	91.50	86.25	80.00	61.25	23.75	2.50	0.00

Table 4: Statistical parameters for representative percentiles in d-scale (mm)

Sample	d_{10}	d_{25}	d_{50}	d_{60}	d_{75}	d_{90}	M	S_o	S_K
Sample 1	0.32	0.38	0.51	0.58	0.73	0.9	0.51	0.3	1.1
Sample 2	0.35	0.45	0.45	0.78	1.1	1.4	0.45	0.2	2.4
Sample 3	0.25	0.34	0.45	0.5	0.6	1.4	0.45	0.3	1.0
Sample 4	0.65	0.75	0.95	1.2	1.2	1.4	0.95	0.3	1.0
Sample 5	0.17	0.24	0.37	0.42	0.55	0.9	0.37	0.2	1.0
Sample 6	0.42	0.63	0.88	0.98	1.4	1.8	0.88	0.2	1.1
Average	0.4	0.5	0.60	0.7	0.9	1.30	0.60	0.3	1.2

A well sorted sandstone is one in which all the grains are of the same size; the porosity of a sandstone is directly proportional to the degree of sorting.

Table 5: Statistical parameters of six representative grain size percentiles in Phi (φ) scale

Sample	$(\phi)_5$	$(\phi)_{16}$	$(\phi)_{25}$	$(\phi)_{50}$	$(\phi)_{75}$	$(\phi)_{84}$	$(\phi)_{95}$	GM	GSTD	GSK	GK
1	-0.85	-0.75	-0.70	-0.60	-0.37	-0.24	0.05	-0.53	0.01	0.05	0.12
2	-0.80	-0.71	-0.65	-0.45	0.10	0.80	2.80	-0.12	0.68	0.75	1.11
3	-0.95	-0.82	-0.75	-0.65	-0.50	0.05	2.00	-0.47	0.38	0.23	0.30
4	-0.52	-0.40	-0.32	-0.10	0.28	0.44	0.74	-0.02	0.24	0.10	0.31

5	-1.00	-0.95	-0.89	-0.72	-0.55	-0.43	0.40	-0.70	0.04	0.02	0.20
6	-0.75	-0.60	-0.48	-0.15	0.52	1.40	2.90	0.22	0.83	1.10	1.50
Average	-0.81	-0.71	-0.63	-0.45	-0.09	0.34	1.48	-0.27	0.36	0.37	0.59

A well sorted rock has a greater porosity than a poorly sorted one. The estimated values of grain sorting are consistent with those obtained by Folk and Ward (1957) for the Brazo River bar. Table 5 shows the statistical parameters of the grains in phi (ϕ) scale. The graphic mean (GM) which is a measure of the overall representation of the true (optimal average value of the grain size) in the Phi (ϕ) scale, was used to estimate the average mean in the Phi (ϕ) scale (Folk and Ward, 1957), this is because the median Phi, (ϕ_{50}), could be misleading since it depends only on one phi (φ) value. The GM values obtained in this study, based on the phi (ϕ) scale (Table 5) range from - 0.70 to 0.22 (average -0.67). The graphic standard deviations (GSTD) from Table 4.6, ranges from 0.01 to 0.83 (samples 1 and 6 respectively) with an average of 0.36, which implies that samples 1, 4 and 5 are very well sorted, sample 3 is well sorted and samples 2 and 6 are moderately sorted.

The inclusive graphic skewness of the grains ranges from 0.05 – 0.75 (average 0.37). All sediments evidently positively skewed and are therefore composed of fine 'tails'. The inclusive graphic kurtosis of the grains ranges from 0.12 – 1.5 (average 0.59); sediments 1, 3, 4 and 5 are therefore classified as very platykurtic (very deficiently peaked) being less than 0.67 while sediment 2 is said to be mesokurtic and sediment 6 is classified as leptokurtic or excessively peaked (relatively better sorted in the central parts than in the tails).

3.3 Porosity from grain-size

Porosity (φ) is a vital hydraulic parameter which is necessary for the estimation of aquifer hydraulic conductivity, K, and other hydraulic parameters. In this study, porosity was determined using grain size analysis. Porosity (φ) is a dimensionless quantity with its magnitude being lesser than one, and usually expressed in percentage (%) and sometimes in fraction. Porosity is a significant criterion in characterizing an aquifer. Salem (2001) has observed that fine-grained sediments exhibit higher porosities (φ) than coarse-grained sediments because the number of contacts between fine grains tends to increase, leading to a looser packing.

By employing Equations 10 and 11, the grain coefficient of uniformities (η) and porosities shown in Table 3, for the six sample sediments were respectively obtained. The coefficient of uniformity (η) evaluated ranges from 2.81 to 5.6 for samples 1 and 3 respectively; while the porosity values estimated ranges from 0.34 (34%) to 0.43 (43%) for samples 2 and 4 respectively.

Table 6: Estimated porosities from grain size

Sample	η	φ_g

Sample 1	2.81	0.41
Sample 2	4.00	0.38
Sample 3	5.60	0.34
Sample 4	2.15	0.43
Sample 5	5.29	0.35
Sample 6	4.29	0.37

Table 3 indicates that the uniformity coefficient obtained in this study (with values ranging from 2.81 to 5.6), implies that the grains are well graded, as they fall below the value of 10 (Powrie, 2004).

4.0 Conclusion

Grain size analysis has been successfully carried out in this study, for the aquifer sediments of parts of Bayelsa State, Southern Nigeria. From grain size analysis statistical parameters and porosities have been estimated. From the grain size analysis and statistical evaluation of aquifer sediments, executed in parts of Bayelsa State, Nigeria, it is revealed that the area is dominated by medium sand to coarse sand grain sediment types, which are seen to be **very well sorted, well sorted and moderately sorted.** The dominating sediments in the study are positively skewed composed of fine tails. The skewedness of the distributions are very platykurtic (very deficiently peeked), mesokurtic and leptokurtic (excessively peeked, relatively better sorted in the central parts than in the tails). The porosity of the aquifers range from 0.34 (34%) to 0.43 (43%) with an average of 0.38 (38%), implying that the grains medium to coarse sand grains. All the samples analyzed are homogeneous at the localized sites, wit single mode values. .

The study establishes a veritable basis for the evaluation of the depositions environment of the study area.

5.0 Acknowledgement

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