Journal of Geosciences and Geomatics, 2019, Vol. 7, No. 4, 191-200
Available online at http://pubs.sciepub.com/jgg/7/4/4
Published by Science and Education Publishing
DOI:10.12691/jgg-7-4-4

Textural and Heavy Minerals Characterization of Coastal Sediments in Ibeno and Eastern Obolo Local Government Areas of Akwa Ibom State – Nigeria

Clement E Bassey[1], Aniefiok E. Ite[2,3,*], Ekpedeme R. Asuaiko[1,*], Emmanuella E. Aidoko[1]

[1]Department of Geology, Akwa Ibom State University, P. M. B. 1167, Uyo, Akwa Ibom State, Nigeria
[2]Department of Chemistry, Akwa Ibom State University, P.M.B. 1167, Uyo, Akwa Ibom State, Nigeria
[3]Research and Development Unit, Akwa Ibom State University, P.M.B. 1167, Uyo, Akwa Ibom State, Nigeria
*Corresponding author: aniefiokite@yahoo.co.uk

Received July 08, 2019; Revised August 12, 2019; Accepted August 29, 2019

Abstract Textural characterization and heavy mineral studies of beach sediments in Ibeno and Eastern Obolo Local Government Areas of Akwa Ibom State were carried out in the present study. The main aim was to infer their provenance, transport history and environment of deposition. Sediment samples were collected at the water–sediment contact along the shoreline at an interval of about 3m. Ten samples were collected from study location 1 (Ibeno Beach) and twelve samples were collected from study location 2 (Eastern Obolo Beach). A total of twenty–two samples were collected from the field and brought to the laboratory for textural and compositional analyses. The results showed that the value of graphic mean size ranged from 1.70Φ to 2.83Φ, sorting values ranged from 0.39Φ – 0.60Φ, skewness values ranged from -0.02 to 0.10 while kurtosis values ranged from 1.02 to 2.46, indicating medium to fine grained and well sorted sediments. This suggested that the sediments have been transported far from their source. Longshore current and onshore–offshore movements of sediment are primarily responsible in sorting of the heavy minerals. The histogram charts for the different samples and standard deviation versus skewness indicated a beach environment of deposition. This implies that the sediments are dominated by one class of grain size; a phenomenon characteristic of beach environments. The heavy mineral assemblages identified in this research work were rutile, zircon, tourmaline, hornblende, apatite, diopside, glauconite, pumpellyite, cassiterite, epidote, garnet, augite, enstatite, andalusite and opaque minerals. The zircon-tourmaline-rutile (ZTR) index ranged from 47.30% to 87.00% with most of the samples showing a ZTR index greater than 50%. These indicated that the sediments were mineralogically sub-mature and have been transported far from their source. The heavy minerals identified are indicative of being products of reworked sediments of both metamorphic (high rank) and igneous (both mafic and sialic) origin probably derived from the basement rocks of the Oban Massif as well as reworked sediments of the Benue Trough. Therefore, findings from the present study indicated that erosion, accretion, and stability of beaches are controlled by strong hydrodynamic and hydraulic processes.

Keywords: *coastal sediments, heavy minerals, grain-size analysis, Akwa Ibom State, Nigeria's Niger Delta Region*

Cite This Article: Clement E Bassey, Aniefiok E. Ite, Ekpedeme R. Asuaiko, and Emmanuella E. Aidoko, "Textural and Heavy Minerals Characterization of Coastal Sediments in Ibeno and Eastern Obolo Local Government Areas of Akwa Ibom State – Nigeria." *Journal of Geosciences and Geomatics*, vol. 7, no. 4 (2019): 191-200. doi: 10.12691/jgg-7-4-4.

1. Introduction

A larger portion of the world's surface including the ocean floor and coastal area is covered with thick deposits of sedimentary particles. The sediments may be derived from offshore and catchments area deposits of the world and evidence was found to suggest that these deposits are being eroded by tidal currents. According to Basu [1], sedimentation is mainly driven by tectonic forces, subordinated by climatic and eustatic forces, and to a minor extent in response to impact processes. The nature of the deposition and their formation is mainly dependent on the distribution of particles of different sizes [2]. Sediment particle size and mineral content are two of the characteristic factors that define erosion potential of sediments. Grain size is the most fundamental property of sediments that affect their entrainment, transport and deposition. Grain size studies of beach sediments therefore provide important information on the sediment provenance, intrinsic properties of sediments, transport history and depositional environment [3,4,5,6]. Over the past decades, heavy minerals in sands have been used in petrogenetic and provenance studies [7-11]. Some researchers have used the relationship between certain heavy minerals or the presence of a particular assemblage of heavy minerals to indicate the original sources of sands. While other researchers have used the characteristics of certain heavy minerals as provenance indicators. Understanding of sedimentary provenance is essential when investigating the origin of sediment and can also provide a rich source of information in sediment–based paleoenvironmental reconstruction [1,5,11-16]. Over the years, it has been observed that the complex coastal processes have left their imprints in the sediments and as such, the sedimentology of beach sediments plays a vital role in documenting the depositional history of a region [5,11,17]. In a study, Pettijohn *et al*. [18] used the heavy minerals to trace sediment transport paths and map the paths to outline sand bodies, as well as find provenance. According to Mazumder [11], sediment transport is commonly associated with erosion, bank undercutting, sandbar formation, aggradation, gullying, plugging, bed form migration and generation of primary sedimentary structures.

Coastal sediments, which have been studied by various researchers around the world [1,2,3,4,7-11,19-44], are very important in the provenance studies and/or depositional history of a given region. Over the years, it has been reported that detrital sediments retain a record of eroded crustal material and better understanding of geological history is gleaned from provenance studies [1,27,29]. Size, mineral content and shape of sediment vary at different locations of the same river system, depending on distance traversed by particles, gradient of the river and the geological formation of the river course and catchment area [28]. A better understanding of particle size distribution and the assemblages of heavy minerals in sediment make it possible to effectively locate and use essential minerals to predict their dispersal pattern when they re-enter the natural environment thus giving information about the source of the sediment or provenance and environment of deposition [1,18]. Grain size parameters, which could be seen as an essential tool for classifying sedimentary environments, are required and their mean size has proved to be a useful measure of the speed of the depositing flow [26,45,46]. In the Nigeria's Niger Delta region, there is paucity of information on the provenance, transport history and environment of deposition of beach sands particularly in Ibeno and Eastern Obolo Local Government Areas of Akwa Ibom State. Therefore, the present study was conducted to utilize textural parameters obtained from grain size analysis and heavy mineral content of these sediments to infer their provenance, transport history and environment of deposition.

2. Materials and Methodology

2.1. Study Area

The present study was conducted in the coastline of two oil–producing host and oil–rich communities viz Ibeno and Eastern Obolo Local Government Areas in the coastal area of Akwa Ibom State. Akwa Ibom State, which is currently the largest oil–producing state in the Nigeria's Niger Delta region, is located in the coastal southern part of the country (i.e. South–South geopolitical zone) (Figure 1) [31,47]. Akwa Ibom State (Figure 2) covers a total land area of 8412 km^2 and lies between latitudes 4°32′N and 5°33′N, and longitudes 7°25′E and 8°25′E [47]. The state is bordered on the east by Cross River State, on the west by Rivers State and Abia State, and on the south by the Atlantic Ocean and the southernmost tip of Cross River State. Although the coastline in the present study is endowed with less geomorphic features, it has various management problems such as shoreline erosion, flooding and environmental degradation. The first study location, Ibeno Local Government Area (L.G.A.) occupies the largest Atlantic coastline of more than 129 km in Akwa Ibom State (Figure 2 & Figure 3; 4^{0}32′N, 4^{0}36′N and 7^{0}48′E, 8^{0}17′E) and based on data from 2006 Nigeria's national census [48], it is home to 74, 840 people and ExxonMobil Producing Nigeria Unlimited – Qua Iboe Terminal (QIT) [49]. The second study location, Eastern Obolo L.G.A. is located in the Niger Delta fringe between Imo and Qua Iboe Rivers estuaries and lies between latitudes 4°28′N and 4°53′N and longitudes 7°50′E and 7°55′E. It is bounded in the North by Mkpat Enin L.G.A, North East by Onna L.G.A, West by Ikot Abasi L.G.A., South East by Ibeno L.G.A and in the South by the Atlantic Ocean (Figure 2 & Figure 3). Eastern Obolo L.G.A lies on the coastline of the Qua Iboe River with a landmass of 117.00 km^2 and based on data from 2006 Nigeria's National Census [48], it is home to 60,543 people.

The geological information of the study area, Ibeno and Eastern Obolo Beach, indicates that it is part of the coastal plain sediment in Nigeria belonging to the Tertiary Benin Formation. The study area which extends horizontally along the landward/seaward boundary with the Atlantic Ocean is characterized by semi-diurnal tide with a meso-tidal range of 2.4m and a low gradient (<5°). The coastal terrain of Ibeno and Eastern Obolo is characterized by two distinct seasons viz the wet and the dry seasons. The wet or rainy season lasts between eight to nine months starting from mid–march till the end of November. Depending on the area, it is worthy to note that the mean annual rainfall ranges from 2,000mm to 3,000 mm and the wet season is usually interrupted by a short dry period in August. The dry season has a short duration of between the last week of November or early December and lasts till early March. In the present study, the climate in the study area is uniformed due to influence of the adjoining ocean and rainfall is expected every month of the year due to the hot maritime air mass along the Atlantic Ocean coastline. Average temperature in the study area ranges from 23°C to 31°C. The vegetation pattern changes from mangrove swamp on the coast to lowland rainforest towards the north. In a recent study, Udoudo et. al [50] reported that the vegetation in Ibeno and Eastern Obolo L.G.As accounts for 50.04% (10615.77 hectares coverage) and 46.49% (4672.53 hectares coverage), respectively.

2.2. Sample Collection

Coastal sediment samples were collected from Ibeno beach and Eastern Obolo beach along Atlantic Ocean coastal area of Akwa Ibom State during various missions realized during July 2017 and June 2018. Samples were collected at the water–sediment contact along the shoreline at an interval of about 3m. The coordinates of each sampling point was recorded using handheld Global Positioning System (GPS) with a precision of 4 to 5 m. Collected sediment samples were carefully labeled and preserved in polyethylene bags accordingly. Ten samples were collected from study location 1 (Ibeno Beach) and twelve samples were collected from study location 2 (Eastern Obolo Beach). A total of twenty–two samples collected from the field were transported to Akwa Ibom State University (AKSU) Sedimentology Laboratory for textural and compositional analyses.

2.3. Procedure for Grain–Size Analysis

In the laboratory, debris and dead shells were separated from sediments and the mixed saline content was removed from the beach sediments by washing with water. Consequently, the sediment samples were dried in an oven at 60^{o}C to remove any moisture content present. 50mg of each of the 22 dried samples was taken by conning and quartering method in order to subject them to standard method of sieving using stacked sieve sets with a mesh opening of 2.00 1.00, 0.50, 0.25, 0.125, 0.063 and 0.043 mm. The nominal sieve opening allows for better discrimination of the sub–populations and a receiving pan was placed under these set of sieves to collect the finest fractions. The set-up was covered with a lid and the grain size distribution was carried out by using a Ro-Tap sieve shaker (at 15 minutes interval). The fraction retained in each sieve and that of the pan after shaking, was weighed and recorded. Weight retained in each sieve (representing a particular grain size) was measured using an electronic balance and recorded and this was done for all the samples. From this data, weight % and cumulative weight % were calculated. From the results obtained, cumulative frequency curves were plotted, using the semi-log graph paper. Textural parameters like the graphic mean, standard deviation or sorting, inclusive graphic skewness and kurtosis were calculated using values for 5phi, 16phi, 25phi, 50phi, 75phi, 84phi and 95phi, where applicable. These parameters were used for the construction of scatter plots needed for environmental interpretation.

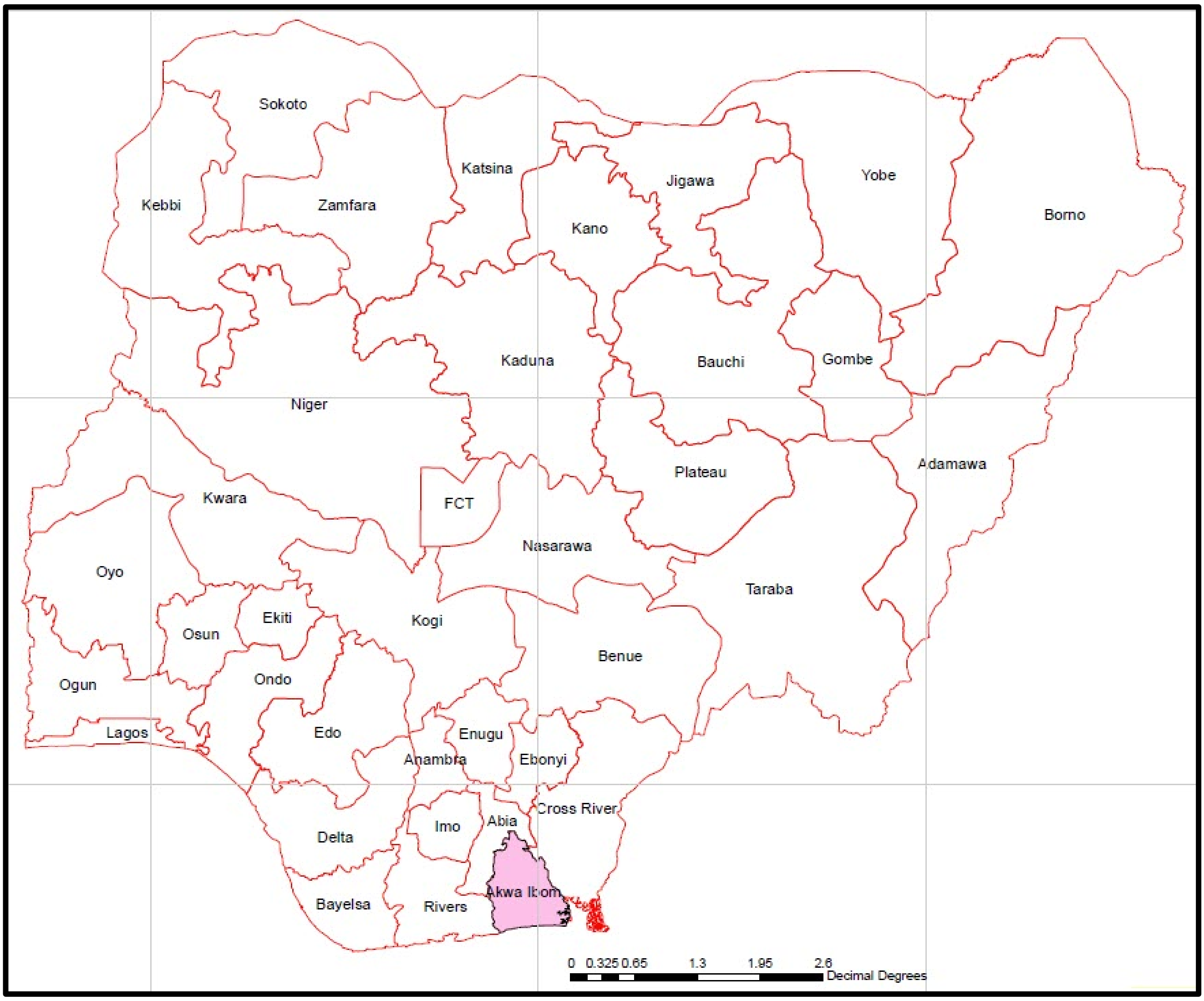

Figure 1. Map of Nigeria showing location of Akwa Ibom State

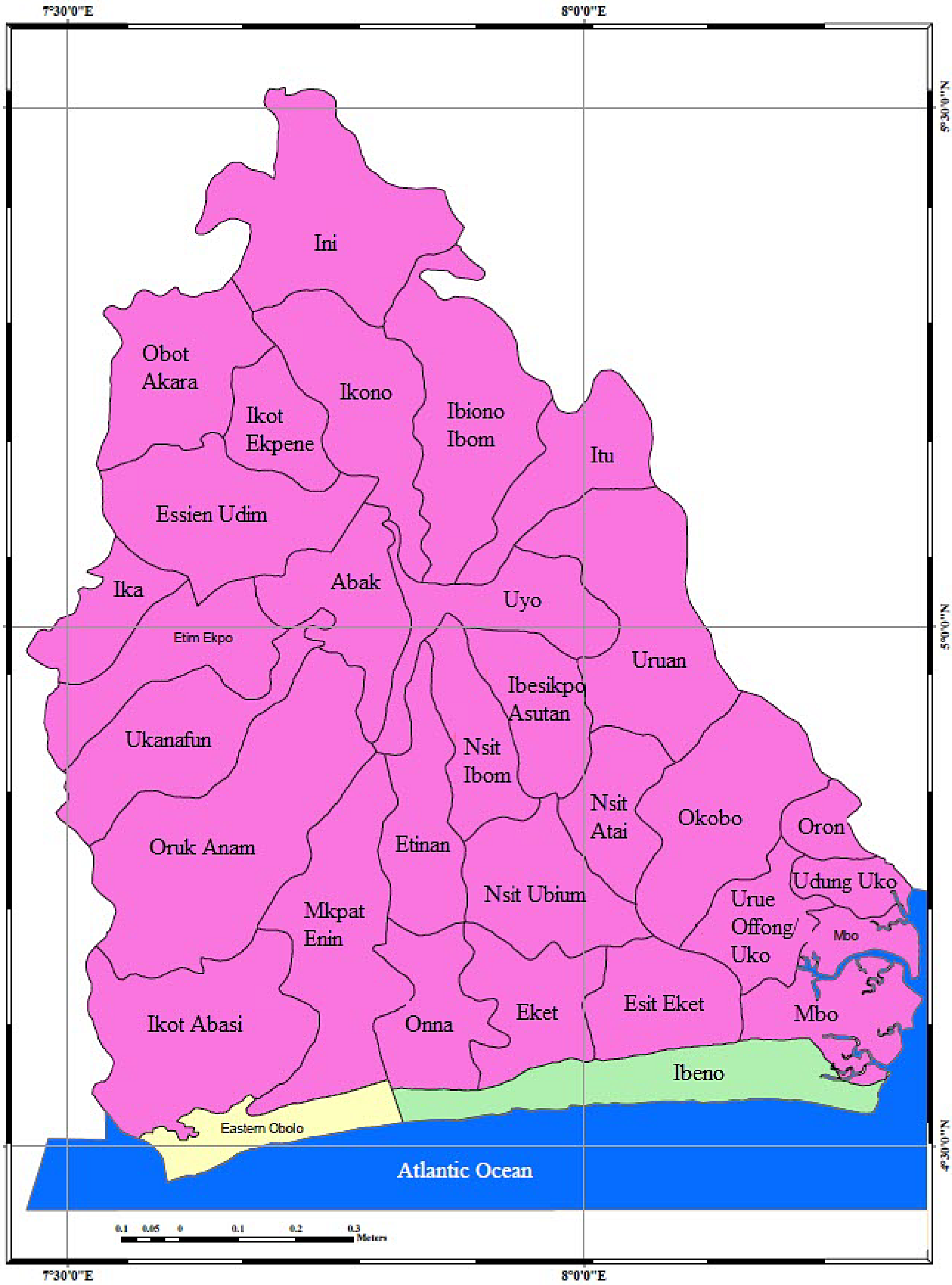

Figure 2. Map of Akwa Ibom State Showing Study Area (Ibeno and Eastern Obolo L. G. As)

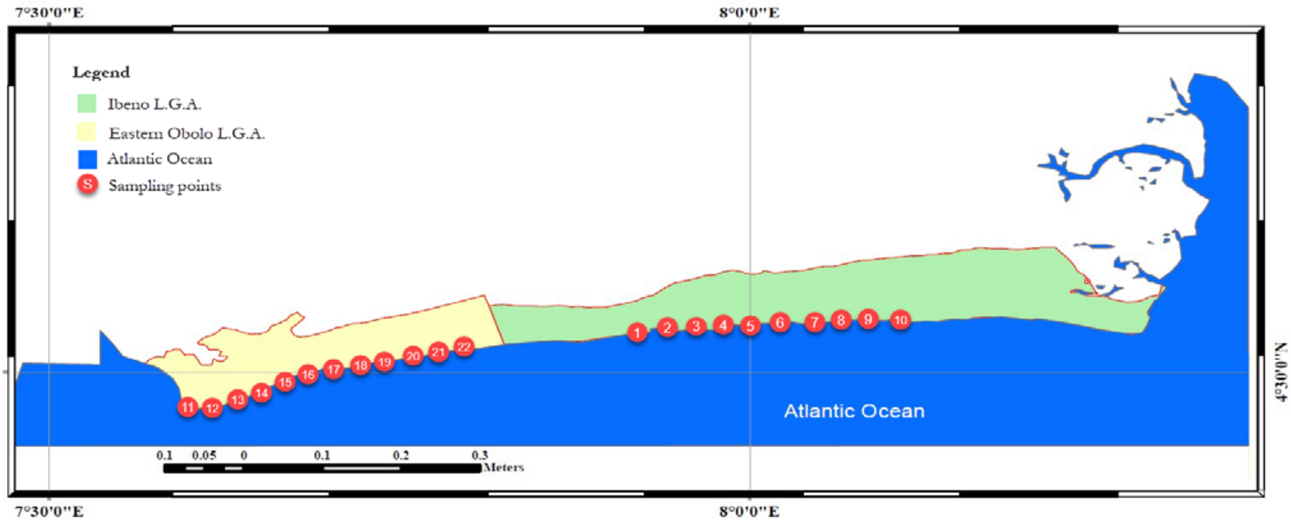

Figure 3. Cross Section Map of Akwa Ibom State Showing Study Area (Ibeno and Eastern Obolo L.G.As)

2.4. Procedure for Heavy Mineral Analysis

Ten (10) samples were selected for heavy minerals separation, five from each location**.** The samples were sieved and the fraction from 125µm was used**.** 40g of sodium hemataphosphate (salt) was measured and dissolved in 1 litre of distilled water. The mixture was shaken vigorously until the whole salt dissolved. 10g of sand fraction retained on the 125µm mesh was measured using the weighing balance and soaked in the salt solution for twenty four hours. After that, the sample was washed with distilled water until the dirt was completely removed. The washed sample was dried in the oven for about thirty minutes. 5g of each washed sample was poured into a separating funnel containing bromoform (Bromoform of specific gravity 2.85 was the heavy liquid used as the separating medium). The mixture was rigorously stirred and then allowed to settle. The separating funnel tap was opened to allow all heavy minerals that settle to its stem to be collected into a filter paper fitted into a glass funnel in a conical flask. The separated heavy minerals were then washed with acetone (to remove the effects of the bromoform), oven-dried and mounted on glass slides with Canada balsam. Examination and identification of the heavy minerals were carried out in accordance with Krumbein and Pettijohn [51]. The mineral identification was done under a transmitted light flat stage petrographic microscope on the basis of their optical properties like color, pleochroism, absorption, relief, extinction, and birefringence. The number, size and shape of the different opaque and non-opaque minerals were also noted. The maturity index or "ZTR index" was calculated and used as a scale for the estimation of the degree of modification or maturity of the entire heavy mineral assemblage of the samples. The "ZTR index" is calculated in percentage, using a formula known as Hubert's scheme [21], written below:

$$\text{ZTR INDEX} = \frac{\text{Zircon} + \text{Tourmaline} + \text{Rutile}}{\text{Total number of non-opaque minerals}} x100.$$

From the calculated percentage, ZTR < 75% implies immature to sub mature sediments while ZTR > 75% is indicative of mineralogically mature sediments.

3. Result and Discussion

3.1. Grain–Size Analysis

Grain size statistical parameters have been employed for characterizing and interpreting various depositional processes and environment [4,18,19,22,52-56]. The grain–size statistical parameters used in describing the particle size distribution are mainly categorized into four major groups: (i) the mean, (ii) standard deviation (sorting), (iii) skewness, and (iv) kurtosis. Although these parameters can be easily acquired by mathematical or graphical methods, it has been observed that the mathematical 'method of moments' is the most accurate since it represented the entire sample population [2,51,57].

In the present study, the grain size parameters of the study area [graphic mean, inclusive graphic standard deviation (σ_1), inclusive graphic skewness (SK_1), graphic kurtosis (K_G)] and statistical properties of grain sizes and its interpretations are shown in Table 1 and Figure 3 & Figure 4.

Table 1. Grain size analysis results and interpretations (Source Folk and Ward [19])

Sample Number (S/N)	Graphic mean (M_Z)	Inclusive graphic standard deviation (σ_1)	Inclusive graphic skewness (SK_1)	Graphic kurtosis (K_G)	Interpretation
L1S1	2.28	0.48	- 0.02	1.12	Fine grained, well sorted, near symmetrical, leptokurtic
L1S2	2.82	0.42	0.03	2.46	Fine grained, well sorted, near symmetrical, very leptokurtic
L1S3	2.73	0.52	0.02	1.05	Fine grained, well sorted, near symmetrical, mesokurtic
LIS4	2.83	0.52	0.02	1.23	Fine grained, moderately well sorted, near symmetrical, leptokurtic
LIS5	2.78	0.58	- 0.02	1.37	Fine grained, well sorted, near symmetrical, leptokurtic
L1S6	2.70	0.53	0.06	1.29	Fine grained, well sorted, near symmetrical, leptokurtic
LIS7	2.82	0.39	0.01	1.43	Fine grained, well sorted, near symmetrical, leptokurtic
L1S8	2.77	0.60	0.09	1.23	Fine grained, well sorted, near symmetrical, leptokurtic
L1S9	2.73	0.54	0.02	1.30	Fine grained, well sorted, near symmetrical, leptokurtic
L1S10	2.72	0.60	0.01	1.13	Fine grained, well sorted, near symmetrical, leptokurtic
L2S11	2.62	0.58	0.01	1.02	Fine grained, well sorted, near symmetrical, mesokurtic
L2S12	2.62	0.58	0.01	1.02	Fine grained, well sorted, near symmetrical, mesokurtic
L2S13	2.43	0.55	0.02	1.37	Fine grained, moderately well sorted, near symmetrical, leptokurtic
L2S14	2.53	0.55	0.02	1.17	Fine grained, well sorted, near symmetrical, leptokurtic
L2S15	2.58	0.52	0.02	1.18	Fine grained, well sorted, near symmetrical, leptokurtic
L2S16	2.67	0.54	-0.02	1.30	Fine grained, well sorted, near symmetrical, leptokurtic
L2S17	2.53	0.57	0.02	1.43	Fine grained, well sorted, near symmetrical, leptokurtic
L2S18	2.65	0.58	0.03	1.50	Fine grained, well sorted, near symmetrical, very leptokurtic
L2S19	2.62	0.60	0.01	1.13	Fine grained, well sorted, near symmetrical, leptokurtic
L2S20	2.63	0.58	0.02	1.50	Fine grained, well sorted, near symmetrical, very leptokurtic
L2S21	2.57	0.59	0.01	1.43	Fine grained, well sorted, near symmetrical, leptokurtic
L2S22	1.70	0.51	0.10	1.58	Medium grained, moderately well sorted, near symmetrical, very leptokurtic

$\mathbf{M_z}$ = **g**raphic mean, σ_1 = inclusive standard deviation/sorting, $\mathbf{SK_1}$ = inclusive graphic skewness, K_G = graphic Kurtosis.

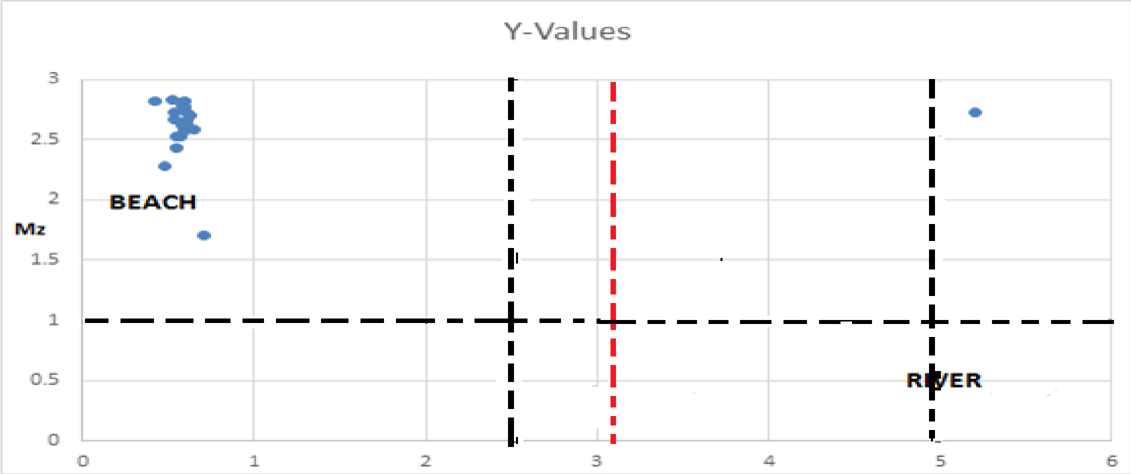

Figure 4. Bivariate plot of graphic mean against inclusive standard deviation/ sorting

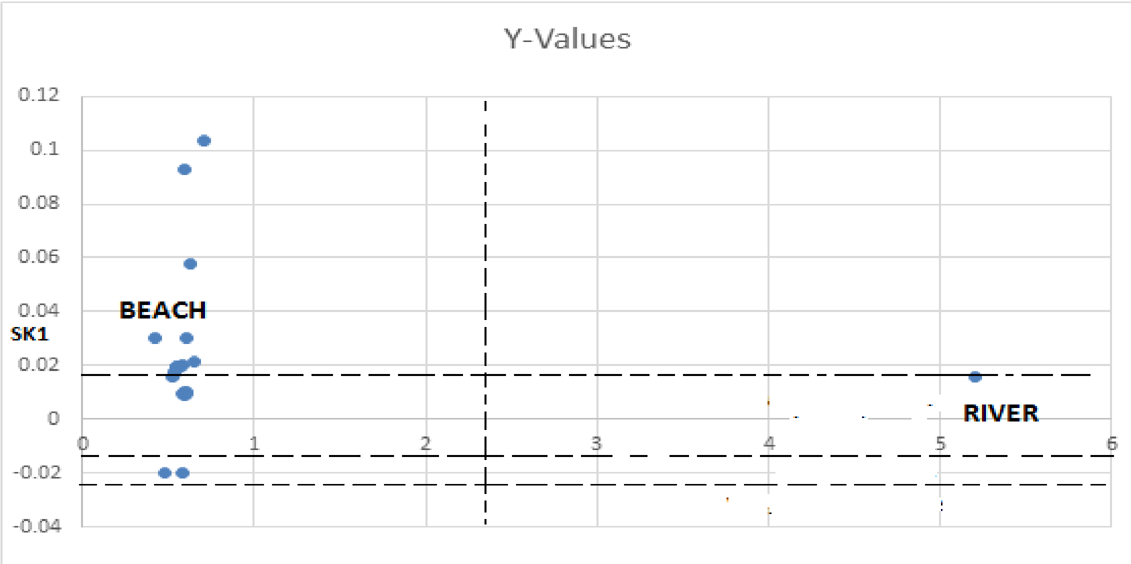

Figure 5. Bivariate plot of inclusive skewness against inclusive standard deviation/ sorting (Moiola and Weiser [23])

3.1.1. Graphic Mean

The mean is the most commonly presented parameter of sediment size analysis and it reflects the overall average size of the sediment as influenced by sediment and depositional environment. In the present study area, mean value ranges from 1.70Φ to 2.83Φ indicating a prominent distribution of medium to fine sand in these study locations. The distribution of medium sand in this region might have accrued from the transport of coarser lighter sediments as a result of high velocity waves and high energy environment [10]. Findings from this present study suggest that the sediments are medium to fine grained indicating that they have been transported far from their source. Overall, it has been observed that samples from beaches undergo repeated wear and tear by wave action and therefore, it is common to have fine nature of sediments [10,19,24,25].

3.1.2. Standard Deviation (Sorting)

Standard Deviation (sorting), which relates to the range of grain sizes, measures the uniformity of the particle size distribution. In the present study, samples analyzed showed a high degree of sorting with values ranging from 0.39Φ – 0.60Φ. This indicates moderately sorted to moderately well sorted nature which may be due to the addition of sediments of different grain size from the reworking of beach ridges or by alluvial action and the prevalence of strong wave convergence throughout the year [10]. In this present study, the average sorting value is 0.50Φ which corresponds to high energy environments. In another related study, similar observations have been reporetd by Vijayam et. al [58] in the East Coast of India. It has been observed that typical environments that display this range of sorting values include most beaches (foreshore), shallow marine shelf, and many inland dunes [20,26]. Moderate to moderately well sorting of sediments indicate low and moderate energy condition in the depositinal environment.

3.1.3. Skewness

Skewness (which lies within the range –1 to +1) measures the asymmetry of a frequency distribution and based on the classification of Folk and Ward [19] the skewness values of these sands vary from negatively skewed to very positively skewed. In the present study, the samples analyzed have skewness values ranging from -0.02 to 0.10 indicating that the sediments are near symmetrical. The average skewness value of the analyzed samples is 0.04 which corresponds to near symmetrical. In addition, most of the skewness values are positive which indicate skewness towards the finer grain sizes. However, the negative values indicate skewness towards the coarser grain sizes. In a similar study, Sathasivam et. al [30] reported that the negative skewness values indicate coarse-skewed material, whereas the positive values represents more material in fine skewed. In the present study, fine sediments could be attributed to the prevailing high wave energy condition, the seasonal wave action, coastline erosion and various factors which might have influenced the textural characteristics of coastal sediments. The mixed distribution of coastal sediments could be attributed to washing and backwashing of waves, and as such, coarser sediments are retained and get entrapped amidst finer sediments [10].

3.1.4. Kurtosis

Kurtosis is easily interpreted as a measure of the “peakedness” of the distribution and/or a measure of ratio between the sorting in the tails of the curve and the sorting in the central portion. According to Folk and Ward [19], the graphic kurtosis is the qualitative measure of the part of sediments already sorted elsewhere in a high energy environment and later transported and modified by another type of environment. In the present study, the kurtosis values obtained from the samples analyzed range from 1.02 to 2.46 and the average kurtosis value is 1.74 which shows that the study area is very leptokurtic in nature. The extreme values of kurtosis, leptokurtic and very leptokurtic, indicate that the sediments were transported in high or low energy conditions to a new environment. Beach sediments show extreme kurtosis values due to good sorting achieved in high energy environments [19]. It is generally known that kurtosis is a second indicator of sorting where very flat curves equate to poorly sorted sediments or those with bimodal frequency curves are platykurtic [54]. Friedman [59] suggested that extreme high or low values of kurtosis imply that part of the sediment achieved its sorting elsewhere in a high energy environment. It is known that variation in the kurtosis values is a reflection of the flow characteristic of the depositing medium [41,60,61]. The dominance of finer size of platykurtic nature of sediments reflects the maturity of the sand. This may be due to the aggregation of sediment particle size by compaction, and the variation in the sorting values are likely due to continuous addition of finer/coarser materials in varying proportions [62]. The predominance of medium to fine grained and well sorted sediments suggests that the sediments have been transported far from their source. The histogram charts for the different samples (standard deviation versus mean (Figure 4) and standard deviation versus skewness (Figure 5) indicate a beach environment of deposition [22,23], showing that the sediments are dominated by one class of grain size; a phenomenon characteristic of beach environments.

3.2. Depositional Environment

Determination of the depositional environment for sediment usually requires some knowledge of its shape, internal characteristics and their spatial distribution within it [18,63,64]. In the present study, various textural parameters obtained have not shown many variations and several researchers have expressed similar views over the years [10,23]. The waves that deposit sands on the beaches have significant competence. The incoming waves and outgoing backwash exert winnowing effect on the sediments but tide–generated longshore currents complicate this winnowing process. Findings from this present study showed that standard deviation vs skewness falls within the low water mark and strandline except a few stations at foreshore environment. The bivariant plot of mean vs. standard deviation/sorting (Figure 4) shows that the sediments are poorly sorted irrespective of their coarseness or fineness. As such, this reveal that sorting is independent of grain size and that sorting deteriorates in both coarse and fine sediments [10,42]. Coarse sediments are usually found closest to the source area because they are too heavy to be transported far, while fine sediments such as finer silt travel the farthest. In this study, the scatter plot of skewness vs. standard deviation (Figure 5) also helps to characterize the sediment as a separate cluster. A plot of skewness versus standard deviation indicates samples in a beach or river regime, but fails to separate the two [2]. Generally, standard deviation (sorting) plotted against skewness is widely considered to be an effective discriminator between river and beach [20,22]. The study region, located at the South end of Akwa Ibom State and occupying a vast coastal area, shows the influence of fluvial regime in beach environment.

Table 2. Mineral grains identified and their different proportions

Sample No.	R	Z	T	H	Ap	Di	Gl	Pu	Ca	Ep	Ga	Aug	En	And	Op	ZTR INDEX
L1S1	11	10	9	-	-	-	-	-	-	3	8	5	-	-	59	65.2
L1S3	15	12	10	-	-	-	-	-	-	-	-	7	14	6	60	57.8
L1S5	13	10	3	-	9	8	12	-	-	-	-	-	-	-	48	47.3
LIS7	7	5	8	-	-	-	-	-	-	-	-	-	3	-	61	87.0
LIS10	8	7	10	-	-	-	3	-	-	-	-	5	-	-	58	75.8
L2S12	6	13	10	7	6	-	-	15	-	-	-	-	-	-	73	50.9
L2S14	6	7	8	3	4	-	-	-	-	-	-	-	-	-	30	75.0
L2S15	9	8	8	-	-	3	7	13	-	-	-	-	-	-	48	52.1
L2S17	15	11	13	-	-	-	10	-	9	-	-	-	-	-	35	67.2
L2S19	4	8	6	-	-	-	-	-	-	3	2	-	-	-	38	78.3

R = Rutile, Z= Zircon, T= Tourmaline, H = Hornblende, Ap = Apatite, Di = Diopside, Gl – Glauconite, Pu = Pumpellyite, Ca = Cassiterite, Ep = Epidote, Ga= Garnet, Aug = Augite, En = Enstatite, And = Andalusite, Op= Opaque minerals.

Table 3. Provenance of heavy minerals.

Reworked sediments	Well-rounded grains of Rutile, Tourmaline, Zircon.
Low rank metamorphic	Biotite, Chlorite, spessartite garnet, Tourmaline (especially small euhedral, brown crystals with graphite inclusions).
High rank metamorphic	Actinolite, andalusite, apatite, Almandine, garnet, biotite, diopside, Epidote, clinozoisite, glaucophane Hornblende (including blue-green varieties) ilmenite, kyanite, magnetite, sillimanite, sphene, staurolite, tourmaline, Tremolite, zircon.
Sialic igneous	Apatite, biotite, hornblende, ilmenite, monazite, muscovite, rutile, sphene, tourmaline, zircon.
Mafic igneous	Augite, diopside, epidote, hornblende, hypersthene, ilmenite, magnetite, olivine, oxyhornblende, pyrope garnet, serpentine
Pegmatites	Apatite, biotite, cassiterite garnet, monazite, muscovite, rutile, tourmaline (especially inidicolite)
Ash falls	Euhedral crystals of apatite augite, biotite, hornblende, and zircon.
Authigenic	Hematite, leucoxene, limonite, tourmaline, zircon, euhedral crystals of anatase, brookite, pyrite, rutile, and sphene.

3.3. Heavy Minerals and Provenance

The results of heavy mineral content in the coastal sediments of Ibeno Beach and Eastern Obolo Beach are shown in Table 2. In this study, the result shows that both opaque and non–opaque heavy minerals were identified in the studied samples and ZTR index are shown in Table 2. The results obtained showed that the opaque minerals formed a significant part of the separated heavy fraction. The heavy minerals identified include rutile, zircon, tourmaline, hornblende, apatite, diopside, glauconite, pumpellyite, cassiterite, epidote, garnet, augite, enstatite, andalusite and opaque minerals. In a related study, it has been reported that the heavy minerals are dominated by opaque minerals (16 – 65%) associated with variable proportions of muscovite, chlorite, kyanite, sillimanite, biotite, pyroxene, amphibole, garnet, epidote, zircon, tourmaline, and rutile [38]. In this study, the calculated ZTR index from the result of the heavy mineral analysis for the selected samples ranged from 47.30% to 87.00% with most of the studied samples showing a ZTR index greater than 50%. These findings suggested that the sediments were mineralogically sub-mature and have been transported far from their source [21]. The ZTR index, which is often used to characterized association of ubiquitous minerals, is the sum of the percentage of zircon, tourmaline, and rutile, which are minerals resistant to weathering agents and constitute effective natural tracers for the tracing of the sediment dynamics along the coast [38,39,40]. In this study, heavy minerals analysis suggested a mixed provenance supplied detritus to the Benin Formation (Eocene). The implication is that the samples were reworked sediments of both metamorphic (high rank) and igneous (both mafic and sialic) origin (Table 3). Zircon, tourmaline and rutile crystals have high proportion of rounded and sub roundedness. The round zircon, tourmaline and rutile grains are indicative of reworked sediments. The high-grade metamorphic mineral like andalusite and the igneous mineral suite of apatite, epidote, garnet, etc. suggested that the sediments are derived from both metamorphic and igneous sources. The sources of these sediments are probably from Oban Massif through the Benue Trough and the Calabar Flank which are the closest sedimentary basin to the study area. It is known that heavy mineral assemblages present in marine sedimentary deposits are greatly affected by fluvial sediments derive from adjacent continental areas [11,43,44].

4. Conclusions

The study revealed that, the predominance of medium to fine grained and well sorted sediments suggested that the sediments have been transported far from their source. The transport of sediments in the study area is mainly due to saltation process. Longshore current and onshore–offshore movements of sediment are primarily responsible in sorting of the heavy minerals. The histogram charts for the different samples and standard deviation versus skewness indicated a beach environment of deposition. This implies that the sediments are dominated by one class of grain size; a phenomenon characteristic of beach environments. The heavy mineral assemblages identified in this research work were rutile, zircon, tourmaline, hornblende, apatite, diopside, glauconite, pumpellyite, cassiterite, epidote, garnet, augite, enstatite, andalusite and opaque minerals. Higher concentration of the zircon, tourmaline and rutile in the fine and very fine sand fractions is attributed to high sorting by the waves. The result of ZTR index indicated that the sediments were mineralogically sub-mature and have been transported far from their source. Provenance of sediment has been deduced from heavy mineral assemblages and textural characteristics. The main supplies sources of sediment to the study area come mainly from the basement rocks of the Oban Massif as well as reworked sediments of the Benue Trough. The heavy minerals identified are indicative of being products of reworked sediments of both metamorphic (high rank) and igneous (both mafic and sialic) origin.

Acknowledgements

The authors would like to thank the Research and Development Coordinator of Akwa Ibom State University, Nigeria and Engr. Emem E. Ite of Infiniti Innovative Group – USA for providing all the support for successfully completing this research paper.

References

[1] Basu, A., "Provenance," *Encyclopedia of Sediments and Sedimentary Rocks*, G. V. Middleton, M. J. Church, M. Coniglio, L. A. Hardie and F. J. Longstaffe, eds., pp. 885-896, Dordrecht: Springer Netherlands, 2003.

[2] Syvitski, J. P. M., *Principles, Methods and Application of Particle Size Analysis*: Cambridge University Press, 2007.

[3] Bui, E. N., J. M. Mazzullo, and L. P. Wilding, "Using quartz grain size and shape analysis to distinguish between aeolian and fluvial deposits in the Dallol Bosso of Niger (West Africa)," *Earth Surface Processes and Landforms*, 14 (2). 157-166, 1989.

[4] Rajganapathi, V. C., N. Jitheshkumar, M. Sundararajan, K. H. Bhat, and S. Velusamy, "Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India," *Arabian Journal of Geosciences*, 6 (12). 4717-4728, 2013.

[5] Boggs, S., *Principles of Sedimentology and Stratigraphy: Pearson New International Edition*: Pearson Education Limited, 2013.

[6] Garzanti, E., S. Andò, and G. Vezzoli, "Grain-size dependence of sediment composition and environmental bias in provenance studies," *Earth and Planetary Science Letters,* 277 (3). 422-432, 2009.

[7] Wong, F. L., "Heavy mineral provinces of the Palos Verdes margin, southern California," *Continental Shelf Research,* 22 (6-7). 899-910, 2002.

[8] Mange, M. A., and E. G. Otvos, "Gulf coastal plain evolution in West Louisiana: Heavy mineral provenance and Pleistocene alluvial chronology," *Sedimentary Geology,* 182 (1). 29-57, 2005.

[9] Ramasamy, P., and R. Karikalan, "Distribution and percentage of heavy minerals in coastal geomorphologial landforms in Palk Strait, Southeast Coast of India," *Middle East Journal of Scientific Research,* 5 (1). 49-53, 2010.

[10] Suresh Gandhi, M., and M. Raja, "Heavy mineral distribution and geochemical studies of coastal sediments between Besant Nagar and Marakkanam, Tamil Nadu, India," *Journal of Radiation Research and Applied Sciences,* 7 (3). 256-268, 2014.

[11] Mazumder, R., *Sediment Provenance: Influences on Compositional Change from Source to Sink*: Elsevier Science, 2016.

[12] Nagarajan, R., J. S. Armstrong-Altrin, F. L. Kessler, and J. Jong, "Chapter 7 - Petrological and Geochemical Constraints on Provenance, Paleoweathering, and Tectonic Setting of Clastic Sediments From the Neogene Lambir and Sibuti Formations, Northwest Borneo," *Sediment Provenance*, R. Mazumder, ed., pp. 123-153: Elsevier, 2017.

[13] Scott, R. A., H. R. Smyth, A. C. Morton, and N. Richardson, *Sediment Provenance Studies in Hydrocarbon Exploration and Production*: Geological Society, 2014.

[14] Arribas, J., S. Critelli, and M. J. Johnsson, *Sedimentary Provenance and Petrogenesis: Perspectives from Petrography and Geochemistry*: Geological Society of America, 2007.

[15] Scott, R. A., H. R. Smyth, A. C. Morton, and N. Richardson, "Provenance studies linking sediment to source," *Sediment Provenance Studies in Hydrocarbon Exploration and Production*, R. A. Scott, H. R. Smyth, A. C. Morton and N. Richardson, eds., p. 0: Geological Society of London, 2014.

[16] Weckström, K., K. M. Saunders, P. A. Gell, and C. G. Skilbeck, *Applications of Paleoenvironmental Techniques in Estuarine Studies*: Springer Netherlands, 2017.

[17] Angusamy, N., and G. V. Rajamanickam, "Coastal processes of Central Tamil Nadu, India: clues from grain size studies," *Oceanologia,* 49 (1). 41-57, 2007.

[18] Pettijohn, F. J., P. E. Potter, and R. Siever, *Sand and Sandstone*: Springer New York, 2012.

[19] Folk, R. L., and W. C. Ward, "Brazos River bar [Texas]: a study in the significance of grain size parameters," *Journal of Sedimentary Research,* 27 (1). 3-26, 1957.

[20] Friedman, G. M., "Distinction between dune, beach, and river sands from their textural characteristics," *Journal of Sedimentary Research,* 31 (4). 514-529, 1961.

[21] Hubert, J. F., "A zircon-tourmaline-rutile maturity index and the interdependence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones," *Journal of Sedimentary Research,* 32 (3). 440-450, 1962.

[22] Friedman, G. M., "Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands," *Journal of Sedimentary Research,* 37 (2). 327-354, 1967.

[23] Moiola, R. J., and D. Weiser, "Textural parameters; an evaluation," *Journal of Sedimentary Research,* 38 (1). 45-53, 1968.

[24] Friedman, G. M., "Differences in size distributions of populations of particles among sands of various origins: addendum to IAS Presidential Address," *Sedimentology,* 26 (6). 859-862, 1979.

[25] Rea, D. K., and S. A. Hovan, "Grain size distribution and depositional processes of the mineral component of abyssal sediments: Lessons from the North Pacific," *Paleoceanography,* 10 (2). 251-258, 1995.

[26] Blott, S. J., and K. Pye, "GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments," *Earth Surface Processes and Landforms,* 26 (11). 1237-1248, 2001.

[27] Morton, A. C., "Heavy minerals," *Encyclopedia of Sediments and Sedimentary Rocks*, G. V. Middleton, M. J. Church, M. Coniglio, L. A. Hardie and F. J. Longstaffe, eds., pp. 574-578, Dordrecht: Springer Netherlands, 2003.

[28] Thapa, B., R. Shrestha, P. Dhakal, and B. S. Thapa, "Problems of Nepalese hydropower projects due to suspended sediments," *Aquatic Ecosystem Health & Management,* 8 (3). 251-257, 2005.

[29] Roberts, N. M. W., M. J. Van Kranendonk, S. Parman, and P. D. Clift, "Continent formation through time," *Geological Society, London, Special Publications,* 389 (1). 1-16, 2015.

[30] Sathasivam, S., R. S. Kankara, S. C. Selvan, M. Muthusamy, A. Samykannu, and R. Bhoopathi, "Textural Characterization of Coastal Sediments along Tamil Nadu Coast, East Coast of India," *Procedia Engineering,* 116 794-801, 2015.

[31] Ite, A. E., U. U. Ubong, U. M. Etesin, E. W. Nsi, E. J. Ukpong, A. N. Ekanem, U. F. Ufot, and A. I. Udo, "Heavy Metals in Epiphytic Lichens and Mosses of Oil–Producing Communities of Eket and Ibeno, Akwa Ibom State – Nigeria," *American Journal of Environmental Protection,* 4 (2). 38-47, 2016.

[32] Achab, M., J. P. M. Cardona, J. M. Gutiérrez-Mas, A. S. Bellón, and J. L. González-Caballero, "Sedimentary Provenance and Depositional History of Cadiz Bay (SW Spain) Based on the Study of Heavy Minerals Surface Textures," *Thalassas: An International Journal of Marine Sciences,* 33 (1). 29-42, 2017.

[33] Rosales-Hoz, L., A. Carranza-Edwards, R. G. Martinez-Serrano, M. A. Alatorre, and J. S. Armstrong-Altrin, "Textural and geochemical characteristics of marine sediments in the SW Gulf of Mexico: implications for source and seasonal change," *Environmental Monitoring and Assessment,* 187 (4). 205, 2015.

[34] Carranza-Edwards, A., E. Centeno-García, L. Rosales-Hoz, and R. Lozano-Santa Cruz, "Provenance of beach gray sands from western México," *Journal of South American Earth Sciences*, 14 (3). 291-305, 2001.

[35] Armstrong-Altrin, J. S., Y. I. Lee, J. J. Kasper-Zubillaga, A. Carranza-Edwards, D. Garcia, G. N. Eby, V. Balaram, and N. L. Cruz-Ortiz, "Geochemistry of beach sands along the western Gulf of Mexico, Mexico: Implication for provenance," *Geochemistry,* 72 (4). 345-362, 2012.

[36] Singh, P., "Geochemistry and provenance of stream sediments of the Ganga River and its major tributaries in the Himalayan region, India," *Chemical Geology,* 269 (3). 220-236, 2010.

[37] Mishra, P. K., S. Parth, Y. Ankit, S. Kumar, V. Ambili, V. V. Kumar, S. Singh, and A. Anoop, "Geochemical and sedimentological characteristics of surface sediments from Ashtamudi Estuary, Southern India: implications for provenance and modern sedimentary dynamics," *Environmental Earth Sciences,* 78 (14). 395, 2019.

[38] Kermani, S., M. Boutiba, A. Boutaleb, and N. Fagel, "Distribution of heavy and clay minerals in coastal sediment of Jijel, East of Algeria: indicators of sediment sources and transport and deposition environments," *Arabian Journal of Geosciences,* 9 (1). 36, 2015.

[39] Joshua, E. O., and O. A. Oyebanjo, "Distribution of Heavy Minerals in Sediments of Osun River Basin Southwestern Nigeria," *Research Journal of Earth Sciences,* 1 (2). 74–80, 2009.

[40] Joshua, E. O., O. A. Oyebanjo, N. N. Jibiri, and O. O. Fasunwon, "Osun River basin sediments heavy mineral distribution," *Pacific Journal of Science and Technology,* 11 (1). 598-605, 2010.

[41] Seralathan, P., and D. Padmalal, "Textural studies of the surficial sediments of Muvattupuzha river and central Vembanad Estuary, Kerala," *Journal of the Geological Society of India,* 43 (2). 179-190, 1994.

[42] Kannaiyan, N., M. Suresh Gandhi, R. Elango, G. Sujita, and S. M. Hussain, "Heavy Minerals and Granulometric Studies in Coastal Sediments from Keelakarai to Periyapattinam, Gulf of Mannar, East Coast of India," *Water Resources in Arid Areas: The Way Forward.* pp. 283-294.

[43] Mezzadri, G., and E. Saccani, "Heavy mineral distribution in late Quaternary sediments of the southern Aegean Sea; implications for provenance and sediment dispersal in sedimentary basins at active margins," *Journal of Sedimentary Research,* 59 (3). 412-422, 1989.

[44] Frihy, O. E., and K. M. Dewidar, "Patterns of erosion/sedimentation, heavy mineral concentration and grain size to interpret boundaries of littoral sub-cells of the Nile Delta, Egypt," *Marine Geology,* 199 (1). 27-43, 2003.

[45] McCave, I. N., "Chapter 8 Size Sorting During Transport and Deposition of Fine Sediments: Sortable Silt and Flow Speed," *Developments in Sedimentology,* M. Rebesco and A. Camerlenghi, eds., pp. 121-142: Elsevier, 2008.

[46] López, G. I., "Grain Size Analysis," *Encyclopedia of Geoarchaeology*, A. S. Gilbert, ed., pp. 341-348, Dordrecht: Springer Netherlands, 2017.

[47] Ite, A. E., T. A. Harry, C. O. Obadimu, and I. O. Ekwere, "Comparison of Indoor Air Quality in Schools: Urban vs. Industrial 'Oil & Gas' Zones in Akwa Ibom State – Nigeria," *Journal of Environment Pollution and Human Health*, 7 (1). 15-26, 2019.

[48] NPC, *2006 Population and Housing Census of the Federal Republic of Nigeria: National and State Population and Housing Tables*, Federal Republic of Nigeria - Abuja: National Population Commission (NPC), 2009.

[49] Ite, A. E., I. I. Udousoro, and U. J. Ibok, "Distribution of Some Atmospheric Heavy Metals in Lichen and Moss Samples Collected from Eket and Ibeno Local Government Areas of Akwa Ibom State, Nigeria," *American Journal of Environmental Protection*, 2 (1). 22-31, 2014.

[50] Udoudo, N. P., E. J. Emengini, and J. I. Igbokwe, "Coastal Flood Mapping of Eastern Obolo and Ibeno LGAs of Akwa Ibom State of Nigeria, using SRTM and Satellite Imageries," *International Journal of Advances in Scientific Research and Engineering*, 4 (11). 71-76, 2018.

[51] Krumbein, W., and F. Pettijohn, "Manual of Sedimentology Petrography," *Appleton-Century crofts Inc, New York*, 549, 1938.

[52] Flugel, E., and E. Flügel, *Microfacies of Carbonate Rocks: Analysis, Interpretation and Application*: Springer, 2004.

[53] Nelsom, C. S., "Grain-size parameters of insoluble residues in mixed terrigenous-skeletal carbonate sediments and sedimentary rocks: some New Zealand examples," *Sedimentology*, 24 (1). 31-52, 1977.

[54] Shennan, I., A. J. Long, and B. P. Horton, *Handbook of Sea-Level Research*: Wiley, 2015.

[55] Lindholm, R., *A Practical Approach to Sedimentology*: Springer Netherlands, 2012.

[56] Shrivastava, K. L., and P. K. Srivastava, *Frontiers of Earth Science*: Indian Science Congress Association, Kolkata, 2015.

[57] Friedman, G. M., and K. G. Johnson, *Exercises in sedimentology*: Wiley, 1982.

[58] Vijayam, B. E., U. Aswathanarayana, and C. Mahadevan, "Sand movement on the Waltair Beach Pro." pp. 142-150.

[59] Friedman, G. M., "On Sorting, Sorting Coefficients, and the Lognormality of the Grain-Size Distribution of Sandstones," *The Journal of Geology*, 70 (6). 737-753, 1962.

[60] Baruah, J., P. Kotoky, and J. Sarma, *Textural and geochemical study on river sediments: a case study on the Jhanji River, Assam*, 1997.

[61] Ray, A. K., S. C. Tripathy, S. Patra, and V. V. Sarma, "Assessment of Godavari estuarine mangrove ecosystem through trace metal studies," *Environment International*, 32 (2). 219-223, 2006.

[62] Ramanathan, A., K. Rajkumar, J. Majumdar, G. Singh, P. N. Behera, S. Santra, and C. Sabarathinam, "Textural characteristics of the surface sediments of a tropical mangrove Sundarban ecosystem India," 38 (4). 397-403, 2009.

[63] Pettijohn, F. J., P. E. Potter, and R. Siever, "Sand Bodies and Environment," *Sand and Sandstone*, pp. 439-543, New York, NY: Springer US, 1972.

[64] Hampson, G. J., *Recent Advances in Models of Siliciclastic Shallow-marine Stratigraphy*: SEPM (Society for Sedimentary Geology), 2008.