Grain Size Distribution of a Modern Tidal River: A Case Study of Calabar River, South-South Nigeria

Lawrence Oghale O. O.[1], Edeme Antia[2], Soronnadi-Ononiwo G. C.[3], Powedei Debekeme[4]

[1, 2, 4] Department of Geology, Niger Delta University

[3] Department of Geology, University of Calabar

Abstract: ***The influence of sedimentary processes and environmental factors on the distribution of grain size facies in a modern day river with daily tidal influence was investigated using statistical parameter from grain size analysis of sediments derived from 45 sampled locations over a 15km segment and bathymetric readings from nine (9) transect of the Calabar tidal river, Southern Nigeria. The bathymetry of the river was deduced from depth sounding and were transformed into contour values. The distribution of the four grain size parameters; mean (Mz), sorting (OT), skewness (SKI) and kurtosis (KG), were sensitive to current energy changes which influences the dynamics of erosion, transportation, and depositional velocity controlled in the Calabar River by daily ebb and flood tidal regime and the gravitational downstream flow direction of the river. The mean grain size was observed to be coarser upstream and within the meander, fining gradually towards the river mouth downstream. Sorting, improved downstream, from extremely poorly sorted, at the meander to moderately sorted at the river mouth. The skewness indicated negative skeweness downstream while positively skewed upstream. While the kurtosis was generally leptokrtic downstream and very leptokurtic upstream. Based on the mean grain size parameter the sediments were differentiated into coarse, fine, and mud grained facies.***

Keywords: Bathymetry, Calabar river, Grain size, Kurtosis, Mean, Sorting and Skeweness.

1. Introduction

Sedimentary rocks are deposits that are formed in different environment from a variety of sedimentary processes. They are commonly described in terms of their textural characteristic principally of which is their grain size. The concept of grain size facies, sedimentological is commonly used in a broad descriptive sense to reflect the dominant sedimentary process responsible for their formation, e.g. tidal regimes that occur in tidal rivers.

Tidal rivers are classified based on the intensity of the tide; micro tide (0 - 2 m), meso tide (2 - 4m), macro tide (above 4 m) and also on the daily cycle of successive high and low water mark. The observed grain size distribution of modern day tidal river is principally defined by the morphology of the channel, the amount of sediment supplied, and the sequence of sedimentation. The morphology of the river channel entails its shape (straight, meandering, or roughness), depth and length, they mainly control the current velocity at the various bathymetric depths. The current velocity in turn controls the grain size facies distribution, in the long stretch of a river the sediment tends to become finer downstream, so meanders are common in the lower reaches of a river (Plummer et. al. 2003). The rate of sedimentation and sequences of sediment within a channel is controlled by the balance between erosion and deposition phases, resulting in sedimentary features such as sand bodies and bedforms which are typical of tidal river channels.

The origin and net accumulation of sediment in a tidal river, their grain size distribution, and their various features and physical parameters have been evaluated by Van Staanten and Kueneen (l957),Van Staanten (1954), Folk, and Wald, (1957).
Studies from Wadden along coastal areas of the North Sea and Mississippian tidal rivers by Postma (1957), Guiciher (1963), Gibbs (1973), Semeniuk (1981), all agreed that the average grain sizes tend to increase from the tidal inlet, in tidal rivers towards the upstream but finer (clay) towards tidal flats.

Van Staaten and Kueneen (1957) in their study of the Dutch Wadden tidal river described the net accumulation of sediments near the high water line. When current drops fine grain facies predominate the upper transition zone and high flats due to settlement and scour lag. Postma (1967) used distance-velocity and time-velocity curves to explain the relationship between settlement and scour lag and fine grain sedimentation. He concluded that the process of sorting usually establishes equilibrium between the bottom, suspended sediments and the current velocity. Studies from Solani and Vaigai tidal river systems India, Awashi (1969), Gujar et al., (1975), showed that skewness is sensitive to current energy changes.

The aims of this article includes the following:

1) To evaluate the various grain size faices of the Calabar Tidal River in relation to the effect of current velocity at different bathymetric levels and evaluate the possible factors responsible for the distribution.
2) To develop a hypothetical model from tidal effect on grain size distribution in the Calabar River for the purpose of paleostratigraphic reconstruction of tidal river deposit and as a model for further tidal river research in the country.

2. Location of Study

The area under focus is the Calabar River (fig 1), a tributary of the Cross River estuary which empties at the Atlantic Ocean located on the South-East coast of Nigeria. The area of study within the river is a 15km segment extending from the Creek town upstream to the point where it discharges into the estuary.

Located between longitudes 8^0 15'E and 8° 20'E and latitude 4° 54' N and 5° N.

Cross River coastal area, which encompasses the Calabar River is a humid tropical rain forest that is characterized by a dense vegetative cover mainly to the eastern bank, while the west bank is less forested with some human activity. The area has a clearly marked dry and raining season with an annual rain fall of about 3050mm per annum with relative humidity of about 87%.

The area is bounded by the Oban massif to the north which is a basement complex consisting of igneous and metamorphic rocks of Precambrian age. The Calabar River takes its root both, hydro and sediment from the Oban massif, with other small streams as tributaries to it. It flows through the alluvial fan and the coastal plains before emptying into the Cross River estuary. The Calabar River is about 126km from its source area to the estuary.

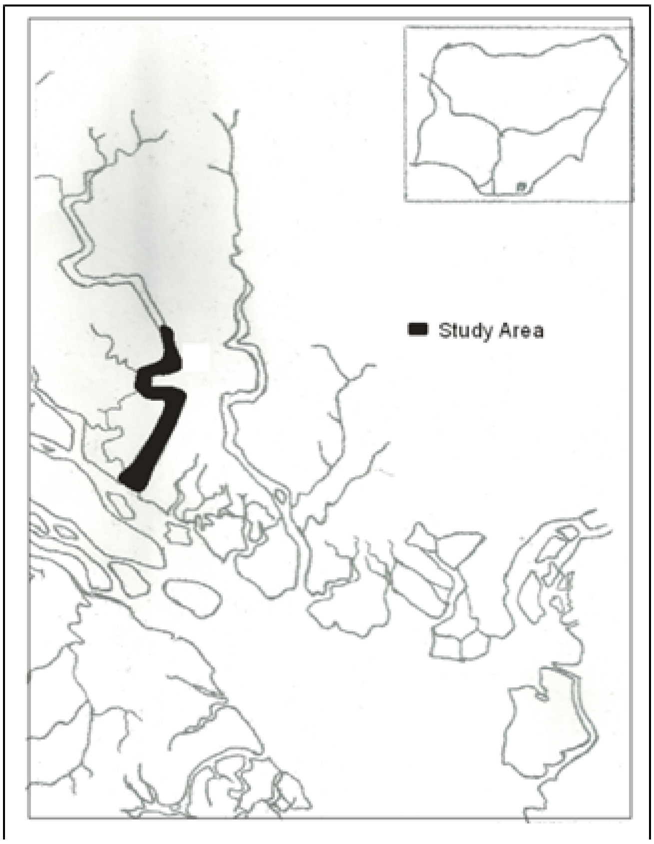


Figure 1: Calabar River Study Area

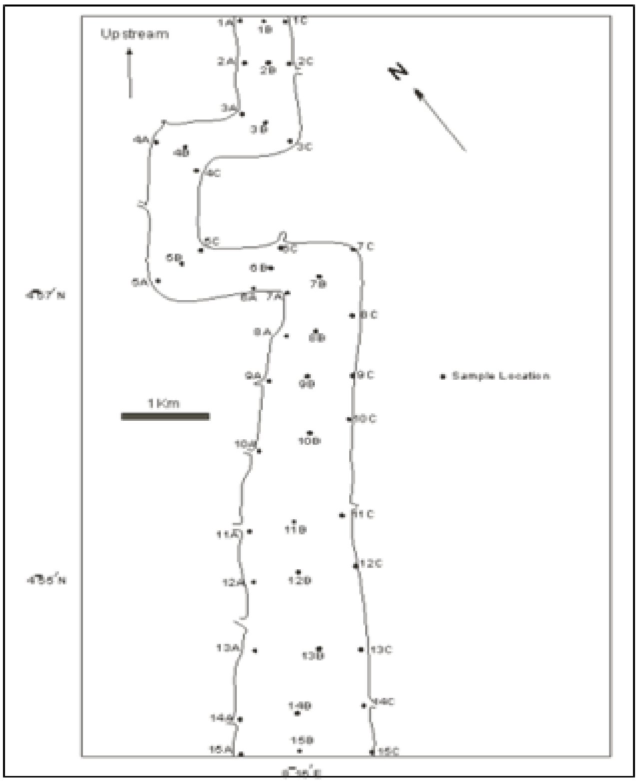


Figure 2: Sample locations

3. Methods

Sampling

The sampling method employed helped in ensuring representative sampling of the river channel. Samples were collected from the Calabar River at three points across the river transect for every kilometer interval of the 15km portion of the river sampled (fig. 2). A total of 45 samples were collected, the samples were collected at the center of the river channel and on both sides of the tidal flat. Each sample location was georeferenced. Depth sounding was taken for all sample points, the tidal effect was corrected for using a tidal table. The corrected readings were then used as contour values which enabled the construction of bathymetric profiles for nine transect (A to L) that have unique bottom morphology. (fig. 3)

Data Analysis

Grain Size Analysis

The samples were oven dried at temperature of 60°C and the sediments were then mixed to get a representative sample for sieving, the lumps mainly clay and clayey sands were disintegrated before sieving. The technique used during sieving include the following; sediment samples weighed were passed through a set of ATSM sieves (British, 0.5 range), the sieves where arranged in a downward decreasing mesh diameter and mechanically vibrated for a fixed period of 10 minutes each, the weight of the sample retained on the sieves was taken and converted to percentage of the total sediment weighed. The cumulative weight and percentage cumulative weight were also determined. The grain size is reported in phi (0) which equals one unit on Wentworth scale.

4. Results

Bathymetry

The bathymetic result obtained from the river as read off on a depth sounder and corrected with a tidal table (fig. 3) indicates that the river channel is shallower upstream dipping downstream with a fairly even depth range of 4 -6m at the main channel which decreases towards the banks, with exceptions around the meander. The width upstream is about 500m which becomes narrower and deep necked at the meander with a depth of about 14.4m off the bank of Caleamco Jetty, the river width downstream is about 1040m. The deepest point within the main river channel is located at the meander with a depth of 14.4m which gradually shallows downstream. On the bank the deepest point is located at the meanders eastern bank with a depth of 6m. The Calabar River is generally very steep at the meander and on the eastern bank downstream. At the up and downstream the river gradient is gentle.

Grain size distribution

The river grain size distribution shows a mean distribution of fine to very fine sand on the banks and coarse to medium within the main channel with very coarse grains upstream and at the meander. The skewness indicates that negatively skewed sediments occurred mainly downstream while the positively skewed sediments occurred upstream. The river sediment also showed a general gradation from poorly sorted upstream and at the meander to moderately sorted at the river mouth. The kurtosis generally decrease from very leptokurtic upstream, to mesokurtic downstream.

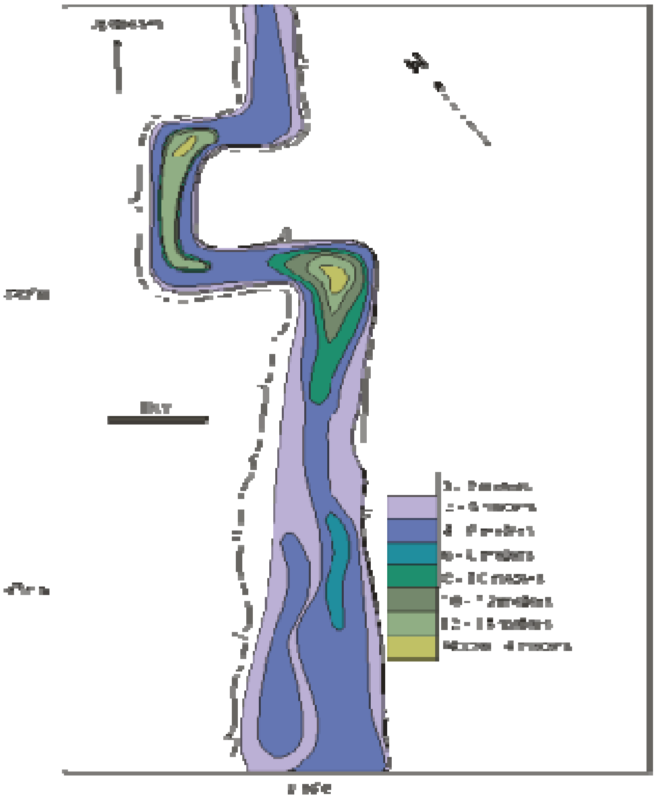
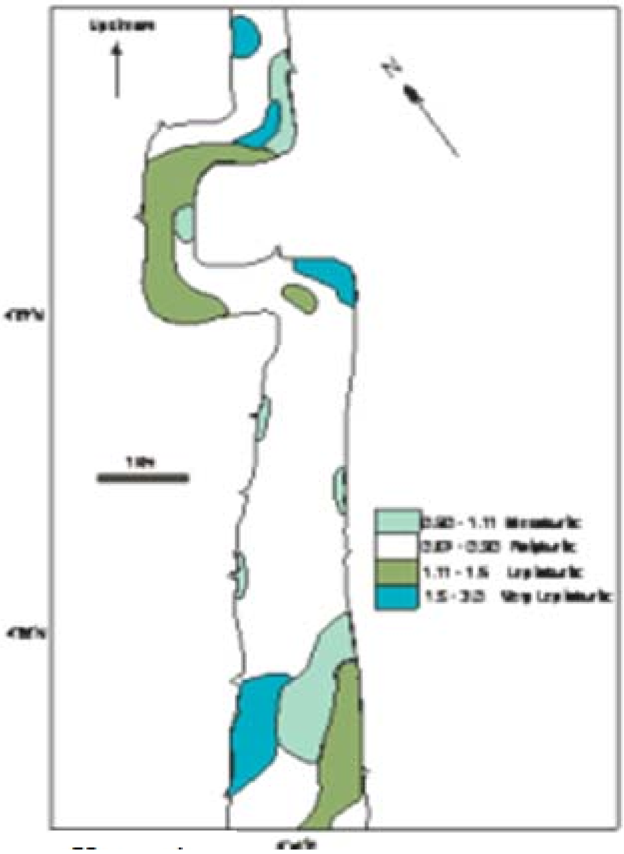


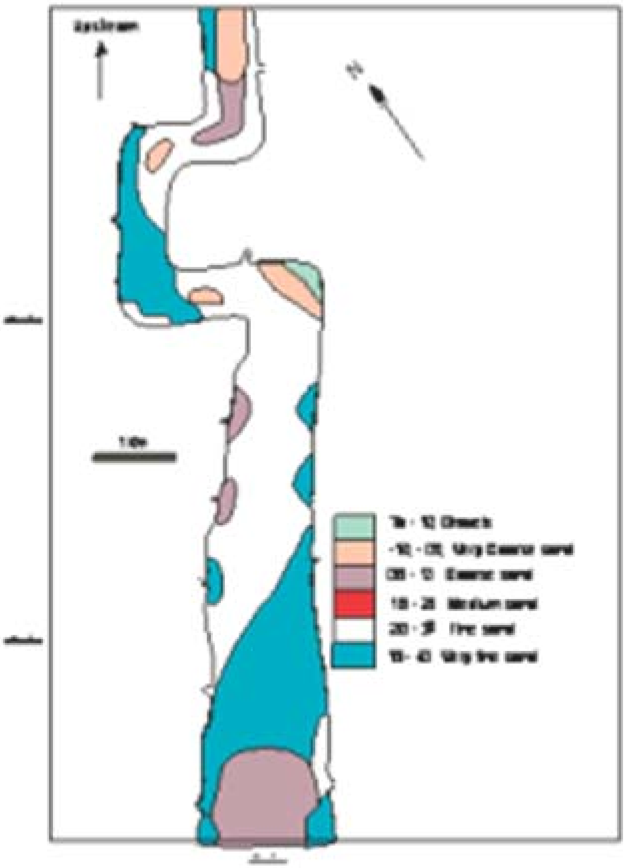
Figure 3: Bathymetic profile of Calabar Tidal River



Kurtosis

Sorting

Skeweness



Mean

Figure 3: Grain size statistical parameters of the Calabar Tidal River

5. Discussion of Results

The observed grain size distribution and the grain size statistical parameters of the Calabar Tidal River conforms to geological assumption for grain size facies distribution within a tidal river with a net directional flow downstream. The dynamics of sediment erosion, transportation, and deposition velocity and the resultant grain size facies distribution, follows after the work of Postma (1957) and reexamined by Postma (1967), which attributed sediment distribution to the prevailing current energy condition. Sediment are set in motion at the critical erosional velocity which is the minimum current velocity at which sediments of a particular size begins to move, the movement stops at the lowest transport velocity at which they are deposited according to the different grain sizes with the heavier ones deposited first and as the current energy reduces more finer sediments come to rest. Thus, the grain size distribution depends on the current velocity, which in the Calabar River is controlled by daily ebb and flood tidal regime and the gravitational downstream flow direction. The current velocity and grain size distribution relationship in the Calabar River was observed in the downstream sediment fining as the current velocity which is high upstream and at the meander decreased downstream towards Tobacco Island at the river mouth with finer mud occurring towards the western and eastern banks. Based on this observation a differentiation of coarse sand, fine sand within the main channel, a mud facies on the banks can be identified and examined with the rivers mean grain size distribution.

The river grain size distribution shows a mean distribution of fine to very fine sand on the banks and coarse to medium facies within the main channel. This distribution agrees with the Postma (1957 and 1967) which showed that based on their size, fine grain sediments are winnowed to the banks where the rivers current energy is at its lowest and are difficult to erode when they come to rest, because of the cohesive nature of clay minerals which inhibits movement of the individual particle also their microscopic relief makes it difficult to erode in an area of low energy, while the coarse clastics remains in the main channel where the current energy is high. Also within the main channel the grain size gradually fines towards the river mouth downstream with coarse grains upstream and at the meander. This is due to the effect of current energy which decreases downstream and towards the banks. This is also in agreement with Chakrabarti (1974), that it is a general rule for the mean grain size of sediments to decrease (become finer) in the direction of current flow.

According to Awasthi (1969), the skewness parameter is the most sensitive to changes in current energy in a depositional environment, this suggested that finer sediments are weighed to the negative from the near symmetrical, while coarser sediments are weighed to the positive depending on the prevailing energy condition and the homogeneity of the sediment supply. The skewness distribution of sediments indicates that negatively skewed sediments occurred mainly downstream while the positively skewed sediments occurred upstream, which follows after Awasthi (1969), who proposed that positive skewness is indicative of a high current energy which usually occurs upstream and at the meander while negatively skewed sediments are indicative of low energy condition usually downstream at the river mouth.

The observed sorting distribution in the Calahar River sediment (fig. 3) agrees with the general rule, which stated that sorting of sediments within a channel would improve with transport, this is improved by the bidirectional nature of flow due to tidal effect in tidal channels like the Calabar River. The sediment showed a general improvement from poorly sorted upstream and at the meander to moderately sorted at the river mouth. In bivalent plots of sorting against mean, the mean decreasing in the direction of flow, while sorting improved. This is in agreement with Chakrabarti (1974).

The kurtosis distribution of sediments in Calabar River reveals a general decrease from very leptokurtic upstream, to mesokurtic downstream (fig. 3), when compared, kurtosis and sorting, shows a relationship which according to Folk and Ward (1957), leptokurtic to very leptokurtic sediments are associated with well sorting. Also observed is the relationship between kurtosis and skewness; skewness was observed to increase from negative to positively skewed with slight increase in kurtosis.

Sediment Facies

Based on field and statistical parameter from grain size analysis, the Calabar River sediments can be generally differentiated into coarse sand facies, fine sand facies within and, a mud facies.

The coarse sand facies can be identified mainly within the main river channel upstream and extending through the meander (fig. 3), the sediments at the meander were found to be the most coarse of all the river sediments, with the occurrence of gravel. According to Postma (1967) this is due to very high current velocity usually at the river head (upstream) and at meanders and is assisted by continuous winnowing of the finer grain sediments downstream and the finer ones, towards the banks.

The fine grain facies occurred mainly within the main channel downstream grading from a coarse grained facies at the meander, this agrees with Postma (1967, 1975) and Chakrabarti (1974), that as the current velocity of the transporting medium reduces finer sediments are deposited downstream. This is typified in the Calabar tidal River which flows downstream into the Calabar Estuary.

The mud facies are located on the tidal flats, both on the western and eastern bank of the river channel which are areas of very low energy according to Postma (1967), after the fine grain suspended sediment that settles to form the mud has been winnowed from the main channel by current action, they accumulate at a certain current velocity that occurs at a particular time lag between the turn of the tide (from ebb to flood) when the current velocity is zero on the banks, then the sediments reaches the bottom. Due to the low energy nature of this area they are hardly re-eroded.

6. Conclusion and Recommendations

Based on the above observations and analysis, the following conclusions were arrived at;

1) It was observed that the various size parameter and facies distribution and all other measured parameter agrees with geological predictions for a tidal river, typified by the Calabar Tidal River.
2) It was observed that the Calabar Tidal River sediment based on the mean grain size parameter can be differentiated into coarse grained facies, fine grained, and mud facies.
3) The confinement of sediments of a particular grain size facies based on the various facies distribution is believed to have resulted from hydrological movement, which in the Calabar Tidal River is controlled by daily ebb and flood tidal regime and the gravitational downstream flow direction.
4) In order to develop a hypothetical model for grain size distribution in tidal rivers for the purpose of paleostratigraphic reconstruction of tidal river deposits and as a model for further tidal river research.
5) It is recommended that more research work should be done on comparing tidal river sediments from different tidal rivers.
6) It is recommended that apart from grain size facies distribution, research should also be carried out on tidal river sediment mineralogical and mineral distribution.

References

[1] Awasthi, A. K. (1969). Skewness as an environmental indicator in the Solani River System, Roorkee India. Jour. Sedi. Geol., Vol, 4.pp 177-183.

[2] Bagnold R. A. (1956).The flow of cohesionless grains in fluids. In Reineck, H. E. and Singh I., Depositional sedimentary environments, Second Edition. Springer verlag, New York. 549pp.

[3] Chakrabarti, A. K. (1974). Study of Sediment Movement at the entrance of a tidal river. Sedi. Geol., Vol,. 6. pp 111- 127.

[4] Barth N. Ekwueme, (2004). Field Geology and geological map production and interpretation. Pg 49-75, 87-93.

[5] Ekwueme, B. N., Nyong, E. E. and Petters, S. W. (1995). Geological excursion guild book to oban massif and Calabar Flank, and Mamfe Embayment, southeastern Nigeria. Decfort publicating company, Calabar. 32pp.

[6] Folk, R. L. and Wald, W. C. (1957).Brazos River Bar- a study in the significance of grain size parameters. Jour. Sedi. Pectrology. Vol.27. pp3-27.

[7] Gibbs R. J., (1973). Amazon River Estuarine system, in: Hail J., and Carl A. (1975). Near shore sediments dynamics and sedimentation. John Wiley and sons. London. 363 p.

[8] Gujar (1975). Characterization of opaque off Konkan coast Masharashtra, Central. West Coase of India. Jour. Of Minerals and Material Characterization and Engineering. Vol. 6. No.1 pp53-67.

[9] Guileher, A., (1963). estuary, delta shelf slope. In the sea. In sediment Transport and sedimentation in the Estuary Environment. ArcK Neerl. Zoo!., 12: 319 - 349.

[10] Inman D. L., (1952).Measures for Describing the size distribution of sediments. Jour. Sedi. Petr. Vol. 22. pp 125-145.

[11] Postma, H. (1957). hydrography of the Dutch Wadden sea. In sediment Transport and sedimentation in the Estuary Environment. Arch. Neerl. Zool., 12: 319-349.

[12] Postma, H. (1967). sediment Transport and sedimentation in the Estuary Environment. Arch. Neerl. Zool., 12: 319 - 349.

[13] Semeniuk V. (1981). Sedimentology and stratigraphic sequence of a tropical tidal flat, King Sound, N. Western Australia. Sedi. Geol. Vol. 29. pp 195-221.

[14] Sundbor A., (1956). The river K.laralvea: a study of fluvital processes. In Reineck, H. E. and Singh I., Depositional sedimentary environments, Second Editon. Springer verlag, New York. 549pp.

[15] Van Straanten, L. M., and Pit H. Kuenen, (1957). Accumulation of fine grain sediments in the Dutch Wadden Sea. In Postma, H. 1967. sediment Transport and sedimentation in the Estuary Environment. Arch. Neerl. Zool., 12: 319 - 349.

[16] Van Straanten, L. M. J. U., (1954). Composition and structure of recent marine sediments in Netherland. hi Postma, H. 1967. sediment Transport and sedimentation in the Estuary Environment. Arch. Neerl. Zoo!., 12: 319-349.

Table 2: Grain Size Parameters and Interpretation

Station	Sorting (OT)	Interpretation	Mean	Interpretation	Kurtosis (KG)	Interpretation	Swekness (SKI)	Interpretation
1A	0.85	M-sorted	3.12	V-fine sand	0.97	Mesokurtic	0.18	Negatively skewed
1B	0.89	M-sorted	0.90	Coarse sand	1.11	Leptokurtic	0.42	S-positively skewed
1C	0.83	M-sorted	3.00	V-fine sand	0.92	Mesokurtic	0.17	Positively skewed
2A	1.05	P-sorted	2.74	Fine sand	0.56	Platkurtic	0.28	S-positively skewed
2B	1.02	P-sorted	0.97	Coarse sand	1.96	V-leptokurtic	0.68	S-positively skewed
2C	0.76	M-sorted	2.60	Fine sand	1.21	Leptokutic	0.28	Near symmetrical
3A	0.61	M-well sorted	2.83	Fine sand	0.67	Platykurtic	0.84	S-positively skewed
3B	0.76	M-sorted	2.92	Coarse sand	0.84	Plartykurtic	0.09	Near symmetrical
3C	0.79	M-sorted	3.15	V-fine sand	1.81	Leptokutic	0.07	Near symmetrical
4A	0.80	M-sorted	3.22	V-fine sand	1.15	Leptokutic	0.05	Near symmetrical
4B	0.82	M-sorted	3.10	V-fine sand	1.04	Mesokurtic	0.06	Negatively skewed
4C	0.81	M-sorted	3.24	V-fine sand	0.98	Mesokurtic	0.30	Negatively skewed
5A	1.12	P-sorted	2.49	Fine sand	7.10	E-leptokutic	0.07	Near symmetrical
5B	1.06	P -sorted	2.42	Fine sand	1.04	Mesokurtic	0.12	Positively skewed
5C	0.89	M-sorted	3.03	V-fine sand	0.92	Mesokurtic	0.19	Negatively skewed
6A	0.87	M-well sorted	2.92	V-fine sand	1.07	Mesokurtic	0.02	Near symmetrical
6B	1.12	P-sorted	2.75	Fine sand	1.04	Mesokurtic	0.14	Positively skewed
6C	0.70	M-sorted	2.47	Fine sand	1.73	V- Leptokutic	0.07	Near symmetrical
7A	0.81	M-sorted	0.63	Coarse sand	1.62	V- Leptokutic	0.58	S- Positively skewed
7B	0.82	M-sorted	2.60	Fine sand	1.03	Mesokurtic	0.78	S- Positively skewed
7C	0.85	M-sorted	3.12	V-fine sand	1.00	Mesokurtic	0.08	Near symmetrical
8A	0.69	M-sorted	3.28	V-fine sand	1.10	Mesokurtic	0.07	Near symmetrical
8B	1.18	P –sorted	2.80	Coarse sand	1.30	Mesokurtic	0.12	Positively skewed
8C	1.50	P –sorted	0.38	Coarse sand	1.69	V- leptokurtic	0.02	Near symmetrical
9A	0.95	M-sorted	2.71	Fine sand	0.91	Mesokurtic	0.05	Near symmetrical
9B	1.81	P –sorted	0.41	V-fine sand	1.14	Leptokurtic	0.02	Near symmetrical
9C	5.18	E- P -sorted	2.80	Gravel	0.72	Platykurtic	0.45	S- negatively skewed
10A	0.85	M-sorted	3.20	V-fine sand	0.06	Mesokurtic	0.02	Near symmetrical
10B	1.71	P-sorted	0.31	V-fine sand	0.90	Mesokurtic	0.18	Positively skewed
10C	0.95	M-sorted	3.18	V-fine sand	0.94	Mesokurtic	0.03	Near symmetrical
11A	0.86	M-sorted	1.67	Fine sand	1.40	Leptokurtic	0.67	E-negatively skewed
11B	0.89	M-sorted	3.18	V-fine sand	1.35	Leptokurtic	0.05	Negatively skewed
11C	0.82	M-sorted	3.12	V-fine sand	2.10	V-leptokurtic	0.06	Near symmetrical
12A	0.85	M-sorted	3.24	V-fine sand	0.99	Mesokurtic	0.07	Near symmetrical
12B	0.89	M-sorted	1.63	Fine sand	1.15	Leptokurtic	0.08	Near symmetrical
12C	0.83	M-sorted	2.70	Fine sand	1.23	Leptokurtic	0.11	Positively skewed
13A	1.12	P-sorted	2.78	Fine sand	1.04	Mesokurtic	0.18	Positively skewed
13B	0.83	M-sorted	0.57	Coarse sand	1.46	Leptokurtic	0.10	Positively skewed
13C	1.09	P-sorted	2.49	Fine sand	8.60	E- leptokurtic	0.07	Near symmetrical
14A	0.67	M-sorted	3.34	V-fine sand	1.06	Mesokurtic	0.08	Near symmetrical
14B	1.22	P-sorted	0.37	Coarse sand	2.09	V- leptokurtic	0.28	Negatively skewed
14C	1.09	P-sorted	2.35	Fine sand	8.10	E- leptokurtic	0.08	Near symmetrical
15A	0.77	M-sorted	3.33	V-fine sand	1.22	Leptokurtic	0.09	Near symmetrical
15B	1.17	P-sorted	0.33	V-fine sand	0.74	Platykurtic	0.32	S-negatively skewed
15C	1.16	P-sorted	2.60	Fine sand	0.97	Mesokurtic	0.07	Near symmetrical

Key: M- Moderately, P- Poorly, V- Very, E- Extremely