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FLOW VELOCITY AND IMPLICATION ON PARTICLE SIZE OF BOTTOM SEDIMENT IN THE COMMODORE CHANNEL LAGOS, SOUTHWESTERN NIGERIA

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ABSTRACT

Flow velocity generally influences the erosion, transport and deposition of sediments. Flow velocity and in relation to particle size distribution in the Commodore channel was investigated with the Acoustic doppler current profiler (ADCP), echosounder and veen van grab. Those equipment were deployed through a low draft survey boat to acquire acoustic and sediment data covering the study area. The ADCP measured the current velocity along fourteen established transect lines while twenty surface sediments samples were collected along the banks and center of the channel respectively. Sediment samples were analyzed for grain size distributions and mineralogicaly composition while the acoustics data were analyzed with Matlab software to produce velocity profiles for the channel area. The study aimed to determine the magnitude and direction of flow of water along the channel with a view to ascertain the sediment transport process. Results indicated no significant difference in flow velocities along the different channel points. The flow velocity was however slightly higher around the channel mouth than in mid and upper reaches of the channel. The flow velocities showed negative correlation of (– 0.54 and – 0.28) with the sediment characteristics indicating that the sediment particle size distributions is unrelated to the flow velocity. This anomaly in the equilibrium flow velocity suggest the impact of dredging and the continuous ebbing and flooding of tidal water which resulted to reworking of the sediment particle sizes prior to deposition. The sediment distributions were fine sand, moderately sorted, fine skewed with leptokurtic peaked. Significant fractions of the sediments were deposited in fluvial and shallow marine environments while a few were deposited in the beach and turbidity environment. Sediments and acoustic data interpreted from the study suggest that sediment supply to the area was by fluvial processes through the barrier lagoon drainage basin.

INTRODUCTION

The Commodore channel is a major navigational route for commercial and economic activities in the Nigerian territorial waters. Foreign merchant vessels enters and exits the Lagos Port through this channel (Vijverberg et-al., 2012). The channel is therefore continuously dredged in order to maintain the channel depth and to avoid sediment accumulation or siltation such that vessel entering or leaving the port do not run aground. Water circulation in the channel is mainly driven by tide and flow velocity such that the sediments are in continuous phase of movement and reworking prior to deposition (Bentum 2012).

Flow velocity generally shape the bottom morphology and sediment transport processes in the coastal area The geoscientist uses flow velocity condition to make inferences on energy of deposition, provenance, sediment transport and tidal fluxes (Dinehart and Burau 2005; McLaren et al 1979). Flow velocity and sediment dynamics data can also be applied in hydro-power generation and hydrodynamic model calibration. The flow of current is one of the strongest environmental factor that determines the distribution and deposition of sediment in a water body. Hydrodynamics forces generally impact the land surface erodes, break and transport the sediments through different episodes of flow regimes and subsequent deposition on the bottom floor. The

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bottom floor or river bed of lagoons, estuaries and adjoining seas are thus rarely flat surfaces due to the effect of those littoral force. Through the interaction between water currents and sediments, different geologic features are produced such as ripples, bedforms, sand ridges and dunes. These features affects the bottom morphology thus influencing flow conditions in the channel of coastal waters. Similarly sediment distributions on the bottom are controlled by physical properties of the particles, geologic configuration of the sediment source or provenance and the magnitudes of the current velocity. Coarse grained sediment for instance, due to strong current can be deposited in shallow coastal waters while fine sediment due to weak current velocities can be deposited in relatively deeper bottom. Sediments on the bottom floor are therefore redistributed and sorted base on particles size and stress due to water movement. This study aimed to investigate the variation of flow velocity in relation to the textural characteristics of bottom sediments along the Commodore channel. This was achieved through the deployment and running of a boat mounted Acoustic Doppler current profiler (ADCP) along the channel area. The ADCP was used to acquire flow velocity dataset along established transects while the Van veen grab was used to collect bottom sediments on the banks and center of the channel respectively. Raw acoustic data acquired were analyzed using Matlab software to obtain profiles of the stream-wise current velocity while sediment samples were analyzed to obtain their particle size distributions. Results are then interpreted to understand the geological significance of the sediment characteristic in relation to the flow and competence of the transporting agents.

GEOLOGIC SETTING

The study area is located within the barrier lagoon geomorphic zone which is an intricate parts of the Lagos lagoon. (Ibe et al 1988) It is a coastal inlet and the only significant connection between the Lagos Lagoon and the Atlantic Ocean (Figure 1). The area falls within the eastern part of the Dahomey basin. The eastern Dahomey basin is bounded to the north by the Precambrian basement complex of Southwestern Nigeria, the gulf of Guinea to the south and eastward by the Okitipupa ridge. The geology is dominated by continuous stretch of clayey and sandy horizons. Those horizons exhibited some lateral continuity in few places but in most parts those lithology pinches out along the coastline (east-west). The stratigraphy sequence is made up sand which grades into clay, sandy-clay and coarse gravel and conglomerates sand and shale at deeper level. In the hinterland northern section, the stratigraphy is made up of reddish lateritic clay horizon at the top grading into sands clay, sandy clay and shale at deeper level.

Figure 1: Location of the Commodore channel

MATERIALS AND METHOD

Field procedure and data acquisition was designed such that fourteen transects lines spaced at 100 m apart covering the study area were established. Flow velocity along the different transect lines were measured using the Acoustic Doppler current profiler while bottom sediment were collected along on the mid and channel banks (Figure 2). The ADCP measures the water velocity by applying the Doppler principle to the frequency shift of an emitted acoustic signal that reflected off suspended matter in the water column (Oberg and Muller 2007). An external GPS was mounted directly over the ADCP transducer and integrated it into the acquisition software to record the position of each pings.

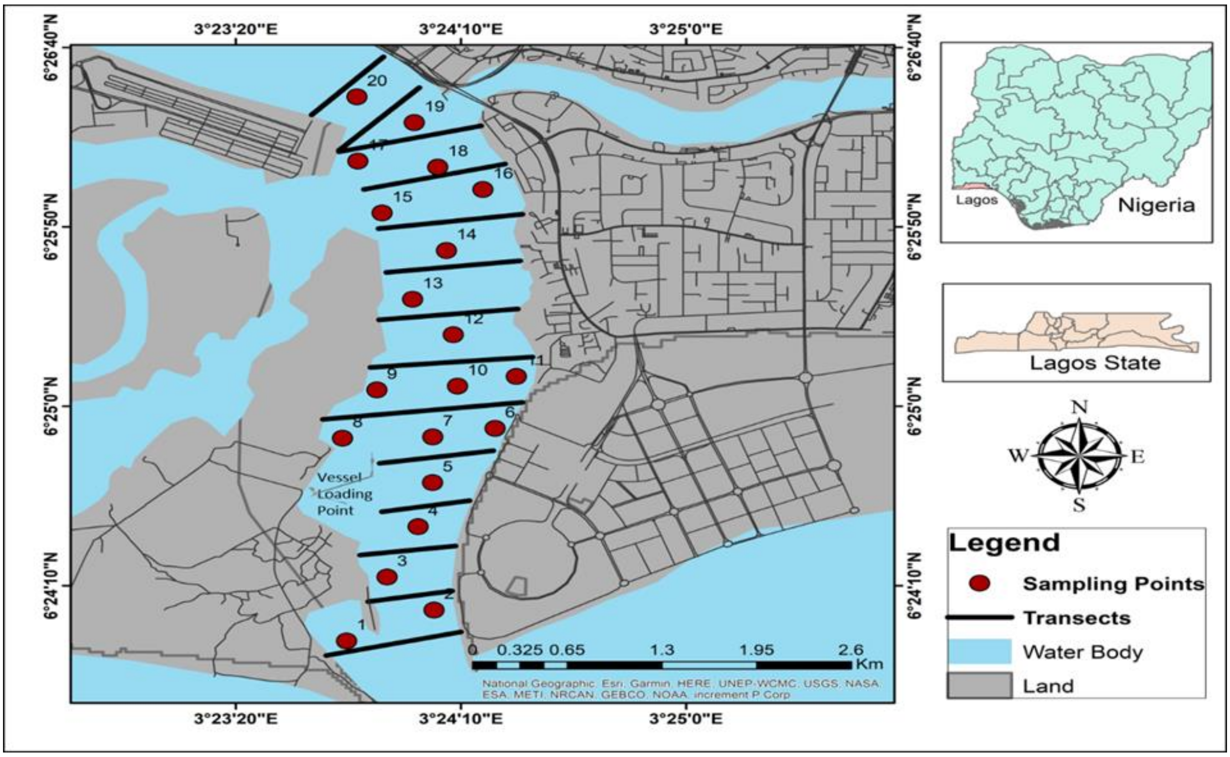

Figure 2. Study location showing transects lines and sediments sampling points

DATA ANALYSIS

Acoustic data

The ADCP data analysis was done in accordance with the United States Geological Survey (USGS) guide lines. The acquired raw data achieved as in WinRiver acquisition software was first converted to ASCII file and exported to MATLAB software. Using the velocity mapping toolbox in MATLAB, the datasets was processed into standard units. The velocity components were then processed to produce plots of streamwise velocity and depth averaged velocity (DAV) profiles respectively (Dinehart and Barua 2005) The streamwise velocity is the flow velocity along the channel recorded as the boat moves from bank-to-bank across the channel or along the transect line, while the depth averaged velocity (DAV) is the effective velocity averaged over the entire depth of the water column within a transect cross-section. The streamwise velocity maps are produced as filled contour layers with the secondary flow vectors overlain, while the DAV are produced using quiver algorithm to represent flow vectors, with arrow-head indicating direction of flow. The descriptive statistical information of the flow velocity in the study area were also extracted.

Sediment data

In the laboratory, 50 grams of each samples was first treated with 10 % Hydrochloric acid (HCL) and 15% Hydrogen peroxide (H_20_2) to remove carbonates organic matter (Mange and Maurer 1992) Samples were then placed in an oven at 50^0 C, dried samples were run on a set of Rotap sieve shaker for fifteen minutes (Folk 1974). Fractions of samples retained on sieve were weigh and weight values obtained were imported into Matlab software to obtain the statistical parameters of the grain size distribution. Correlation and discriminant function analysis was done on the samples in order to make inference of the deposition environment (Freidman 1967).

RESULTS

Flow velocity along the channel mouth

Analysis of flow characteristics along the channel mouth showed, a maximum and minimum velocity magnitude of 1.86 and 1.14 m/s while the mean and most occurring velocity magnitudes are 0.17 and 0.07 m/s. The depth average velocity flow vector is towards the north indicating a flood flow direction at a magnitude of between 0.2 to 1.4 m/s (Figure 3a and b)

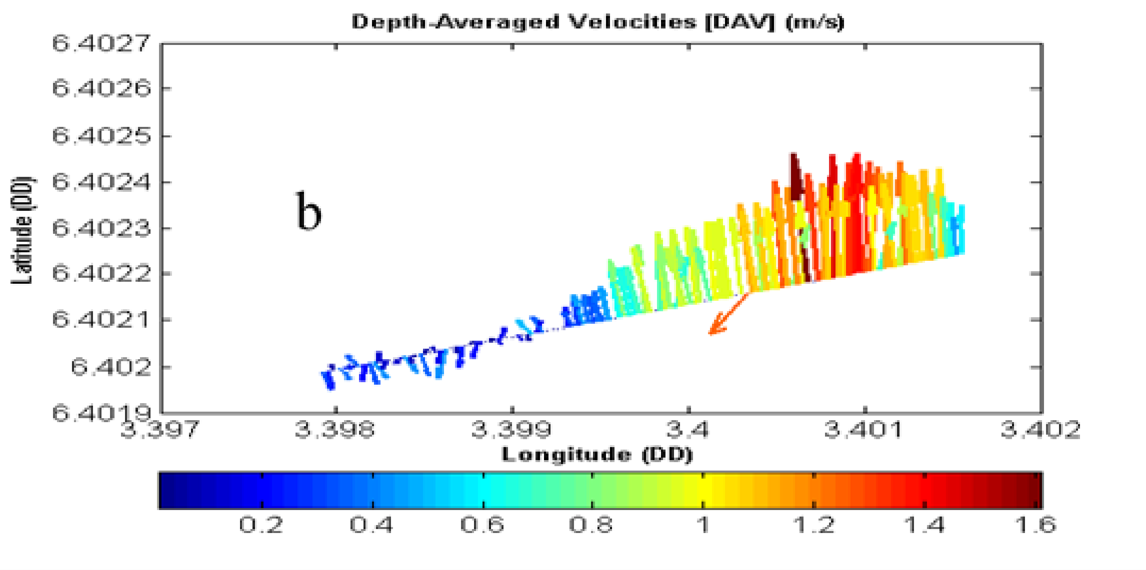

Figure 3: Streamwise current velocity and depth average velocity along channel mouth

Flow velocity along transect mid channel

Flow characteristics along the mid-channel, shows a maximum and minimum velocity magnitudes of 1.33 and 0.98 m/s while the mean and most occurring velocity magnitudes are 0.17 and 0.36 m/s respectively. The depth average velocity flow vector is towards the south indicating an ebb flow direction at a velocity magnitude of 0.2 to 1.4 m/s (Figure 4a and b)

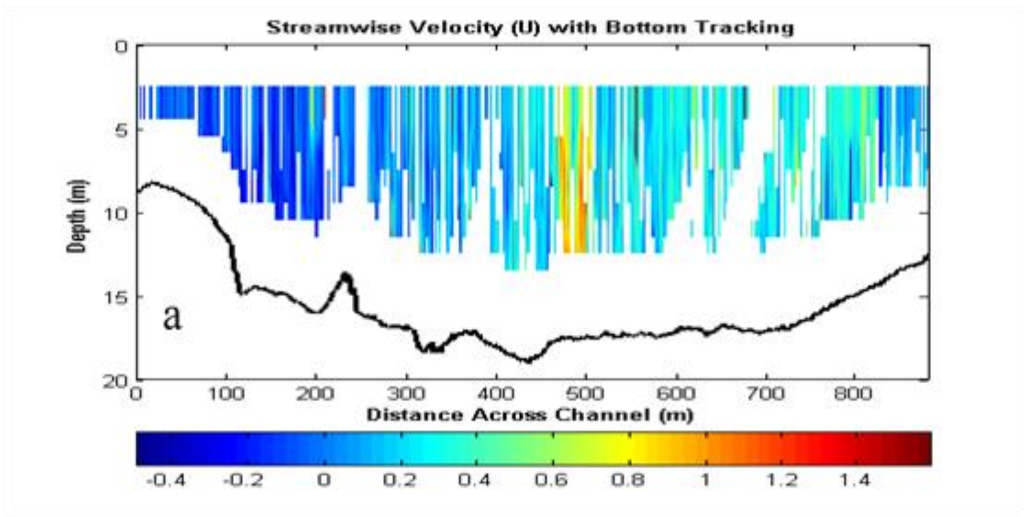

Figure 4: Streamwise current velocity and depth average velocity along mid channel

Flow velocity along the upper channel

Flow characteristic along the upper channel, showed a maximum and minimum velocity magnitudes of 1.44 and 1.2 m/s while the mean and most occurring velocities are 0.09 and 0.17 m/s respectively. The depth average velocity flow vector is towards the south indicating an ebb flow direction at velocity magnitude of between 0.3 to 0.6 m/s (Figure 5a and b)

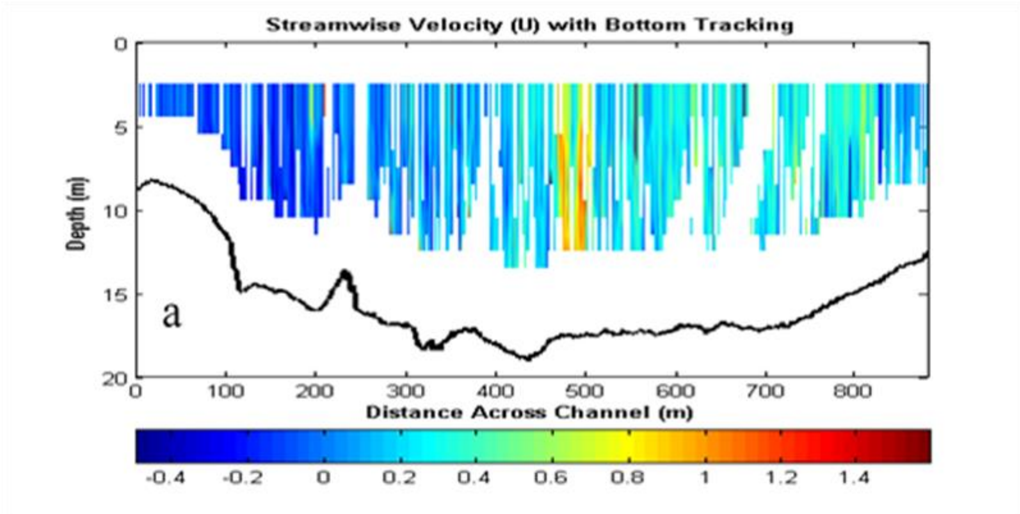

Figure 5: Streamwise current velocity and depth average velocity along the upper channel

Grain size Analysis

The grain size distribution is generally fine sand, moderately sorted fine skewed and leptokurtic peaked (Table 1). The mean varied from 0.183 Ø to 3.146 Ø with an average value of 2.030 Ø indicating coarse to very fine sand. Predominantly fine sand contributes about 51%, medium sand 25% and coarse sand 24%. The samples exhibited maximum standard deviation value of 3.25 and minimum of 1.68 with an average value of 0.919 indicating poorly and very well sorted sediment. 50% of the total population are poorly sorted with marginal changes in standard deviation value. Other exhibits moderately sorted 40% well sorted 20% and moderately well sorted 68 % The samples exhibited maximum standard deviation value of 3.25 and minimum of 1.68 with an average value of 0.919 indicating poorly and very well sorted sediment. 50% of the total population are poorly sorted with marginal changes in standard deviation value. Other exhibits moderately sorted 40% well sorted 20% and moderately well sorted 68 %. Samples exhibits wide range in Skewness value from -0.356 to 0.640 (strongly coarse skewed to strongly fine skewed) with average value of 0.166 indicating fine skewed. About 80% of the total distributions are positively skewed while 20% showed negative skewness. Samples exhibits a minimum kurtosis value of 0.578 (very Platykurtic) and maximum value of 1.847 (very leptokurtic) with average kurtosis value of 1.170 indicating leptokurtic. The total population of kurtosis distribution showed that 55% are leptokurtic, 25% are Mesokurtic, 10% very leptokurtic, 10% very Platykurtic and 5% Platykurtic. Along the channel mouth samples showed a maximum kurtosis value of 1.87 (very leptokurtic) and a minimum value of 0.878 (Platykurtic) with average value of 1.272 (leptokurtic).

Table 1: Grain size distribution along the Commodore channel

Sample ID	Mean	STD	Skewness	Kurtosis	Classifications
St. 1	2.109	0.416	0.040	1.196	Fine sand, Well sorted, Near symmetrical, Leptokurtic (peaked)
St. 2	2.130	0.490	0.174	1.208	Fine sand, Well sorted, Fine skewed, Leptokurtic (peaked)
St. 3	1.993	0.965	0.101	1.430	Medium sand, moderately sorted, Fine skewed, Leptokurtic (peaked)
St. 4	1.996	1.256	0.035	0.878	Medium sand, Poorly sorted, Near symmetrical, Platykurtic
St. 5	2.370	1.042	0.547	1.847	Fine sand, Poorly sorted, Strongly fine skewed, Very leptokurtic
St. 6	0.950	0.871	0.027	1.088	Coarse sand, moderately sorted, Near symmetrical, Mesokurtic
St. 7	2.613	0.958	0.517	1.261	Fine sand, moderately sorted, Strongly fine skewed, Leptokurtic (peaked)
St. 8	2.677	1.014	0.505	1.351	Fine sand, Poorly sorted, Strongly fine skewed, Leptokurtic (peaked)
St. 9	2.197	1.028	0.036	0.910	Fine sand, Poorly sorted, Near symmetrical, Mesokurtic
St. 10	1.367	1.501	-0.356	0.622	Medium sand, Poorly sorted, Strongly coarse skewed, Very Platykurtic
St. 11	0.509	0.654	-0.229	1.072	Coarse sand, moderately well sorted, Coarse skewed, Mesokurtic
St. 12	2.728	0.874	0.495	1.305	Fine sand, moderately sorted, Strongly fine skewed, Leptokurtic (peaked)
St. 13	3.050	0.325	0.050	1.189	Very fine sand, very well sorted, Near symmetrical, Leptokurtic (peaked)
St. 14	2.569	1.109	0.640	1.361	Fine sand, Poorly sorted, Strongly fine skewed, Leptokurtic (peaked)
St. 15	2.987	0.993	0.578	1.751	Fine sand, moderately sorted, Strongly fine skewed, Very leptokurtic
St. 16	1.012	1.618	-0.108	0.575	Medium sand, Poorly sorted, Coarse skewed, Very Platykurtic
St. 17	2.077	1.360	0.353	0.944	Fine sand, Poorly sorted, Strongly fine skewed, Mesokurtic
St. 18	3.146	0.354	0.020	1.209	Very fine sand, Well sorted, Near symmetrical, Leptokurtic (peaked)
St. 19	1.947	1.017	-0.144	0.998	Medium sand, Poorly sorted, Coarse skewed, Mesokurtic
St. 20	0.183	0.535	0.043	1.195	Coarse sand, moderately well sorted, Near symmetrical, Leptokurtic (peaked)
AVEARGE	**2.030**	**0.919**	**0.166**	**1.170**	**Fine sand, Moderately sorted, Fine skewed, Leptokurtic (peaked)**

Discriminant function analysis

The concept of (Sahu 1964) was used to discriminate between various parameters of the sediment grain size into different depositional environment Table 3). The results showed that Y_1 is greater than -2.7411 for majority of the samples. 85% of the samples has values greater than -2.7441 suggesting deposition by beach process while 15% of the samples has values less than -2.7411. In Y2 55% of the sample has values greater than 65.360 suggesting deposition in shallow agited water and 45% of the samples showed values less than 65.360 pointing to deposition in beach environment. In Y3 65% of the samples has values less than – 7.4190 indicating deposition in fluvial environment and 35% of the samples has values greater than – 7.4190, indicating deposition in shallow marine environment. For Y4 75% of the samples has values greater than 9.843 indicating deposition through fluvial process and 25% of the samples has values less than 9.843 indicating deposition in a turbidity condition

Table 2: Discriminant function Analysis of the Commodore channel sediment

Station ID	Depth (m)	Y1 Value	Interp.	Y2 Value	Interp.	Y3 Value	Interp.	Y4 Value	Interp.
St. 1	18.00	-1.66702	BEV	80.3888	SHM	-3.7857	SHM	12.1038	FLV
St. 2`	22.00	-1.54031	BEV	87.8693	SHM	-4.8404	SHM	12.71212	FLV
St. 3	19.00	1.37881	BEV	120.005	SHN	-8.6574	FLV	12.29304	FLV
St. 4	16.00	0.87921	BEV	133.144	SHM	-11.113	FLV	10.50302	FLV
St. 5	15.00	0.354583	BEV	139.106	SHM	-10.059	FLV	17.10224	FLV
St. 6	16.00	4.06409	BEV	88.7215	SHM	-7.4223	FLV	6.29094	TUV
St. 7	16.00	-1.90363	BEV	132.132	SHM	-10.009	FLV	15.8918	FLV
St. 8	16.00	-1.65697	BEV	139.895	SHM	-10.405	FLV	16.68624	FLV
St. 9	15.00	-0.25616	BEV	116.916	SHM	-8.7155	FLV	11.50539	FLV
St. 10	16.00	3.968254	BEV	123.958	SHM	-11.445	FLV	4.832221	TUV
St. 11	15.00	5.082925	BEV	66.0704	SHM	-5.2236	FLV	3.99614	TUV
St. 12	15.00	-2.49405	BEV	127.808	SHM	-9.0887	FLV	16.41578	FLV
St. 13	17.00	-5.7091	TUV	87.7089	SHM	-2.9364	SHM	15.98073	FLV
St. 14	14.00	-1.20889	BEV	144.764	SHM	-11.649	FLV	16.44598	FLV
St. 15	16.00	-2.61747	BEV	148.281	SHM	-9.9665	FLV	20.04107	FLV
St. 16	17.00	3.029335	BEV	152.254	SHM	-15.565	FLV	7.322686	TUV
St. 17	15.00	0.29439	BEV	141.092	SHM	-12.563	FLV	12.08283	FLV
St. 18	14.00	-5.78824	TUV	91.7771	SHM	-3.2459	SHM	16.71662	TUV
St. 19	15.00	1.034289	BEV	108.104	SHM	-7.7926	FLV	9.873693	FLV
St. 20	16.00	5.298732	BEV	55.5705	BEV	-4.5439	SHM	3.556598	TUV

Note: BEV = Beach environment, FLV = Fluvial environment, SHM = Shallow marine environment, TUV = Turbidity environment

Correlation Analysis

The average flow velocity of each transect cross-section and the sediment textural characteristics along the channel have been correlated at 95% confidence interval. The results obtained have been presented in (table 2 and figure 7) respectively.

Table 4: Correlation between sediment grain size and flow velocity in the Commodore channel

Variable	Mean ±STD	Pearson Correlation (r)	R^2
Sediment Grain Size (phi)	2.235±0.451	- 0.545	
Flow Speed of Water (m/s)	0.522±0.186	(y = 2.93 – 1.32x)	0.297

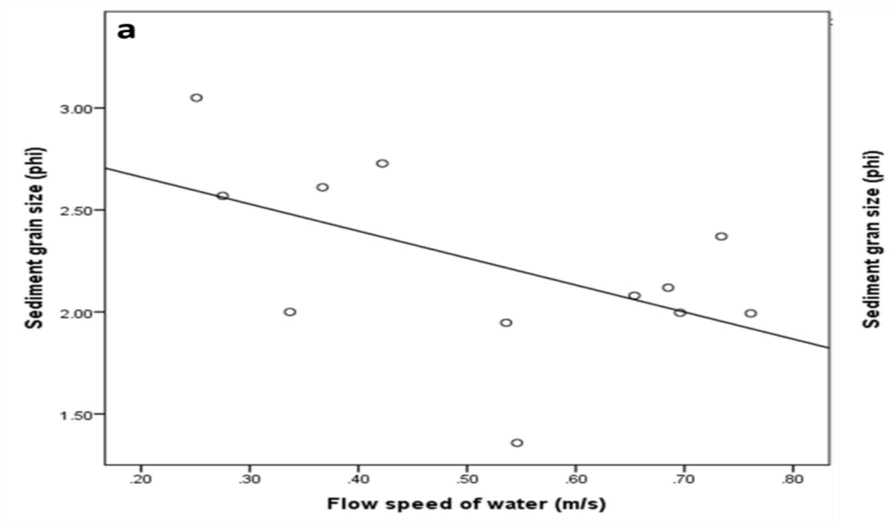

Figure 7: Correlation between flow velocity and sediment grain size

DISCUSSION

Flow characteristics

A maximum and minimum velocity magnitude of 1.46 and -1.17 m/s was observed along the channel entrance while a maximum and minimum velocity magnitude of 1.46 and -1.36 m/s was recorded along the mid-channel. The maximum and minimum velocity magnitudes along the upper reach of the channel was 1.09 and -1.59 m/s. This showed no significant difference in stream flow along the different channel points. The flow was slightly stronger in the channel entrance than along the upper reaches of the channel. Strong current velocities occurred mostly along the channel center while weak current velocities occurred more often along the channel banks. This variation in flow velocity implied that the channel centre are areas of high energy while the channel boundaries are low energy points. This flow condition affect the bottom morphology and sediment distributions along the channel such that the channel centre being high energy areas are prone to sediment erosion while the channel banks being low energy areas are susceptible to siltation or sediment accretion. Vijverberg (2012) and Bentum (2012) reported velocity values of 1.17 m/s and 1.13 m/s at the Commodore channel entrance and parts of the Lagos lagoon, respectively. Those values were slightly different from those recorded in this study which are 1.45 m/s channel mouth and 1.09 m/s upper channel. Vijverberg however, used a fixed bottom ADCP with transducer facing up to measure the flow velocity at the channel while we used a boat mounted ADCP with its transducer beam facing down in our measurement.

Textural characteristics

The mean size reflects the central tendency of the sediment due to energy variation. It indicates the average kinetic energy and velocity of deposition (Sahu, 1964) The different samples analyzed in this study showed a mean grain size that varied from 0.183 Ø to 3.146 Ø with an average value of 2.030 Ø indicating coarse to very fine sand. Predominantly fine sand contributes about 51%, medium sand 25% and coarse sand 24%. Along the channel mouth the mean grain size has a maximum value of 2.370 Ø and minimum value of 0.950 Ø indicating fine sand and coarse sand. Samples along the middle reach of the channel has maximum mean size of 3.050 Ø and minimum mean grain size of 0.509 Ø indicating fine sand and coarse sand. Samples Along the upper reach of the channel samples has maximum mean grain size of 3.146 Ø and minimum grain size of 0.183 Ø indicating very fine sand and coarse sand. The general variation in mean grain size along the different section of the channel can be attributed to change in in flow velocity. The average mean size value (2.030 Ø) of the Commodore channel samples showed the dominance of fine grained sand with minor variation in the grain size. These slight variations in the mean size value suggest fluctuation in the energy condition in the channel during transport and sedimentation (Ludwick 1987).

Deposional Environments

The variation in energy condition and flow characteristic tends to have strong correlation between grain size parameters and the environment in which the sediments were deposited. The concept of (Sahu 1964) was used to discriminate between various parameters of the sediment grain size into different depositional environment. Y1 discriminate between Aeolian and Beach environment, Y2 discriminate between Beach and Shallow agited water environment, Y3 discriminate between Shallow Marine and Fluvial/ Deltaic environment and Y4 discriminate between Turbidity and Fluvial environment. In this study, Y_1 is greater than -2.7411 for majority of the samples. 85% of the samples has values greater than -2.7441 suggesting deposition by beach process while 15% of the samples has values less than -2.7411. In Y2 55% of the sample has values greater than 65.360 suggesting deposition in shallow agited water and 45% of the samples showed values less than 65.360 pointing to deposition in beach environment. In Y3 65% of the samples has values less than – 7.4190 indicating deposition in fluvial environment and 35% of the samples has values greater than – 7.4190, indicating deposition in shallow marine environment. For Y4 75% of the samples has values greater than 9.843 indicating deposition through fluvial process and 25% of the samples has values less than 9.843 indicating deposition in a turbidity condition.

Textural characteristics in relation to flow velocity

The correlation between the sediment grain size and the flow velocity along the channel was done at 95% interval with a coefficient determination of 6.7 and 29.7% respectively. Result presented showed a strong negative correlation between the flow velocity and the sediment texture, depicting that these variables are independent of each other. This indicated that sediment deposition along the channel was not directly related to the flow velocities. Also the effective flow velocity along the area is 0.522 m/s, indicating a strong current and high energy environment while the effective sediment grain size is 2.235 indicating a fine sand. In a situation where fine sand was deposited in a high energy environment suggest that other factors like dredging or flooding/ebbing of tidal water could be possible contributors to the sediment transport process and subsequent deposition along the channel. Generally, flow regimes is a significant hydrodynamic variable that influences sediment transport and deposition. Since the Commodore channel is continually dredged to avoid vessels entering or exiting the port from grounding due to siltation, we suggest that this activity have significantly impacted the sediment transport process and deposition along the channel. Similarly, the flooding and ebbing of tidal current between the channel and the sea usually reworked the sediment prior to deposition.

CONCLUSION

Flow characteristics generally provides sediments flow path and deposition on the bottom floor. Flow velocity in relation to sediment distribution along Commodore channel has been investigated. Results showed that there was no significant difference in streamflow along the entire channel area. The flow velocity was however stronger along the mouth and mid channel than the upper reaches. Maximum velocity occurred along the channel center while minimum velocity values generally occurred along the channel banks. The strong and weak velocity magnitude observed within the centre of the channel and along the channel boundaries, implied high and low energy conditions. The mean grainsized indicated a fining upward sequence towards the lower, middle and upper reaches of the channel. The upper reach of the channel are predominantly well sorted sand while the lower reaches consisted of moderately sorted sand. The predominance of well sorted sand in the channel could be due to the activities of reworked sediment due to flooding and ebbing of tidal current. There was a strong negative correlation between the flow velocity and the sediment texture. This suggest that sediment distributions along the channel was not a direct function the flow velocity but also due to anthropogenic activities such as dredging operations and the flooding/ebbing of tidal water within the channel.

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