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DETERMINATION OF SEDIMENT DISTRIBUTION AND SUSPENDED SEDIMENT DISCHARGE IN THE KUTUBDIA CHANNEL OF BANGLADESH

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ABSTRACT

This study deals with the determination of sediment distribution and sediment discharge to understand the sediment depositional processes in the Kutubdia Channel of the Cox's Bazar. The study area lies in the complex as well as diverse geological and hydrodynamic conditions. Total suspended solid (TSS), turbidity and sediment discharge have been studies to understand the input amount of sediment in the channel. Also, sediment mixing zone has been identified from the TSS study. From the analysis it is observed that the depositional system of the channel is active and undergoing accretion of sediment deposition. The channel mainly consists of fine sand sediment. The Kutubdia Channel has well connection with the Bay of Bengal in the north and south. Different grain-size parameters i.e, mean size, sorting, skewness, kurtosis, cumulative curve, provability curve along with bivariate plots of each parameter have been studied to delineate sediment distribution of the study area. Linear discrimination function (LDF) and Multigroup Discrimination Function (MDF) applied to differentiate sedimentary sub-environment shows shallow marine and deltaic environment setting. The source of sediment of the Kutubdia Channel may be medium to far distance and faced uniform energy condition with reworking wave process along the channel.

Keywords: Kutubdia Channel, Sediment Distribution, Depositional Process, Sediment Discharge

INTRODUCTION

Determination of sediment discharge and interpretation of sediment data are very important to investigate fluvial system (Portfield, 1972). Sediment discharge can be calculated using water discharge and concentration of suspended sediment or total suspended solids (Portfield, 1972). However, geologists frequently employ grain-size features to identify hydrodynamic conditions, depositional processes, and depositional habitats (Boggs, 2009). According to Edwards (2001), grain-size analysis is a crucial technique for defining depositional settings, classifying sedimentary rocks, and texturally determining sediment characteristics. Additionally, grain size data offer helpful hints regarding the origin of the sediment, the mechanism of transportation, and the depositional conditions (Blott and Pye, 2001). Numerous authors, including Passega (1957), Passega (1964), Friedman (1967), Moiola and Weiser (1968), Passega and Byramjee (1969), Boggs (2009), and others, have demonstrated that each sedimentary environment does, in fact, exhibit distinctively different grain-size

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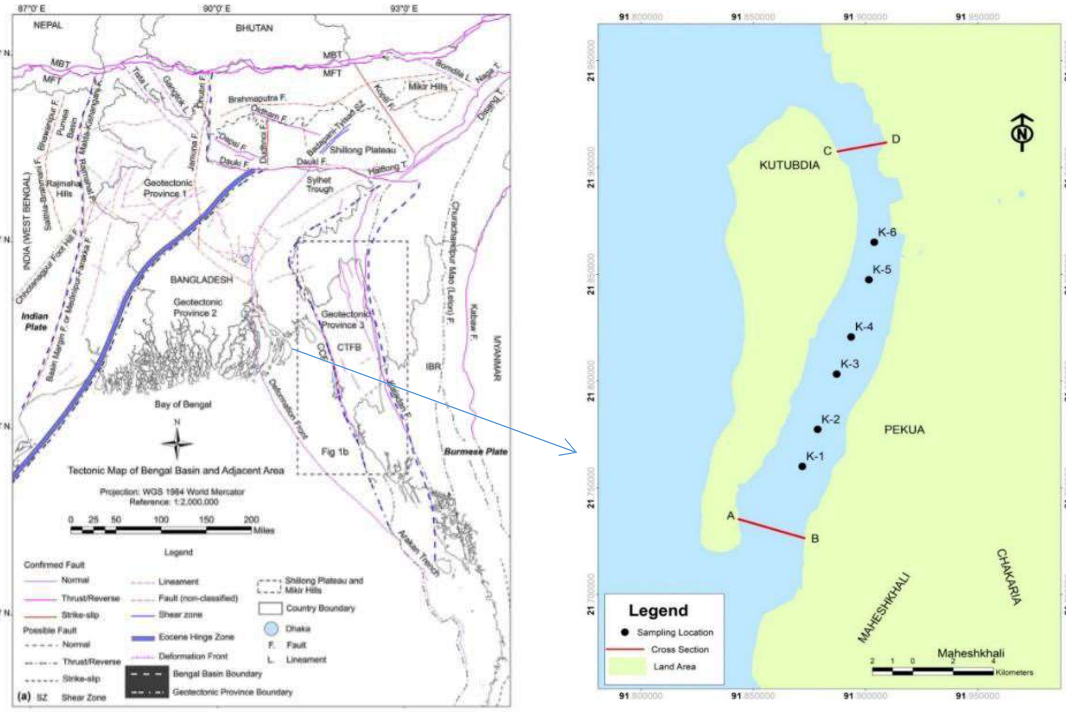
characteristics that set it apart from sediments deposited in other environments. Boggs 2009, Boggs 1995, and Tucker 2001 brought attention to the difficulty of applying grain-size analyses to depositional environments, nevertheless. According to Boggs (1995), other available tools should be used for environmental purpose along with grain size-distribution. So, this study deals



(a) (b)

Figure 1: (a) Simplified tectonic map of the Bengal Basin and its surroundings (Modified after Hossain et al., 2019) showing the study area; (b) Study area map showing the sampling point locations along the Kutubdia Channel, Cox's Bazar

with the determination of sediment depositional processes as well as sedimentary environments using grain-size characteristics and sediment discharge of the Kutubdia Channel. The study area lies in the Kutubdia Channel of Cox's Bazar district where it is surrounded by Kutubdia Island in the west, Pekua Upazila in the east, north and south is open to Bay of Bengal. The area is bounded by N 21.65 to N 21.92 latitudes and E 91.84 to E 91.92 longitudes (Fig.1).

The Kutubdia Channel has become very important in the recent year. Recently, Bangladesh government taken several development projects such as LNG terminal, deep sea port and power station in the area of Matarbari Island. The study is very important because of sediment deposition process and depositional environment have effective role on sustainability of a development activity.

Geological and Geomorpholocal Settings:

The study area lies in the Folded Flank of Tectonic Structure which is located in the south-eastern part of Bangladesh (Khan, 2002). The axial trend of the regional structure may extend up to Kutubdia Island through middle of Matarbari Island (Majlis et al., 2013) (Fig. 2). Majlis et al. (2013) studied on the geology and geomorphology of the area. According to Majlis et al. (2013), Bangladesh's eastern coast's Moheshkhali and Kutubdia offshore islands are part of a complex and distinctive geological system (Fig. 2).

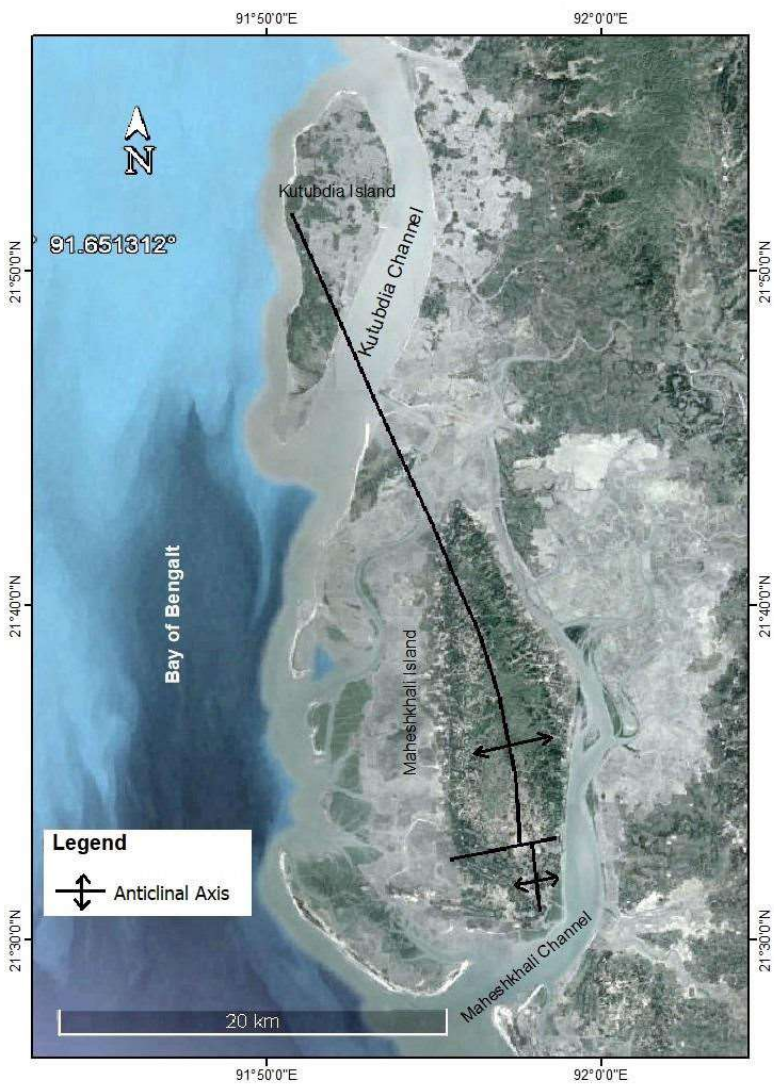
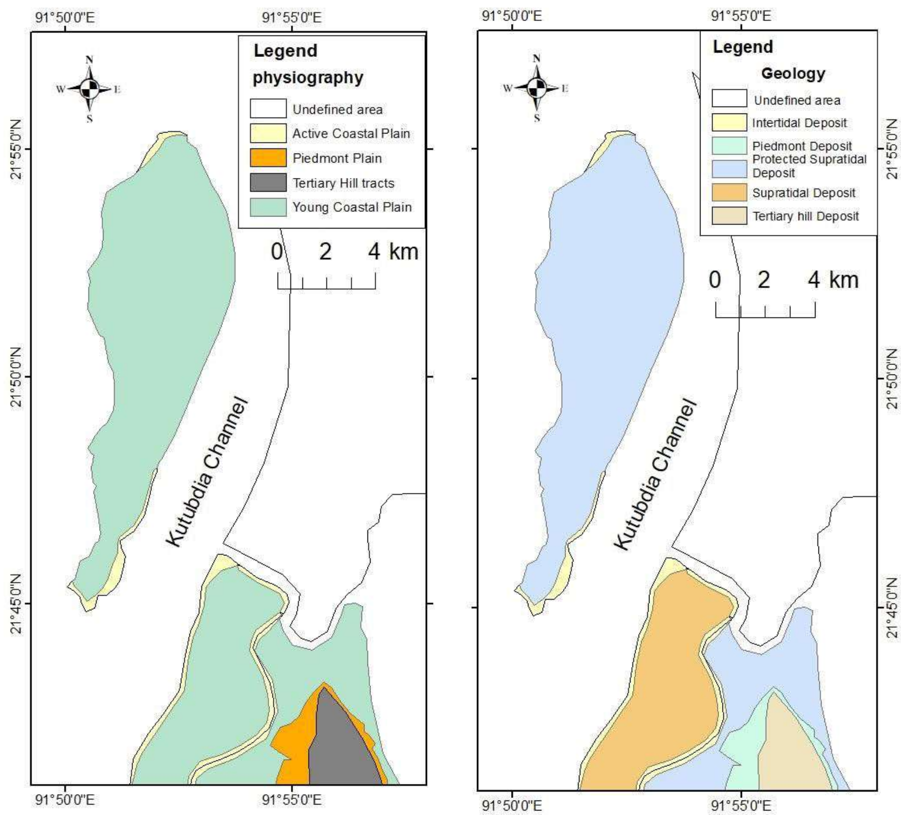


Figure 2: Morphodynamic setting of the study area (modified from Majlis et al., 2013)

Matarbari Island including surrounding area is undergoing gaining phase since 1972 where 47 sq. km area has been added in 38 years with 1.2 sq. km rate per year. Kutubdia Island is undergoing its loosing phase and eroding approximately 9 sq. km in las 38 years (Islam et al, 2011). Also, Majlis et al. (2013) mentioned that geologically the study area is mainly consisting of Holocene unconsolidated coastal deposits. Kutubdia and Matarbari islands are occupied by the young coastal plain of recent time (Fig. 3). Plain area of the two islands exhibits beaches, dunes, and tidal flats. Active Coastal plains are the areas between high and low tide levels fall in this unit. Most of the peripheral areas, circumferencing the young coastal plain of Kutubdia, Matarbari, Moheshkhali and Sonadia Islands constitute the active coastal plain.



A **B**

Figure 3: Generalized (A) physiographic and (B) geological map of Kutubdia and surrounding islands (modified from Mojlis et al, 2013)

The bedrock of the Kutubdia Island and Matarbari Island lies in the depth of 25-38 m and 21-23 m respectively where erosional surface and wave cut platform facing at sea (Majlis et al., 2013).

Climate and Hydrodynamic Conditions:

This region gets semi-diurnal tides (Rose and Bhaskaran, 2015), with a tidal range of approximately 3.5 to 4 meters (Khan, 2018). In Cox's Bazar, there are four distinct seasons: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November), and dry (December to February) (Siddik and Rahman, 2014; Bari et al., 2016). Generally, most of the cyclones occur in the area during the early summer (April-May) and late rainy season (October-November) (Khan, 2018). Rahaman and Rahman (2013) demonstrated that the predominant directions of Cox's Bazar wind during pre-monsoon or monsoon periods—with wave heights of 3.55 m, 4.13 m, and 4.74 m for 25, 50, and 100 years of return periods, respectively—are south (S), southwest (SW), and west (W). Between 1877 and 2017, 154 cyclones struck Bangladesh, including 43 cyclones, 53 severe cyclonic storms, and 68 tropical depressions, of which at least 17 struck Cox's Bazar (Khan, 2018). In April 1991, the estimated water height in the coastal plain of Cox's Bazar was 7.58 meter (Khan, 2018).

MATERIALS AND METHODS

Field Investigation:

The field investigation has been carried out in the Kutubdia Channel area during April to May, 2021. For systematic study of the area, traversing and spot location methods were used. Samples have been collected along the Channel mid-line. Sampling has been done using Van Veen Grab Sampler by local fishing boat. Surface and near bottom water samples have been collected using Niskin Water Sampler for investigating total suspended sediments (TSS). Secchi depth has been measured using Secchi Disk in the area to measure Turbidity. Water discharge has been measured along the A-D and C-D cross-sections from Acoustic Doppler Current Profiler (ADCP) measurement.

Sedimentary Texture:

At first sedimentary texture has been delineated using laboratory measurement. After field investigation, grain size distributions were measured by dry sieving methods. 100g of sediment samples taken to perform sieving method using ASTM standard sieve mesh no. such as 18, 35, 60, 120, and 230 to separate different sand size particles. 230 mesh (0.063mm size) used to separate silt and clay from sand size sediment in the sieve method. The equation given by Folk and Ward (1957) was used to calculate the statistical characteristics of grain-size distribution. The following equation was used to compute the graphic mean, standard deviation, skewness, and kurtosis from the cumulative graph values (ϕ10, ϕ25, ϕ60, ϕ75, ϕ99).

Graphic mean (M_Z)	$M_Z = \frac{\varnothing_{16} + \varnothing_{50} + \varnothing_{84}}{3}$
Inclusive graphic standard deviation (σ_i)	$\sigma_i = \frac{\varnothing_{84} - \varnothing_{16}}{4} + \frac{\varnothing_{95} - \varnothing_{5}}{6.6}$
Inclusive graphic skewness (SK_i)	$SK_i = \frac{(\varnothing_{84} + \varnothing_{16} - 2\varnothing_{50})}{2(\varnothing_{84} - \varnothing_{16})} + \frac{(\varnothing_{95} + \varnothing_{5} - 2\varnothing_{50})}{2(\varnothing_{95} + \varnothing_{5})}$
Graphic kurtosis (K_G)	$K_G = \frac{(\varnothing_{95} - \varnothing_{5})}{2.44(\varnothing_{75} - \varnothing_{25})}$

Where $\varnothing_5$, $\varnothing_{16}$, $\varnothing_{25}$, $\varnothing_{50}$, $\varnothing_{75}$, $\varnothing_{84}$ and $\varnothing_{95}$ represents 5th, 16th, 25th, 50th, 75th, 84th and 95th percentile, respectively, on the cumulative curve.

Depositional Environment:

Based on the textural changes of the sediment, bivariate scatter plots were used to distinguish between different depositional contexts. Bivariate plots of graphic mean vs. skewness, graphic mean vs. kurtosis and skewness vs. kurtosis have been used to discriminate depositional environment in this study. The deposition processes and habitats were identified and distinguished using Sahu's (1964) linear discriminant function (LDF). Also, multigroup discriminant function has used to discriminate the environment as per Sahu's (1983) method.

Total Suspended Solid (TSS) Measurement:

Particles greater than 2 microns that are present in the water column are known as total suspended solids (TSS) (Langland and Cronin, 2003). To measure the mean concentration of suspended sediment, the water samples from different depths of the channel water column were collected using Niskin Water Sampler. The collected water samples were carried out through plastic bottle to the laboratory. After that vacuum pump and filtration unit were used to separate solid particle from the water. Whatman 1 type filters has been used to collect solid and dried in oven over night and take weight of the samples to measure Total Suspended Solid (TSS) in gm per liter of the water sample.

Turbidity Measurement:

The optical measurement of water clarity is turbidity (Wetzel, 2001). Light will be spread more widely the more particles there are. Turbidity and total suspended solids are therefore linked (Wetzel, 2001). Turbidity can be caused by organic matter like algae, plankton, and decomposing debris as well as suspended sediments like silt or clay. The Secchi depth is the limit of the visible range of a high-contrast pattern on a submerged disk. Secchi depth is used to gauge how transparent the water is (Lee et al., 1995). Based on measured turbidity data, the Secchi depth (in feet) can be calculated (Rasmussen at el., 2009). A regression model of Secchi depth as a function of turbidity was developed using measurements of the Secchi depth close to the monitor location:

$$Secchi\ Depth = 11.123 \times Turbidity^{-0.637} \text{------------} \qquad (1)$$

Where, Secchi depth is in feet, and Tbdy is turbidity in FNU. So, the Turbidity of the area can be calculated as:

$$Turbidity = \sqrt[0.637]{\frac{11.123}{Secchi\ Depth}} \text{----------------} \qquad (2)$$

Suspended Sediment Discharge Calculation:

Sediment discharge rate is very important for channel input of sedimentation. Discharge rate of the north and south mouth of Kutubdia Channel has been calculated using ADCP. At the same time water sample were collected from different depth to calculate sediment discharge. Suspended sediment's (TSS) mean concentration was measured in the laboratory using filter method. After measured water discharge directly using ADCP and sediment discharge (TSS) measured in the laboratory, the suspended sediment discharge (tons per day) was calculated using below equation (Porterfield, 1972):

$$Qs = Qw \times Cs \times k \quad \text{----------------} \qquad (3)$$

Where, Qs = suspended sediment discharge (sediment flux) in tons per day.
Qw = water discharge in cubic meter per second
Cs = mean concentration of suspended sediment (mg/liter)
k = a coefficient based on the unit of measurement of water discharge that assumes a specific weight of 2.65 for sediment, and equals 0.0027 in inch-pound units, or 0.0864 in SI units.

Sediment discharge can be measured based on discrete and periodic way of sample collection. In this study, discrete data of water discharge along two points of Kutubdia Channel has been collected. There are two sections considered where one is along the southern mouth of the channel (A-B section) and other is northern mouth of the channel (C-D section) (Fig.1). Water discharge measured in the sections for seven times during 7:00 to 16:00 hours of 5th May, 2021 along A-B section and 6th May, 2021 along C-D section. May to July is the most sediment discharge period in the area because of monsoon effect of Bangladesh during this time. The suspended sediment (TSS) has been calculated using mean water discharge and suspended solids during the time of measurement. This is a fundamental method to calculate suspended sediment discharge of a river or channel used by U.S Geological Survey (Porterfield, 1972). The method that is most frequently applied is based on the development of a temporal relation by interpolating between recorded suspended-sediment concentration values and using measured and estimated concentration values with time-weighted water discharge data to compute suspended sediment discharges (Porterfield, 1972).

RESULTS

Total Suspended Solid (TSS) and Turbidity:

Total suspended solids of surface and bottom water have been measured for the six samples location along the Kutubdia Channel (Fig. 1). The TSS value of the study area ranges from 0.0993 to 0.0123 mg/l where bottom water contains higher value of TSS than surface water except sample no. K1 (Table 1). In the sample K1, the TSS value in surface is high as 0.0993 mg/l than bottom (0.0893 mg/l). The sample K5 contains shows low value of surface (0.0123 mg/l) and bottom (0.0262 mg/l) TSS. Besides TSS, Secchi depth has been measured at the K1 to K6 sampling point. The range of secchi depth is 0.328 to 1.312 m where sampling location K4 and K6 shows higher value of secchi depth (1.312 ft). Also, turbidity has calculated from the secchi depth value. High turbidity found in the K1, K2 and K3 sampling location which is 252.497 FNU and low value (28.649 FNU) found in the K4 and K5 locations (Table-1).

Table 1: Total Suspended Solid and Turbidity data of the sampling location

Sample ID	Surface TSS, gm/L	Bottom TSS, gm/L	Secchi Depth (ft)	Turbidity, FNU
K1	0.0993	0.0893	0.328	252.497
K2	0.0619	0.0984	0.328	252.497
K3	0.0519	0.0798	0.328	252.497
K4	0.075	0.0971	1.312	28.649
K5	0.0123	0.0262	1.312	28.649
K6	0.0524	0.0974	0.492	133.603

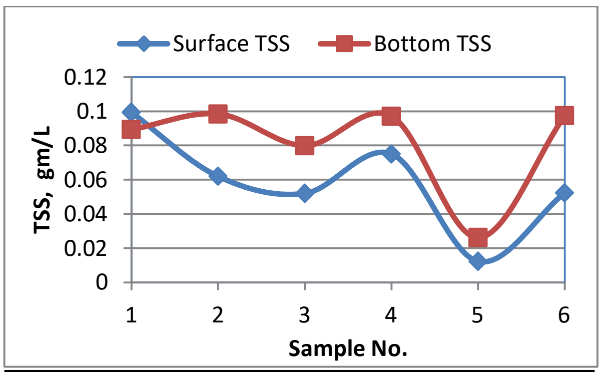


Figure 5: Total Suspended Solid (TSS) of surface and bottom water of Kutubdia Channel

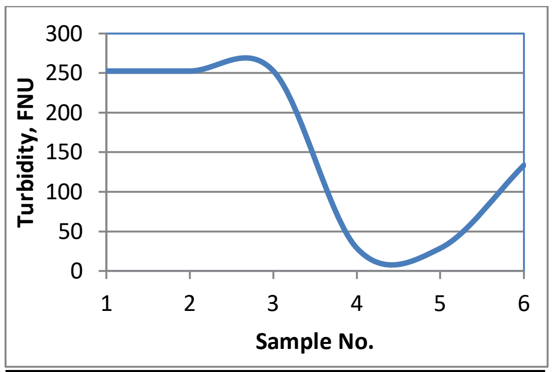


Figure 6: Surface water Turbidity graph of the Kutubdia Channel

In the fig. 5, the surface and bottom TSS shows similar trend of change along K1 to K6 location. In the fig. 6, the turbidity shows similar trend like TSS. High turbidity found along the southern mouth of the channel (Fig. 1).

Sediment Discharge:

Along A-B section, the Kutubdia Channel width is about 3150 m and depth is around 10 m. Channel profile shows the bottom is quite flat and very steep in the eastern bank than the western bank (Fig. 7). Along the C-D section, the channel profile width is about 1700 m and maximum depth is 17m. The channel profile is shallow in the eastern bank and gradually increases depth towards the western side (Fig. 8). Mean concentration of suspended sediments were measured from the vertical average of the suspended, middle point and bottom point values (Table 2). Along A-B section, the average TSS is 0.0943 mg/l where surface water sample shows higher TSS value (0.0994 mg/l) than bottom water sample (0.0891mg/l). Along C-D section, the bottom water sample contain higher TSS (0.0749 mg/l) than surface water (0.0516mg/l) where average TSS value along this section is 0.0749 mg/l.

Table 2: Calculation of average total suspended solids (TSS) along A-B and C-D sections

Section	Surface TSS, mg/l	Mid TSS, mg/l	Bottom TSS, mg/l	Average TSS, mg/l
A-B section	0.0994	0.0944	0.0891	0.0943
C-D section	0.0516	0.0759	0.0972	0.0749

The sediment discharge has been calculated along the A-B and C-D sections based on water discharge data and average TSS measured in the middle point of the sections. From ADCP, the mean current speed along A-B and C-D sections are 0.812 and 0.753 m/s respectively (Table 3).

Table 3: Calculation of sediment discharge along the A-B and C-D sections of Kutubdia Channel

Section	Mean current speed, m/s	Water Discharge, m^3/s	Average TSS, mg/l	Sediment Discharge, tons/day	Total sediment discharge (tons/day) to the channel from bay
A-B section	0.812	-679.19	0.0943	-5.5337	6.4812
C-D section	0.753	146.41	0.0749	0.9475	

The sediment discharge has been calculated along the A-B and C-D sections using equation-3 shows 5.5337 and 0.9475 tons/day respectively. The net sediment come from bay to the channel is 6.4812 tons/day (Table-3).

Water discharge measured by ADCP along the A-B and C-D sections also. Along the A-B and C-D sections, the water discharge value is 679.19 and 146.41 cubic meter per second respectively. In the matter of ADCP operation during survey to measure water discharge, the north to southward direction of flow of channel water considered as positive (+) value and south to northward direction of flow considered as negative (-) value of discharge (Fig. 1). So, in the table, the negative sign of A-B section means bay to channel ward and positive sign along C-D section means bay to channel ward direction of flow. So, along the both sections the flow of water direction shows bay to channel ward.

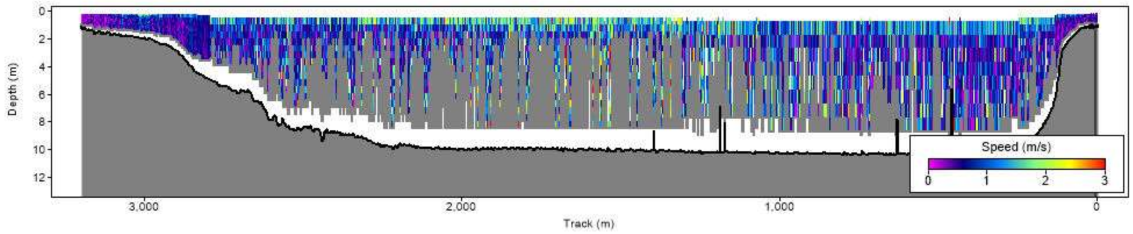


Figure 7: Cross section along A-B of the Kutubdia Channel

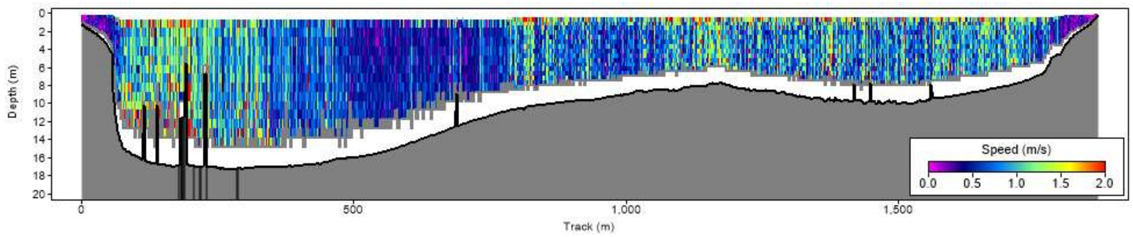


Figure 8: Cross section along C-D of the Kutubdia Channel

Sediment Distribution and Texture:

(a) Textural classifications of sediments

For textural classification both graphical and statistical methods have been used. Sand, silt and clay percentages are plotted in a triangular diagram (Shepard, 1954; Folk, 1956) for basic classification of the sediment of Kutubdia Channel. Triangular diagram (Fig.7) shows that the sediments of the area belong to sand (Fig. 9).

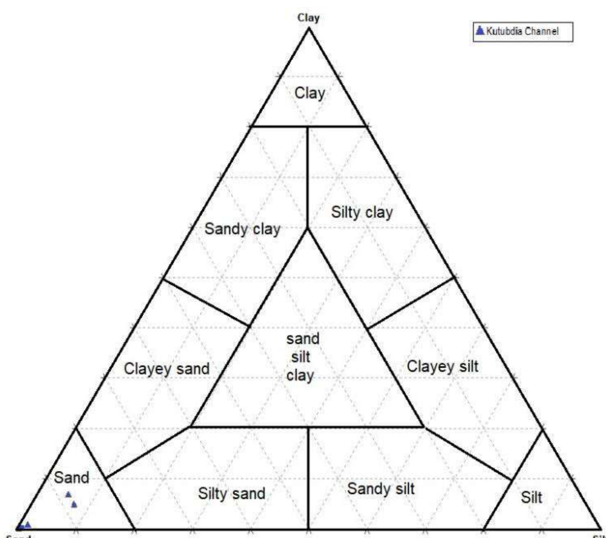


Figure 9: Triangular diagram for textrual classification of sediment in the Kutubdia Channel (Shepard, 1954)

The study area consisted higher percentage of sand size sediment ranges from 88.050 to 99.816. The silt percentage are ranges from 0.129 to 7.170 and clay are ranges from 0.055 to 6.57 (Table 4).

Table 4: Weight percentage of different type of sediments of the study area

Sample ID	Depth, m	Sand	Silt	Clay
K1	6.5	88.050	7.170	4.780
K2	6.4	99.667	0.267	0.067
K3	5.5	98.033	1.377	0.590
K4	7.5	99.816	0.129	0.055
K5	7	88.050	5.378	6.573
K6	5	99.586	0.290	0.124

(b) Graphic statistical classification of sediment

i. Frequency curve

A frequency curve is essentially a histogram constructed to determine the modal size (Boggs, 1995). The figure 10 shows that the sediment size of the study area shows different range but mostly belongs to sand size range (2 to 0.063mm). It has been found form the table that the size of sand lies mostly in the 0.25mm to 0.125mm range. From the graph it is found that the sediment is unimodal population.

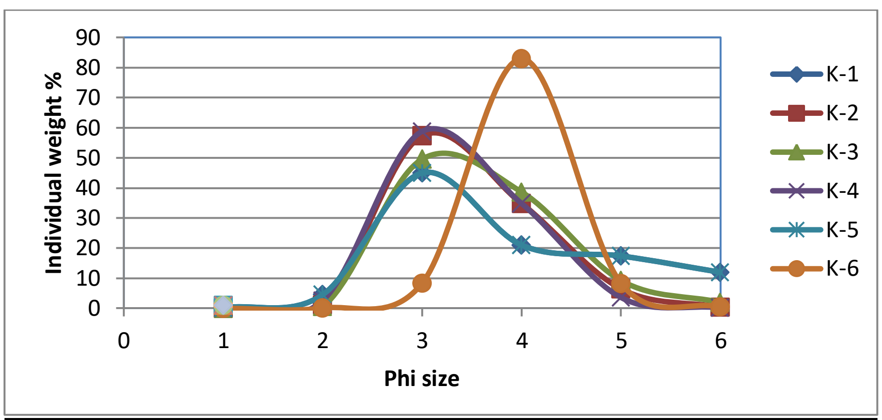


Figure 10: Frequency curve based on sediment size and individual weight percentage of The Kutubdia Channel

ii. Cumulative curve

The cumulative weight percentage frequencies are displayed against the phi values, highlighting the many mechanisms of sediment movement and deposition and their significance in the genesis. Boggs (1995) mentioned that the cumulative curve is the most useful of the grain-size plot. The curve usually shows S-shaped trend in the arithmetic scale.

Most of the samples are fine-grained, but some are also very fine-grained sand size. The curve (Fig. 11) shows moderately steep slope and S-shaped.

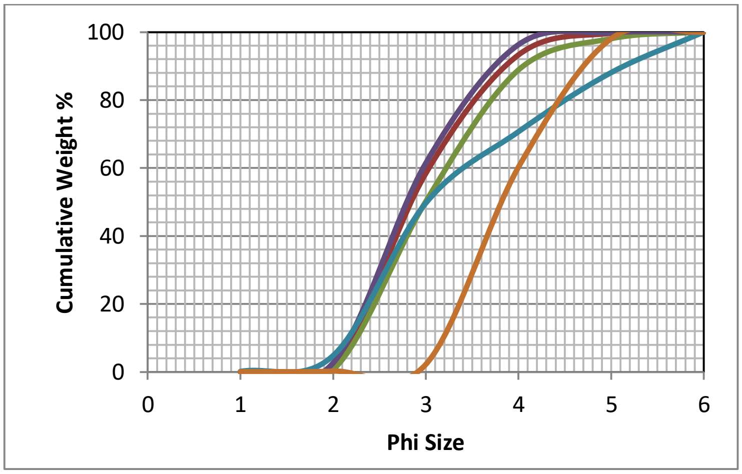


Figure 11: Cumulative weight percentage logarithmic curve based on grain size of the Kutubdia Channel

iii. Grain-size parameters

Table 5 shows the calculated value of different grain size parameter such as graphic mean, standard deviation, skewness and kurtosis of the Kutubdia Channel deposits. The calculations have been carried out using Folk and Ward (1957) method.

Table 5: Statistical parameter of sediment texture of the area

Sample ID	ϕ5	ϕ16	ϕ25	ϕ50	ϕ75	ϕ84	ϕ95	Graphic Mean	Standard Deviation	Skewness	Kurtosis
K1	2.00	2.30	2.50	3.00	4.25	4.75	5.60	3.35	1.16	0.44	0.84
K2	2.10	2.32	2.45	2.85	3.40	3.65	4.10	2.94	0.64	0.23	0.86
K3	2.15	2.35	2.55	3.00	3.60	3.85	4.45	3.07	0.72	0.20	0.90
K4	2.08	2.30	2.42	2.80	3.30	3.75	3.95	2.95	0.65	0.27	0.87
K5	2.01	2.30	2.49	3.00	4.25	4.75	5.56	3.35	1.15	0.44	0.83
K6	3.10	3.30	3.45	3.82	4.30	4.55	4.88	3.89	0.58	0.18	0.86

Mean Grain Size: This depicts the average particle size or the central tendency of particles. The mean size of the sediment of Kutubdia Channel lies between 2.94 to 3.89 phi sizes which belong to very fine to fine sand (Fig. 12a).

Standard deviation: This evaluates the homogeneity or sorting of the grains, reflecting the energy conditions present during transport and deposition. The value of standard deviation described as sorting of the sediments. In table-5, the standard deviation value ranges from 0.58 to 1.16. Sample no. K1 and K5 shows higher standard deviation indicate poorly sorted sediment. Other four sample shows low standard deviation (0.72 to 0.58) indicate moderately well sorted sediment (Fig. 12b).

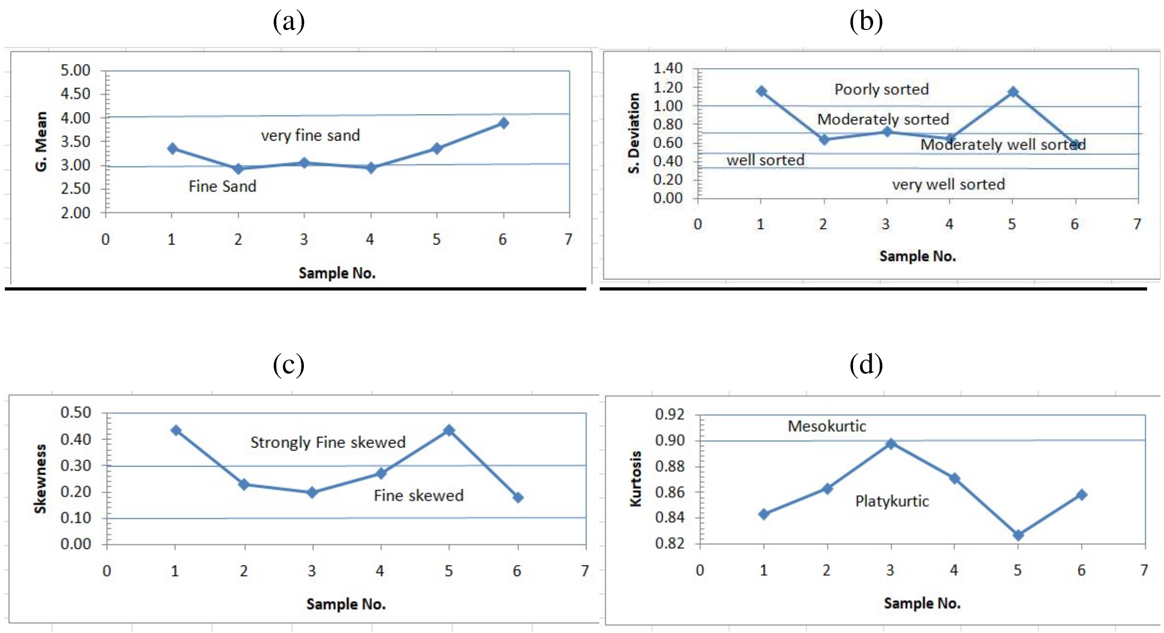


Figure 12: Graphical plot of (a) mean size, (b) standard deviation, (c) skewness, and (d) kurtosis of the sediment

Skewness: Skewness, or the percentage of coarse or fine fractions, is a statistic for symmetrical distribution. A symmetrical curve indicates a zero value; one with excess fine material displays a positive value, while one with excess coarse material displays a negative value. The skewness value of the sediment ranges from 0.18 to 0.44 (Table-5). The sample no. K1 and K5 shows high skewness value (0.44) indicate strongly fine skewed sediment and other samples shows low value of skewness (0.18 to 0.27) indicate fine skewed sediment (Fig. 12c).

Kurtosis: The kurtosis expresses the packedness of the grain size distribution. Table-5 shows that the kurtosis values of the sediments range between 0.83 to 0.90. Sample no. K3 have kurtosis value 0.90 which can be considered as mesokurtic nature and other sample lies in the range (0.83 to 0.87) of platykurtic nature of sediment (Fig. 12d).

(c) Sedimentary Environment

There appears to be a strong association between the various processes and depositional conditions and the application of statistical analysis to explain the variations in energy and fluidity parameters during and before sediment deposition (Sahu, 1964). The following equation applies the linear discriminant functions (LDF) to distinguish between various processes and the depositional environment:

$$Y_{1(SA:B)} = -3.5688M + 3.7016r^2 - 2.0766SK + 3.1135KG \quad \text{(i)}$$

Y1 value < -2.7411, indicates "shallow agitated water" and Y1 value > -2.7411, indicates "beach" environment.

$$Y_{2(B:SM)} = 15.6534M + 65.7091r^2 + 18.1071SK + 18.5043KG \quad \text{(ii)}$$

Y_2 value < -63.3650, indicates "beach" and Y_2 value > -63.3650, indicates "shallow marine" environment.

$$Y_{3(SM:F)} = 0.2852M - 8.7604r^2 - 4.8932SK + 0.0482KG \quad \text{(iii)}$$

Y_3 value > -7.4190, indicates "shallow marine" and Y_3 value < -7.4190, "deltaic or lacustrine" environment.

$$Y_{4(F:T)} = 0.7215M - 0.4030r^2 + 6.7322SK + 5.2927KG \quad \text{(iv)}$$

Y4 value < 9.8433 indicates turbidity current deposition and Y4 value > 9.8433 indicates deltaic deposition. Here M, r, SK and KG represents mean grain size, standard deviation, skewness and kurtosis, respectively.

In the above equations, the equation (i) distinguish shallow agitated water (SA) and beach (B), (ii) distinguish beach (B) and shallow marine (SM), (iii) distinguish shallow marine (SM) and deltaic or lacustrine (L), and (iv) distinguish deltaic (D) and turbidity current deposit environments.

Table 6: Shows the LDF value and associate depositional environment of the study area

Sample ID	Y1	Environment	Y2	Environment	Y3	Environment	Y4	Environment
K1	-5.2736	Shallow Agitated Water	164.0502	Shallow Marine	-12.8863	Deltaic/ Lacustrine	9.2775	Turbidity
K2	-6.7812	Shallow Agitated Water	92.6279	Shallow Marine	-3.7666	Shallow Marine	8.0499	Turbidity
K3	-6.6210	Shallow Agitated Water	102.5788	Shallow Marine	-4.6320	Shallow Marine	8.0800	Turbidity
K4	-6.8335	Shallow Agitated Water	94.5918	Shallow Marine	-4.0925	Shallow Marine	8.3884	Turbidity
K5	-5.3873	Shallow Agitated Water	162.5772	Shallow Marine	-12.7286	Deltaic/ Lacustrine	9.1902	Turbidity
K6	- 10.3286	Shallow Agitated Water	102.2956	Shallow Marine	-2.6969	Shallow Marine	8.4209	Turbidity

In the table 6, the LDF values shows that the depositional environment of the channel belongs to shallow agitated water, shallow marine, turbidity and some belongs to deltaic environment.

Tucker and Vacher (1980) questioned about the effectiveness of liner discrimination function. As LDF yield result for two environment conjugately, so Sahu (1983) employed Multigroup Discrimination Function (MDF) to find out distinguished environment for the sediment deposition. In this case of MDF, discriminating Eigen's vector V1 and V2 used and expressed as-

$$V1 = 0.48048M + 0.62301r^2 + 0.40602SK + 0.44413KG$$

$$V2 = 0.24523M + (-0.459051r^2) + 0.15715SK + 0.83931KG$$

Where M, r, SK and KG represents mean size, standard deviation, graphic skewness and graphic kurtosis respectively.

Table 7: Shows the Multigroup Discrimination Function value of the sediment

Sample ID	V1	V2
K1	3.00	0.98
K2	2.14	1.30
K3	2.28	1.30
K4	2.17	1.31
K5	2.98	0.98
K6	2.53	1.55

The value obtained for V1 and V2 (Table-7) has been plotted in the diagram after Sahu (1983). The position of the point falls in the shallow marine and river in the diagram (Fig. 13).

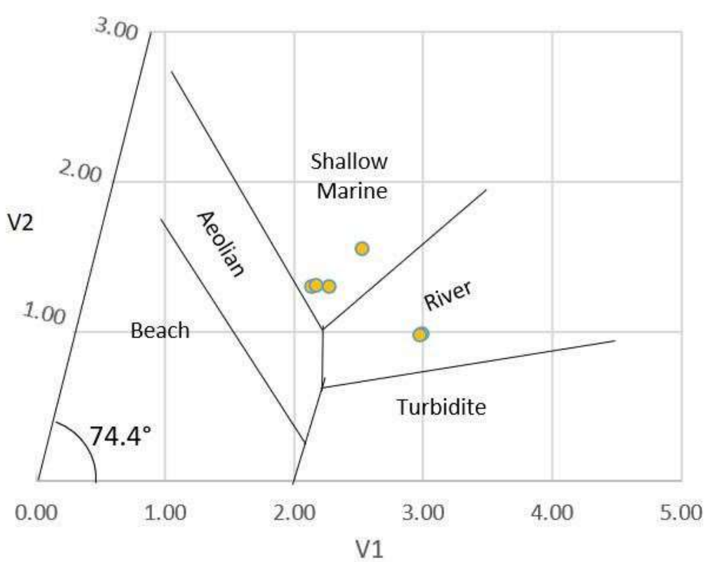


Figure 13: Discrimination of depositional environment of the study area using V1-V2 plot after Sahu (1983)

DISCUSSIONS

Sediment Discharge:

The total suspended solids of the surface water are less than the bottom water indicate bed load sediment is higher than the suspended sediment in the channel area. In the sample no.

K1, bottom water TSS is less than the surface water TSS which may because of reworking and mixing activity at the sample location which is situated near the southern opening of the channel. The turbidity shows similar nature as TSS in the channels (Fig. 6). TSS and turbidity of the channel is higher in the southern opening indicate more influence of marine forces along the southern opening of the channel may occur. The sediment discharge along A-B section is higher than the C-D section (Table-). A-B section is lies in the southern part where C-D section lies in the northern part of the channel. Also, the current speed is higher along the A-B section than C-D section which implies the current speed is higher along the southern opening of the channel than northern opening. So, the current speed may control the sediment discharge in the channel. The input through A-B and C-D sections is 5.5337 and 0.9475 tons/day respectively (Table 2). The total input of sediment to the Kutubdia Channel is 6.4812 tons/day which indicate accretion occurring in the Channel during May (monsoon season). The dry season scenario can be different.

Sediment Distribution:

The maximum depth of the study area is 7 meter and minimum depth is 5 meter which reveals the depth of the study area is mostly uniform. The study area is dominated by fine sand deposit. From the histogram, the sediment shows unimodal curve (Fig. 8) which indicates the process of sediment deposition is consistent during the sediment settled (Baiyegunhi et al., 2017). Also, the unimodal curve are characteristics of fluvial setting (Shettima et al., 2012).

According to Boggs (1995), low kinetic energy and velocity can be identified when the curve shows broad and gentle slope where very steep slope indicate good sorting. So, the cumulative frequency curve (Fig. 9) indicates S-shape with medium slope reveals moderate kinetic energy and velocity may exist during sediment deposition in the channel. According to Folk (1964), the mean size of the sediment reflects overall average size of the sediment influence by source of sediment supply and environment of deposition. Mean size of the sediment of the Channel shows (Fig. 10a) fine to very fine in size indicates moderately low energy condition (Baiyegunhi et al., 2017). Also, very fine to fine grained suggest that the deposition may be gone under phase of little reworking and redeposition (Kukal, 1971). Standard deviation described as sorting of sediments. Sorting can be used as tool to measure uniformity of current (Folk, 1964) and suggest changes in the depositional environment's hydrodynamic characteristics (Sahu, 1964). The sorting of the sediment of the channel is moderately well sorted indicates moderate to uniform energy condition of current and moderately well sorted nature of the sediment may be due to partial winnowing action (Angusamy et al., 2006; Rajesh, et al., 2007; and Ramanathan et al., 2009). Also sorting indicate distance of transportation where the studied samples show moderately well sorted sediment implies moderate to far distance of sediment source (Abdel-Wahab et al., 1992;

Reineck and Singh, 1973; Shettima et al., 2012). Folk and Ward (1957), mentioned that extreme high and low value of kurtosis imply that the sediment achieved its sorting in high energy environment.

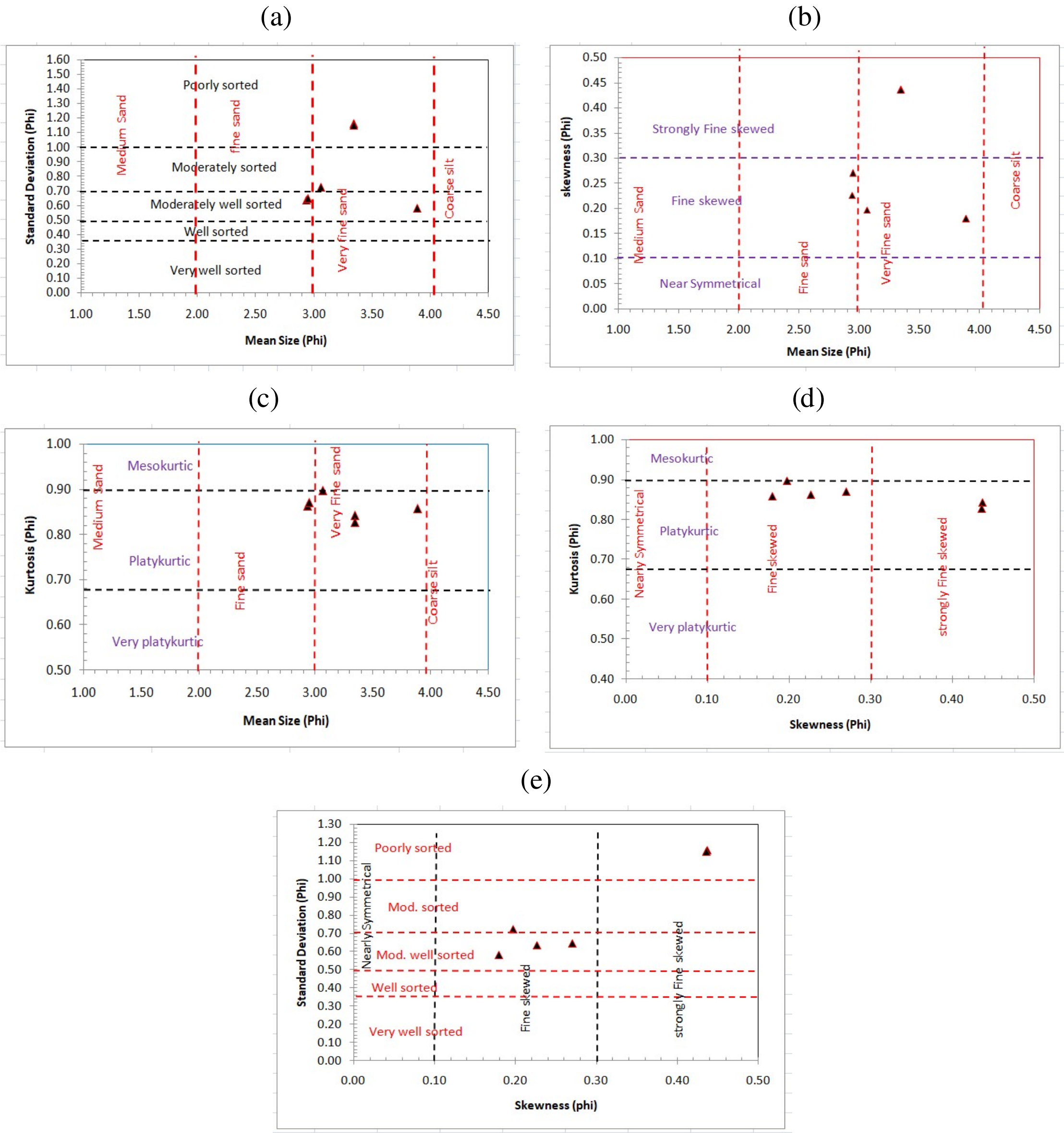


Figure 12: Bivariate plot between (a) mean size and standard deviation, (b) mean size and skewness, (c) mean size ands kurtosis, (d) skewness and kurtosis, (e) skewness and standard deviation

The result of kurtosis showed in this paper as platykurtic which very low value ranges 0.83 to 0.87. Also, the sorting showed moderately well sorted nature of sediment indicates high energy depositional environment of the study area. Positive skewed indicate fine fraction abundant in the sediment (Baiyegunhi et al., 2017). As per Folk (1964), strongly skewed samples were obtained from zones of environmental mixing. In this paper, the sediments are lies in the strongly fine skewed and fine skewed nature indicate zone of environmental mixing in the study area. On the premise that they represent variations in the fluid-flow mechanisms of sediment transit and deposition, bivariate plots of various statistical parameters are created to distinguish between various depositional settings (Sutherland and Lee, 1994). The presence of well-sorted sediments can be attributed to the activity of tractive currents in the beach sub-environment (Folk, 1980). The more fast rounding of these sediments is also caused by the continual back and forth of grains in such a sub-environment (Folk, 1980).

The bivariate plot between standard deviation and mean size for sediment shows variations of sorting but mean size is very fine sand (Fig. 12a). The sediment energy diagram shows samples are belongs to wave process with some are indicate quite water process (Fig. 13a). The bivariate plot between skewness and mean size shows mostly fine skewed to strongly fine skewed indicates dominant of fine size fraction (Fig. 12b). Also, the bivariate plot shows wave process is dominant during sediment deposition in the area (Fig. 13b). Bivariate plot between kurtosis and skewness shows fine skewed and mesokurtic to platykurtic indicate moderate size is dominant but fine tails are not prominent. The sorting and skewness bivariate plot show fine skewed and moderately well sorting. The bivariate plots indicate uniform and moderate energy of sediment deposition with prominent wave process in the channel.

(a) (b)

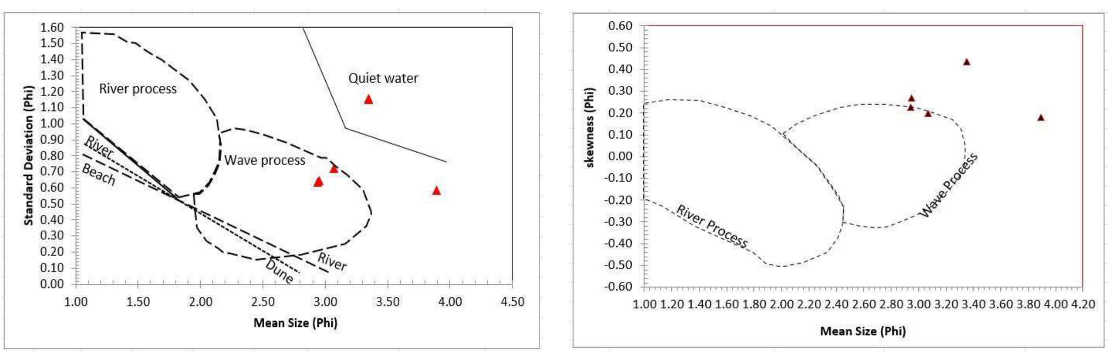


Figure 13: Energy process diagram of statistical parameter for the sediment samples between (a) mean size vs standard deviation (after Stewart, 1958; Moiola and Weiser, 1968), (b) mean size vs skewness (Stewart, 1958)

Visher Diagram:

The log-probability curves show the mechanism of transportation of the sediment in the area. Visher (1969) diagram can be applied in the modern sediment. The transport mechanism such as traction, saltation and suspension can be finding through the diagram. In this diagram, cumulative distribution of grain size on the probability graph have used. The probability scale represents the data to segment of two or three straight line which reflect different mode of transportation of sediment.

Visher diagram (Fig. 14) shows dominants of double saltation (saltation I and altation II) population with single suspension and traction population. Variation showed in the traction population where suspension shows quite similar in nature. In the diagram, wash load break (break between saltation II and suspension) and swash-backwash separation break zone (break between saltation I & II) is similar for all samples but zone of mixing (near to the break between traction & saltation) shows variations.

Visher (1969) indicated that three sand population curves are associated with wave zones and two sand population curves are associated with fluvial setting. The graph shows three sand population settings indicate wave zone of sediment process (Fig. 14).

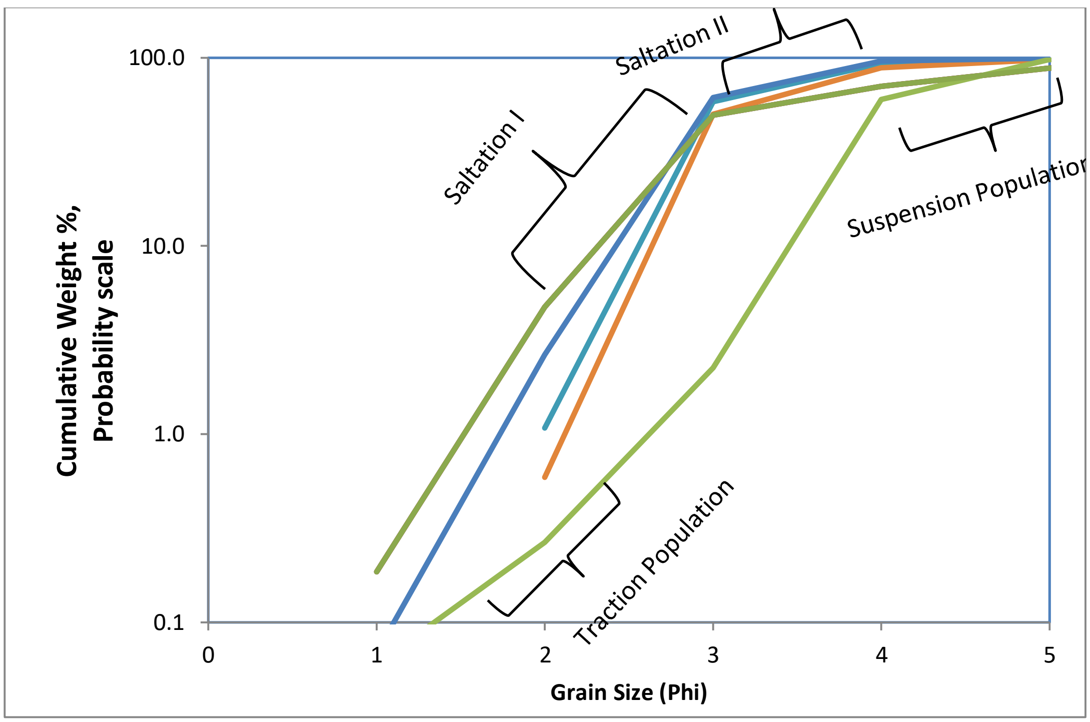


Figure 14: Cumulative weight percentage probability curve (Visher diagram) of the Kutubdia Channel

Dike (1972) mentioned two sand population indicate unidirectional current system where the studied sediment shows three sand population which also indicate sediment deposited in this area are not from unidirectional current. The most common means of transportation can be categorized as traction and saltation. Provenance regulates it (Visher, 1969). So, the source area of the sediments may be moderate distance from the channel. The sediments of the study area do not show results in C-M diagram after Passega, 1964.

Depositional Environment:

Linear discriminant functions used for the analysis of different depositional environment as well as interpret the variations of fluid factors and energy of sediment deposition. Sahu's (1964) linear discriminant functions has been used to identify shallow agitated water and beach (Y1), beach and shallow marine (Y2), shallow marine and deltaic or lacustrine (Y3) and turbidity and deltaic (Y4). In the Table 6, it has been shown that the depositional environment belongs to shallow agitated water, shallow marine and turbidity depositional processes.

The bivariate plot of LDF values between Y1 and Y2 indicate beach and shallow marine environment and Y2 and Y3 shows shallow marine and deltaic or lacustrine. In case of Y3 and Y4 bivariate plot, the graph shows the sediment belongs to turbidity current/shallow marine and deltaic or lacustrine environment of sediment deposition (Fig. 13).

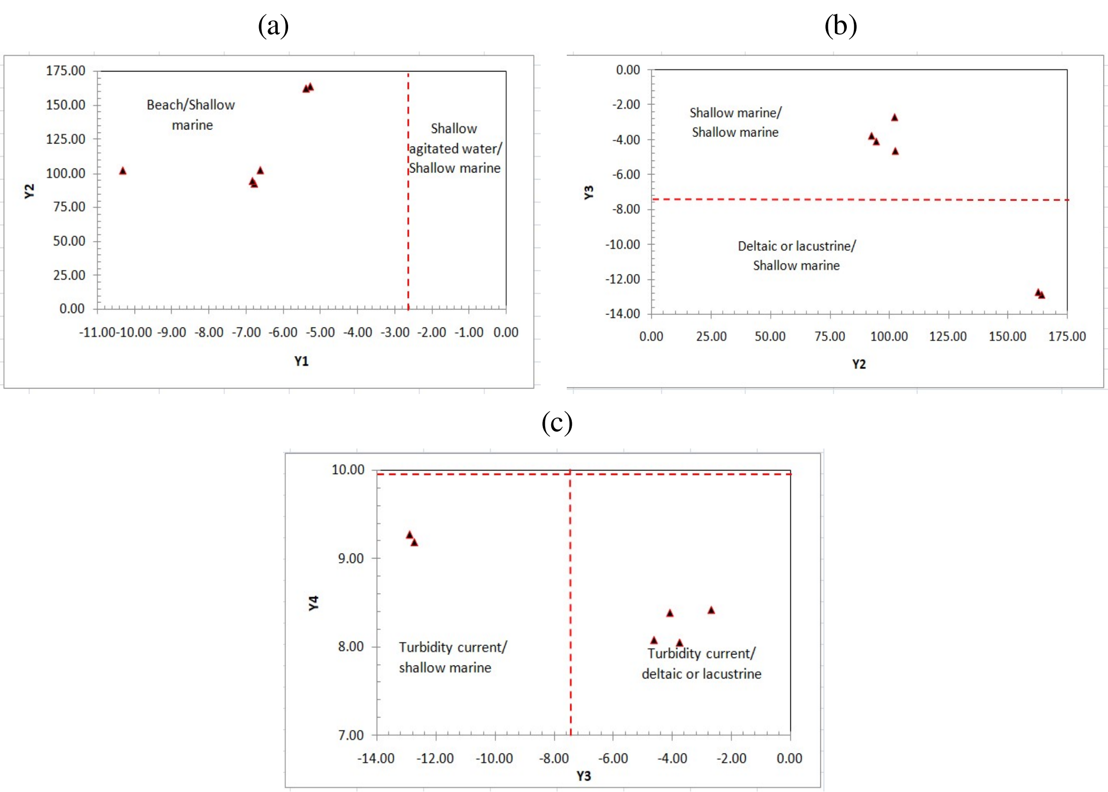


Figure 15: Bivariate plot between (a) Y1 vs Y2, (b) Y2 vs Y3, (c) Y3 vs Y4

The deltaic environment shows for two samples indicate there have some influence of fluvial deposition from the eastern connected rivers. Depositional sub-environment can be discriminate according to Sahu's (1983) MDF diagram based on V1 and V2 value. As per MDF, the sample no. K2, K3, K4, and K6 shows shallow marine environment where sample no. K1 and K5 shows river environment of sediment deposition. May be river input influence the sediment deposition process in the sample location of K1 and K5.

CONCLUSIONS

The study area lies in the complex and unique geological system in the eastern coast of Bangladesh. The depositional system of the study area also may be controlled by the geological system. The suspended solid and turbidity is high in the Kutubdia Channel where 6.4812 tons of sediment enters to the channel daily indicate active depositional condition controlled by current where accretion is occurring in the channel. In case of sediment distribution of the channel, unimodal fine sand nature of sediment reveals consistent sediment settled process where cumulative curve shows moderate kinetic energy and velocity during sediment deposition. The mean size and sorting of the sediment indicate uniform distribution of energy condition with reworking process during deposition. The skewness and kurtosis nature of the sediment implies high energy environment and zone of environmental mixing. From the TSS study, the mixing zone are present in the southern opening of the channel. The bivariate plots of grain-size parameter indicate uniform and moderate energy of sediment deposition with prominent wave process in the channel. The Visher diagram shows three sand populations and dominate saltation mode of sediment transportation also indicates the wave zone of sediment process. Besides, Visher diagram and sorting of the sediments indicate moderate to far distance of sediment source in the area. From the LDF and MDF study, the channel sediments show shallow marine with some deltaic environment of sediment deposition.

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