Grain Size Analysis and Depositional Environment for Brahmaputra River Sand of Kurigram District, Bangladesh

M. Sahiduzzaman

Bangladesh Petroleum Institute (BPI), Uttara Model Town, Dhaka-1230, Bangladesh
Email: *sahid6833[at]gmail.com*

Abstract: ***The work analyzed the grain size spectrum and texture parameters, namely mean, sorting, skewness and kurtosis etc. of Brahmaputra River Sand from Kurigram District, Bangladesh. ASTM sieves was used for grain size determination. Twenty samples were analyzed for this purpose. The results of the sieve analysis revealed that the samples from the study area ranged from fine to medium grained sand with lower sized particles. The statistical analyses were made by moment computation and graphical method which reveal that the sediments are fine to medium sand which are moderately sorted and platykurtic to leptokurtic in nature. Abundance of the fine sand to medium sand shows the prevalence of comparatively moderate to high energy conditions in the study area. The river bank and river channel deposits have been taken place in fluvial process with gradual suspension transportation system.***

Keywords: Grain-size, Sand, Environment, Fluvial

1. Introduction

Sand is an extremely necessary material for construction, but this important material must be purchased with utmost care and vigilance. It is an extremely fine aggregate used in many different applications including concrete, backfill, landscaping, surface treatment etc.Sand materials are used in a variety of sustainable engineering practices such as materials engineering and mechanical engineering. Sand is also used in agriculture due to its suitability as a soil with high permeability properties to lighten heavy clay soil. It can also be used as a filter material in soil engineering, chemical engineering and petroleum engineering. It is also commonly used for temporary and sometimes permanent road construction. The particle shape and size of sand is considered to be one of the most important factors affecting the behavior of the sand when used for various purposes[1]. The demand for sand is increasing and the costs are also increasing. There are also recoverable valuable heavy mineral components in the Brahmaputra River[2].Certain factors such as abrasion, sorting etc. tend to concentrate the heavier minerals in the predominantly finer-grained Particles [3].Grain size refers to the dimensions of a particle and is a fundamental physical property of sediments[4], [5].The grain size are indicators for elucidating the origin, transport and deposition environment of sediments[6]. The large size of particles in sandy soil reduces the water holding capacity of the soil, which can promote soil erosion by weather influences such as wind and water.Therefore, grain size is widely used to characterize and distinguish sediments associated with various environments. For an example, sand content can provide an indication of the contribution of river sediments. A significant proportion >100 μm in the effective size distribution is a feature of this system and regardless of whether it reflects flocculation processes in the river or the input of larger composite particles from tributaries or river banks erosion [7]. Among the grain size, mean grain size *M*), sorting (σ), skewness (Sk) and kurtosis (K) are most commonly used to know the characteristics of the sediments.Grain size studies of sediments provide a wealth of information about the intrinsic properties of sediments and their depositional environments. However, there are very few or no studies on the grain size for the Brahmaputra River Sand of Kurigram District, Bangladesh. In this study, the grain size of Brahmaputra River sediments in Kurigram District is investigated to examine its nature (physical properties) and environment of deposition.

This study has been conducted to have more knowledge about the Brahmaputra River Sand and for validation and future reference. It aims at gathering the information regarding the size, sorting, skewness, kurtosis, depositional environment and transportation system of Brahmaputra River Sand of the study area.In addition, this will help to study the nature and energy flow of the sediments' diverse means of transport.

2. Geologic Overview

Bengal Basin is considered to be the largest fluvio-deltaic to shallow marine sedimentary basin on Earth. The onshore section of the basin, together with the offshore Bengal Fan beneath the Bay of Bengal, forms the largest fluvio-deltaic sedimentary system on Earth[8]. The Bengal Basin itself is a peripheral Himalayan foreland basin formed by the continent-continent collision of the Indian and Eurasian plates. Several authors such as Mukherjee et al.[8]examined the geological setting, evolutionary history and regional stratigraphic context of the basin and concluded that development began with the breakup of Gondwanaland about 126 million years ago in the Cretaceous. The subsequent basin formation was influenced by the interaction between the Eurasian, Indian and Myanmar plates, which formed the Indo-Burman Mountains and the extensive Himalayan-Tibetan orogen. These plate collisions also played a crucial role in the exhumation and transport of sediments into the Bengal foreland basin. It is the main tributary to the south and eventually flows into the Padma River, the main tributary of the Ganges.

The sedimentology, sediment discharge, sediment bed load distribution and geomorphology of the Brahmaputra-Jamuna river system have been discussed in several previous studies[9], [10], [11]. The sedimentary sequences comprise mainly alluvial sands and silts (Fig. 1) The sediments in the northern part of this system are mostly rich in quartz and feldspar (>80-85 wt%)[12]. The origin of sand deposits is believed to be mainly in the Shillong Plateau and Darjeeling Himalayas[13].

3. Sampling and Analytical Procedures

3.1 Sampling

The samples examined in the current study came from sandbars of Kurigram District, Bangladesh. The Brahmaputra River is a braided river system with numerous ephemeral and/or stable sandbars. The samples were collected from 4 separate boreholes. The boreholes were drilled by hand augur (split spoon). The sample locations were a few kilometers north of the confluence of the Brahmaputra River and the east-flowing TistaRiver (Figure1).The depth of the samples ranged from the surface to approximately 5.0 m and 2 kg of sample was collected from every 1.0-meter depth in each site for the characterization and preparation studies. The samples were stored in polyethene bag. To carry out all laboratory tests, the samples were air dried.

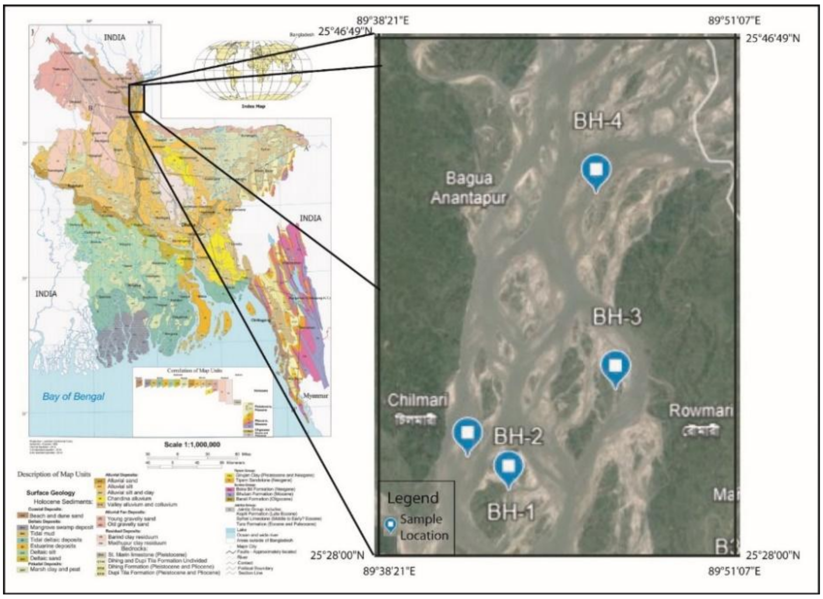

Figure 1: Geological Map of Bangladesh including location of the analyzed sample at Brahmaputra River of Kurigram District, Bangladesh. Modified after[14].

3.2 Analytical Procedures

3.2.1 Sieve Analysis

According to the standard method for sieve analysis ASTM D422, the sieve number corresponds to the mesh size, expressed in mm for large sizes and in micrometers for small sizes [15]. The set of ASTM D422 Sieve No. 200, 100, 50, 30, 16, 8 and 4 were used for fine sieve analysis, consisting of 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm and 4.75 mm aperture size respectively.In the dry sieve analysis, 1 kg of dry sand was taken [16] and sieved through a selected set of sieves arranged according to their size, with the largest perforated sieve at the top and the smallest perforated sieve at the bottom. A collection tray is kept at the bottom and a lid is placed on the top sieve of the stack. Shaking was made by the mechanical shaker. The amount of sand sample retained on each sieve is weighed to the nearest 0.1 g. Based on the total weight of the sample taken and the sample weight retained on each sieve, the percentage of the total weight of the sand sample that passes each sieve (also referred to as the "finer percent finer than") can be calculated.

Size ranges define boundaries of classes, which are named after the Wentworth scale (or Udden-Wentworth scale). The Krumbein Phi (ϕ) scale is a modification of the Wentworth scale created by W. C. Krumbein in 1934[17]and is a logarithmicscale calculated using the equation

$$\phi = -\, log_2 \frac{D}{D_0} \qquad (1)$$

Here, ϕ is the Krumbein phi scale, D is the diameter of the particle or grain in millimeters (Krumbein and Monk's equation)[18]and$D_0$is a reference diameter, equal to 1 mm. From the above equation, ϕ was determined and used in graphical formula and moment method for the analysis of the frequency distribution of grain size.Mean grain size (*M*), standard deviation (sortingσ), skewness (Sk) and kurtosis (*K*) were calculated as follows:

1. Moment computation: The most mathematically elegant method for determining the parameters of a frequency distribution is to use the moment method, a calculation technique in which the entire frequency distribution is included in the determination and not just a few selected percentiles. This technique was proposed for sediment analysis by, Hatch and Choate, Van Orstrand,

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Wentworth[19], [20], [21]. Krumbein adapted the technique for use with his ϕ scale[22]. The first moment is the mean. The second moment about the mean is the variance as

$$\sigma m^2 = \frac{E(x-\mu)^2}{100} \quad (2)\ [23]$$

The standard deviation σ is the square root of the variance and describes the width or scale of a distribution (Sorting). The third moment is skewness is measured as

$$Sk_m = \sum_{i=1}^{N} \frac{(x-\mu)^3}{(N-1)\sigma^3} \quad (3)$$

and the fourth moment is known as kurtosis and measured as

$$k_m = \sum_{i=1}^{N} \frac{(x-\mu)^4}{(N-1)\sigma^3} - 3 \quad (4)[24]$$

2. Graphical formula: The Mean grain size (M_G), standard deviation (sorting σ_G), skewness (Sk_G) and kurtosis (K_G) also calculated from following equation

$$\text{Mean, } M_G = \frac{\varphi_{16}+\varphi_{50}+\varphi_{84}}{3} \quad (5)\ [25]$$

The Sorting (graphic standard deviation) was measured as

$$Sorting\ (\sigma_1) = \frac{\varphi_{84}-\varphi_{16}}{4} + \frac{\varphi_{95}-\varphi_5}{6.6} \quad (6)\ [26]$$

The graphic skewness was measured as

$$Skewness(Sk_G) = \frac{\varphi_{16}+\varphi_{84}-2\varphi_{50}}{2(\varphi_{84}-\varphi_{16})} + \frac{\varphi_5+\varphi_{95}-2\varphi_{50}}{2(\varphi_{95}-\varphi_5)} \quad (7)[26]$$

The graphic kurtosis was measured from the equation of

$$Kurtosis\ (k_G) = \frac{\varphi_{95}-\varphi_5}{2.44(\varphi_{75}-\varphi_{25})} \quad (8)[26]$$

Skewness is used to assess the extent to which a variable distribution is symmetrical. If the distribution of responses for a variable extends toward the right or left tail of the distribution, the distribution is said to be skewed. A negative skewness indicates a greater number of larger values, while a positive skewness indicates a greater number of smaller values. As a general guideline, a skewness value ranges from −1 to +1 is considered excellent, but a value between −2 and +2 is generally considered to be acceptable. Values beyond −2 and +2 are considered as substantial nonnormality indicator [27].

Kurtosis is a measure of whether the distribution is too narrow (a very narrow distribution with most answers in the middle). A positive kurtosis value indicates a distribution that is more pronounced than normal. In contrast, negative kurtosis indicates a flatter shape than normal. Analogous to skewness, a general guideline is that if the kurtosis is greater than +2, the distribution is too pronounced. Likewise, a kurtosis of less than −2 indicates that the distribution is so much flat. If both skewness and kurtosis are close to zero, the response pattern is considered a normal distribution [27], [28].The φ values (Figure 2) in the graphic method were measured from the corresponding representative points in the cumulative grain size distribution curve. The Folk-Word equation is applied to determine the grain size i.e., 5, 16, 25, 50, 75, 84, and 95 percent[29]. According to Folk, R.L. and Ward, M.C [29]the sorting, skewness and kurtosis can be categorized as physical descriptive terms with respect to their corresponding values (Table- 1).

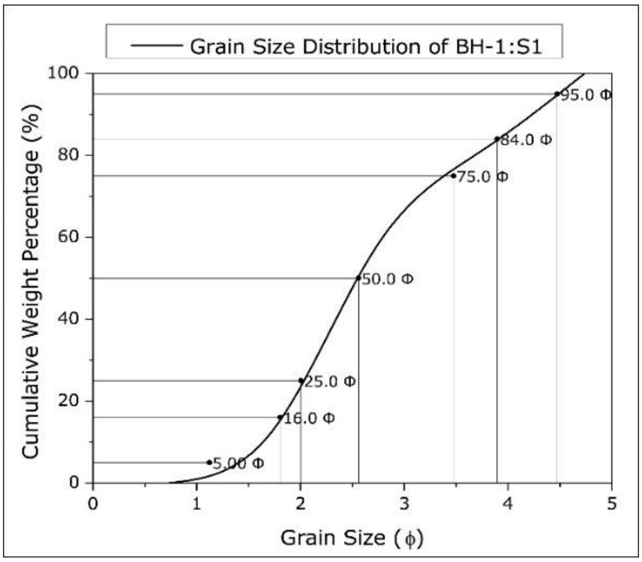

Figure 2: Schematic diagram of the principle of the graphic methods

Table 1: The Physical descriptive term of sorting, skewness and kurtosis categories corresponding to their value [29].

Sorting (σ)		*Skewness (Sk)*			*Kurtosis (K)*		
Physical descriptive term	*Graphic method and moment method*	*Physical descriptive term*	*Graphic method*	*Moment method*	*Physical descriptive term*	*Graphic method*	*Moment method*
Very well sorted	<0.35	Very coarse skewed	−0.3 to −1.0	<−1.30	Very platykurtic	<0.67	<1.70
Well sorted	0.35–0.50	Coarse skewed	−1.0 to −0.3	−1.30 to −0.43	Platykurtic	0.67–0.90	1.70–2.55
Moderately well sorted	0.50–0.70	Symmetrical	−0.1 to 0.1	−0.43 to 0.43	Mesokurtic	0.90–1.11	2.55–3.70
Moderately sorted	0.70–1.00	Fine skewed	0.1–0.3	0.43–1.30	Leptokurtic	1.11–1.50	3.70–7.40
Poorly sorted	1.00–2.00	Very fine skewed	0.3–1.0	>1.30	Very leptokurtic	1.50–3.00	>7.40
Very poorly sorted	2.00–4.00				Extremely leptokurtic	>3.00	—
Extremely poorly sorted	>4.00						

The method of moments measures a slightly different property than the graphical methods, but does not have a particularly sacred aura of fundamentality [30].

The discriminate function[31] was applied to the sediment grain size for characterizing the depositional environment. To differentiate the fluvial deposit and turbidity current influenced deposit, the equation $Y4 = 4.5129Mz -$

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$1.2837\delta^2 + 3.5904Sk + 4.1038K$ is used where the M is the grain size mean, δ referred to as sorting (inclusive graphic standard deviation), SK referred to as skewness, and K referred to as kurtosis. If Y4 ≥ 9.81, the condition shows fluvial deposit; Y4 <9.81 shows the influence of turbidity current.

4. Results and Discussion

4.1 Sediment Grain Size Grouping

Most soil scientists are interested in the proportion (usually weight percentage) of particles within a given size class, which is defined by an upper and lower limit. Size classes are usually identified by their name, e.g. clay, silt or sand, and each class corresponds to a grade[32]. The weight percentage with respect to particle size of 20 samples are summarized in Table- 2. According to Wentworth grain size classification, on an average 5% particles are silt, 10% particles are very fine-grained sand, 54% particles are fine grained sand, 30% particles are medium grained sand and 1% particles are coarse grainedsand (Fig. 3).It is common practice, particularly among sedimentologists, to describe a deposit based on its main particle size class, such as sand quality. Soil scientists use a similar system when they construct so-called texture triangles or particle size class triangles from material components of different size fractions. The particle size class triangles were evaluated using Shepard's classification scheme[33], which is simple and allows for rapid sediment classification and sample comparison (Figure 4). Figure 4 shows that the sediments at the studied site are predominantly Sand fraction.

Table 2: Weight percentage of Brahmaputra River sand of various depth obtained from sieve analysis

			Sieve Size																
			1.18 mm (-0.239 ϕ)			*0.6 mm (0.737 ϕ)*			*0.3 mm (1.737 ϕ)*			*0.15 mm (2.737 ϕ)*			*0.075 mm (3.737 ϕ)*			*Pan*	
Sl.No.	*Sample ID*	*Sample Depth Range*	*Material retained in gm*	*Material retained in %*	*Material passed in %*	*Material retained in gm*	*Material retained in %*	*Material passed in %*	*Material retained in gm*	*Material retained in %*	*Material passed in %*	*Material retained in gm*	*Material retained in %*	*Material passed in %*	*Material retained in gm*	*Material retained in %*	*Material passed in %*	*Material retained in gm*	*Material retained in %*
1	BH-1:S1	0.0 - 1.0	0	0	100	2	0	100	132	13	87	445	45	42	230	23	19	190	19
2	BH-1:S2	1.0 - 2.0	0.1	0	100	3	0	100	388	39	61	476	48	13	66	7	6	66	6
3	BH-1:S3	2.0 - 3.0	0	0	100	2	0	100	275	28	72	546	55	17	94	9	8	82	8
4	BH-1:S4	3.0 - 4.0	0	0	100	4	0	100	225	22	78	566	57	21	145	14	7	60	7
5	BH-1:S5	4.0 - 5.0	0.1	0	100	9	1	99	353	35	64	434	43	21	126	13	8	77	8
6	BH-2:S1	0.0 - 1.0	0	0	100	2	0	100	103	10	90	759	76	14	107	11	3	29	3
7	BH-2:S2	1.0 - 2.0	0.1	0	100	12	1	99	624	62	37	270	27	10	68	7	3	25	3
8	BH-2:S3	2.0 - 3.0	0	0	100	5	1	99	232	23	76	639	64	12	104	10	2	19	2
9	BH-2:S4	3.0 - 4.0	0.1	0	100	9	1	99	389	39	60	532	53	7	57	6	1	11	1
10	BH-2:S5	4.0 - 5.0	0.1	0	100	6	1	99	216	22	77	581	58	19	173	17	2	22	2
11	BH-3:S1	0.0 - 1.0	0	0	100	2	0	100	75	7	93	562	56	37	222	22	15	139	15
12	BH-3:S2	1.0 - 2.0	0	0	100	7	1	99	378	38	61	500	50	11	34	3	8	81	8
13	BH-3:S3	2.0 - 3.0	0.1	0	100	0	1	99	427	43	56	511	51	5	33	3	2	19	2
14	BH-3:S4	3.0 - 4.0	0	0	100	7	1	99	266	27	72	664	66	6	35	4	2	27	2
15	BH-3:S5	4.0 - 5.0	0.2	0	100	21	2	98	508	51	47	348	35	12	54	5	7	67	7
16	BH-4:S1	0.0 - 1.0	0	0	100	1	0	100	246	25	75	613	61	14	120	12	2	20	2
17	BH-4:S2	1.0 - 2.0	0	0	100	3	0	100	170	17	83	685	68	15	106	11	4	37	4
18	BH-4:S3	2.0 - 3.0	0.1	0	100	2	0	100	105	11	89	726	73	16	152	15	1	15	1
19	BH-4:S4	3.0 - 4.0	0.1	0	100	10	1	99	266	27	72	616	62	10	93	9	1	14	1
20	BH-4:S5	4.0 - 5.0	0.1	0	100	18	2	98	506	51	47	397	40	7	65	6	1	14	1
Average			0	0	100	6	1	99	294	30	70	544	54	15	104	10	5	51	5

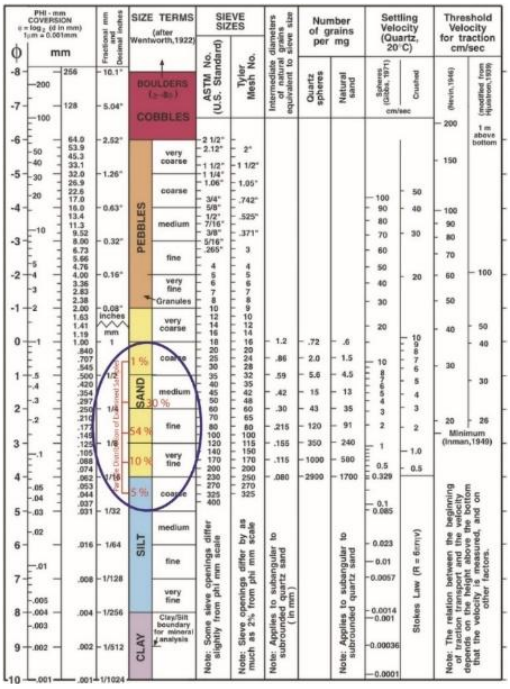


Figure 3: Particle Size distribution of the examined Brahmaputra River Sand corresponding the Φ Scale (modified after Wentworth, 1922).

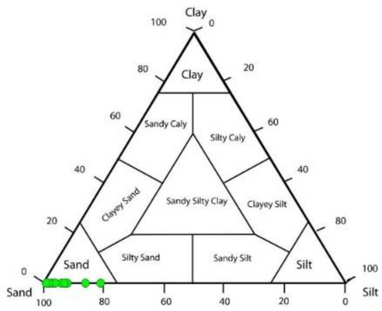


Figure 4: Triangular diagram for classification of different sediment types Shepard (1954).

4.2 Grain Size Frequency Distribution Characteristics

Grain size frequency curves are a valuable tool for characterizing depositional environments and identifying sediment sources because they display the distribution's status and concentration of different sizes[34]. The analyzed samples from Brahmaputra River show essentially distributions with "fine tail" characteristics on their grain size frequency curves (figure-5). This "fine tail" is connected to the fine grain sized particles. The faint peaks located at 4.75φ in the majority of the samples' curves indicate the presence of coarse silt deposits.

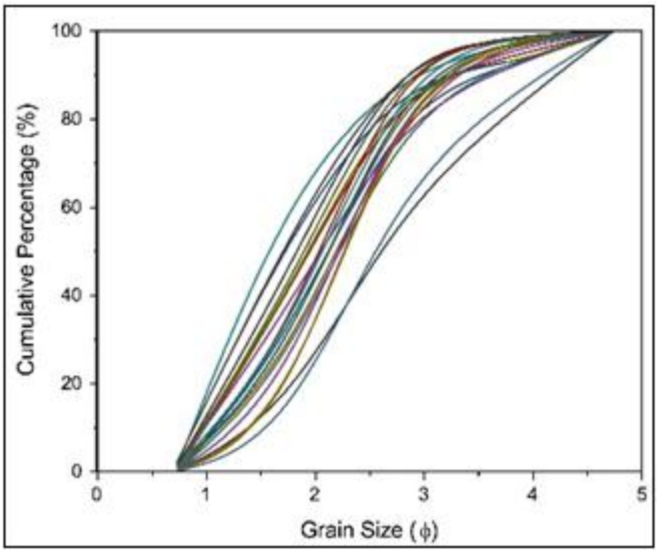


Figure 5: The cumulative distribution frequency curves of grain size in Brahmaputra River.

4.3 Grain Size Characterization Parameters

Four indicators (Mz, σ, Sk, and K) for characterizing grain size were calculated and analyzed by graphic method and moment computation. The cumulative curves (Figure 2) were used to calculate the 5, 16, 25, 50, 75, 84, and 95 percentile grain size (table 3).

Table 3: Graphic Measurement of values from cumulative curve

Serial No.	*Sample ID*	*Graphic Measurement of values from cumulative curve*						
		ϕ5	*ϕ16*	*ϕ25*	*ϕ50*	*ϕ75*	*ϕ84*	*ϕ95*
1	BH-1:S1	0.82	1.80	2.00	2.56	3.48	3.89	4.47
2	BH-1:S2	0.44	0.86	1.20	1.97	2.49	2.67	3.90
3	BH-1:S3	0.51	1.10	1.58	2.14	2.59	2.85	4.11
4	BH-1:S4	0.59	1.33	1.79	2.23	2.67	3.09	4.02
5	BH-1:S5	0.85	1.17	1.42	2.06	2.64	3.12	4.11
6	BH-2:S1	0.99	1.82	1.93	2.26	2.59	2.71	3.56
7	BH-2:S2	0.80	0.98	1.12	1.53	2.18	2.51	3.45
8	BH-2:S3	0.91	1.39	1.75	2.14	2.53	2.67	3.44
9	BH-2:S4	0.84	1.12	1.35	1.93	2.40	2.57	3.07
10	BH-2:S5	0.92	1.42	1.77	2.20	2.63	2.91	3.56
11	BH-3:S1	1.45	1.90	2.06	2.50	3.28	3.69	4.40
12	BH-3:S2	0.84	1.13	1.37	1.96	2.46	2.64	4.11
13	BH-3:S3	0.83	1.09	1.30	1.85	2.34	2.52	2.74
14	BH-3:S4	0.89	1.29	1.63	2.07	2.45	2.59	2.99
15	BH-3:S5	0.80	1.01	1.19	1.68	2.37	2.62	4.02
16	BH-4:S1	0.55	1.20	1.74	2.15	2.56	2.70	3.49
17	BH-4:S2	0.69	1.65	1.85	2.22	2.59	2.72	3.65

18	BH-4:S3	0.93	1.81	1.93	2.27	2.61	2.74	3.47
19	BH-4:S4	0.89	1.29	1.63	2.09	2.50	2.64	3.29
20	BH-4:S5	0.80	1.01	1.19	1.68	2.29	2.51	3.07

The statistical parameters of grain-size (Mz, σ, Sk, and K) were measuredaccording to the equations of folk and Ward [26]. The Grain-size parameters reflecting these indicators according to depth are shown inTable 4. The graphic mean of the grain size distribution ranges from 1.67 ϕ to 2.75 ϕ where the mean from moment computation ranges from 1.72 ϕ to 2.72 ϕ. The graphic sorting ranges from 0.61 to 1.08 where the sorting from moment computation ranges from 0.69 to 1.25. The minimum skewness has been computed from graph as -0.17 (from moment as -1.37). The maximum skewness is 0.37 for graphic computation (0.48 for moment computation). The kurtosis values vary from 0.74 to 1.65 for graphic measurement (1.45 to 2.86 for moment measurement). The table 4 shows that on the basis of graphic measurement, about 5% samples are poorly sorted, 60% samples are moderately sorted and 35% samples are moderately well sorted. But moment computation shows about 40% samples are poorly sorted, 50% samples are moderately sorted and 10% samples are moderately well sorted. The graphic measurement shows about 10% (5% for moment computation) sediments are Positive (fine) skewed, 55% (5% for moment computation) are symmetrical / nearly symmetrical, 15% (85% for moment computation) are Negative (coarse) skewed and 15% (5% for moment computation) are Strongly negative (very coarse) skewed. According to graphic measurement about 35% samples are Leptokurtic, 30% samples are Mesokurtic, 15% samples are Platykurtic and 20% samples are platykurtic. By moment computation, about 25% samples indicate Mesokurtic, 65% samples indicate Platykurtic and 10% samples indicates very leptokurticnature.

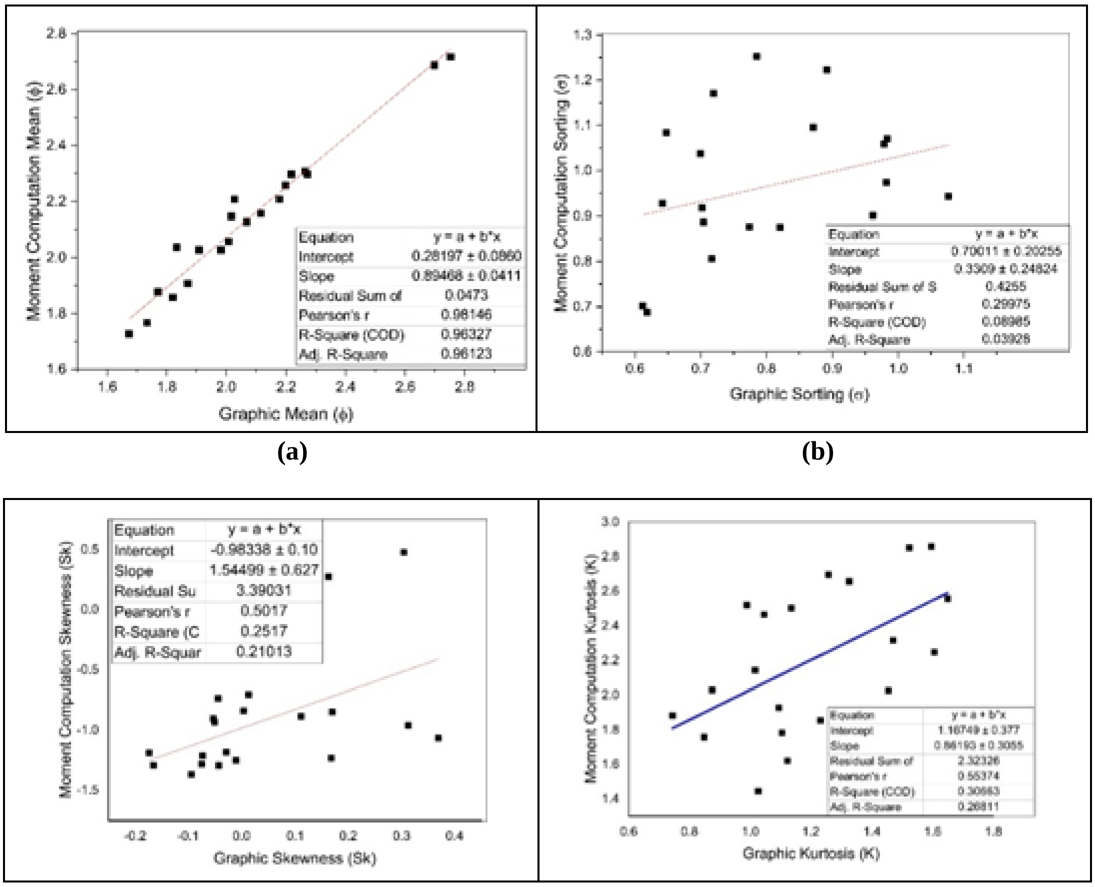
Table 4: Grain size for the graphic and moment methods of Brahmaputra River sediments

Sl. No.	*Sample ID*	*Depth range (m)*	*Graphic Measurement*					*Moment Commutation*				
			Mean	*Sorting*	*Skewness*	*Kurtosis*	*Remarks*	*Mean*	*Sorting*	*Skewness*	*Kurtosis*	*Remarks*
1	BH-1:S1	0.0- 1.0	2.75	1.08	0.16	1.02	Poorly sorted, Negative phi values, Mesokurtic	2.72	0.94	0.27	2.14	Moderately sorted, Near symmetrical, Platykurtic
2	BH-1:S2	1.0 - 2.0	1.83	0.97	-0.05	1.11	Moderately sorted, Symmetrical, Mesokurtic	2.04	1.06	-0.93	1.78	Poorly sorted, Negative (coarse) skewed, Platykurtic
3	BH-1:S3	2.0 -3.0	2.03	0.98	-0.04	1.45	Moderately sorted, Symmetrical, Leptokurtic	2.21	0.97	-0.74	2.02	Moderately sorted, Negative (coarse) skewed, Platykurtic
4	BH-1:S4	3.0- 4.0	2.22	0.96	0.01	1.61	Moderately sorted, Symmetrical, Very leptokurtic	2.30	0.90	-0.70	2.25	Moderately sorted, Negative (coarse) skewed, Platykurtic
5	BH-1:S5	4.0- 5.0	2.12	0.98	0.17	1.09	Moderately sorted, Negative phi values, Mesokurtic	2.16	1.07	-0.85	1.93	Poorly sorted, Negative (coarse) skewed, Platykurtic
6	BH-2:S1	0.0- 1.0	2.26	0.61	0.00	1.60	Moderately well sorted, Symmetrical, Very leptokurtic	2.31	0.70	-0.84	2.86	Moderately well sorted, Negative (coarse) skewed, Mesokurtic
7	BH-2:S2	1.0- 2.0	1.67	0.79	0.37	1.03	Moderately sorted, Very negative phi values, coarse, Mesokurtic	1.73	1.25	-1.07	1.45	Poorly sorted, Negative (coarse) skewed, Very platykurtic
8	BH-2:S3	2.0- 3.0	2.07	0.70	-0.07	1.33	Moderately well sorted, Symmetrical, Leptokurtic	2.13	0.89	-1.28	2.66	Moderately sorted, Negative (coarse) skewed, Mesokurtic
9	BH-2:S4	3.0- 4.0	1.87	0.70	-0.04	0.87	Moderately well sorted, Symmetrical, Platykurtic	1.91	1.04	-1.29	2.03	Poorly sorted, Negative (coarse) skewed, Platykurtic
10	BH-2:S5	4.0- 5.0	2.18	0.77	-0.01	1.26	Moderately sorted, Symmetrical, Leptokurtic	2.21	0.88	-1.25	2.70	Moderately sorted, Negative (coarse) skewed, Mesokurtic
11	BH-3:S1	0.0 - 1.0	2.70	0.90	0.30	0.99	Moderately sorted, Very negative phi values, coarse, Mesokurtic	2.69	0.83	0.48	2.52	Moderately sorted, Positive (fine) skewed, Platykurtic
12	BH-3:S2	1.0- 2.0	1.91	0.87	0.11	1.23	Moderately sorted, Negative phi values, Leptokurtic	2.03	1.10	-0.88	1.85	Poorly sorted, Negative (coarse) skewed, Platykurtic
13	BH-3:S3	2.0- 3.0	1.82	0.65	-0.07	0.74	Moderately well sorted, Symmetrical, Platykurtic	1.86	1.08	-1.21	1.88	Poorly sorted, Negative (coarse) skewed, Platykurtic
14	BH-3:S4	3.0- 4.0	1.98	0.64	-0.17	1.05	Moderately well sorted, Positive phi values, Mesokurtic	2.03	0.93	-1.29	2.47	Moderately sorted, Negative (coarse) skewed, Platykurtic
15	BH-3:S5	4.0- 5.0	1.77	0.89	0.31	1.12	Moderately sorted, Very negative phi values, coarse, Leptokurtic	1.88	1.22	-0.96	1.62	Poorly sorted, Negative (coarse) skewed, Very platykurtic

16	BH-4:S1	0.0- 1.0	2.02	0.82	-0.17	1.47	Moderately sorted, Positive phi values, Leptokurtic	2.15	0.88	-1.19	2.31	Moderately sorted, Negative (coarse) skewed, Platykurtic
17	BH-4:S2	1.0- 2.0	2.20	0.72	-0.05	1.65	Moderately sorted, Symmetrical, Very leptokurtic	2.26	0.81	-0.90	2.56	Moderately sorted, Negative (coarse) skewed, Mesokurtic
18	BH-4:S3	2.0- 3.0	2.27	0.62	-0.03	1.52	Moderately well sorted, Symmetrical, Very leptokurtic	2.30	0.69	-1.18	2.85	Moderately well sorted, Negative (coarse) skewed, Mesokurtic
19	BH-4:S4	3.0- 4.0	2.01	0.70	-0.09	1.14	Moderately well sorted, Symmetrical, Leptokurtic	2.06	0.92	-1.37	2.50	Moderately sorted, Invalid data, Platykurtic
20	BH-4:S5	4.0- 5.0	1.73	0.72	0.17	0.85	Moderately sorted, Negative phi values, Platykurtic	1.77	1.17	-1.23	1.76	Poorly sorted, Negative (coarse) skewed, Platykurtic
Average			2.07	0.80	0.04	1.21	Moderately sorted, Symmetrical, Leptokurtic	2.13	0.97	-0.92	2.21	Poorly sorted, Negative (coarse) skewed, Platykurtic

4.4 Correlation Analysis of Grain Size Obtained from Different Methods

The scatter plot of the mean grain size data (figure 6a) shows a good fit of linear regression between data obtained by the moment and graphical methods. The pearson's coefficient is 0.982.This result suggests that there is a very high correlation between graphic mean and mean from moment computation. The data calculated using the two methods can be interchanged. Compared to the mean grain size distribution, sorting data for the methods is relatively more discrete (figure 6b). The pearson's coefficient is 0.30. Hence the correlation of sorting is low correlation. The skewness data are also more discrete (figure 6c) and the pearson's coefficient is -0.50. So, there are very lowcorrelation between the skewness data obtained by the moment and graphical methods. The kurtosis data obtained from both methods are also discrete (figure 6d), but these are also characterized by linear relationships that can be nearly expressed by y = x +c as the slope is 0.85. More over the pearson's coefficient is 0.55. Hence the correlation of kurtosis shows moderate correlation [35].



(a) (b) (c) (d)

Figure 6: Correlation analysis of grain size between graphical and moment computation methods. (a), (b), (c) and (d) correspond to Mean, Sorting, Skewness and Kurtosis respectively.

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4.5 Correlation Analysis of Linear Discriminant Functions Obtained from Different Methods

The process and environment of deposition were decoded by Sahu's linear discriminate functions[31] of Y4 (fluvial/ Turbidity Current).The pearson's coefficient is 0.87 (figure 7). These result suggests that there is a very high correlation between graphic measurement and moment computation of linear discriminant function Y4 [35]. The data calculated using the two methods can be interchanged.

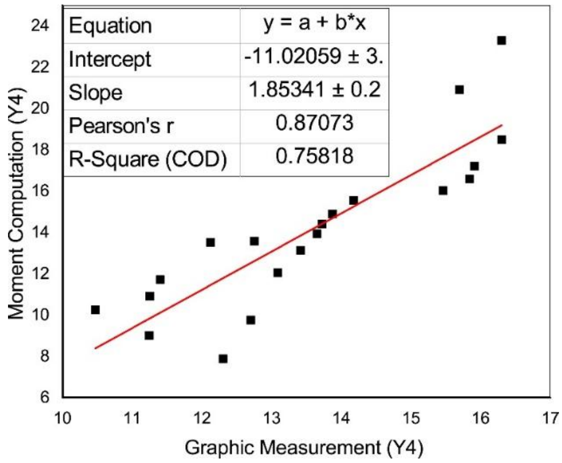


Figure 7: Correlation analysis of linear discriminant function Y4 obtained from graphical and moment computation methods.

4.6 Determination of the Mechanisms and Environments of Deposition by Linear Discriminant Function

Based on the linear discriminant function Y4, all the samples (graphic values) were identified as Fluvial deposit. By the moment calculations for the present study, about 85% samples were identified as Fluvial deposit where rest 15% show the turbidite condition (Table-5). The average values of Y4 obtained from both graphic measurement and moment computation show fluvial depositional process.

Table 5: The linear discriminant function with corresponding environment derived from graphic and moment calculations (FD= Fluvial Deposit and TCD= Tidal Current Deposit)

Serial No.	*Sample ID*	*Graphic Measurement*		*Moment Computation*	
		discriminate function Y4	*Suggested Environment as Y4*	*discriminate function Y4*	*Suggested Environment as Y4*
1	BH-1:S1	15.69	FD	20.90	FD
2	BH-1:S2	11.40	FD	11.72	FD
3	BH-1:S3	13.72	FD	14.40	FD
4	BH-1:S4	15.46	FD	16.02	FD
5	BH-1:S5	13.41	FD	13.12	FD
6	BH-2:S1	16.30	FD	18.50	FD
7	BH-2:S2	12.30	FD	7.89	TCD
8	BH-2:S3	13.87	FD	14.90	FD
9	BH-2:S4	11.25	FD	10.91	FD
10	BH-2:S5	14.18	FD	15.55	FD
11	BH-3:S1	16.30	FD	23.29	FD
12	BH-3:S2	13.09	FD	12.04	FD
13	BH-3:S3	10.47	FD	10.25	FD
14	BH-3:S4	12.12	FD	13.52	FD
15	BH-3:S5	12.70	FD	9.75	TCD
16	BH-4:S1	13.65	FD	13.93	FD
17	BH-4:S2	15.84	FD	16.60	FD
18	BH-4:S3	15.90	FD	17.21	FD
19	BH-4:S4	12.75	FD	13.57	FD
20	BH-4:S5	11.24	FD	9.01	TCD
Average		13.61	FD	14.18	FD

4.7 Grain Size Distribution

The mean grain size reflects the overall average size of the samples, which is influenced by the sample source, mode of transport, and depositional environment [30], [36]. The grain size of the deposited sediments determines the transportation mode and the distance: the finer the size, the greater the distance. More than half of the sediments are fine sand and rest are medium and very fine sand (figure-3). These circumstances suggest that the sediments were deposited under very low to moderate energy condition, as sediments usually become coarser with increase in energy of the water and other transporting medium[25].

The standard deviation evaluates the uniformity of the grain size distribution. This depends on the size span of the source rock, the intensity of weathering, the transport distance and the energy variation of the deposition medium [29], [37]. Table 4 shows that one-half or more of the sand samples are moderately sorted. Generally the river sands tend to be moderately sorted[38]. A moderately sorting indicates that an average selection of grains has taken place during transport or deposition. This might be explained as the result of moderately variable energy, turbulent conditions and average energy condition. Based on graphic calculation, most of the samples are symmetrically Skewed (Table 4). Thus, indicating the dominance of medium fraction in Brahmaputra river sediments. But the moment analysis shows the samples are skewed towards the coarser grain sizes, indicating moderate to high energy condition. The examined sand samples are of platykurtic, Mesokurtic and leptokurtic type. But most of the samples exhibits platykurtic phenomena. The distribution of kurtosis value at which platykurtic sediments predominate over others probably indicates that velocity fluctuations in the area were not confined to the middle part of the average velocity for a longer period than normal [39].

According to Fork and Ward [26], extremely high and low kurtosis values may indicate that some sediment elsewhere in a high-energy environment has been sorted and transported, essentially unchanged in size, to another environment where it can be fixed with a different species of the material. The new environment is one with less effective sorting energy. In other words, this implies a fluctuating hydrodynamic state in the depositional environment and its effects on sediment distribution.

4.8 Relationship between Granulometric Parameters

The relationship between granulometric parameters is important for interpreting the transport and deposition environment of sediments, as highlighted by several authors [26], [40], [41], [42], [43], [44], [45], [46]. To build up the relationship between granulometric parameters the data obtained from graphic calculation are used. The bivariate diagram sorting vs skewness (Figure 8) shows the samples occupied in the river sand zone. The bivariate diagram sorting vs mean size (Figure 9) also shows the sample representation in the river sand zone.

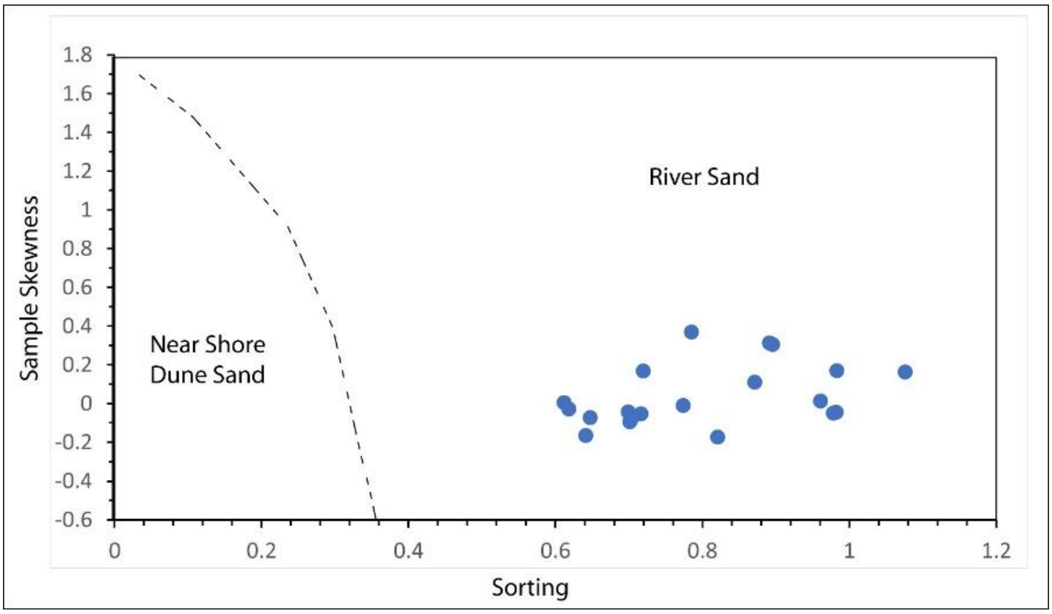


Figure 8: Depositional environment discrimination bivariate diagram of the collected sediments from Brahmaputra Sand Bar modified from [4].

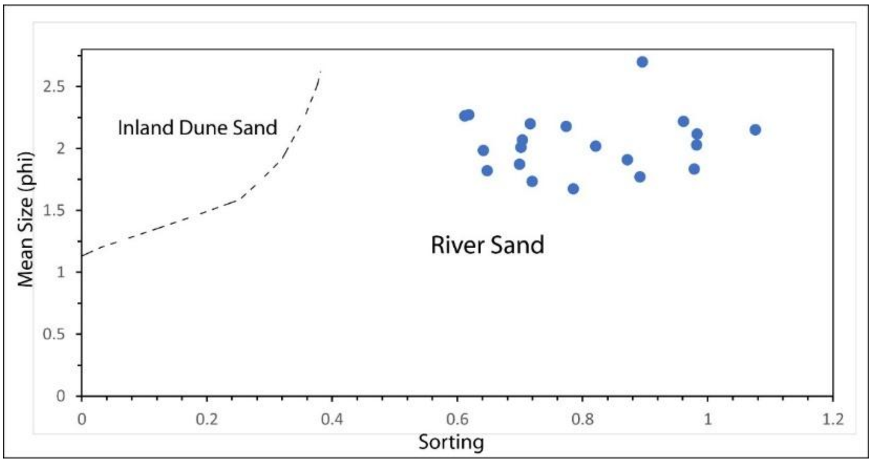
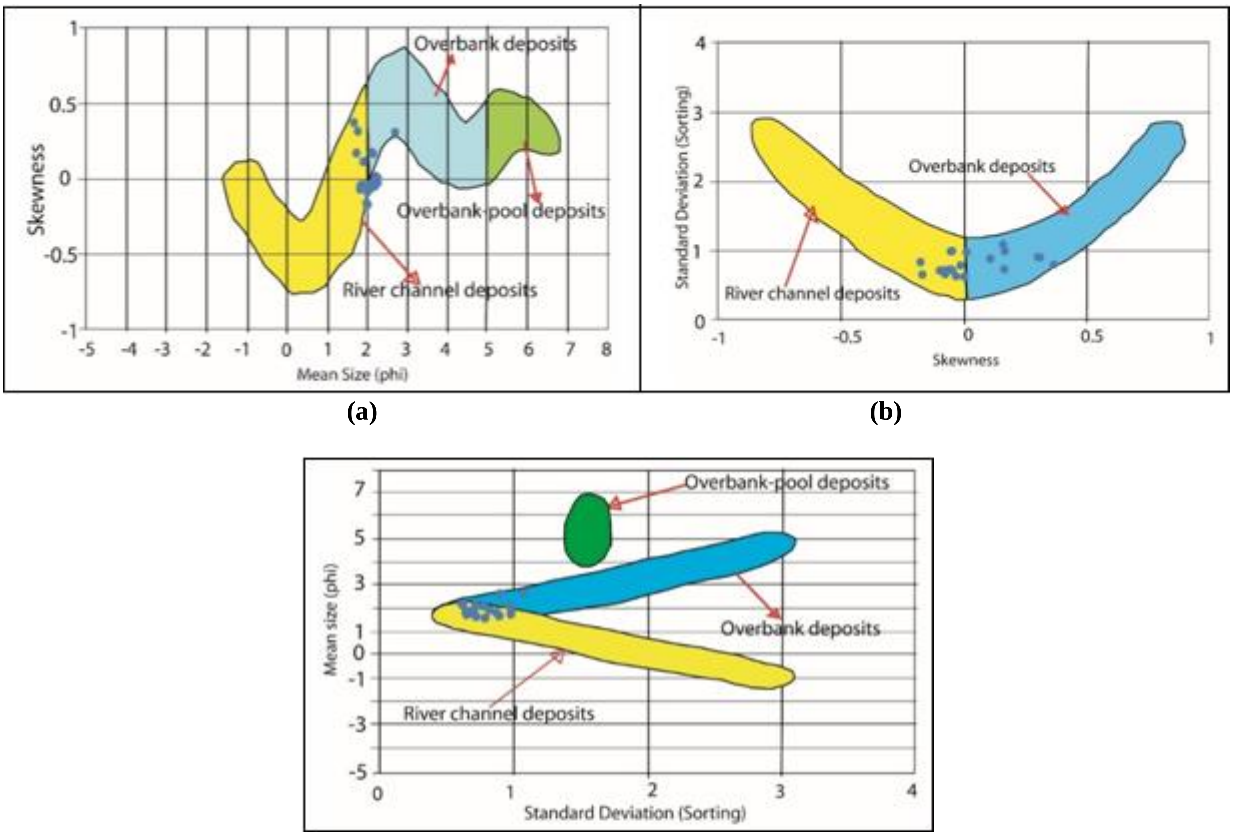


Figure 9: Depositional environment discrimination bivariate diagram of the collected sediments from Brahmaputra Sand Bar modified from [43].

Plots that distinguish between overbank deposits, overbank-pool deposits, and river channel deposits are based on granulometric aspects is shown in Figure 10. Most of the sediments from the Brahmaputra River sand plotted in the area of the river channel., The overlap of two fields (river channel deposits and overbank deposits shown in figure 10(c) corresponds to the well sorted grain size, which is about 2Φ [47]. The boundary between the two facies in figure 10(b) also lies in the zone of best sorting and zero value of skewness [47].



(a) (b)

(c)

Figure 10: Relationships of Folk & Ward textural aspects, (modified from [40], [48] (a) Skewness vs. mean grain size; (b) Standard deviation (sorting) vs. skewness; (c) Mean grain size vs. standard deviation sorting.

The bivariate plot between mean grain size and sorting (standard deviation) shows that the grains are sands (Figure 11). The predominance of sand throughout the section clearly indicated deposition by fluvial processes [49]. The sands are mainly moderately sorted and consist mainly of medium-grained sand and fine-grained sand. Moderately sorted sand deposits are common in fluvial environments where water flow is strong enough to transport and sort sediments but is not overly turbulent.Medium-grained and fine-grained sands are often associated with river channels and the adjacent floodplains.The moderately sorted nature of the sands suggests that energy conditions were not particularly high during deposition. This could indicate moderate to intermittent water flow, allowing sorting without complete processing of the sediment.The presence of both medium-grained and fine-grained sands suggests that energy conditions fluctuated during deposition.

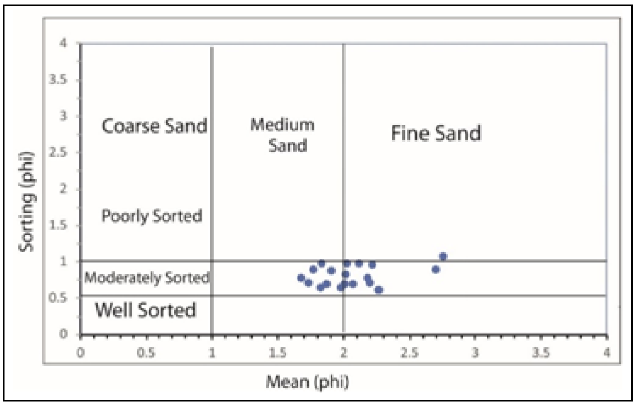


Figure 11: The bivariant diagram showing the relationship between Grain size (ϕ) and Sorting [4].

The bivariate plot diagram of mean grain size and skewness showing that most of thesamplesare occupied in symmetrical and fine skewed zone (figure 12). The scatter plot diagram of mean grain size and kurtosis showsa wide range of plots from platykurtic to very leptokurtic with most of plots in the platykurtic and very platykurtic zones (figure 13).

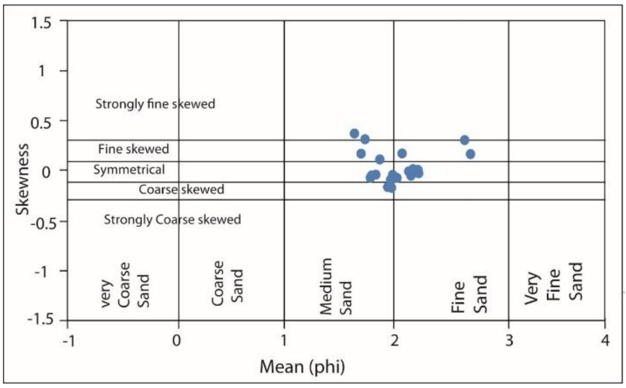


Figure 12: Bivariate plot diagram of mean grain size (sand class) and Skewness. Fields modified after [4].

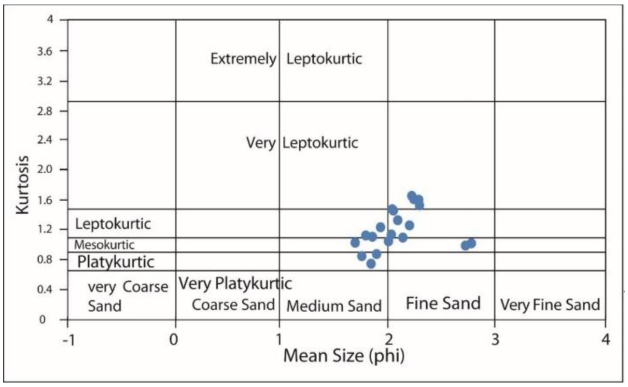


Figure 13: Bivariate plot diagram of mean grain size (sand class) and Kurtosis. Fields modified after [4].

4.9 C-M Pattern

The variations in energy and fluidity factors appear to correlate excellently with the various processes and environment of deposition [45].The C-M pattern or Passega diagram can be used to determine the environmental conditions under which sediments were deposited based on the parameters C (one percentile of the grain size distribution) and M (the median: 50th percentile of the grain size distribution). This is useful in hydrodynamic interpretation of grain size data. The Passega diagram (C-M pattern) in figure 15 shows several fields, pelagic suspension (the T field), uniform suspension (the SR field), gradual suspension (the QR field), suspension and rolling (the QP field), rolling and suspension (the PO field) and rolling (the ON field) according to the different transport and sedimentation conditions in the marine, coastal or fluvial areas. From the Passega diagram (figure 14) near about half of the examined samples plotted directly within the parameter zones. They occupied the gradual suspension (the QR field) zone directly. Rest of the samples plotted outside the featured fields.

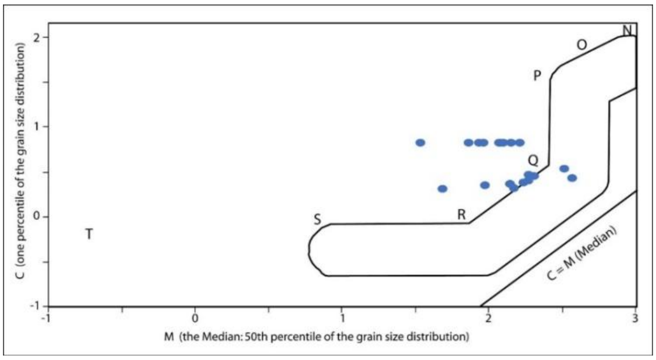


Figure 14:P assega diagram (C-M pattern) for the examined samples of Brahmaputra River Sand, modified after [42].

5. Conclusion

Grain size analysis of 20 sediment samples from Brahmaputra River bar was performed in this study. The sediments are generally fine to medium grained, moderately sorted, symmetrical to fine skewed and mostly platykurtic to very leptokurtic in nature. The preponderance of medium grained sediments and lack of coarse sands suggest moderate to high energy conditions of deposition. The kurtosis values show a fluctuating hydrodynamic condition of the depositional environment. The energy process discriminant functions of the sediments indicated that they were deposited predominantly by fluvial process. The sorting and skewness show that the sediments are river sand. The relationships of Folk & Ward textural aspects show that the sediments comprise river bank and river channel deposits. The Passega diagram reveal that the transportation process of the sediments was gradual suspension.

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Author Profile

Md. Sahiduzzaman received the B.Sc. (Honours) and M.Sc. degrees in Geology and Mining from University of Rajshahi, Bangladesh in 2006 and 2007, respectively. During 2009-2012, he worked as a Geologist in Padma Mining & Energy Corporation Limited. During 2012-2018, he worked as a Senior Geologist at Carbon Mining Bangladesh Limited. From 2018 to till now he is working as a Senior Scientific Officer (SSO) in Bangladesh Petroleum Institute (BPI), under the ministry of Power, Energy of Mineral Recourses, Government of Bangladesh.