

Significance of Finer River Bank Sediment Analysis on an Ungauged River: A Case Study of Rakti Khola on Darjeeling Foothill Region, West Bengal

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Abstract : *The paper deals with the textural analysis of sand sized particles of bank sediments in a certain stretch along Rakti khola at Darjeeling Himalayan foothills. Rakti khola is a stream under the Mahananda River system. The finer bank sediments are collected from several layers of Rakti bank. The study gives emphasis on the textural analysis of finer sediments to understand the probable transport mechanism of such particles and depositional environment through which the particles have been settled. Mean of phi, skewness, sorting and kurtosis of fine sand have been used as statistical parameters. The sediment of surveyed bank layer shows the variation of textural parameters with a change of bank height. The variation refers the change in channel competency, occurred due to change in discharge regime.*

Key words: *Finer bank sediment, Textural analysis, Depositional environment.*

Introduction

There is great importance of the knowledge of textural characteristics of the riverine sediments for differentiating various depositional environments (Ramesh and Subramanian, 1992). Sediment texture deals with the various aspect of size, shape and three-dimensional arrangements of constituent grains of a sediment or sedimentary rock and these properties are closely related to the mode of transport and energy of the transport medium (Sonowal and Laskar, 2017). Sediment deposits are the result of combined effect of sediment transportation and stream hydraulic action in connection with the grain size distribution and energy fluctuation among the different river course in span of pre-monsoon, monsoon, or post-monsoon season (Bhattacharya, Chatterjee and Dolui, 2016). The grain size distribution is effected by the nature of source material, distance from the source, topography (Suvarna et al., 2017).

This paper deals with the study of transportation and depositional history and to identify the erodibility through bank sediment analysis. Wentworth (1922) studied about the sediment particles size on his paper, “A scale of grade and class terms for clastic sediments”. Folk and

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Ward (1957) discussed the significance of the grain size parameters through statistical analysis to identifying the behavior of transportation process on Brazos River. Some statistical parameters like mean (ϕ), mode, skewness (ϕ), sorting (ϕ), standard deviation (ϕ) and kurtosis (ϕ) was used to analyze grain size parameter. Blott and Pye, (2001), discussed about the Gradistat Program for the grain size and statistical analysis of unconsolidated sediments. Gradistat program is used to calculate various statistical parameters like mean, sorting, skewness, kurtosis and statistical formulae used after the modified form of Krumbein and Pettijohn (1938) and Folk and Ward (1957) calculation of grain size parameters. Roslan *et al.* (2013) discussed about river bank erosion risk potential with regards to soil erodibility. 'ROM Scale' is used to determine the degree of soil erodibility index which is a modified form of 'Bouyoucos Erodibility Index'. Arun *et al.*, (2019) studied the textural characteristics of sediments on Periyar River basin, Kerala. This study was carried out to understand the nature of the distribution of grain size within the sediments sample collected from Periyar River. Textural analysis was done by standard sieving and pipette analysis method followed by (Carver, 1971) and statistical parameter was calculated by using the modernized GRADISTAT Software followed by (Folk and Ward, 1957).

Study Area

The area in the foothill regions carries a different characteristic. The sudden change of slope in different stretch modifies the flow velocity. The bank sediments give us an idea about the past discharge regime of that area. The studied area is located in the Terai region of Darjeeling district near Siliguri of West Bengal. Rakti River joins the Balason River as its left bank tributary. Rakti river has been surveyed from 18241 m downstream to the confluence of Rakti-Balason, which comes under the extension of 26°45'54" N to 26°45'31" N and 88°19'45" E to 88°20'39" E (Fig 1 and 2).

Objectives

The objectives of the present research are as follows:

- To assess the textural characteristics of fine sand-sized bank sediment of Rakti channel under the surveyed area.
- To understand the transportation process and depositional environment of bank sediment layers which are basically the imprint of several discharge regimes of Rakti channel in past.
- To estimate the erodibility of bank sediment layers at selected stations along the Rakti bank.

Methodology

An intensive field work has been carried from 12.04.2019 to 16.04.2019 at Rakti channel under the Sukna region, Darjeeling, West Bengal to study the hydro-geomorphological and

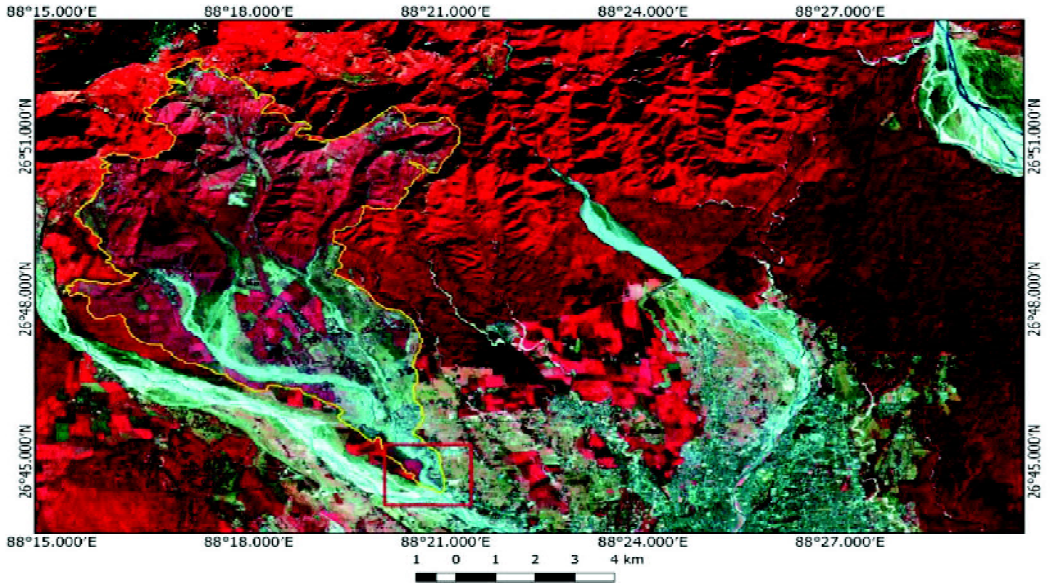


Figure 1: Location of surveyed area along Rakti Khola, on the LISS 3 image (NG45K05-107-052 and NG45K06-107-053) on January 2019 (extracted from Bhuvan, data repository ISRO and modified by authors).



Figure 2: Location of fine sand- sized bank sediment (G_10_15 and G_10_19) collection points in Rakti River bank on Google Earth image (extracted from Google Earth Pro and modified by authors).



Photo 1: RL survey on Rakti River at the confluence of Rakti and Balason River by auto level on 15/04/2019



Photo 2: Collection of the bank sediment from different layer and measuring the bank height by measuring tape.



Photo 3: Sediments are dried by hot air oven at 100° centigrade (28/05/2019).



Photo 4: Sediment samples are classified into several phi classes by using digital sieve shaker (28/05/2019).



Photo 5: Labeling and packing of sediment samples, classified into several phi classes by using digital sieve shaker (28.05.2019)



Photo 6: Measuring the weight of the sediment by electronic balance (28/05/2019).

sedimentological characteristics. Sediment samples have been collected at two representative right bank sites of Rakti channel near Rakti-Balasan confluence. Samples are initially collected from different visible bank layers based on the textural variation as visible by bare eye. The location of the collected sediments was marked by GPS. The elevation of the bank was measured (Photo 2). The finer bank sediments were collected from river bank and brought to soil laboratory. Those samples are dried in hot air oven at 100° C (Photo 3). The sediments were then dry-sieved by using digital sieve-shaker (Photo 4). All the sediments were categorized into different phi classes (Photo 5). The sediments from each phi class were measured using the weighing machine (Photo 6). Results were analyzed by GRADISTAT 8.0 software. Erodibility index has been used to determine the variability of bank erosion of the deposited sediment layers.

Result and Discussion:

Statistical parameters have been tested for the finer bed sediment particles of the representative Rakti bank sediments after Folk and Ward, 1957 (Table 1). It provides an overall idea about the textural characteristics of a foothill stream lying on the Darjeeling Terai plain. Textural

Table1: Modified after Folk and Ward (1957)

Skewness (phi)		Sorting (phi)		Kurtosis (phi)		Mean (phi)	
Very fine skewed	+1.0 to +0.3	Very well sorted	< 0.35	Very platykurtic	<0.67	Very coarse-grained sand	-1.0 to 0
Fine skewed	+0.3 to +0.1	Well sorted	0.35-0.5	Platykurtic	0.67 to 0.90	Coarse grained sand	0.0 to 1.0
Symmetrical	+0.10 to -0.10	Moderately sorted	0.5-1.0	Mesokurtic	0.90 to 1.11	Medium grained sand	1.0 to 2.0
Coarse skewed	-0.10 to -0.30	Poorly sorted	1.0- 2.0	Leptokurtic	1.11 to 1.50	Fine grained sand	2.0 to 3.0
Very coarse skewed	-0.30 to -1.0	Very poorly sorted	2.0- 4.0	Very leptokurtic	1.50 to 3.00	Very fine-grained sand	3.0 to 4.0
		Extremely poorly sorted	> 4.0	Extremely-leptokurtic	>3.00	Coarse silt	4.0 to 5.0
						Medium silt	5.0 to 6.0
						Fine silt	6.0 to 7.0
						Very fine silt	7.0 to 8.0
						Clay	> 8.0

differences in deposited layers of Rakti bank also provides an idea regarding the depositional provenance and changing energy condition of such foothill streams like Rakti khola. Skewness (ϕ)

Representative Site 1: Right Bank of Rakti channel (G10_15)

Five layers of different textural composition have been observed by the bare eyes at this representative site of Rakti bank. Sample 1 (Fig. 3) of the first representative site is collected from bottom most layer of Rakti bank of that site. The height of the layer is 0-1 m which shows the base of the bank. The frequency distribution curve represents several ϕ classes, sorted from very coarse sand to very coarse silt. It is bimodal very platykurtic (0.594ϕ) in nature, represents dominance of two transportation processes. Poorly sorted (1.108ϕ) samples represent the fine sediments, which may be transported by the process of saltation with suspension. The sample is fine skewed (0.319ϕ) with a peak showing normal distribution and another peak showing dominance of negative ϕ value and dominance of high to moderate energy to transport the sediment. One peak is situated at medium sand (1.5ϕ) and another peak at coarse sand (-1.00ϕ) of distribution curve. Mean (0.506ϕ) refers a coarse sand sample.

Sample 2 is collected from the height of (1-4 m) at the same sample site. The frequency distribution curve (Fig. 3) shows unimodal tendency with a secondary peak. It is very leptokurtic (1.761ϕ), which may refer the dominance of one transportation process. Moderately sorted (0.732ϕ) trend represents dominance of saltation with rolling as process of transportation. The sample

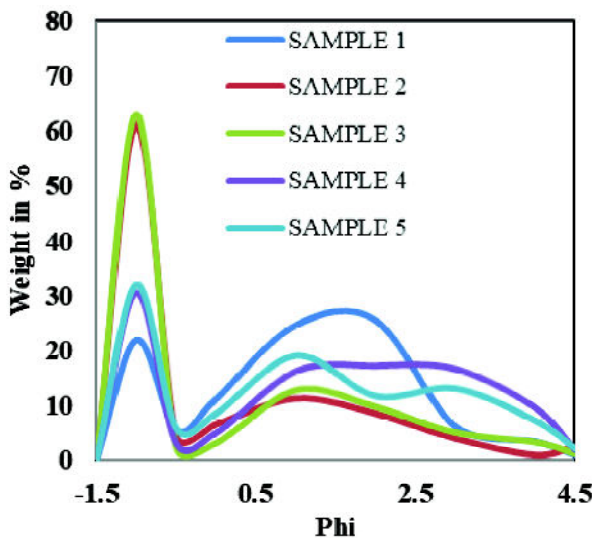


Figure 3: Sample wise graphical representation of sample weight of finer (sand size) bank sediment of Rakti khola under the representative site 1 at right bank.

is very fine skewed (1.703ϕ) which may refer the dominance of high energy. The dominant peak is located at coarse sand (-1.00ϕ) whereas a minor secondary peak is located at medium size sand (1.00ϕ) of distribution curve. Mean (-0.019ϕ) refers a very coarse sand sample.

Sample 3 (Fig. 3) is collected from the height between 4-6 m which represents third layer of the bank of Rakti khola. This frequency distribution curve shows a unimodal trend with a minor secondary peak. Leptokurtic (1.30ϕ) trend represents the dominance single transportation process. Moderately sorted (0.835ϕ) character refers sediments are transported by the process of saltation with rolling. The sample is very fine skewed (1.588ϕ) with

the dominance of negative phi value which may replicate the dominance of high energy environment. The dominant peak is located at coarse sand (-1.00ϕ) whereas a secondary peak is located at medium size sand (1.00ϕ). Mean (0.087ϕ) refers a coarse sand sample.

Sample 4 is collected from the height of (6-7.3 m) which represents the fourth layer. It is bimodal in nature (Fig. 3) and it is very platykurtic (0.522ϕ) represents the involvement of two transportation processes. Poorly sorted (1.396ϕ) sample represents the dominance of saltation with suspension. The sample is very fine skewed (0.392ϕ) with the dominance of negative phi value. The dominant peak is located at coarse sand (-1.00ϕ) whereas a secondary peak is located at medium size sand ($1.50 \phi - 2.5 \phi$).

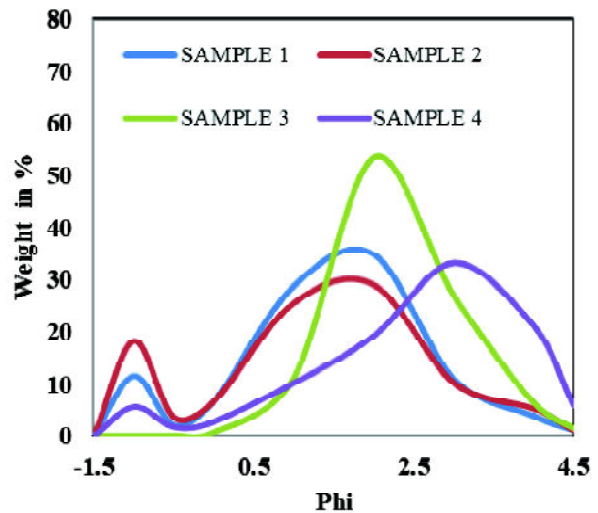


Figure 4: Sample wise graphical representation of sample weight of finer (sand size) bank sediment of Rakti khola under the representative site 2 at right bank.

Sample 5 (Fig. 3) is collected from top most layer of the bank which is the fifth top-most layer and the height of this layer is delimited between 7.3-7.7 m. The frequency distribution curve (Fig. 3) represents bimodal in nature and it is very platykurtic (0.598ϕ) which signifies the dominance of two transportation processes. Poorly sorted (1.322ϕ) refers sediments are transported by the process of saltation with suspension. The sample is very fine skewed (0.684ϕ) with the dominance of negative phi value and dominance of high energy. The dominant peak is located at coarse sand (-1.00ϕ) whereas a secondary peak is located at medium size sand (1.00ϕ) of distribution curve. Mean (0.729ϕ) refers a coarse sand sample.

Representative Site 2_Right Bank (G10_19): Four different textural layers with different composition has been observed by the bare eyes at this representative site of right bank of Rakti channel near Balasan confluence. Sample 1 (Fig. 4) of this second representative site is collected from the bottom-most layer (0-1 m.). The frequency distribution curve (Fig. 4) shows a unimodal trend with a minor secondary peak and it is a platykurtic (0.886ϕ) represents one transportation process dominance. Poorly sorted (1.10ϕ) character refers transportation process of sediments are suspension with saltation. The sample is symmetrical (-0.001ϕ) which may refer the dominance of moderate energy. Fine sized sand particles are dominant than the coarse-grained sand. The dominant peak is located at fine sand (2.0ϕ), whereas a secondary peak is located at coarse sand (-0.10ϕ).

Sample 2 (Fig. 4) is collected from the second layer (1-2.5 m.). Frequency curve (Fig 4) shows a bimodal and platykurtic in nature (0.735ϕ) represents two transportation process are dominance. Poorly sorted (1.1274ϕ) refers transportation process of sediment are suspension with saltation. The sample is fine skewed in nature (0.105ϕ) indicates the dominance of high energy. The dominant peak is located at fine sand (2.0ϕ) whereas a secondary peak is located at coarse size sand (-0.10ϕ) of distribution curve. Mean (0.678ϕ) refers a coarse sand sample.

Sample 3 (Fig. 4) is collected from the third layer (2.5-5.7 m.). The frequency distribution curve represents a unimodal and leptokurtic (1.117ϕ) which shows sediments are transported by one dominant process. Moderately sorted (0.865ϕ) refers sediments are transported by the process of saltation with rolling. The sample is fine skewed (-0.170ϕ) and dominance of negative phi value and dominance of high energy. The dominant peak is located at fine sand (2.0ϕ) of distribution curve. Mean (1.829ϕ) refers medium sized sand.

Sample 4 (Fig. 4) is collected from the top most layer of the bank (site 2). Height of this layer is between 5.7-8.8 m. The frequency distribution curve represents several phi classes sorting from very coarse sand to very coarse silt. It has a unimodal with a secondary peak and it is a mesokurtic (1.088ϕ) refers one transportation process is dominance. Poorly sorted (1.489ϕ) denotes transportation processes of sediments are suspension with saltation. The sample is coarse skewed in nature (-0.237ϕ), where fine sized particles are dominant than the coarse grain size. The dominant peak is located at fine sand (3.0ϕ) of distribution curve. Mean (2.128ϕ) refers fine sand.

Bank layerwise variation of statistical parameters of site1, Right bank (G10_15):

Particle size: Graphic mean size reflects the overall average size of the sediment (Sonowal and Laskar, 2017). Source of sediment supply, transporting medium and the energy condition of

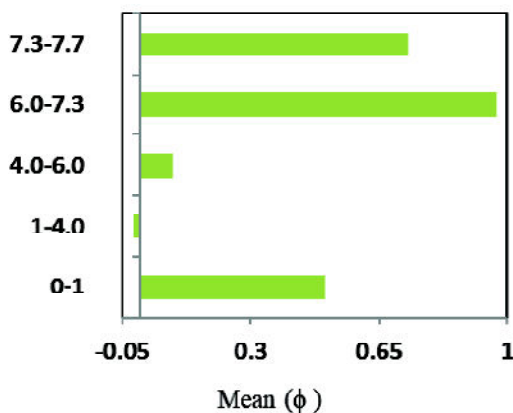


Figure 5: Bank layer (height in m in vertical axis) wise variation of particle size at representative site 1, Rakti right bank

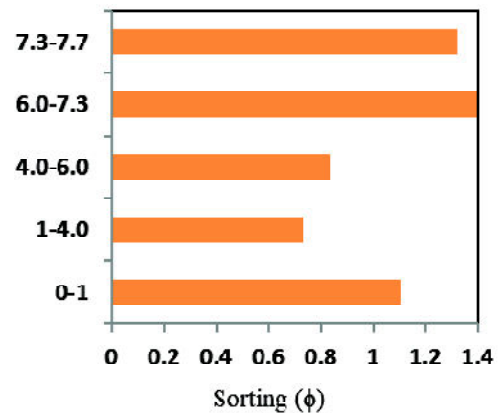


Figure 6: Bank layer (height in m) wise variation of sorting at representative site 1, Rakti right bank.

the depositing environment influence mean size of the sediment (Venkatesan, Singarasubramanian and Sukanraj, 2017). Graphic mean size gives a concept of the average kinetic energy of the depositing agent (Sahu, 1964). Sediment samples are taken from five different layers (Figure 5) of the right bank of the Rakti River. Graphic mean value ranges between -0.019ϕ to 0.973ϕ (Table 1) which indicates that the deposited sediments are very coarse to coarser in nature. The sediments which were taken from the height of 1 m to 4 m (figure 5) represents very coarse (-0.019) sand sized particles (Table 1), which may reflect that the sediments are deposited in very high energy condition. Sediments of other different layers are also coarser (Figure 5), represents the involvement of high energy condition for settling the particles. The variation in particle size refers the involvement of differential energy condition (Riyaz and Jeelani, 2015) which led to deposition of sediments in form of different layers.

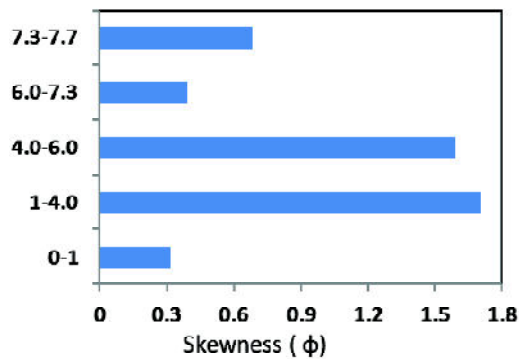


Figure 7: Bank layer (height in m) wise variation of mean values at representative site 1, Rakti right bank

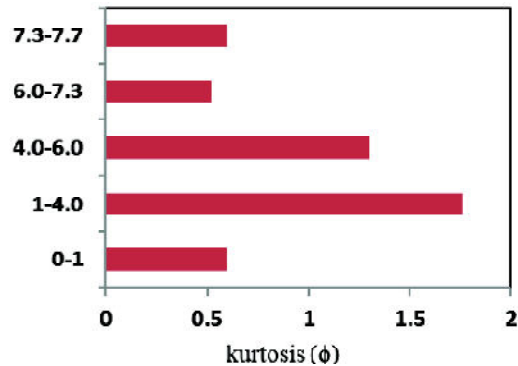


Figure 8: Bank layer (height in m) wise variation of mean values at representative site 1, Rakti right bank

Standard deviation: Graphic standard deviation measures the sorting value which indicates that the fluctuation of kinetic energy condition of the depositing agent and about its average velocity (Sahu, 1964). It is an important parameter of sediment analysis as it reflects the energy condition of depositional environment (Visser, 1969; Venkatesan *et. al.*, 2017). Sorting ranges between 0.732ϕ to 1.396ϕ , which represent that sediments are moderately sorted to poorly sorted (Fig. 6). Sediments are transported by the process of saltation with suspension. Sediments of both layers are moderately sorted (1 m to 4 m and 4 m to 6 m) which may reflect that the deposited sediments are deposited in moderate energy environment. Sediments of the other upper layers are poorly sorted, which may reflect the involvement of low energy condition regarding deposition. Variation in sorting value indicates the higher fluctuation velocity (Arun *et.al*, 2019) and variation in water turbulence during transportation.

Skewness: Difference between the mean with respect to the median is measured by the skewness (Sahu, 1964). Signature of skewness reflects the riverine environmental energy condition (Valia and Cameron, 1977; Bhattacharya *et.al*, 2016). Here the skewness value occurs more than

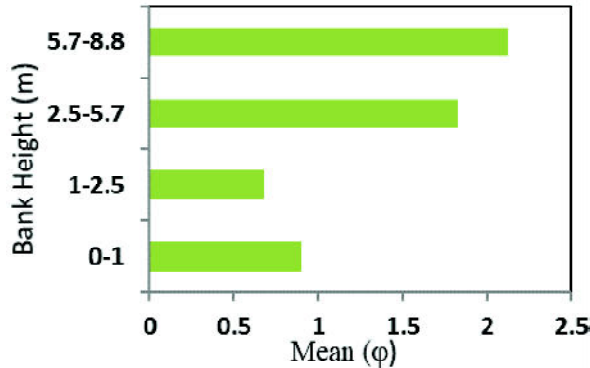


Figure 9: Bank layer wise variation of particle size at representative site 2, right bank Rakti

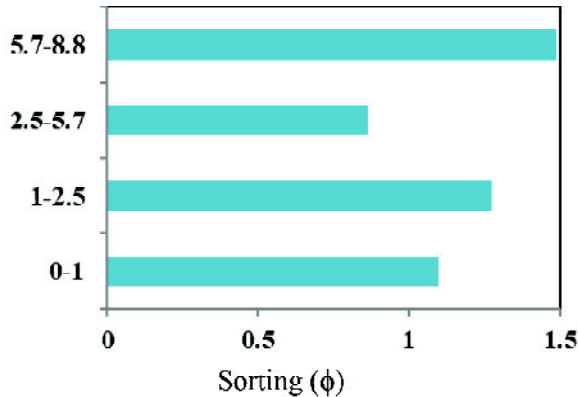


Figure 10: Bank layer (height in m) wise variation of sorting at representative site 2, right bank Rakti

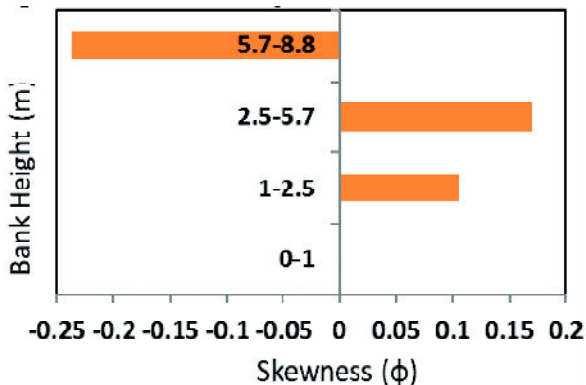


Figure 11: Bank layer wise variation of skewness at representative site 2, right bank Rakti

0.319 ϕ . Positive skewness or finely skewed distribution indicates the unidirectional transport (Riyaz and Jeelani, 2015) and the sediments are deposited in low energy of the riverine environment. Negative skewness or coarsely skewed particles indicate the deposition at higher energy condition. The lower most layer (0-1m) of this representative site shows the character of fine skewed (0.319 ϕ) distribution. It also represents that the sediment particles are transported and settled here by high energy influence.

Kurtosis: The graphic kurtosis is the peaked-ness of the distribution and measures the ratio between the sorting in the tail and central portion of the curve (Venkatesan and Singarasubramanian, 2016). Magnitude of kurtosis of site 1 ranges between 0.522 ϕ to 1.761 ϕ which shows the trend of very platykurtic to very leptokurtic character of distribution (Table1). The variation of magnitude of kurtosis (Figure 8) indicates the fluctuation in the velocity of the depositing medium.

Bank layer wise variation of statistical parameters of site2, Right bank (G10_19)

Particle size: The graphic mean ranges between 0.678 ϕ to 2.128 ϕ at representative site 2, implies that sediment particles are coarse grained sand to fine grained sand (Table1). Sediment of the height between 0-1 m and 1-2.5 m (Figure 9) are coarse grained, implies the deposition took place in high

energy condition, whereas the sediment deposit of the height between 2.5-5.7 m and 5.7-8.8 m are finer, reflects low energy depositional environment.

Standard deviation: Magnitude of sorting at representative bank site 2 ranges between 0.865ϕ to 1.489ϕ , which indicate that moderately sorted to poorly sorted character (Table1). The settled sediments are moderately sorted at the bank layer located between 1-2.5 m. It may reflect the dominance of saltation process. Sediments of other layers are poorly sorted, where the dominant transportation process is suspension with saltation.

Skewness: At the representative site 2, skewness magnitude ranges between -0.237ϕ to 0.17ϕ , which shows the coarse skewed to fine skewed character (Table 1). At the height between 0- 1 m (Figure 11) the skewness is recorded symmetrical which indicates the sediments are deposited at moderate energy environment and the settled sediment particles of the height between 1-2.5 m are finely skewed. It may reflect energy of the depositing environment is low. But at the height between 5.7-8.8 m, sediments are coarsely skewed, which may reveal that sediments are deposited in higher energy influence.

Kurtosis: The range of magnitude of kurtosis at this representative site 2 is 0.735ϕ to 1.117ϕ , which may imply that it is platykurtic to very leptokurtic in nature (Table 1). The variation of the kurtosis value reflects the flow peculiarity within the deposition medium

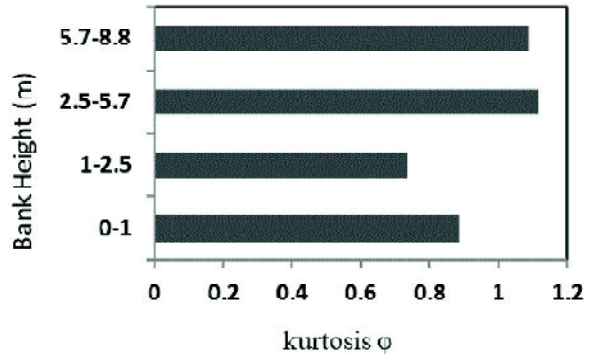


Figure 12: Bank layer wise variation of kurtosis at representative site 2, right bank Rakti

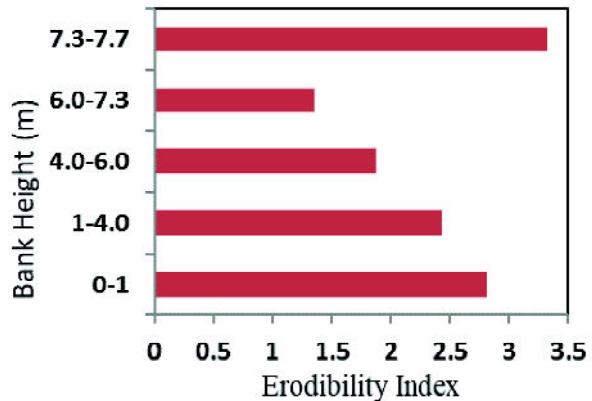


Figure 13: Bank height wise variation of soil erodibility of sand- sized bank sediment, representative site 1, right bank

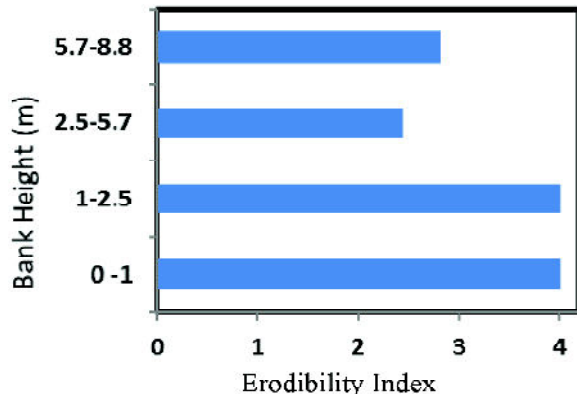


Figure 14: Bank height wise variation of soil erodibility of sand- sized bank sediment, representative site 2, right bank.

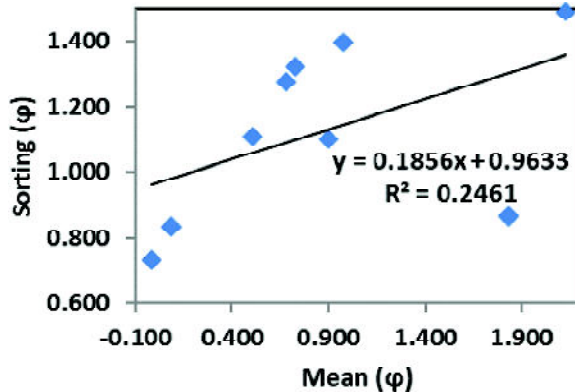


Figure 15: bivariate relationship between mean and sorting of finer sand size sediment.

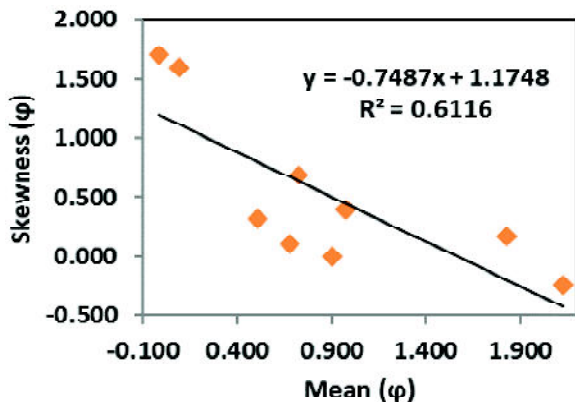


Figure 16: bivariate relationship between mean and skewness of finer sand size sediment.

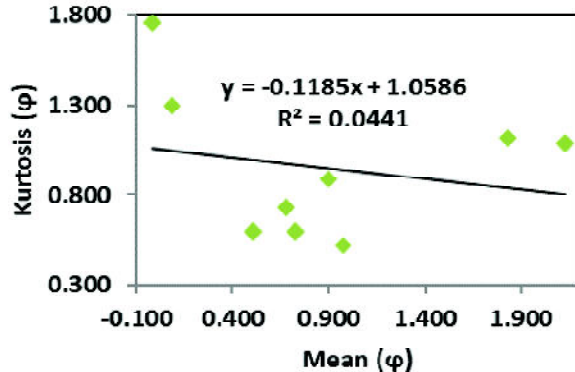


Figure 17: bivariate relationship between mean and kurtosis of finer sand size sediment.

(Arun *et.al*, 2019). The kurtosis value of the height between 0-1 m and 1-2.5 m are 0.886ϕ and 0.735ϕ respectively, indicate the platykurtic character. Observed trend is very leptokurtic at 2.5-5.7 m bank-height. Sediment distribution is mesokurtic for the settled particles at the height of 5.5-8.8 m (figure 12).

Bank height-wise Variation of Soil Erodibility of Fine sand-sized sediment particles: The resistance power of soil particles against the detachment and transportation by erosive agents is known as soil erodibility (Mazumdar and Talukdar, 2018). Erodibility index is calculated by ROM Scale (EIROM) after the name of researcher Roslan and Mazidah, which is developed from Bouyoucos erodibility index (Das and Deka, 2020). Soil erodibility index is analyzed by the soil textural composition of sand, silt and clay particles (Roslan *et. al.*, 2013).

The soil erodibility index ranges between 1.35 to 3.33 at representative site 1 (Figure 13) which refers that the soil erodibility is low to moderate. The erodibility index of the layer 0-1m is 1.35 which indicates this layer is less erosion-prone. The degree of erodibility of other layers is moderate which may indicate that the layers are moderately erosional prone. But the top most layer is comparatively susceptible to erosion (Figure 13). The soil erodibility ranges between 2.44 to 4.02 at representative site 2 (Figure 14) which represents the degree of erodibility is moderate to high. The degree of erodibility is moderate in

nature at the bank height of 2.5-5.7 m and 5.7-8.8 m, which indicate that the layers are moderately susceptible to erosion. The degree of soil erodibility is higher at the bank-height of 0-1 m and 1-2.5 m, represents higher risk of erosion.

The energy conditions, medium of transportation and mode of deposition can be explained by the bivariate analysis (Bhattacharya *et. al*, 2016). Folk and ward (1957) stated that the mode of deposition and environmental condition can be identified by the various inter relationship. An attempt has been made here to use these bivariate plots to study their inter-relationships of the representative bank sediments of Rakti khola. Bivariate analysis of mean and sorting (Fig 15) of the bank sample shows that it is poorly linearly associated (0.2461).

The relation between mean and sorting reveals that sorting decreases with the increase of grain size. Mean and skewness represents a negative relation (Fig 16) and strongly linearly associated (0.6116) with each other. It indicates that coarser sediments are deposited in high energy environment. Mean and kurtosis (Fig 17) represent a negative relation and it is very weakly correlated (0.0441) and it is not well associated to each other. Sorting and skewness shows (Fig 18) the strongly negative relation. It shows that poorly sorted sediments are tending to coarsely skewed. Relation between sorting and kurtosis (Fig 19) of the bank samples are strongly associated (0.5165) which may refer that the well sorted

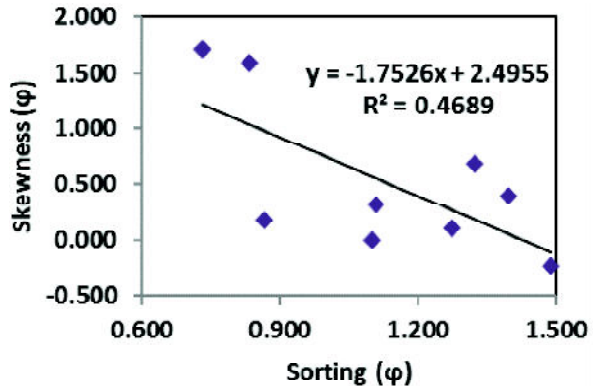


Figure 18: bivariate relationship between Sorting and Skewness of finer sand size sediment.

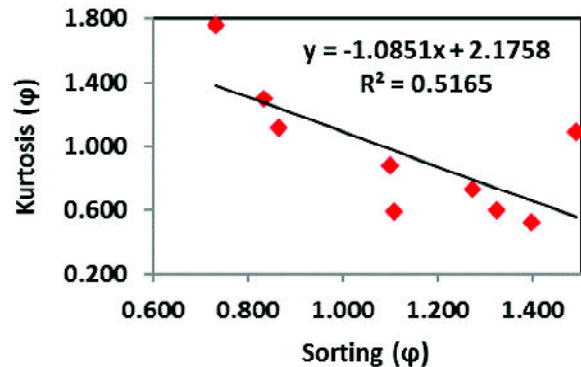


Figure 19: bivariate relationship between Sorting and Kurtosis of finer sand size sediment.

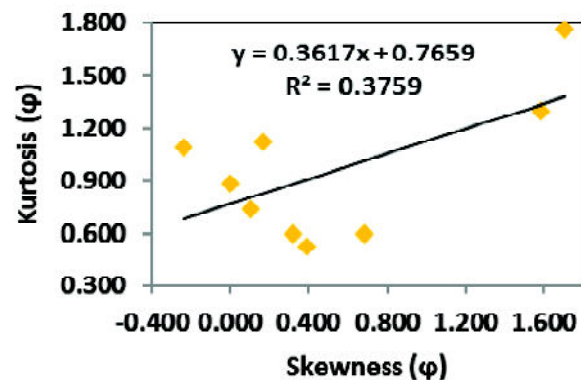


Figure 20: bivariate relationship between skewness and kurtosis of finer sand size sediment.

sediments are tend to be leptokurtic in nature. It indicates no mixing of sediment. Skewness and kurtosis (Fig 20) represent poor linear relationship (0.319) and they are not well associated. Kurtosis values are increasing with the increase of skewness value, which may represent that there is no fluctuation of energy during the span of deposition.

Conclusion

The present study establishes the existence of textural variability of finer bed sediment of Rakti khola, which has been collected from field by using scientific observation. Change in magnitude of statistical parameters of textural characteristics of the finer sand-sized sediment particles denotes the differential depositional environment is responsible for such difference in texture. Change in energy in this riverine environment may occur due to change in discharge regime. Change in transport procedure (on the basis of existing stream energy and particle diameter) may also responsible for occurring the deviation in sediment texture. Coarse skewed tendency has been enhanced with decrease of particle size of finer sand-sized bed sediment. Leptokurtic trend has been converted into platykurtic as the particle size reduces for Rakti bank sediment. Erodibility of bank layers reduce with the decrease of sand-particle size.

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