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Textural characteristics of fluvial sediments in the Kosi River Basin, Bihar, India

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ABSTRACT

The fluvial sediment samples collected from the Kosi River Basin, Bihar were subjected to textural analysis. The textural parameters were computed using the appropriate phi values. Statistical metrics including mean, standard deviation, skewness, and kurtosis were estimated. From the findings, the mean size of river sand has been observed from medium to fine-grained nature (between 0.97 Φ and 2.72 Φ). Within the range of 0.50 Φ to 0.77 Φ, the standard deviation denotes a moderately well-sorted to moderately sorted nature. The sediment samples exhibit skewness values ranging from -0.344 Φ to 0.267 Φ. The Kurtosis varies between 0.86 Φ and 1.9 Φ, indicating a leptokurtic to mesokurtic nature. Thus, the statistical measures have revealed that sediments are dominant in the medium sand category, moderately well sorted, finely skewed, and fall under leptokurtic character. The bivariate plots constructed between the statistical metrics indicate the unimodal nature of sediments.

Keywords: Textural analysis, Statistical Parameters, Bivariant plots, CM pattern, Kurtosis

INTRODUCTION

River basins are indispensable ecosystems, providing vital water resources crucial for human survival, agricultural irrigation, and environmental decontamination (Siderius et al., 2022; Zhao et al., 2021; Ramos-Vázquez et al., 2022). Nevertheless, the escalating significance of environmental issues, such as the diminishing self-purification ability of river basins and the deterioration of ecological functions, can be attributed to the devastation of ecological habitats caused by human activities and the excessive exploitation of natural resources (Zhu et al., 2021; Dai et al., 2022). It is generally recognized that sediment grain-size distribution can be utilized to address changes in material sources, transit modes, and other sedimentation processes (Folk and Ward, 1957; Liu et al., 2016; Chougong et al., 2021). Reconstructing the hydro dynamics that were linked with the climatic conditions and environment has been done extensively through the use of various grain size statistics, such as mean size (Mz), standard deviation (σ1), skewness (Sk1) and kurtosis (KG) (Xiao et al., 2009; Wang et al., 2009; Anaya-Gregorio et al., 2018; Madhavaraju et al., 2021).

Numerous researches have been done to use granulometric components to differentiate various environments of the formation of sediments (Krumbein, 1963; Keller, 1949; Folk & Ward, 1957; Friedman, 1961; Wang, 2009; Kanhaiya and Singh, 2014; Venkatesan et al., 2021; Yadav, 2023). Analyzing the grain size is crucial to identifying the transportation history and depositional environment (Folk and Ward, 1957; Friedman, 1979; Bui et al. 1989, Ganesh et al. 2013; Liu, 2017). Understanding the textural characteristics of sediments is vital for achieving a higher degree of success in determining their depositional environments (Pettijohn, 1984; Balamurugan, 2014). The characteristics of grain size distribution within sediments depend upon source materials, weathering process, and sorting during sediment transport and deposition (Irfan, 2022). Analyzing the textural studies of frequency curves comprised of mean, standard deviation, skewness, kurtosis and to facilitated the interpretation of sediment deposition of the prevailing environment (Venkatesan and Singarasubramanian, 2016).

However, there exists a notable gap in the literature concerning the nature of the sediments carried by the river. Sediment transport plays a crucial role in interpreting river processes as it is the group of mechanisms that link the running water and the channel boundary. The present work aims to understand the transport mechanism of river sediments based on textural parameters.

STUDY AREA

The Kosi River is the most prominent left-bank tributary of the Ganga River in northern Bihar. The study area forms part of the Saharsa and Supaul districts. The area falls between latitudes N 25° 16' 18.5" to N 29° 7' 30.4" and longitude E 83° 59' 22.5" to E 88° 57' 53.3" in the survey of India toposheet no 72J/8, 72J/12, 72K/5, 72K/9, 72K/10, 72K/14 (Scale 1:50,000) (Fig. 1). The Kosi River has its source in the Himalayas at an elevation of 7000 meters above the sea level. Also, it is a significant transboundary river that serves as one of the primary left-bank tributaries of the Ganga River system (Rai, 2018). The geology of the megafan consists of unconsolidated sediments of Quaternary age. The geological characteristics of the Kosi watershed render it inherently unstable, making it prone to substantial erosion and sediment accumulation, ultimately resulting in an elevated sediment load within the flowing river (Agarwal, 1992, Sinha et al., 2008). The escalating sediment load in the Kosi River significantly disrupts its natural flow dynamics, leading to alterations in its course over time (Wells and Dorr, 1987; Gole and Chitale, 1966, Shrestha et al., 2010; Sinha et al., 2019).

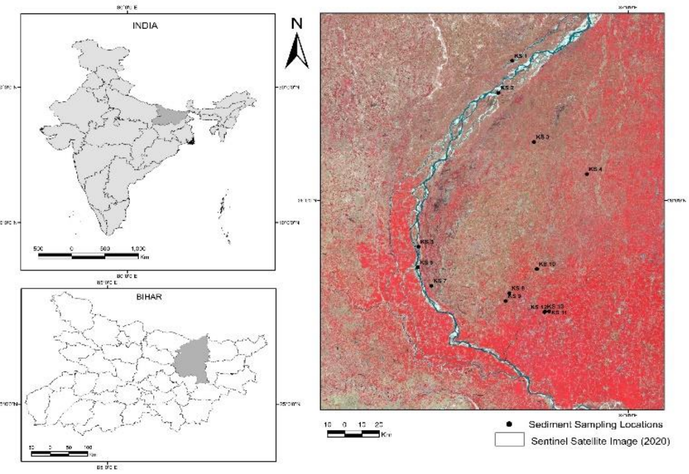
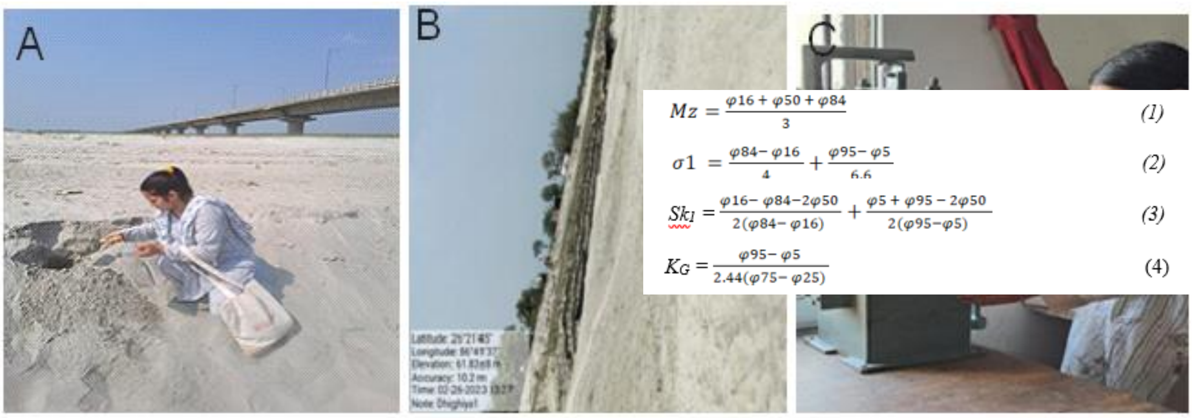


Fig. 1. Map showing sampling locations in the Kosi River Basin

METHODOLOGY

Sediment samples were obtained from specific locations in the Northwestern section of the Kosi River Basin (Fig. 2). The samples were gathered and placed in dry, clean polythene bags for further laboratory analysis.



$$M_z = \frac{\varphi 16 + \varphi 50 + \varphi 84}{3} \quad (1)$$

$$\sigma 1 = \frac{\varphi 84 - \varphi 16}{4} + \frac{\varphi 95 - \varphi 5}{6.6} \quad (2)$$

$$Sk_1 = \frac{\varphi 16 - \varphi 84 - 2\varphi 50}{2(\varphi 84 - \varphi 16)} + \frac{\varphi 5 + \varphi 95 - 2\varphi 50}{2(\varphi 95 - \varphi 5)} \quad (3)$$

$$K_G = \frac{\varphi 95 - \varphi 5}{2.44(\varphi 75 - \varphi 25)} \quad (4)$$

Fig. 2. A and B showing the collection of sediment samples from the Megafan area, and C) grain size analysis at the laboratory

Totally, 13 surface sediment samples of about 1 kg each from Megafan were collected in precise positions using a Global Positioning System (GPS) receiver. The samples were frequently washed, dried, and consistently mixed. In order to obtain the desired 100-gram weight of sediments, consecutive coning and quartering were performed. The dried samples were kept in topmost ASTM sieve and placed in a set of assembled sieves starting from 38 mesh (5Φ), 63 mesh (4Φ), 125 mesh (3Φ), 250 mesh (2Φ), and 500 (1Φ) mesh. The sieving of the sediments samples was done for 15 min in Ro-top mechanical sieve shaker.

Following the sieve analysis, the sediments from each sieve were weighed with a digital balance. The weight percentage and cumulative weight percentage were recorded manually. Analytical data have been applied to generate cumulative frequency curves and calculate statistical parameters using standard techniques of Folk and Ward (1957). The formulae established by Folk and Ward (1957) were used to interpret the grain-size parameters. The grain size was computed using phi (φ) units (φ = - log2d, where d is size of grain in millimeters), and measured by applying domains like mean size (Mz), standard deviation (σ1), skewness (Sk1) and kurtosis (KG), as determined by the following formulae,

The evaluation of granulometric characteristics were done by using G- Stat software, it includes frequency curves, scatter plots, triangle diagrams, and CM patterns (Venkatesan et al., 2017).

RESULTS

FREQUENCY CURVES

The distribution of sediments grain size in the Kosi river basin has been plotted in the form of frequency distribution curves (Fig. 3). A Frequency distribution curve serves as a visual illustration of the weight percentages of different fractions of sediment and is used to outline the characteristic of sediments (Arun, 2019). The frequency curves of the sediment sample exhibit distinct unimodal behavior. The chief modes are located within the size range of 1Φ to 2.5Φ which indicates that the majority of sediments fall in the medium to fine class. There is one subsidiary mode in the finer class i.e. KS12.

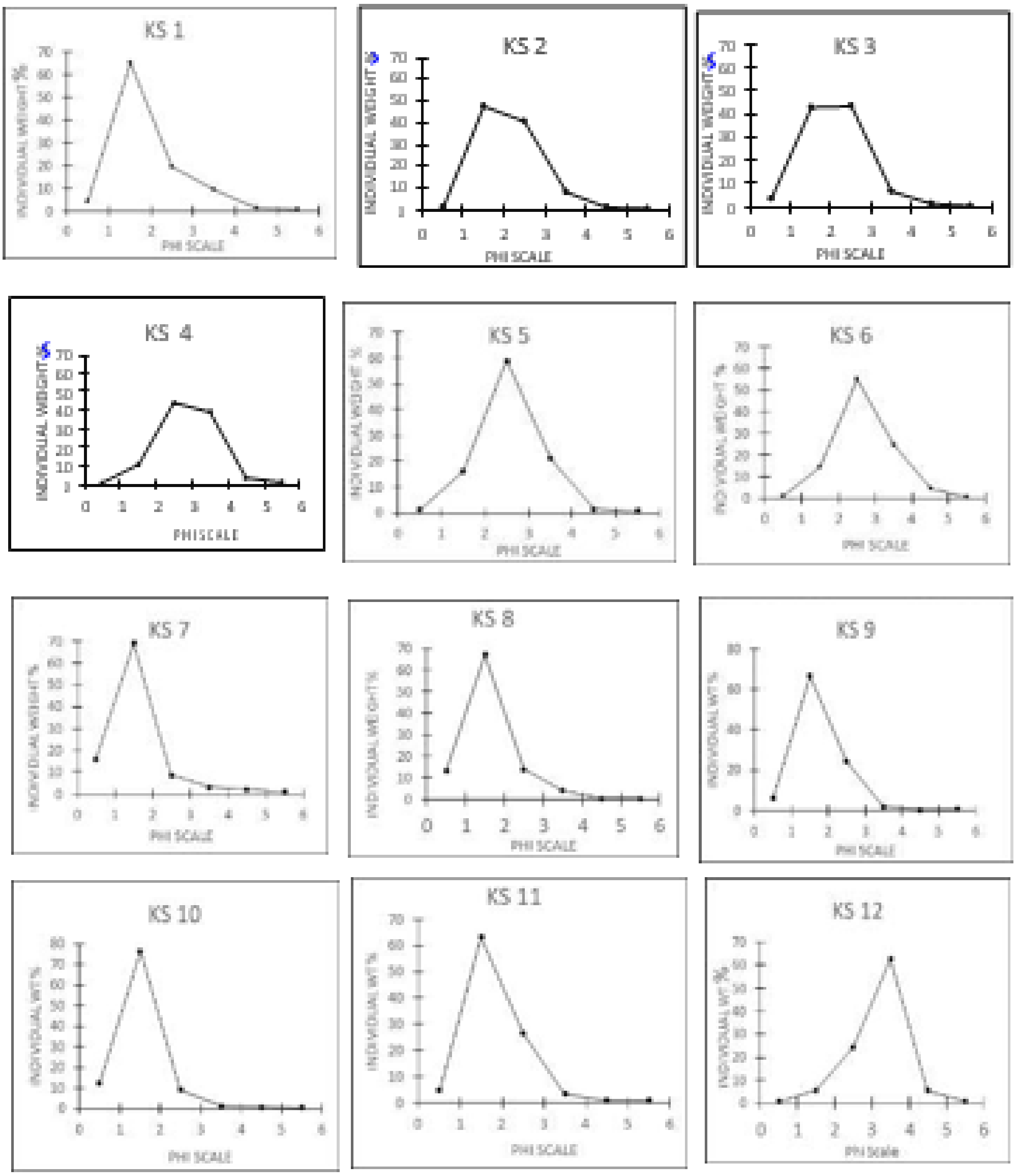


Fig. 3. Showing frequency distribution curves of sediments in different locations of the Kosi River basin.

CUMULATIVE CURVE

The cumulative curves are integral of frequency polygons. The pattern of the cumulative curves of the Kosi River basin is given in Figure 4. The curves of the sample i.e KS4, KS5, KS6, and KS12 start with the range of 0-1Φ with the initial low slope, it maintains a rising trend up to 2.5Φ, and then it becomes steep and attains maximum at 5.5Φ. Rest all the samples are straight in the size range of 0.5Φ to 1.5Φ, then it became steep and attain maximum at 5.5Φ. From the cumulative curve, it is indicated that the sediments are moderately well sorted to moderately sorted in nature.

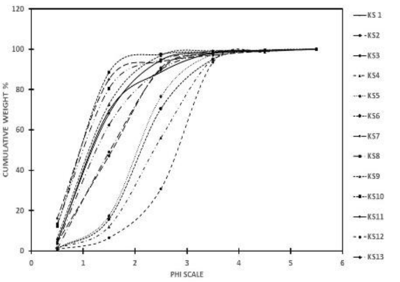


Fig. 4. Cumulative curves showing the grain size trends of sediment samples.

GRAIN SIZE PARAMETERS

Granulometric analysis is the most adopted methodology to reveal the sedimentation process like transportation, deposition, and energy level. The hydrodynamic factors that were formed at the time of the sedimentation process in a basin were determined using textural parameters like mean, standard deviation, skewness, and kurtosis. (Folk and Ward, 1957; Friedman, 1979; Passega, 1964). Various authors adopted different statistical approaches by using various formulas (Friedman, 1961; Passega, 1964; Sahu, 1964). The formulas provided by Folk and Ward (1957) are thought to be the most common and are used to compute the textural parameters of the sediments (Table 1 and Table 2).

MEAN GRAIN SIZE (MZ)

The transporting agents, energy level of deposition and the source of sediments are the prominent factors that influence the mean grain size (Folk and Ward, 1957). The mean size

value range from 0.967Φ to 2.716Φ, with an average value of 1.622Φ (Fig. 5a). The majority of samples, 53.84%, are classified as medium sand, while 30.76% fall into the coarse sand category, and 15.38% fall into the fine sand category (Table 1). The average sediment size is determined by the sediment source, the mode of transportation, and the depositing medium's energy conditions (Ventakesan, 2016; Durai, 2017). Variation of mean size from the medium to coarse pinpoints the high-energy conditions during its deposition (Ganesh et al., 2013).

SEDIMENT SORTING (σ1)

The variation in the velocity of the depositing medium and its kinetic energy was specified by the degree of sorting of the sediments. The degree of sorting could be determined by measuring the Standard deviation of the sediments (Sahu, 1964). Sorting and standard deviation have an inverse relationship. Sorting and standard deviation have an inverse relationship. Standard deviation measures the difference in kinetic energy that corresponds to the depositing agent. Standard deviation measures the difference in kinetic energy corresponds with the mode of deposition. The standard deviation of the samples ranges between 0.5Φ to 0.766Φ, with an average of 0.673Φ (Fig. 5b). About 53.84% of samples were well sorted, 46.15% were moderately well sorted in nature. In the study area, sediment characteristics ranging from moderately well-sorted to well-sorted indicate a quick smack or back-and-forth action by the depositing agent. The dominant characteristics of moderately well-sorted and moderately sorted sediments suggest the impact of strong energy conditions in the basin (Rita Chauhan et al., 2014). The tough energy conditions of depositing agents or the predominance of strong energy conditions in the basin are indicated by the predominant well-sorted and moderately well-sorted results.

SEDIMENT SKEWNESS (Sk1)

Skewness is a statistical measure that indicates the degree of asymmetry in a frequency distribution. Duane (1964) ascertained that the positively skewness deposition area has changed to negative skewness due to the cyclic current pattern. This pattern is pointing to the high-energy environment that abound in the area. In the River Kosi, minimum and maximum skewness values are -0.344Φ and 0.44Φ respectively with an average value of 0.104Φ (Fig. 5c). However, a positively skewed category is dominant in the samples of the Kosi River. Among the total volume, 53.84% in positively skewed, 30.76% near symmetrical nature. 7.69% of the samples fall in very positively skewed and very negatively skewed (Table 1). In the depositional environment, an excess of coarser particles in the sediment distribution or the tailing of coarser fractions is indicated by a preponderance of positive skewness values.

Near symmetrical nature of sediments indicates the mixing of bimodal sources. Sediments veiled in the low-energy environments show positive skewness, while those deposited in high-energy environments exhibit negative skewness. The change in the skewness values in the region indicates the differential energy condition in their sector. Near symmetrical nature of sediments indicates the mixing of bimodal sources (Venkatesan et al., 2017). The change in the skewness values in the region indicates the differential energy condition in their sector.

SEDIMENT KURTOSIS (KG)

The sediment kurtosis is defined as the peak of grain size distribution based on the mode of environment. It also depicts the level of sorting in the tail and central regions Folk and Ward, 1957). The mesokurtic condition is observed when the tail and center are equally sorted (Parthasarathy et al.,

Table 1. Percentile and C-M values calculated from the grain size data									
Sample No.	Φ95	Φ84	Φ75	Φ50	Φ25	Φ16	Φ5	Φ1	C in micron	M in micron
KS1	3.1	2.15	1.7	1.15	0.8	0.7	0.5	0	1000	450
KS2	2.9	2.3	2.1	1.5	1	0.8	0.6	0.5	700	350
KS3	2.8	2.3	2.1	1.5	1	0.8	0.5	0	1000	350
KS4	3.5	3.15	2.9	2.3	1.9	1.6	1	0.5	700	200
KS5	3.3	2.7	2.5	2.1	1.7	1.5	0.8	0.5	700	230
KS6	3.5	2.9	2.6	2.1	1.7	1.6	0.9	0.5	700	230
KS7	2.7	1.5	1.3	0.9	0.6	0.5	0	0	1000	530
KS8	2.5	1.6	1.4	1	0.7	0.5	0	0	1000	500
KS9	2.4	2.8	1.5	1.1	0.7	0.7	0	0	1000	470
KS 10	1.9	1.4	1.3	0.9	0.7	0.5	0	0	1000	540
KS 11	2.5	2.0	1.7	1.2	0.8	0.7	0.5	0	700	430
KS 12	3.5	3.3	3.1	2.85	2.35	2	1.4	0.5	700	140
KS 13	2.9	2.2	1.9	1.3	0.85	0.7	0.5	0	1000	400

Table 2: Graphic measures of grain size analysis from the Kosi River basin Sediments								
Sample No	Mean	Standard deviation	Skewness	Kurtosis	Remark			
KS1	1.333	0.756	0.44	1.183	Ms	MS	VPS	LK
KS2	1.533	0.723	0.142	0.856	Ms	MS	PS	PK
KS3	1.55	0.723	0.043	0.856	Ms	MS	NLS	PK
KS4	2.366	0.766	-0.024	1.024	Fs	MS	NLS	PK
KS5	2.1	0.678	-0.15	1.281	Fs	MWS	NS	LK
KS6	2.166	0.743	0.186	0.665	Fs	MS	PS	VPK
KS7	0.967	0.659	0.267	1.580	Cs	MWS	PS	VLK
KS8	1.05	0.641	0.171	1.463	Ms	MWS	PS	LK
KS9	1.2	0.639	0.178	1.229	Ms	MWS	PS	LK
KS10	0.967	0.500	0.03	1.297	Cs	WS	NLS	LK
KS11	1.3	0.628	0.265	0.910	Ms	MWS	PS	MK
KS12	2.716	0.643	-0.344	1.075	Fs	MWS	VNS	MK
KS13	1.4	0.738	0.267	0.937	Ms	MS	PS	MK
Minimum	0.967	0.500	-0.344	0.856	Cs	WS	VNS	PK
Maximum	2.716	0.766	0.44	1.580	Fs	MS	VPS	VLK
Average	1.588	0.679	0.113	1.104	Ms	MWS	PS	MK

Fs – fine sand, **Ms** – medium sand, **Cs**- coarse sand; **MS** – moderately sorted, **MWS** – moderately well sorted, **WS** – well sorted; **VPS** – very positively skewed, **PS**- positively skewed, **NLS** – nearly symmetrical, **NS** – negatively skewed, **VNS** – very negatively skewed; **VLK** – very leptokurtic, **LK**- leptokurtic, **MK** – mesokurtic, **PK** – platykurtic

2016). The graphic kurtosis values obtained range from 0.67 Φ to 1.58 Φ, with an average of 1.106 Φ (Fig. 5d). Leptokurtic character (38.46%) is dominant among all, 23.07% of the samples fall in mesokurtic character and platykurtic 7.69% of the samples fall in very platykurtic and very leptokurtic (Table 1). The variability in kurtosis values reflects the flow features of the depositing agents (Seralathan and Padmalal, 1994; Baruah et al., 1997). The various sediment deposition processes are implied by the leptokurtic and mesokurtic characters (Solai et al., 2013; Rumuri, et al., 2021). Based on all statistical parameters, the sediments were most likely deposited during a high-energy period, such as the monsoon season.

BIVARIATE PLOTS

Bivariate plots between the textural parameters provide information about sedimentation environments and delineate overlapping zones of closely related environments. Inman (1952), Folk and Ward (1957), Friedman (1961) and (1979) successfully used the scatter plots to understand the geological significance of the four size parameters. Scatter plots between mean versus standard deviation, mean versus skewness, mean versus kurtosis, standard deviation versus skewness, standard deviation versus kurtosis, and skewness versus kurtosis were drawn to understand the interrelationship between different parameters.

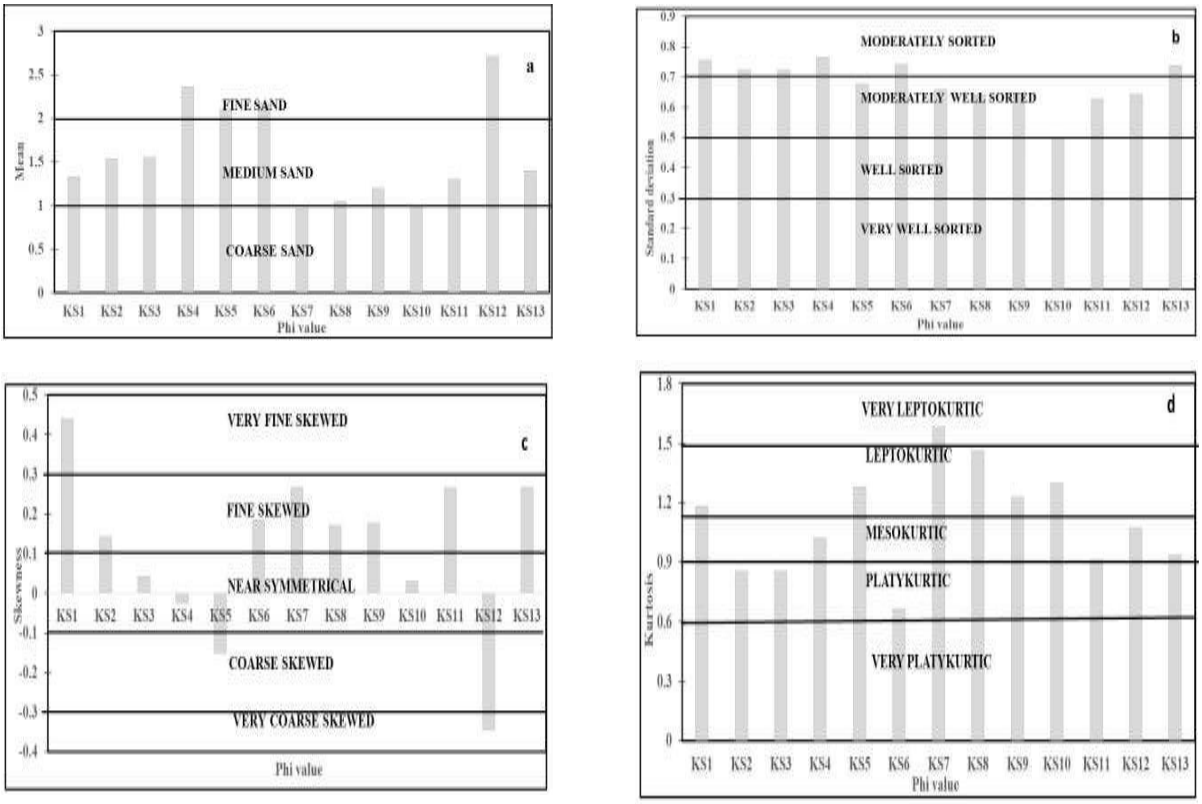


Fig. 5. Comparative histograms of all samples showing variation of a) mean, b) standard deviation, c) skewness, and d) kurtosis

MEAN SIZE VERSUS STANDARD DEVIATION

The scatter plot between the mean size and standard deviation of the Kosi sediments has been shown (Fig. 6a). Most of the sediments fall between 1Φ to 2.5Φ mean size value and indicate moderately well-sorted to moderately sorted nature of the medium to fine-grained sand.

MEAN SIZE VERSUS SKEWNESS

The scatter plot of the mean size versus skewness indicates scattering of medium sands in the positively skewed portion, above the normal curve (Fig. 6b). Below the normal curve, scattering is nearly symmetrical skewed, and only the scatter plot of the mean size against skewness shows dispersion of medium sands in the positively skewed area above the normal curve and only one sample falls in negatively and very negatively skewed i.e. KS5 and KS 12 respectively. The characteristic feature of the river sands is that they exhibit positive skewness (Friedman, 1961) and the same is true for the Kosi river sediments.

MEAN SIZE VERSUS KURTOSIS

In the mean size versus kurtosis plot, the medium-grained river sands are clustering around mesokurtic to leptokurtic values, about the normal curve (Fig. 6c). (Folk and Ward, 1957).

STANDARD DEVIATION VERSUS SKEWNESS

The relationship between standard deviation and skewness reveals that the moderately well-sorted to moderately sorted river sands are mostly positively skewed and few samples exhibit range from very negatively to very positively skewed in nature (Fig. 6d). Typically, as the standard deviation increases, the skewness value also tends to rise in sedimentology. Higher skewness values are indicative of poorer sediment sorting (Friedman, 1961).

STANDARD DEVIATION VERSUS KURTOSIS

The scatter plot of standard deviation versus kurtosis indicates that the moderately well-sorted to moderately sorted river sands are mostly leptokurtic to mesokurtic in nature. Only two samples KS2 and KS3 are moderately sorted and platykurtic (Fig. 6e).

SKEWNESS VERSUS KURTOSIS

As the modes are separated and the depositional environment is sorted, there is a large range of skewness and kurtosis values (Folk and Ward, 1957). The bivalent plot of skewness versus kurtosis corresponds to river sand (Friedman, 1961) as greater amount of the sands are mesokurtic to leptokurtic with positive skewness (Fig. 6f).

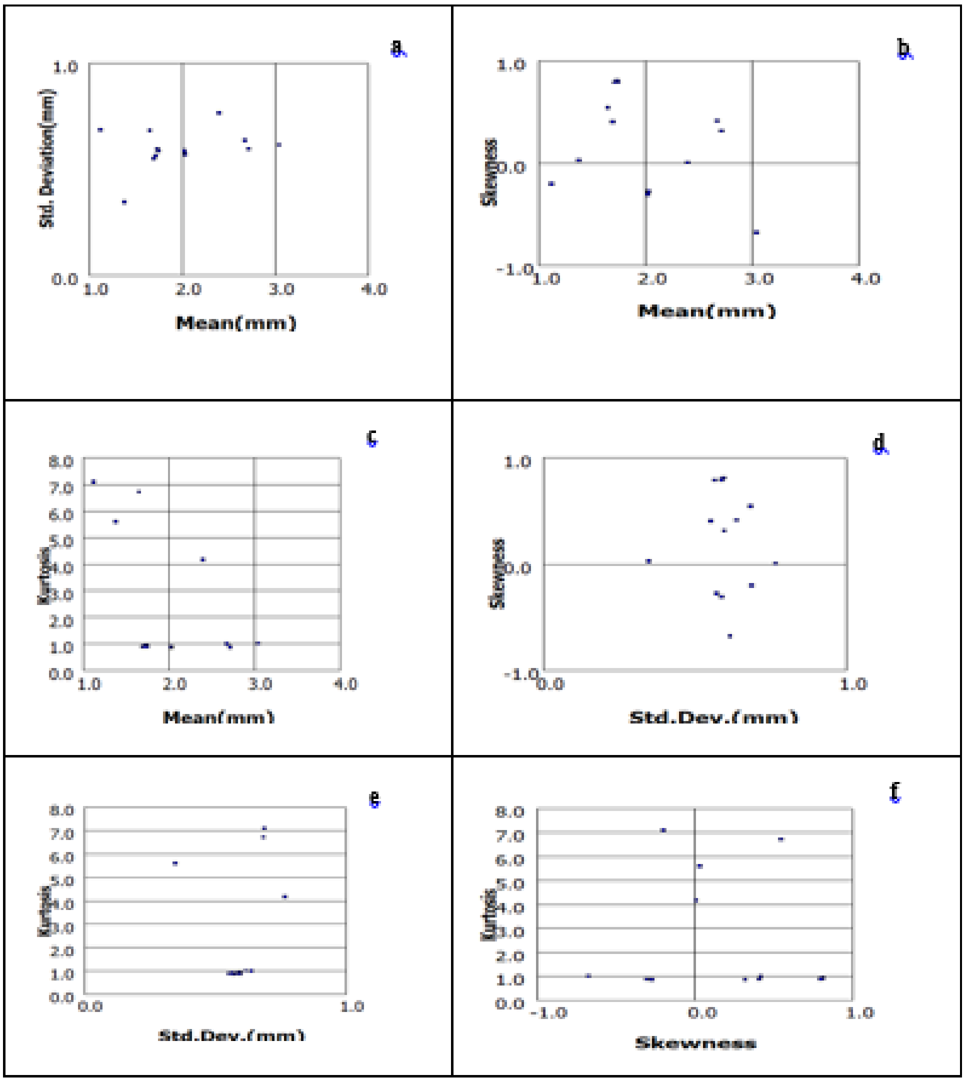


Figure 6. Scatter plots showing the model plot as proposed by Folk and Ward (1957). (a) mean vs standard deviation, (b) mean vs skewness, (c) mean vs kurtosis, (d) kewness vs standard deviation, (e) standard deviation vs kurtosis and (f) skewness vs kurtosis.

CM DIAGRAM

This research aims to determine the depositional mechanism of sediments in the Kosi River Basin through using the technique of CM pattern analysis. By using the corresponding micron values obtained from cumulative curves, the graph was made for the Phi values of parameters C and M, whereas C represents the one percentile of the grain size distribution and M represents the Median. The C and M is categorized based on the nature of bottom turbulence. There are five segments of CM patterns such as rolling (NO), bottom suspension and rolling (OPQ), graded suspension with no rolling (QR), uniform suspension (RS), and pelagic suspension (S) (Fig. 7). Exceeding the amount of sediment samples -from the Kosi River Basin fall into the OP sector, which indicates bottom suspension and rolling mode of deposition, while a few falls into the PQ sector, which indicates undegraded suspension and no rolling mode of deposition.

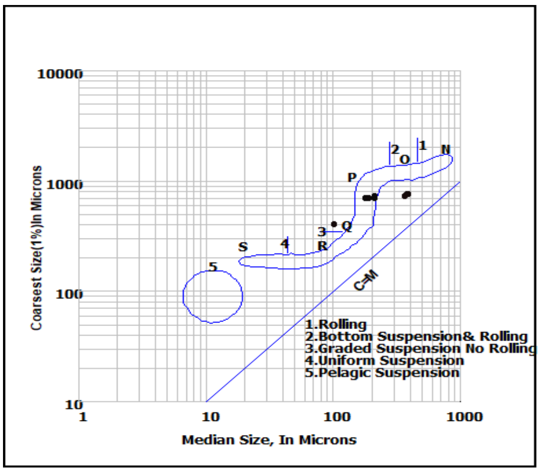


Fig. 7. CM diagram for the Kosi River sediments

CONCLUSIONS

This study aimed to assess the grain size distribution characteristics in sediment samples collected from diverse locations within the Kosi River basin. Parameters for textural characteristics such as mean size, standard deviation, skewness, and kurtosis were estimated for the sediments collected in the study area. The resulting Frequency Distribution Curves intensify that the sediments were mainly composed of medium sand and primarily unimodal in nature. The mean size indicates that the fine sands were deposited with sparsely low energy level conditions. The moderately well-sorted character of sediments indicates that the basin is experiencing greater energy conditions. The sediments are mostly of positively skewed indication of fluvial nature. Kurtosis indicates a leptokurtic to mesokurtic nature. Mesokurtic and Leptokurtic sediments are produced by continuously adding finer and coarser sediments after winnowing and maintaining their original properties during deposition. The relationship plots between the statistical domains highlighted the unimodal sediment characteristics in which, the medium-grained sand is the dominant mode.

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