Spatial Variation of Textural Parameters in a Small River: An Example from Khurar River, Khajuraho, Chhaterpur District, Madhya Pradesh, India

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Abstract: Texture (grain size) is one of the many parameters, which is used in determining depositional environments of sediments and sedimentary rocks. In the present investigation, texture was analysed from sixteen stations in the Khurar River, Madhya Pradesh, India. Here, grain size analysis was carried out employing mechanical sieving method using a sonic shaker. Frequency and cumulative frequency curves were prepared from the grain size data on centimetre and arithmetic probability papers, respectively. The phi values were determined and used to calculate the statistical parameters such as mean, standard deviation, skewness and kurtosis. It is found that the mean size value varies from-0.63to 0.80 with a graphic mean distribution ranging from -0.27 to 0.40 φ, indicating that the size of the river sand is very coarse to coarse-grained. The standard deviation (sorting) shows a range of 0 .69 to 1.65 φ. The skewness values of the sediment samples range from 0.19 to 0.29 φ, thus, indicating the presence of fine fraction to near-symmetrical fraction in the population. The kurtosis varies between 1.03 and 1.09 φ, indicating that 25% of the samples are leptokurtic, 6.25% are very leptokurtic, 50% are mesokurtic and 12.5% are platykurtic. The platykurtic nature in few cases suggests mixing of sediments from two sources. Bivariate plots prepared combining various textural parameters were used to interpret their behaviour in the river sediments. C-M plot was also prepared to understand the dominant mode of sediments transportation in the Khurar River. In this river, all the sediments are dominantly characterized by the rolling process of transportation. This study reveals that sorting varies from poorly sorted to moderately well sorted in the course of the river may be because of dominance of winnowing and selective sorting in the lower reaches of the river.

Keywords: Grain size, Kurtosis, Standard deviation, Sieving, Skewness, Sonic shaker.

1. INTRODUCTION

Texture (grain size) is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition [1]. It helps in determining depositional environment, besides others. Grain size analysis provides important clues to the sediment transportation history, depositional conditions and provenance [2-4]. The downstream distribution of river bed sediments is often used to reflect regional fluvial geomorphological and hydrological settings [5]. There are various techniques for the determination of grain size, such as direct measurement, dry and wet sieving, sedimentation, and measurement by laser granulometer, X-ray sedigraph and Coulter counter. In this study, the textural analysis was carried out involving sieving technique. Stream sediments of Khurar river have been collected (starting from up-steam to down-stream direction) and analysed. Grouped data of grain sizes, obtained by sieving technique, are presented in a Table **1**. The attributes of grain- size frequency distribution are then computed graphically following [2, 3]. Different modes of sediment transportation have been identified by plotting the cumulative frequency distributions of grain sizes on probability paper. The net distribution is then divided into traction load (coarsest fraction), saltation load (medium fraction) and suspension load (finest fraction).

2. GENERAL AND GEOLOGICAL FEATURES OF THE RIVER

The Khurar River flows exclusively on Archean rocks of Bundelkhand carton. This comprises over ~29, 000 km^2 area in north-central India. The carton consists of slivers of Archean greenstone successions within granitoids and gneisses, latter containing components with ages 3.5 Ga [6], 3.3 Ga, 2.7 Ga and 2.56-2.49 Ga [7]. The Khurar River originates from the village Saddupura (Maharajganj) near Khajuraho town in Chhaterpur district, Madhya Pradesh, India. This river is one of the tributaries of Ken River that is a tributary of river Yamuna. It is a small river and the length of the river is about 34 kilometre, and originates from the Beni sagar reservoir (Lat. 24°48’ 3.5” N and Long. 79°52'59.6" E) and confluences with Ken river at Ghadiyal pond, near renneh fall in the area of Panna tiger reserve (Lat. 24°54’ 13.9” N and Long. 80°2'6" E) and flows from SW to NE direction (Figure **1**). The width of the river is ranging from 5 to 15 meter and average velocity is 2.5 meter/second. The river deposits small (2-4m. large) braid-bars in the middle of the channel that deposits sediments during monsoon season mainly.

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Table 1: Percentile Values, C-M Values and GRAPHIC MEASURES calculated from the Grain-Size Data

Sample Nos.	Φ95	Φ84	Φ75	Φ50	Φ25	Φ16	Φ5	Φ1	C in micron	M in micron	M_Z	σ_1	SK	KG	σs	SoS
K_1	2.8	1.5	0.7	-0.6	-1.4	-1.7	-2.5	-3.4	10500	1510	-0.27	1.65	0.29	1.03	1.50	0.09
K_2	2.5	1.3	0.7	-0.8	-1.9	-1.9	-3.1	-4.2	18300	1740	-0.47	1.65	0.24	0.96	1.00	0.09
K_3	2.1	1.5	1.2	0.4	-0.1	-0.4	-1.8	-3.2	9100	750	0.50	1.06	0.02	1.23	-0.50	0.13
K_4	0.7	0	-0.3	-0.4	-0.9	-1.1	-1.9	-2.1	4200	1320	-0.50	0.87	-0.23	1.77	0.40	0.19
K_5	1	0.4	0	-0.5	-1.2	-1.5	-2.1	-2.9	7400	1410	-0.53	0.94	-0.04	1.06	-0.10	0.16
K_6	1.2	0.5	0.2	-0.4	-1.1	-1.4	-2	-2.7	6400	1320	-0.43	0.95	-0.02	0.69	0.00	0.15
K_7	0.9	0.3	0	-0.6	-1.2	-1.4	-2	-2.7	6400	1510	-0.56	0.86	0.05	0.99	0.10	0.17
K_8	1.8	1	0.7	0.2	-0.3	-0.4	-1	-1.7	3200	870	0.60	0.77	0.14	1.14	1.20	0.18
K_9	1.9	0.9	0.6	-0.2	-0.9	-1.2	-2	-3.0	8000	1150	-0.16	0.84	0.04	1.06	0.30	0.12
K_{10}	1.3	0.8	0.4	0.1	-0.4	-0.7	-1.6	-2.7	6400	930	0.03	0.81	-0.11	1.48	-0.50	0.17
K_{11}	1.2	0.8	0.7	0.2	-0.5	-0.8	-1.5	-2.4	5200	860	0.06	0.81	-0.25	0.92	-0.70	0.18
K_{12}	1.4	0.9	0.6	0.1	-0.4	-0.6	-1.6	-2.6	6060	930	0.13	0.83	0.03	1.22	-0.40	0.17
K_{13}	0.8	0.1	-0.1	-0.6	-1.2	-1.4	-2	-2.6	6060	1510	-0.63	0.79	-0.03	1.04	0.00	0.18
K_{14}	1.5	0.9	0.6	0.1	-0.4	-0.9	-1.9	-3.1	8500	930	0.03	0.96	-0.14	1.39	-0.60	0.15
K_{15}	2.3	1.7	1.5	0.9	0.1	-0.2	-1.1	-1.9	3700	530	0.80	0.98	-0.15	0.87	-0.60	0.14
K_{16}	0.9	0.9	0	-0.5	-0.9	-1	-1.5	-2.0	4000	1410	0.40	0.69	0.198	1.09	0.40	0.21

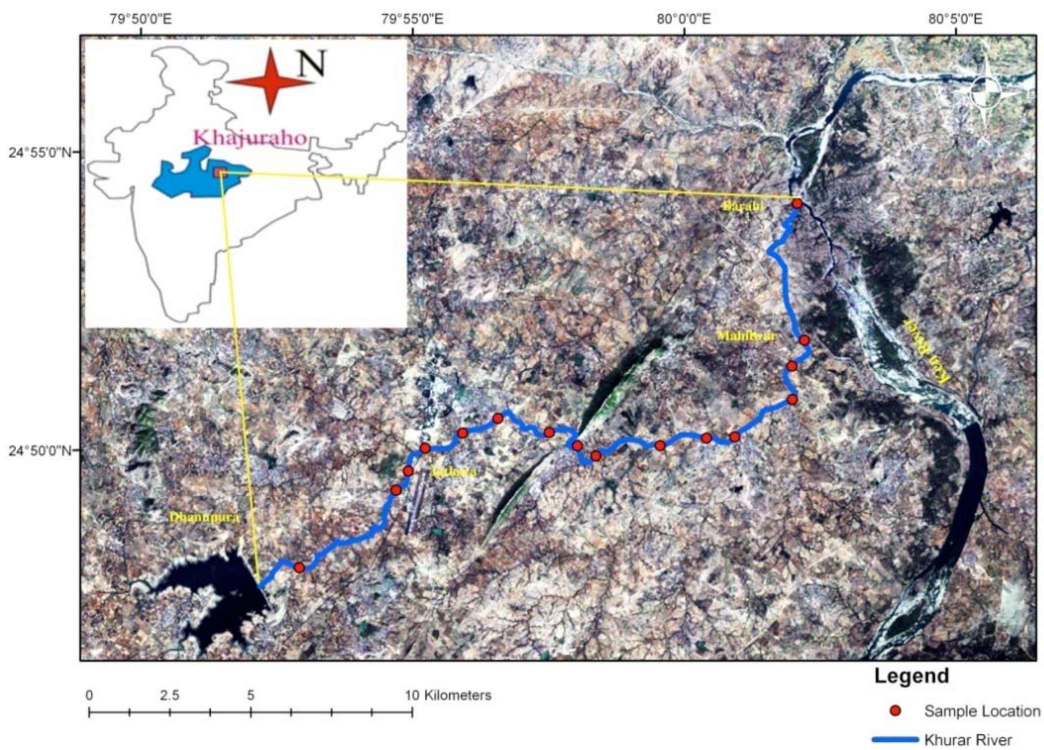

Figure 1: Satellite imagery showing the course of the Khurar River and sampling locations in the course of the river.

3. SAMPLING AND METHODLOGY

A total of forty-eight sediment samples from sixteen stations those occurs on the braid-bars were collected in the entire course of the Khurar River at an interval of about one kilometre (Figure **1**). Sampling sites were positioned by GPS and all the samples were collected from the middle part of the channel. About two hundred gram by weight of the sample was collected in each case. One each sample from each station was utilized for sieving analysis by coning and quartering method. Sieving was carried out at half phi (φ) intervals starting from 10 mesh (-1 φ), 14 mesh (-0.5 φ), 18 mesh (0 φ), 25 mesh (0.5 φ), 35 mesh (1.0 φ), 60 mesh (2.0 φ), 120 mesh (3.0 φ), 170 mesh (3.5 φ), 230 mesh (4.0 φ), and shook for fifteen minutes followed by weighing of each retained fraction. Individual weight percentages were recalculated to hundred for making them in percent. The frequency curves were prepared on simple graph paper. Cumulative curves were plotted on arithmetic probability graph paper as proposed by [8-12]. The graphic parameters proposed by [2], C-M plot to evaluate the hydrodynamic force working during the deposition proposed by [13] and log-probability values proposed by [3] were calculated from the percentile values (in φ units) of the cumulative curves. Bivariate plots were plotted considering various textural parameters along with spatial variation of sorting.

4. GRAIN SIZE DISTRIBUTION

Grain size analysis is a classical tool and provides additional information regarding sediment transport, energy conditions and depositional environment [14-19]. Various textural parameters such as graphic mean, standard deviation (sorting), skewness and kurtosis have environmental significance and are useful for understanding synsedimentary hydrodynamic factors of transportation and deposition in a basin [2, 3, 19-22].

4.1. Cumulative Frequency Curves

Frequency curves show that most of the samples are bimodal in nature, except K4, K8, K15, and K16 (Figure **2**). Also, they show that the sediment population are of very coarse to coarse-grained. The cumulative frequency curves show three to four segments in each case representing traction, saltation I, saltation II and suspension fraction within the sediments. In all, traction and saltation load dominates over suspension load.

5. TEXTURAL PARAMETERS

All the textural parameters were calculated from cumulative curves, based on different phi values. A number of formulas have been proposed by different workers to calculate four main statistical parameters viz. graphic mean, graphic standard deviation, graphic skewness and graphic kurtosis [15, 20, 23-25]. Formulas given by Folk and Ward (1957) are regarded as most suitable and used for calculation of different textural parameter in this paper (Table **1**).

5.1. Graphic Median

Graphic median values i.e. φ50 of all individual samples have been analysed statistically, denoting that half of the particles by weight are very coarse to it and half are coarse grained. The obtained values range

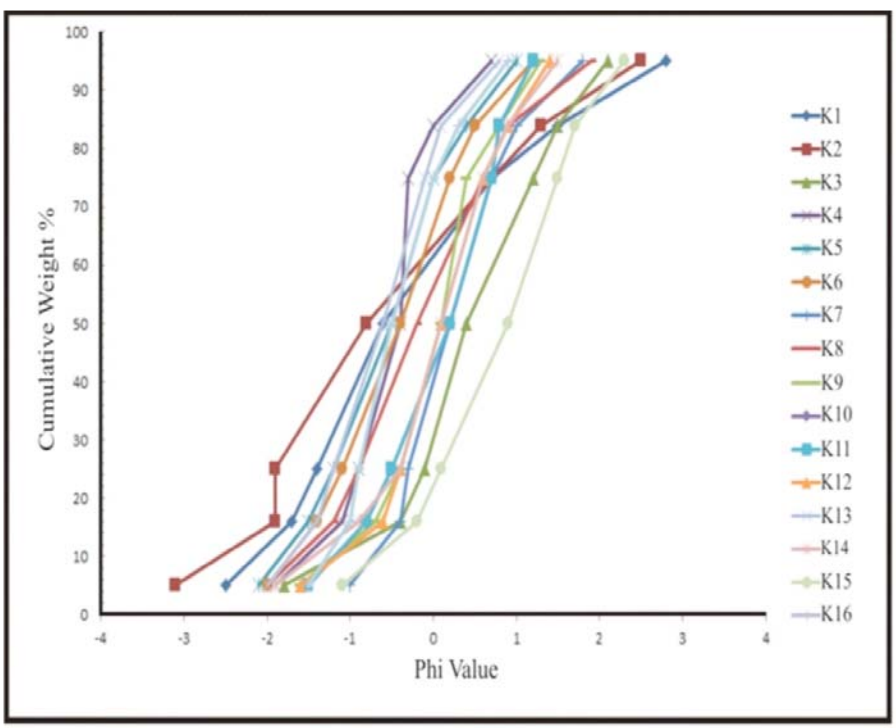

Figure 2: Cumulative curves showing the trends of all the sediment samples.

from -0.08 to 0.90φ, averaging -0.16φ. The average value of median in individual sediment samples, shows the dominance of very coarse-grained sediments. However, out of sixteen, seven samples i.e. K3, K8, K10, K11, K12, K14 and K15 show large percentage of coarse-grained sediments with φ50 values 0.4, 0.2, 0.1, 0.2, 0.1, 0.1, and 0.9φ respectively.

5.2. Graphic Mean

Graphic mean (Mz) is a measure of an arithmetic average of a series of values and is calculated by the formula φ16 + φ50 + φ84 / 3.The calculated values range from -0.63 to 0.80φ with an average value of -1.1φ. The average value of mean of all individual samples denotes that the major sediment class is very coarse grained. But few individual samples i.e. K3, K8 K10, K11, K12, K14, K15 and K16 have comparatively large fractions of coarse- grained sediments (Figure **4a**).

5.3. Graphic Standard Deviations

The graphic standard deviation (σ_1) is a measure of sorting or variation in sizes and is calculated by the formula φ84 - φ16 / 4 + φ95 - φ5 / 6.6. The values obtained range from 0.69 to 1.65φ. Samples are poorly sorted near the source of the river following a trend of moderately shorted as we go towards the downstream side and moderately well sorted near to the confluence of the river with Ken River (Figure **3**). Out of sixteen, some samples such as K1, K2 and K3 are poorly sorted having σ_1 values 1.65, 1.65, and 0.50 φ, but K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14 and K15 are moderately sorted having σ_1 values ranging from 0.77 to 0.98 φ whereas last sample near the point of confluence with Ken River K16 is moderately well sorted having σ_1 value 0.68 φ (Figure **4b**).

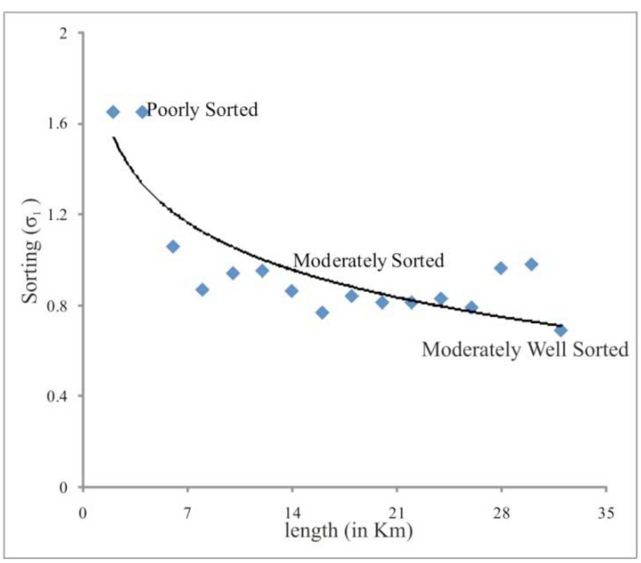

Figure 3: Spacial variation of the sorting values along the length of the Khurar River.

5.4. Graphic Skewness

The graphic skewness (Sk1) deals with the quality, state, or condition of being distorted or lacking symmetry. It is the measurement of systematic distribution or predominance of coarse or fine sediments and usually calculated by the formula φ 84 + φ 16 – 2φ50 / (φ 84 - φ16) + φ95 + φ 5 – 2 φ50 / (φ95 – 2 φ5). The skewness values range from -0.23φ to +0.29φ i.e. near-symmetrical to very fine-skewed. However, there is a dominance of near-symmetrical category in the samples of Khurar River. Seven samples i.e. K3, K5, K6, K7, K9, K12 and K13 are near-symmetrical followed by five samples i.e. K4, K10, K11, K14 and K15 are coarse-skewed and four samples i.e.K1, K2, K8 and K16 are of very fine-skewed (Figure **4c**).

5.5. Graphic Kurtosis

The graphic kurtosis (KG) is defined as the peakedness of the distribution and measures the ratio between the sorting in the tails and central portion of the curve. It is calculated by the formula φ95 - φ 5 /2.44(φ75- φ25). If the tails are better sorted than the central portions, then it is termed as platykurtic, whereas, leptokurtic, if the central portion is better sorted. If both are equally sorted then mesokurtic condition prevails.

The values obtained range from 0.69 to 1.77φ, however, there is a dominance of mesokurtic (a total of eight samples, values ranging from 0.96 to 1.09φ) to leptokurtic (a total of seven samples, values ranging from 1.14 to 1.77 φ). Only two samples K6 (0.69 φ) and K15 (0.87 φ) are platykurtic in nature (Figure **4d**).

6. INTER-RELATIONSHIP OF TEXTURAL PARAMETERS

The inter-relationship between different parameters is recognisance tool to interpret various aspects of depositional environment, as the textural parameters of the sediments are often environmentally sensitive [2, 20, 21, 24, 26, 27]. Following Folk and ward [2], six bivariate scatter plots are prepared by the combination of various textural parameters.

6.1. Mean versus Standard Deviation

The Mean versus standard deviation plot gives a great amount of information about the depositional

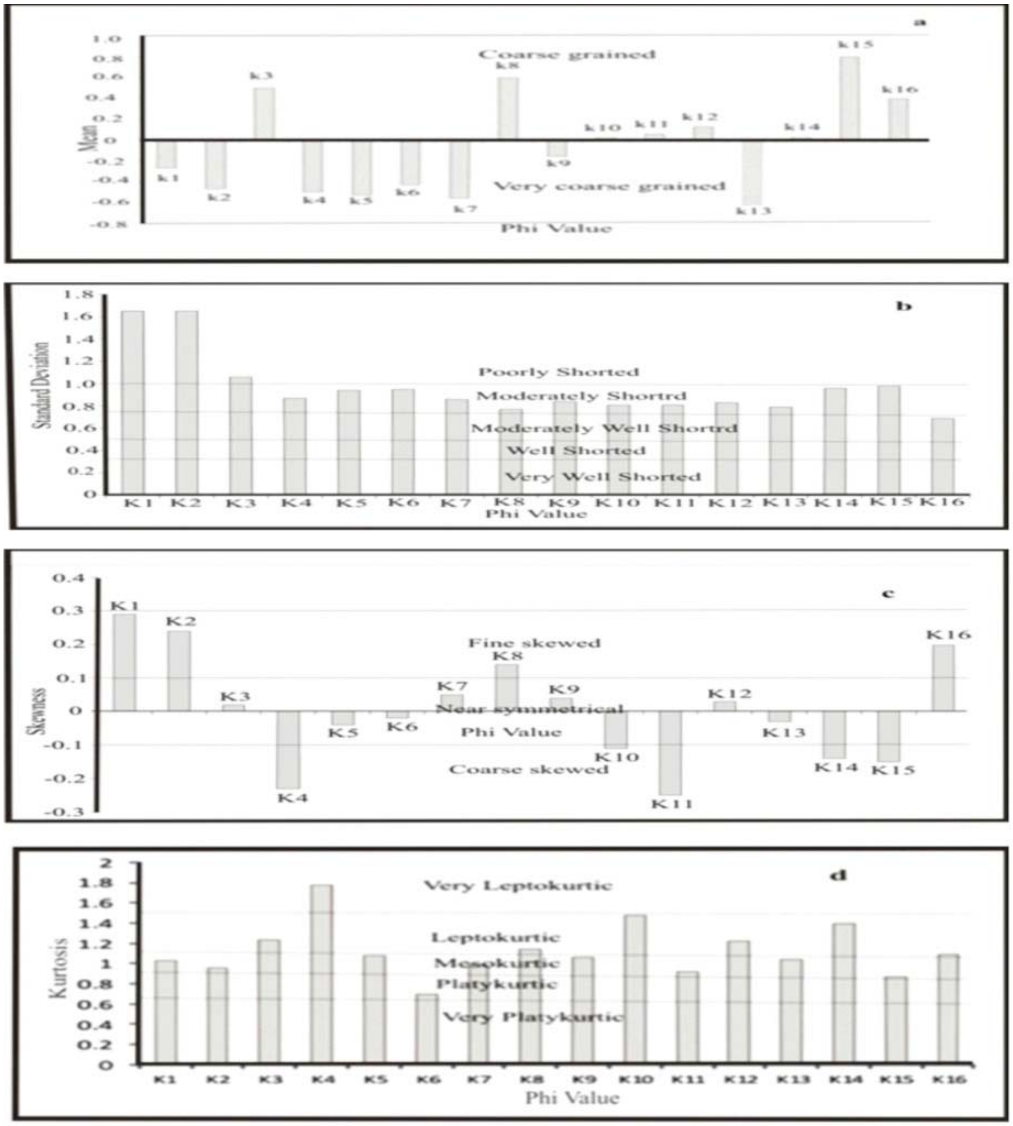

Figure 4: Comparative histograms of all samples showing variations of (**a**) mean, (**b**) standard deviation, (**c**) skewness and (**d**) kurtosis values.

environment [1, 19, 27]. If a wide range of grain size (gravel to clay) is present scatter band often form some segment of a broadened M-shaped trend, only a V-shaped or inverted V-shaped trend develops if the size range is smaller, and if range is very small, only one limb of V may occur [2]. The samples of study area shows inverted V-shape trend due to small particle size range. The distribution pattern shows the clustering of values slightly deviated from the middle position, tending towards the right limb of inverted V-shaped established trend of [2], indicating a smaller size range of the grains (Figure **5a**). The attention of sediment at right limb of V-shape plot suggests mixture of the dominant sand mode with a small amount of silt. This may also be reflected dominantly bimodal and moderately-sorted nature of sediments.

6.2. Mean versus Skewness

The sinusoidal curve of mean versus skewness following [2] was plotted. The sinusoidal nature is because of proportionate admixture of two size-classes of the sediments. In general, the ideal fractions are nearly symmetrical but the mixing produces either positive or negative skewness depending upon the proportions of size-classes in the admixture. According to Friedman [20], river sand is generally positively skewed whereas coarse grained river sand (coarse sand to gravel) may either be positively skewed or negatively skewed [28,29]. In this study the near-symmetrical values are almost confined equally in the positive-skewed area of the graph, as well as negatively skewed, in the mean-size range of -1 to 1φ (Figure **5b**). It strongly suggests a bimodal nature of sediments and mixture of the dominant sand mode with a very small amount of silt.

6.3. Mean versus Kurtosis

The relation between mean-size and kurtosis is complex and theoretical [2]. The model plot of Folk and Ward [2] denotes the mixing of two or more size-classes of sediments, which basically affects the sorting in peak and tails i.e. index of kurtosis. In the present study scattering pattern of all the samples gives rise to a V-shape trend. The nature of the plot also indicates a dominance of mesokurtic (0.90 to 1.11φ) nature of sediments followed by platykurtic (0.90 to 0.67φ) and leptokurtic (1.11 to 1.50 φ). The size of all the particles is showing a range of approximately -1 to 1φ i.e. very coarse to coarse sand (Figure **5c**). It also confirms that the sediment-admixture is dominated by sand (coarse to very coarse) and small proportion of silt. The mixing of sediments with dominant sand mode and some proportion of fine sediment makes the sorting worse, particularly in the tails; hence, there is a presence of mesokurtic along with platykurtic and leptokurtic conditions.

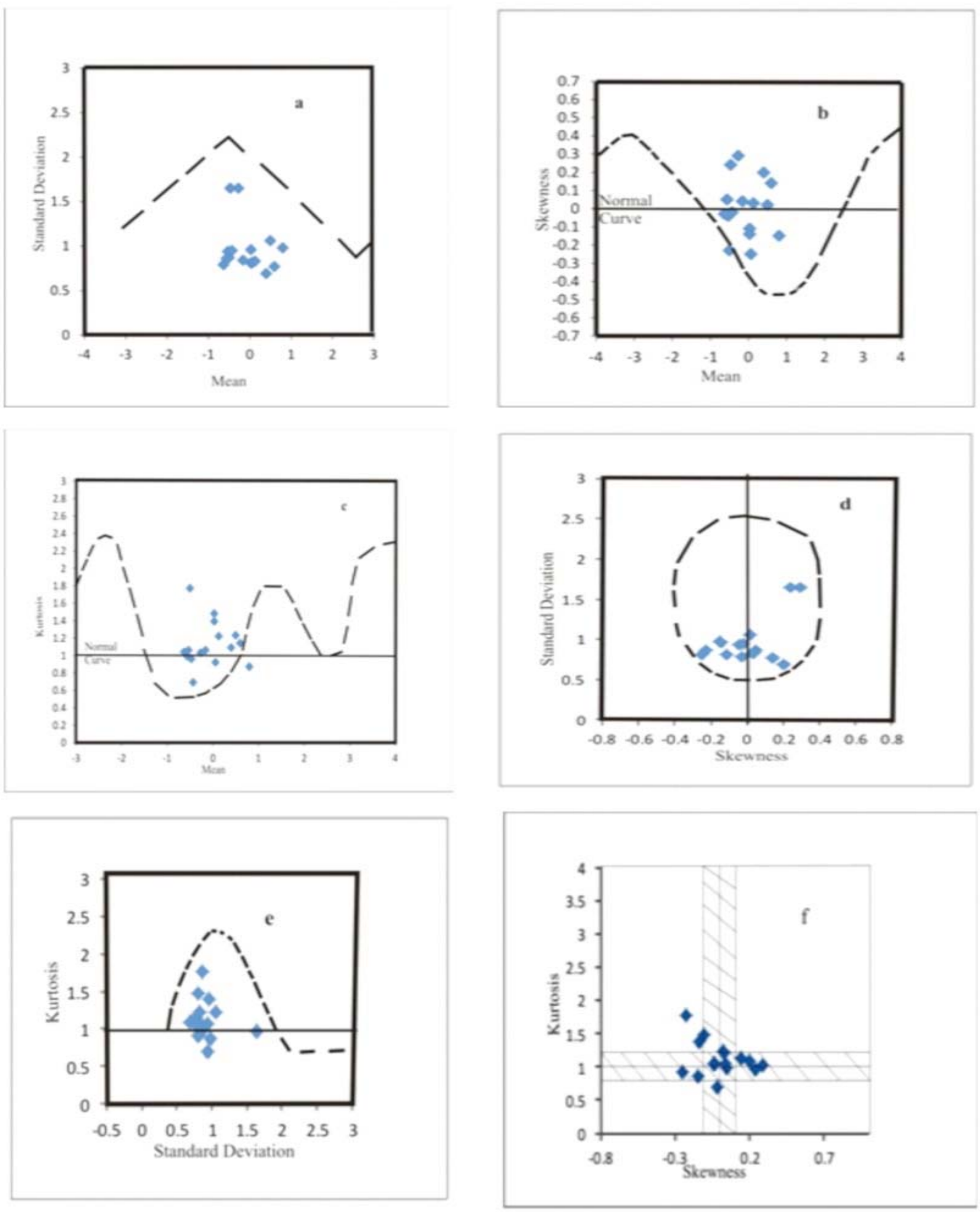

Figure 5: Bivariate plots of the sediment samples of the Khurar River (after Folk and Ward [2]). (**a**) mean vs standard deviation, (**b**) mean vs skewness, (**c**) mean vs kurtosis, (**d**) skewness vs standard deviation, (**e**) standard deviation vs kurtosis and (**f**) skewness vs kurtosis.

6.4. Skewness versus Standard Deviation

The plot between skewness and standard deviation produces a scattered trend in the form of nearly circular ring [2]. It happens due to either unimodal samples with good sorting or equal mixture of two different modes. However, the scattering of present sediments shows even clustering of grains in all sector (Figure **5d**), that suggests the dominance of sand (coarse to very coarse) mode having subordinate silt. The presence of the silt is responsible for the skewness value to deviate into the negative proportion of the plot.

6.5. Standard Deviation versus Kurtosis

Standard deviation versus kurtosis was plotted and correlated with standard plot proposed by [2], which is again followed by mixing of the varying proportions of two size-modes. Worst sorting is found in the bimodal mixtures with unequal amounts of two modes, and these also have lowest kurtosis [2]. In the present case the scatters very slightly differ from the pure sand region of the original curve of [2], indicating presence of small amount of fine-grained sediment. Most of the samples are leptokurtic along with platykurtic and mesokurtic and moderately sorted because of the dominance of sand (coarse to very coarse) size fraction (Figure **5e**).

6.6. Skewness versus Kurtosis

The plot between skewness versus kurtosis depends on two modes and follows a regular path as the mean-size changes [2]. In the present case all the values dominantly fall in an area represented by nearly pure sands, with less than 1% gravel and less than 5% silt of the establish plot of [2] (Figure **5f**).

7. C-M PLOT

In the present study C-M plot proposed by [30] is used to understand the dominant mode of transportation and the environment of deposition. All the hydrodynamic forces working during the deposition of the sediments have been analysed and interpreted by C-M plot [13, 30, 31]. Discussions on parameters C and M show that these parameters are indicators of hydraulic conditions under which sediments are deposited. In C-M diagrams, C is the one-percentile, M is the median of the grain-size distribution, characterize the coarsest fractions of the samples [31]. Percentile of the size distribution (C) in microns has been plotted against the median of the size distribution in microns (M) for the sediments (Figure **6**). It is observed that all the river sediments are above the CR line existing in segment N-O of the pattern. It indicates fairly well sorted sediments, almost entirely transported by rolling. Thus, the sediments dominated by coarse and very coarse sand deposited by the process of rolling in the Khurar River.

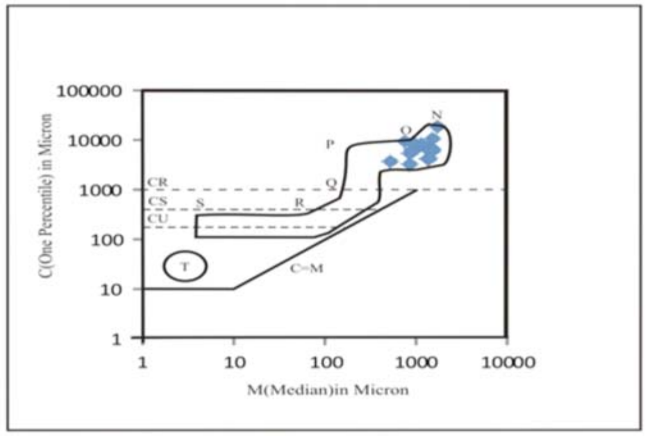

Figure 6: C-M plot showing concentration of sample points in upper left corner.

8. LOG-PROBABILITY CURVES

Log-probability curves proposed by [27] had been plotted on the log probability (ordinate) paper in which Phi values were plotted on X axis and Y axis represents the cumulative frequency percentage of constituent grains. These plots indicate the mode of transportation of sediments within a depositional medium [27, 19]. This plot indicates two or three straight line rather than a single straight line. Each segment of the curve is interpreted to show different sub-population of grains that are transported simultaneously but by different ways i.e. suspension, saltation and traction bed load. Grain size probability plots for river sands are uniquely segmented into three differently sloped components because river move material in three ways: by suspension, by saltation and as bed-load [27]. All the sixteen samples have been plotted on log probability paper and compared with established trend for modern and ancient fluvial deposits proposed by [27], generally showing the dominance of saltation with traction and suspension domain also (Figure **7**). This plot also indicates sorting of the sediment, where most of the sediments are moderately shorted probably due to prolonged transport and winnowing processes[29, 32]. In the present case, the sediments show moderate sorting even in the coarse of short distance may be because of winnowing and selective sorting of the sediments within the river.

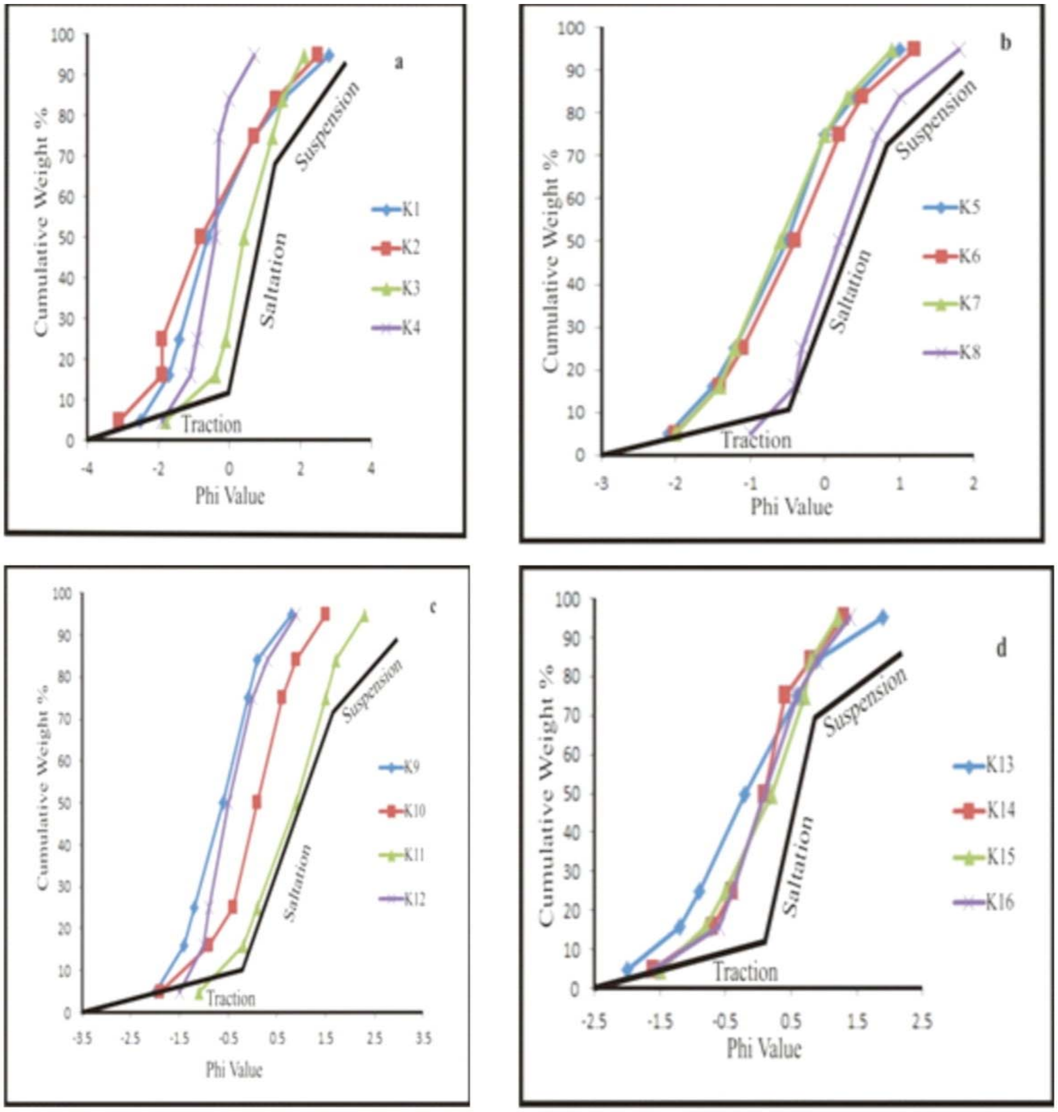

Figure 7: Cumulative frequency curves (a to d) showing the traction, saltation and suspension populations.

9. CONCLUSIONS

Grain-size analysis of sediment samples from sixteen different sites representing coarse to very coarse-grained sand of Khurar River of Khajuraho area has been carried out. The important conclusions drawn are as follows:

i) The frequency curves are dominantly indicative of coarse to very coarse-grained nature of the sediments.

ii) The graphic mean value indicates more or less equal distribution of both very coarse and coarse sand-size particles.

iii) In general, the samples show poor sorting in the beginning followed by moderate sorting to moderately well sorting at last site where the river confluences with river Ken. In most of the samples, both peak and tails are equally sorted giving rise to mesokurtic nature.

iv) All the bivariate plots between mean, skewness, kurtosis and standard deviation are indicative of bimodal nature of sediments where sand-size (very course to course) dominates with subordinate silt.

vi) All the sediments of Khurar River are characterized by the rolling process of deposition.

vii) The log-probability curves of samples are showing dominance of saltation with traction and suspension as proposed by [27].

viii) The change of sorting from poorly sorted to moderately sorted and moderately well sorted suggests that the winnowing and selective sorting is possible even in the small river depending upon the hydrodynamic condition of the river.

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