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Spatial Distribution of the Suspended Sediments in River Ganga at Varanasi, Uttara Pradesh, India

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Abstract: *This paper deals with the preliminary evaluation of the grain size distribution of suspended particles in River Ganga at bend of Varanasi city. Suspended sediments samples were collected from 14 locations along the river and 3 locations across the river. These were analyzed for grain size distribution characteristics. The results indicated a wide variation of sediment particle size across the river but less variation along the river. The increase of grain size of sediments at different locations along the river is responsible for the erosion of the left bank along the ghat side of river Ganga. The erosion at these locations has been verified by the depth profile obtained by ADCP. In addition, the distribution of suspended sediments in each sampling point shows much greater variability across the river and less variation along the river. Results drawn from this study have an important repercussion for gaining understanding of the behaviour of suspended sediment properties.*

Keywords: *Suspended particle, Grain size, Ganga, ADCP*

1. Introduction

Grain size which varies with velocity and gradient of river is an asset of sediment particles. Sediment size affects their transport and deposition rate, and therefore offers imperative evidences to the sediment attribution and depositional settings, Pye [1]. Sediments which are derived from weathering action on existing rocks, Taylor & Mclennan [2]. It leads to distribution in different grain sizes and compositions which are controlled by the physical characteristics of rocks from which they weathered Gromet et al. [3], Mclennan et al. [4], and Xu et al. [5] and they get altered by several geological actions, such as erosion and weathering, Mclennan et al. [4], and Cole et al. [6], as well as diagenesis, Holser [7], Webb and Camber [8], and McQueen [9].

Dynamics of river has major concern about the extent and character of sediment particle movement along the course of rivers instead of their linked pollutant heaps. The foremost problems associated with hydrology were those dealing with the control of soil erosion, e.g. river meandering. However, attentiveness of the widespread ecological consequence of suspended sediment particles as pollutant has headed to an incipient boundary between geo-chemistry and hydrology of river. To answer the hydrology of river, there is a developing appreciation towards the understanding of the chemical as well as physical properties of the sediment and more predominantly its particle size distribution and its characteristics. Study by Walling and Moorehead [10] emphasises on information about the sediment size of suspended sediment and associated problems with the sediment transport. The related literature reveals difference in the distribution of river particle size of sediment from altered rivers and streams in response to disparities in physiographic controls and source of material, Walling and Moorehead [11]. Therefore, it is necessary to establish linkage between the sediment characteristics and resultant processes occurring in the catchment. Up to now, only few studies have been carried out to understand the behaviour of grain-size of river sediment, Hey et al. [12], Bili et al. [13] and Klingerman et al. [14]. Further, the studies on the sediment with fine sediment of streams are very limited. Walling and Moorehead [10,11] in their study of spatial-temporal variations of suspended sediment in British rivers found that, at regional level, the connection of suspended sediment and river discharge is complex,. Xu [15], in his study at River Hanjiang, China concluded that alteration in river course affects the temporal variation of suspended particle at the downstream. Further he also pointed that variation in the distribution of suspended sediment of the Yellow River can be correlated with variations in rainfall and anthropogenic activities, Xu [16].

The accessibility to get the data about the particle size distribution are very rare as compared to river discharge data, but sediment particle distribution does express significant variation at regional and global level, because of the climate change, lithology of river and its conveyance, Walling and Moorehead [11]. Nevertheless, it is recommended in general practice that suspended particle in the water is likely to be in the range of (0.1–200) gm, Palmateer et al. [17]. Sediment particle beyond this range could be in suspension during heavy flow but normal flows of rivers do not have enough potential to re-suspend

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these bigger size particles, Dickinson [18]. Occasionally it has been claimed that flow of river has foremost control on the distribution of sediment, and therefore a correlation between flow of river and the extent of sediment particle size in transport can be established, Walling and Moorehead [11].

In comparison to many other rivers of the world, only few studies have been focused on the understanding of the distribution of sediment grain-size in river Ganga. The actions of the sediments rely more on the fraction of finer particles of the sediment than the coarser particles. Particle dimensions and compactness of the deposited sediment play an important role in determining the extent to which the flow velocity influences sediment transport. Jones and Lawton [19], indicate that faecal pellets of deposit feeders can increase the sediment grain size from fine mud to fine sand i.e. from 16 µm to 250 µm.

Past work on stratification effects on the sediment particle in extremely rigorous sediment, Winterwerp [20], Winterwerp [21] discovered the presence of three flow regimes such as sub-saturated low concentration flow, supersaturated flow, and sub-saturated hyper concentrated flow. Systematic granulomatric studies of various Indian rivers have been done by many investigators Chaudhary et al. [22], Rajamanickam and Gujar [23], Rajamanickam and Gujar [24], Rao et al. [25], Angusamy and Rajamanickam [26], Angusamy and Rajamanickam [27], Gandhi et al. [28] and Anithamary et al. [29]. The sedimentology of coast deposits also plays a key role in supporting the deposition and most of the experts are concerned about following facets of particle size;

- Measurement techniques for grain size distribution and proper scale to represent it
- Quantification of grain size and its presentation in graphical and statistical format
- The hereditary implication of data, Boggs [30]

In this paper, the grain size distribution characteristics of suspended particles in river Ganga at bend of Varanasi city are presented. The samples were collected between 2014 and 2015 which were then analysed to derive information for a better understanding about the circulation of suspended sediment particle along and across the river Ganga.

2. Study Area

To collect suspended sediments, we targeted the main river Ganga at Varanasi that is located between 25˚20'N and 83˚7'E. It is considered as oldest city of India and positioned on the bank of river Ganga as presented in figure 1. The river Ganga is considered as the lengthiest river having a total draining length of about 2525 km from origin to termination.

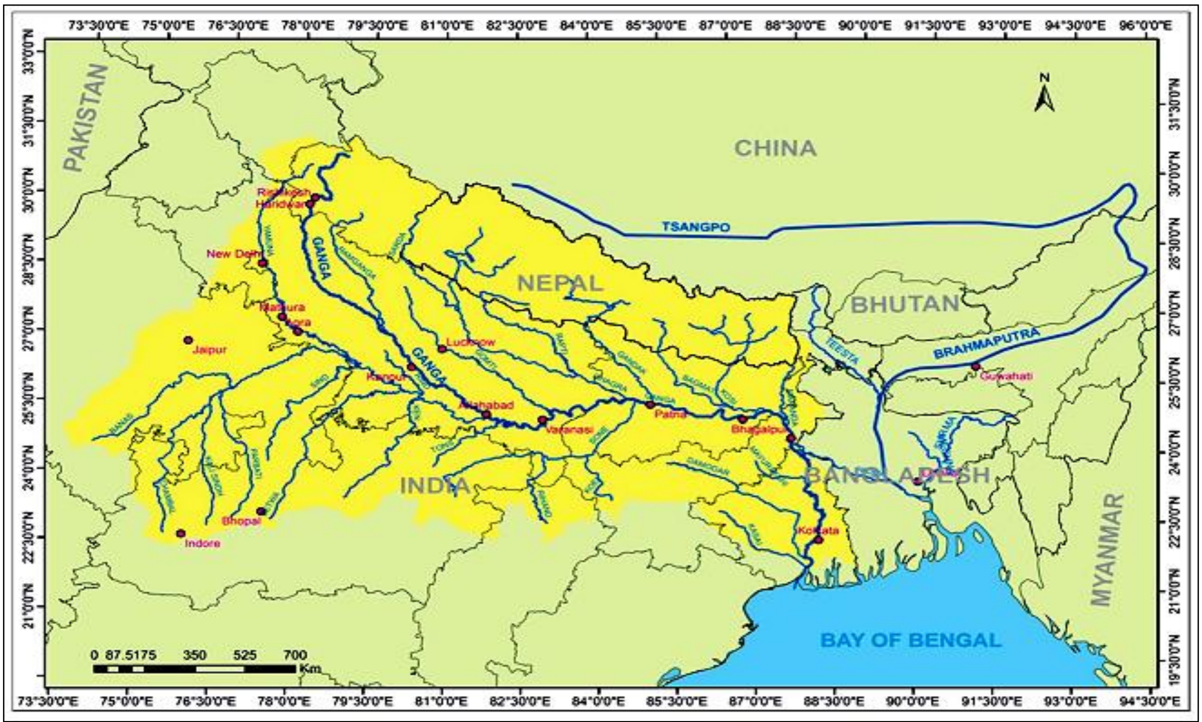

Figure 1. *Map of Ganga basin (Source: Jin et al. [31])*

Rainfall, subsurface flow, glacier and snowmelt from the Himalayas are the prime sources of water in Ganga and its tributaries. Annual precipitation falls stuck between (300-2000) mm, with the western side of the region receiving less rainfall in comparison with the eastern side, Whitehead et al. [32]. The climate of the area is tropical with temperature varying between 5˚C in winter to 45˚C in summer, Singh et al. [33]. The cross sectional dissolved oxygen profile of river Ganga at Varanasi according to Griffiths [34] is shown in figure 2.

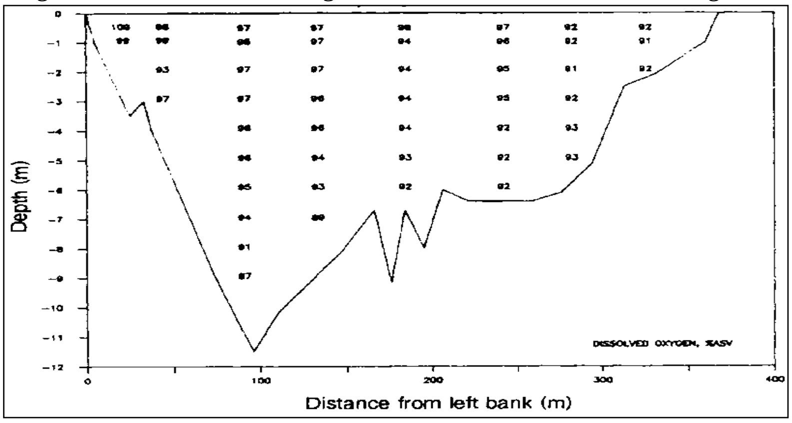

Figure 2. *Profile of cross-sectional dissolved oxygen of the River Ganges at Varanasi (Source: Griffiths [34])*

According to CPCB [35], the total wastewater that discharges into river is 8250 ML per day, which influences the growth of bacteria and other organisms that affects the distribution of sediments along the course. Figure 3 shows the isohytal map of the Ganga basin and the marked circle shows the isohyets of study area.

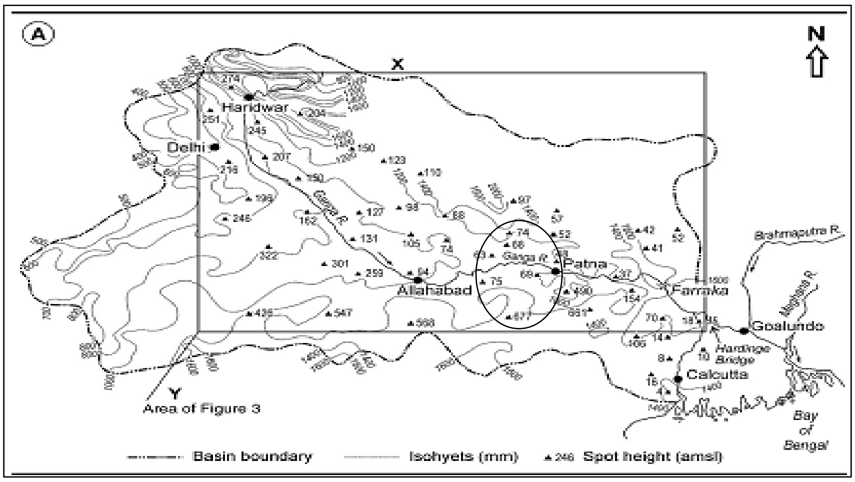

Figure 3. *Rainfall isohyets of Ganga basin (Source: Singh et al., [33])*

Outflow from the river Ganga shows prodigious seasonality (figure 4) as a result of monsoon. Discharge is high (86% of total flow) during the month of June to September whereas during post monsoon (October-December) value is 8% and in winter and summer value is 3%. The maximum annual discharge observed in a year was $46{,}186 \times 10^6$ m^3 Singh et al. [33].

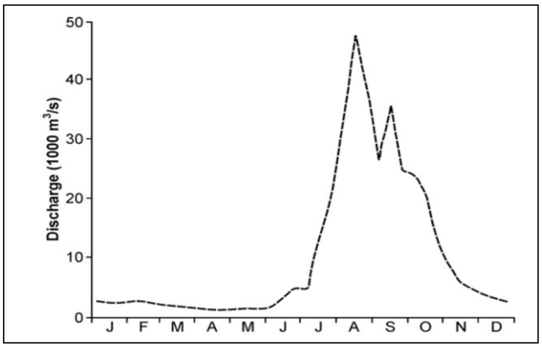

Figure 4. *Hydrograph of river Ganga (Source: Singh et al., [33])*

3. Description of the sampling

In a river, suspended sediments are created due to rolling and saltation and supported by current of the river. To carry out the analysis of distribution of sediment grain size, the sediment samples were collected from three locations i.e. Left bank, middle and right bank at 14 different cross-sections (M1-M14) at Varanasi bend as shown in figure 5. The complete study possesses 14 cross-sections along the river therefore the total number of samples analyzed was 42. All samples were collected during the month of May 2014 when the discharge in the river is low. Sampling locations were chosen carefully to avoid any disturbance from anthropogenic activities.

The study is carried out to define the fraction of different grain sizes within the collected samples. Sieve analysis was performed to determine the distribution of particles of different sizes. The understanding of distribution of altered and grain sizes helps to understand the engineering of sediment over the discharge behaviour. Further, the grain size distribution study is required to classify the sediment samples present over different cross sections which reveal the morphometric of river. Three typical samples of sediment were collected and put in polyethylene bags and kept at 4° C. Before conducting the sediment size analysis, sodium phosphate $(Na_2PO_3)_6$ was added to collected sediments to separate the samples; organic matter and $CaCO_3$ were also removed by adding 10% H_2O_2 and 10% HCL into the collected sample.

Figure 5. *Locations of sampling site (Source: Chauhan [36])*

4. Methodology

The methodology adopted for determining the distribution of grain size is as:

- The collected samples were first oven dried for 24 hours at 100 to 150^0 C to ensure presence of no moisture.
- The oven dried samples were then crushed with the help of a hammer.
- An amount of 500 gm of crushed sample was taken for the sieve analysis.
- The weight of each sieve as well as the bottom pan to be used in the analysis was noted.
- The cleaning of all the sieves was ensured and then these were lumped together in increasing order of sieve size (2000 μm sieve size on the top and 45 μm sieve size at the bottom). The pan was placed below 45 μm sieve. The sediment sample was emptied into the upper sieve and a cover was put over it.
- The sieve stack was placed in the automatic sieve analyzer shaker and it was shaken for 2 minutes.

The stack was taken away from the shaker and carefully weighed and the weight of each sieve with its retained sample was recorded. In addition the weight of the bottom pan with its retained fine soil was recorded.

4.1. Sieve analysis: As per ASTM C136 [37]

- Calculate the weight of sediment particle retained on each sieve by subtracting the weight of the empty sieve from the weight of the sieve and retained soil, and record this on the data sheet as the weight retained. The sum of these retained weights should be approximately equal to the initial weight of the soil sample. A loss of more than two percent is unsatisfactory.
- Estimate the percentage retained on each sieve by dividing the weight retained on each sieve by the original sample weight.
- Calculate the percentage passing (or percent finer) by starting with 100 percent and subtracting the percentage retained on each sieve as a cumulative procedure.

5. Results and Discussion

Suspended particles in river play a key role in ecological dynamics and the transportation of microbial constituents. The analysis of grain size of the suspended sediments which are being transported and are in suspension state in the river Ganga differ from one cross section to another and across the river as shown in figure 7 depending on the grain size weight of the sediment particle. The grain size distribution shown in figure 6 of river Ganga at Varanasi bend, reveals that size of the grain increases on left bank at section, M 3, M 6-8, M 10, M 12, and M 14 .The grain size of sediments at M 1 and M 5 are large whereas the size of sediments at section M 2, M 4, M 9, M 11, and M 13 increases at right bank which is the sedimentation site of the grains. The increase of grain size of sediments at M 3, M 6, M 7, M 8, M 10, M 12 and M 14 is responsible for the erosion of the left bank along the Ghat side of River Ganga.

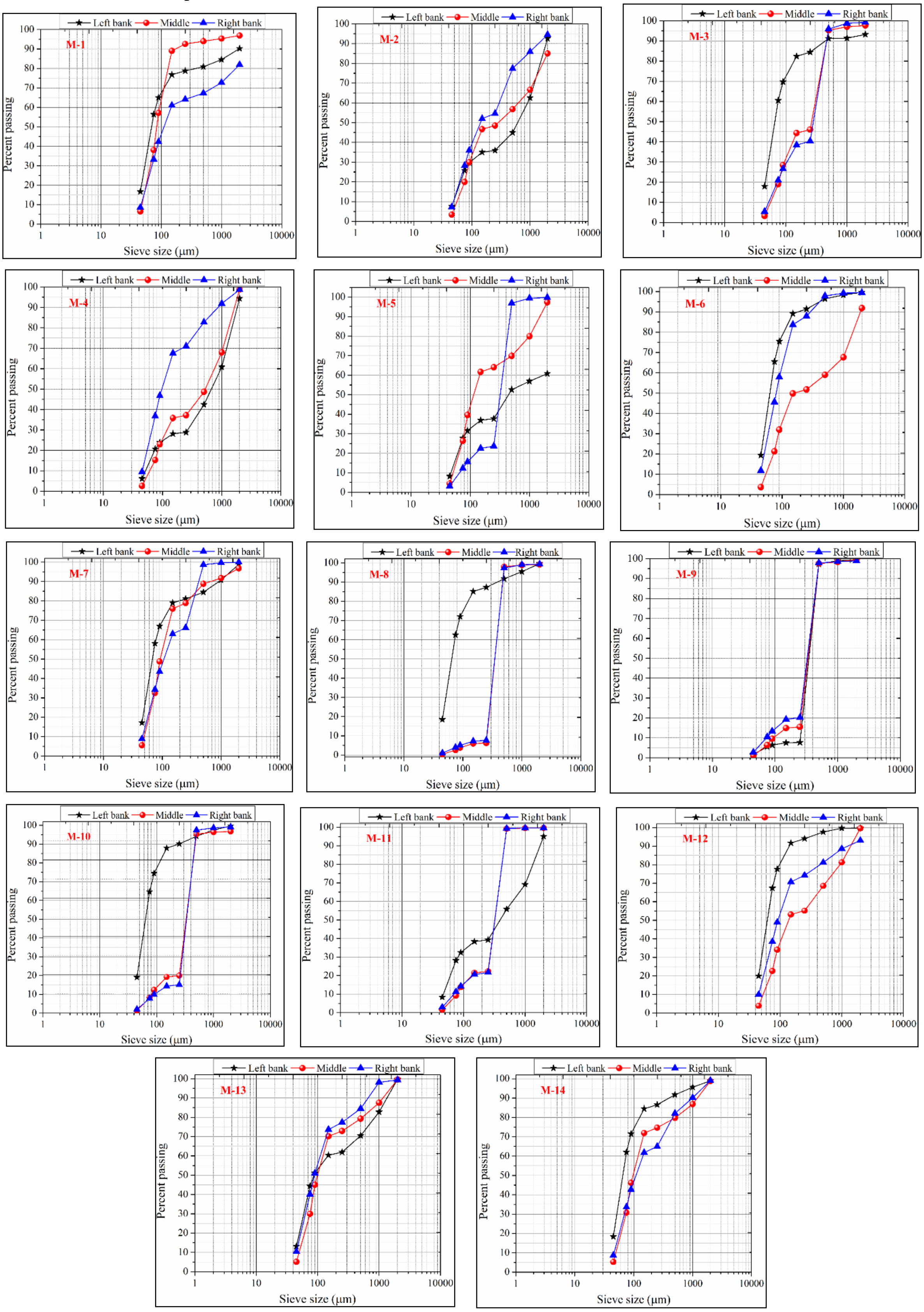

Figure 6. *Distribution of grain size in the river Ganga at different cross-sections (M1 to M14)*

The erosion at these sections can be easily verified by the depth profile obtained at this section by ADCP Chauhan et al. [38] and Chauhan [36] which indicates that with increase of grain size the rate of erosion of sediments increases. These sediment distributions are in good agreement with existing information on the absolute particle size characteristics of suspended sediment Singh et al. [33]. Some differences are to be expected in view of the operationally defined nature of particle size measurement.

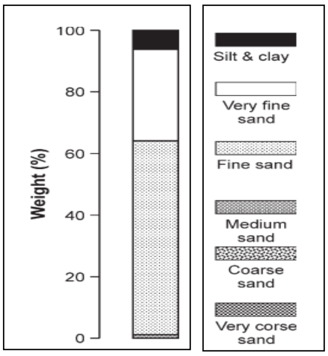

Figure 7. *Sediment distribution*

The sample analysis shows that the sample contains sand, silt and clay grade particles (Figure 7). The sediment particles having high proportion of silt and fine sand are usually most erodible which is mainly dependent upon the particle size distribution, texture, permeability and fibrous organic matter content. The ability of soil to absorb water or surface runoff is characterized by its permeability. The average size of sediment particles in the samples collected from different sampling locations of River Ganga at Varanasi ranged from 46.1–72 µm. Average grain size of sediment from 71% locations (M1-M3, M5-M7 and M11-M14) having size more than 50 µm whereas 29% of sampling locations (M4, M8 – MM10) were having less than 50 µm.

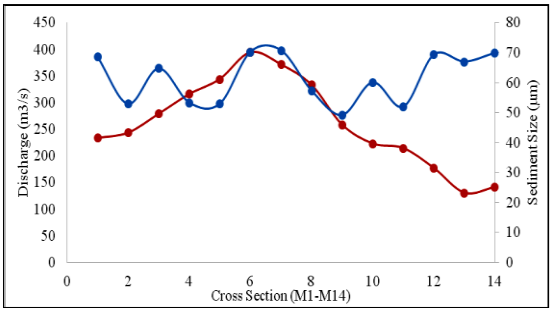

Figure 8. *Average sediment size variation with discharge*

The river Ganga is a meandering river which is specified by the sinuosity defined as the ratio of centreline length to wavelength of meander. Along the bend of river Ganga, centrifugal acceleration influences the flow, which is characterized by a helical motion with a super-elevated free surface. Flow near the free surface is deflected towards the outer bank and near the bed is inclined towards the inner bank. As a river actively curves to flow, obvious erosion takes place at the outer bank (looking convex from the ground alongside the stream) of the bend. The sediment eroded from the outer bank is transported inward and deposited on the inner edge of the next bend downstream, where the flow velocity is slower, building up an inner point bar. Figure 8 depicts the average grain size behaviour with the discharge. The coarser sediments tend to collect near the outer banks with a gradual fining towards the inner banks.

5.1. Sediment statistics

Statistics of the grain-size distribution were computed using U.S. Geological Survey Marine Geology grain-size method, McHendrie [39]. Grain-size statistical parameters and graphic representations were measured in phi (Φ) unit. The phi unit (Φ) is a logarithmic transformation of millimetres into whole integers, according to the formula $\Phi = -\log_2 (D/D_0)$. Where Φ is Krumbein phi scale, and D is the diameter of the particle and D_0 is a reference diameter, equal to 1 mm. The statistical parameters considered for analyses include mean, standard deviation, skewness and Kurtosis and summarised in Table 1. Mean of the particle size describes the average size of the particle and is calculated as:

$$Mean\ (M) = \frac{\Phi 16 + \Phi 50 + \Phi 84}{3} \quad (1)$$

Standard deviation describes the variation in sizes and is calculated as:

$$Standard\ Deviation\ (SD) = \frac{\Phi 84 - \Phi 16}{4} \quad (2)$$

Skewness of particles shows whether the distribution is bell shaped or shifted to side and is calculated as:

$$Skewness(S) = \frac{\Phi 84 + \Phi 16 - 2(\Phi 50)}{2(\Phi 84 - \Phi 16)} + \frac{\Phi 95 + \Phi 5 - 2(\Phi 50)}{2(\Phi 95 - \Phi 5)} \quad (3)$$

Kurtosis shows the shape of distribution whether distribution is bell shaped, very flat, or very peaked and is calculated as:

$$Kurtosis\ (K) = \frac{\Phi 95 - \Phi 5}{2.44(\Phi 75 - \Phi 25)} \quad (4)$$

On analysing mean sediment distribution along the river, the difference in the value of sediment distributions was found along the river course (M1 to M14). The results of this analysis revealed that the particle-size distributions between the samples from different cross sections are statistically identical suggesting no overall difference along the river sediment size. Analysis of kurtosis reveals that the sediments along cross sections (M1-M7 and M12-M14) have kurtosis value less than three which indicates distribution produces fewer and less extreme outliers than does the normal distribution whereas on bend of the river (M8 –M11) the value of kurtosis is more than 3 suggesting that the distribution has tails that asymptotically approach zero more slowly than a Gaussian, and therefore produces more outliers than the normal distribution. The sediment size distribution becomes complicated due to presence of flora, heavy mineral, and other hydraulic factors. Skewness also showed no trend but it can be said that the sediment size distribution was near symmetrical.

***Table 1**: Summary of suspended sediments of the Ganga River at Varanasi*

Cross-Section	Mean	Standard Deviation	Skewness	Kurtosis
M1	0.845	1.54	0.32	1.93
M2	0.542	1.49	0.62	2.31
M3	0.408	1.41	0.79	2.74
M4	0.327	1.44	0.83	2.71
M5	0.640	1.53	0.51	2.11
M6	0.55	1.51	0.59	2.25
M7	0.75	1.53	0.41	2.02
M8	-0.197	0.88	1.22	6.41
M9	-0.03	1.09	1.29	5.11
M10	0.053	1.16	1.22	4.5
M11	0.080	1.19	1.19	4.29
M12	0.534	1.5	0.61	2.28
M13	0.698	1.53	0.45	2.05
M14	0.718	1.54	0.43	2.02

6. Conclusions

The sediments from Ganga River at Varanasi show a mixture of gravel, sand, silt, and clay particles. Understanding of such particle size distribution will enhance our ability to interpret erosion behaviour at bend, its effects on river hydraulics. Statistical analysis of the sediment behaviour reveals that the particle-size distributions along the river course were statistically identical suggesting no overall difference. The lack of any large change in the sediment size and its distribution was a surprise finding for river Ganga. River Ganga at Varanasi showed slight positive skewness, and were consequently found to be positive to very positively skew.

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