Sediment size variation in field sampled Bed Load Transport of an ephemeral Mountain river

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Abstract: Ephemeral channels are ever changing like chameleons and constantly challenges the field researchers. Sampling of bed load and suspended load in a quick response mountainous channel is a test of coordination, skills and luck. The channel shows great variation in sediment size distribution of bed load sediment transport over space and time. The measurement in the field indicates that the variation in sediment size in bed load not only depends upon the favorable slope and thereby flow velocity, but also the sediment fed from the upstream. The single large sediment can affect the whole distribution in a gravel bed stream. The flash floods after the precipitation causes large particles to move due to sudden flow thrust. This could dislodge other large and small sediments in bed during its movement. The movement of large sediment causes variation in sampling as it comes closer to entrance of a bed load sampler. The bed load sampling carried out collected using modified Helley Smith Sampler in a mountain ephemeral river of Gujarat revealed large variation in the sediment size. Sudden spikes in the median diameter of the sediment sample leads to large error in prediction of bed load transport rate using various bed load equations given by different researchers. This significantly and adversely affect the chances of finding an appropriate bed load equation suitable for the study river and often compels field engineers to rely on thumb rules of estimating sediment transport rate, which may sometimes lead to undesirable surprises. This study aims to give an idea about the extent to which this variation in the sediment size is generally observed.

Index Terms: Bed load transport, HS Sampler, mountain river, sediment sampling, Sediment distribution

1. Introduction

Sediment transport rate is an important natural phenomenon. This behaviour of river can significantly affect the design and performance of a hydraulic structure through varying and unpredictable process of erosion and deposition. The dependency of sediment transport phenomenon on large number of stochastic parameter is highlighted by many researchers and is now a common understanding. The attempts to predict mathematically or analytically, the sediment transport behaviour of a channel has found limited success in application. The practical solutions for practicing field Engineers still remain to trust some selected empirical equations suggested by different authors using different approaches. The validity of these equations vary from site to site, sometimes giving large errors, and thus offers no universal solution. Some thumb rules based on the discharge in the river and bed and boundary characteristics can be used for small projects. Any large project across the river requires long term sediment discharge data largely unavailable in Indian context. This highlight the relevance and necessity of field measurement of sediment transport during different discharge conditions.

Sediment transport comprises of Bed Load, Suspended Load and Wash load, often considered as part of Suspended load. CWC (Central Water Commission) has been actively measuring the suspended sediment concentration at different points along with gauge and discharge in the rivers of India. However, some smaller streams, though significant in local context, are still out of its coverage. Such smaller streams include ephemeral rivers in mountain and hills. These streams lack the sediment transport data which is even more important for structures in the hilly region. The regular measurement of Bed Load has not been pursued by any government body or public/private enterprise like construction companies.

The measurement of bed load is a challenging task. It involves the measurement of following parameters:

1) Geometrical Parameters- X-section, Longitudinal slope, side slope, Lateral Slope, Bed Forms, etc.

2) Flow Parameters-Velocity, Depth, Temperature, etc.

3) Sediment Parameters- Concentration, Rate, Density, GSD, etc.

The field measurements in a hilly ephemeral stream are even more challenging. The large spatial and temporal variation of flow characteristics can affect the sediment transport behaviour drastically. Bed configurations in mountain rivers are much more complex than in plain rivers, owing to steep slopes, poorly sorted surface grains [1], [2], wide grain size distributions, heterogeneity in bed topography, large and immobile boulders, pebble clusters, etc. [3]. Soil characteristics of the bed and channel boundaries are vital and the large variation in the bed sediment size, often ranging from Boulders to Sand, can also affect the sediment transport behaviour of the stream. The cross-section of the stream is narrowed by the boulders and acceleration is induced to flow around boulders with remarkable reduction of flow velocity at the upstream of the boulders [4]-[6].

The measurement of field quantities can help in finding the suitable empirical equation for a study area from the available existing bed load equations. The bed load equations were mostly developed on the basis of experimental observations and have been found to overpredict by order of magnitude when tested for natural rivers [7], [8]. A possible reason of overprediction by such equations can be assumption of constant value of critical shear stress for grain entrainment, but measured values can vary by almost an order of magnitude between rivers. [9]. Besides knowing the bed load transport rate, the field measurements also indicate the nature of bed load in terms of sediment characteristics, primarily size. Bed load with different sizes can be grouped into two types: travelling bed load and structural bed load. Travelling bed load is composed of sediment finer than a critical size, Dc, and its transport rate depends mainly on the incoming sediment rate. The transport rate of traveling bed load (D < Dc) can vary significantly, depending on the incoming rate of sediment; while the rate of structural bed load transport depends mainly on water flow [10].

2. study area

The Ambica river basin is selected as study area as it provides an ideal combination of gravel and sand bed composition during different stages of its course. The river originates in Saputara and flows down to meet Arabian Sea.

Ambica River has its basin area of 2715 km2 in Gujarat and Maharashtra. The basin lies between 20° 31' - 20° 57' N latitude and 72° 48'-73° 52' E longitude. It is one of the biggest west flowing rivers. It is divided into two zones. The eastern part consists of rugged mountain chain of Sahyadri Western Ghasts with the elevations ranging from 1050 m to 100 m. The western part consists of hills and valleys which are having elevations less than 100 m. It originates from Saputara Hills. It drains in to Arabian Sea after flowing for the approximate length of 136 km. Kapri, Wallan, Kaveri and Kharera are the important tributaries of the Ambica River. The basin map of Ambica River is shown in Figure 1.

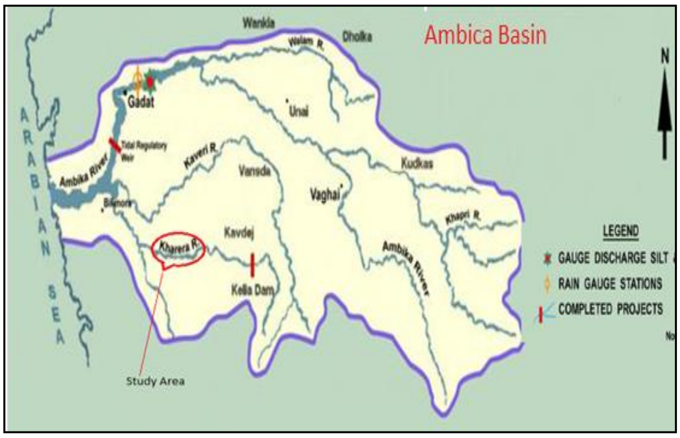

Fig 1. Study Area (Kharera River-Ambica Basin)

(Source: http://www.india-wris.nrsc.gov.in/wrpinfo/images/d/d2/Ambica_basin.png)

The stream bed consists of sand, gravel and cobble. The basin is largely forested with the sparse shrubs. The stream has been selected for the collection of the sample data because of the flow depth of about 0.2 - 0.8 m and the width of the stream at the stream was well defined at the time of monsoon period.

3. field measurements

Field measurements were carried out at the study area during monsoon season at three cross sections at 3, 8 and 13 m distance from Right Bank of river (Fig. 2). Fig. 3 shows the flow conditions of high flow during monsoon. The measurements were performed using standard field equipments like Dumpy level (cross section measurement), current-meter (velocity) and modified Helley Smith Sampler (bed load sampling) (Fig. 4). The collected samples were processed in the laboratory subsequently. The collected samples were oven dried and then sieved using standard sieves to obtain gradation of the bed load.

Fig 2. Cross-sections for sampling

Fig 3. Flow conditions during monsoon

Fig 4. Cross-section measurements at site during monsoon flow

4. Summary of measured Hydraulic and Sediment Data

During the **monsoon** and sufficient flow conditions, the depth and velocity were measured using current meter at the section-A, B, C. The bed load samples were collected using modified H-S sampler. The numbers of points across the section were taken as 3 due to multiple simultaneous data collection and the short period of flow.

The longitudinal slope and cross-section levels were measured before and during the sampling. The flow depth (d) and velocity at 0.2d, 0.6d & 0.8d were measured at each sampling**.** The summary of data collected during the monsoon 2019 is given in Table 1 and the range of Hydraulic data is given in Table 2.

Table 1. Summary of Samples collected during Monsoon

S	Section	Later	Helley

. No.	(Longitudinal)	al Points	Smith Samples
1	A	3	4
		8	5
		13	7
2	B	3	2
		8	3
		13	4
3	C	3	3
		8	2
		13	4

Table 2. Range of hydraulic data collected from field sampling during Monsoon

S. No.	Observed Parameter	Range		
		Min.	Avg.	Max.
1	Flow Depth (m)	0.10	0.406	0.85
2	Mean Velocity (m/s)	0.0719	0.5226	1.1867
3	Discharge (m^3/s)	0.0363	1.2020	4.0283
4.	Median Sediment Size (HS) D_{50}, mm	0	3.539	10.97
5.	Bed Load Transport Rate (g/ms) (HS)	0	1.2689	6.0951

The bed load samples collected from HS sampler show similar composition and have sediments falling in categories of Coarse sand to pebble (0.5-16.0 mm).

Table 3 presents the Grain Size Distribution (GSD) of a sample (R1S2) of bed load measured using HS sampler at site. The plot of GSD is shown in Fig. 5.

Table 3. Grain Size Distribution of a Bed Load Sample using HS Sampler

R1S2				
Sieve size(mm)	weight retained (gm)	% weight retained	Cumulative % weight retained	% finer
20	0	0	0	100
10	12	11.764	11.764	88.235
4.75	14	13.725	25.490	74.509
2.36	11	10.784	36.274	63.725
1.18	29.5	28.921	65.196	34.803
0.5	27	26.470	91.666	8.333

0.3	8.5	8.333	100	0
0.15	0	0	100	0
0.075	0	0	100	0
Total Weight -	102			

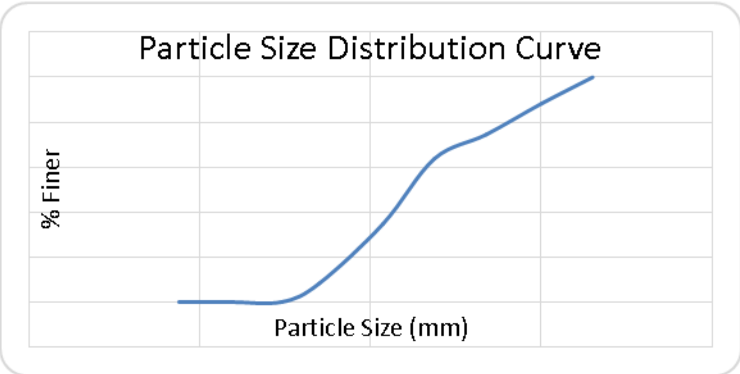

Fig 5. GSD Curve for the Bed Load sample R1S2 by HS Sampler

The GSD curves were plotted for all the bed load samples and various sediment sizes, like d50, d10, d60, etc. were calculated. A sample of observed sediment sizes are shown in Table 4 and the Table 5 shows the sediment size at different laterals of the sections corresponding to the flow rate.

Table 4. Different sediment size (mm) for samples of HS sampler at 13 m from right bank

SAMPLE ID	D10	D16	D30	D35	D50	D60	D80	D84
R1S3	1.42	1.71	2.40	2.81	4.046	4.96	7.93	8.532
R2S3	0.73	0.98	1.79	2.12	4.152	5.98	9.84	11.876
R3S3	0.48	0.60	0.91	1.01	1.521	1.97	5.20	6.167
R4S3	1.35	1.81	4.51	6.35	10.972	12.7	16.3	17.11
R5S3	0.94	1.32	2.13	2.53	4.729	6.43	9.84	11.628
R6S3	0.60	0.87	1.63	1.95	3.668	5.32	9.49	10.886
R7S3	0.84	1.04	1.62	1.84	2.758	3.95	6.85	7.48
R8S3	0.67	0.89	1.53	1.81	3.555	5.93	12.3	14.866
R9S3	1.01	1.34	2.00	2.24	3.794	5.03	8.39	9.062
R10S3	0.41	0.48	0.80	0.91	1.376	1.92	7.76	10.568
R11S3	0.87	1.09	1.56	1.72	2.212	3.07	6.15	6.92

R12S1	1.31	1.65	2.54	3.07	4.67	6.18	9.27	9.893
R12S2	0.63	0.98	1.91	2.25	4.218	6.15	12.6	16.133
R12S3	0.56	0.74	1.15	1.82	4.152	5.45	7.72	8.18
R13S3	0.80	1.09	1.71	1.92	2.964	4.13	9.30	10.987

Table 5. Median Size of sediment for Bed Load measurements by HS

S. No.	**Distance from right Bank**	**Sample ID**	**Bed Load Transport Rate (g/ms)**	**Median Diameter, D50 (mm)**	**Segmental Discharge (m3/s)**
1	3	R1S1	0.0273	1.77	0.273
2	3	R2S1	0.6671	5.21	0.225
3	3	R3S1	0.4593	1.08	0.574
4	3	R4S1	0.0000	5.92	0.547
5	3	R5S1	1.1155	2.84	0.689
6	3	R6S1	0.6671	4.03	0.451
		Avg.	0.4894	3.4739	0.460
1	8	R1S2	0.4703	1.80	0.659
2	8	R2S2	0.1312	2.34	0.494
3	8	R3S2	0.2187	1.67	1.267
4	8	R4S2	0.1750	8.33	1.075
5	8	R5S2	1.4162	9.67	1.109
6	8	R6S2	0.2351	5.07	0.970
7	8	R9S2	0.7218	3.56	0.316
		Avg.	0.4812	4.6328	0.841
1	13	R2S3	1.3233	4.15	1.947

2	13	R3S3	0.0000	1.52	0.963
3	13	R4S3	0.0000	10.97	1.162
4	13	R5S3	0.6999	4.73	1.475
5	13	R6S3	0.9077	3.67	0.903
6	13	R8S3	1.2467	3.56	2.116
7	13	R9S3	0.3992	3.79	1.993
8	13	R12S1	3.2663	4.67	1.199
		Avg.	0.9804	4.6334	1.470
	Overall Average				0.924

A rating curve between segmental discharge and bed load transport rate was plotted (Fig. 6) to obtain the degree of correlation. The equation obtained can be used to predict the bed load transport rate for a given discharge.

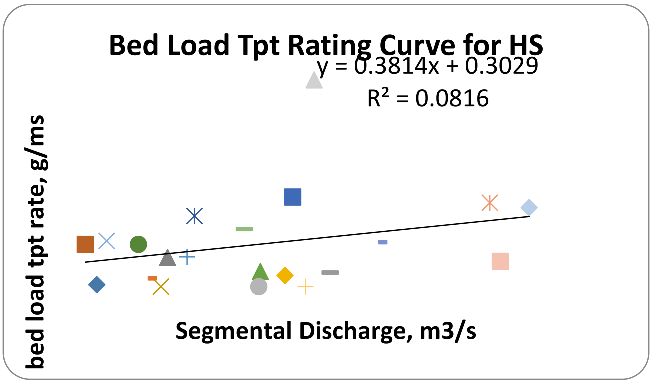

Fig. 6. Rating curve for bed load transport rate

Flow competence curves were plotted for the observed discharge and the median size moved as bed load. A sample curve for 13 m longitude is shown in Fig. 7.

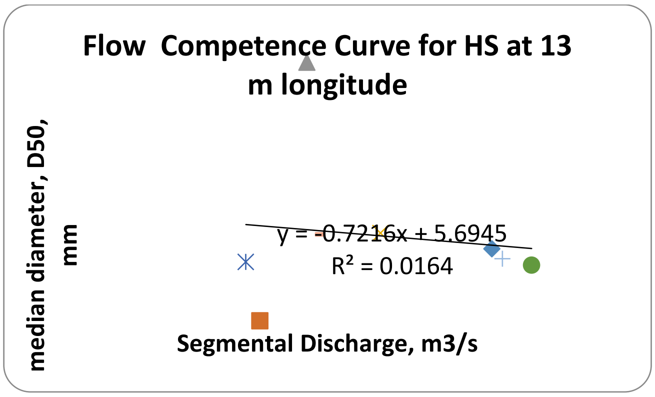

Fig. 7. Flow competence curve for 13 m longitude

It can be observed that for the same discharge the different sediment size can move depending on prevailing hydraulic conditions.

5. Bed load transport ANALYSIS & Results

The prediction of bed load transport rate using different equations proposed by Einstein (1950) and Schoklitsch (1950) was carried out. The predicted bed load transport rate was compared with measured bed load transport rate and the most significant statistical parameter, Discrepancy Ratio (DR) was used to assess the performance of the bed load equations.

The bed load function developed by Einstein (1950) is derived from the concept of probabilities of particle motion. According to Einstein the bed load transport was related to fluctuation rather than the average values of all the forces that flow exert on the sediments particles. He considered bed load as the transport of sediments in a thin layer of two particle diameter thickness just above the bed. These grains move by saltation as of the fluctuation lift force and then perform a jump with a longitudinal distance of about 100 particles diameter. The jump length was related to sediment size and was assumed to be independent of hydraulic conditions.

Einstein's relations contain all pertinent variables of water and sediment transport, however, the data used in the calibration was obtained only from laboratory experiments, the method has not provided satisfactory accuracy in most practical engineering projects. The bed load functions is given as (1)

$$1-\frac{1}{\pi}\int_{-B_*\varphi_*-{}^{1}/{n_o}}^{B_*\varphi_*-{}^{1}/{n_o}} e^{-t^2}dt=\frac{A_*\emptyset_*}{1+A_*\emptyset_*} \qquad (1)$$

Where $\emptyset_*$= intensity of sediment transport

A_*, B_* and n_o are universal constant to be determined from experimental data.

The performance of bed load equations for the measured bed load data is assessed using the most potent statistical measure, Discrepancy Ratio.

The comparison of performance of selected bed load equations is given in Table 6.

Table 6. DR for predicted bed load transport rate

DR for Bed Load Transport Equations			Hydraulic Parameters	
Sample ID	Schoklitsch (1950)	Einstein (1950)	Sediment size, m	Slope
R1S1	-209.26	6.78	0.0018	0.0014
R2S1	-13.10	0.00	0.0052	0.0014
R3S1	179.31	7.07	0.0011	0.0014
R4S1	-60.60	0.01	0.0059	0.0014
R5S1	56.02	4.69	0.0028	0.0014
R6S1	-13.60	0.30	0.0040	0.0014
R7S1	314.98	6.42	0.0022	0.0014
R8S1	-15.23	0.20	0.0009	0.0014
R11S1	31.72	2.76	0.0020	0.0014
R1S2	34.33	0.88	0.0018	0.0021
R2S2	11.13	0.69	0.0023	0.0021
R3S2	125.19	4.14	0.0017	0.0021
R4S2	3.53	0.06	0.0083	0.0021
R5S2	-162.17	0.91	0.0097	0.0021
R6S2	45.70	1.24	0.0051	0.0021
R7S2	834.03	21.09	0.0028	0.0021
R8S2	-12.06	0.00	0.0074	0.0021
R9S2	-206.10	0.58	0.0036	0.0021
R10S2	23.93	0.13	0.0079	0.0021
R13S2	126.88	9.50	0.0006	0.0021
R1S3	1.73	0.05	0.0040	0.0009
R2S3	26.48	0.10	0.0042	0.0009
R3S3	32.96	1.37	0.0015	0.0009
R4S3	-261.12	0.00	0.0110	0.0009
R5S3	1.03	0.02	0.0047	0.0009
R6S3	-1.05	0.18	0.0037	0.0009
R7S3	11.40	0.05	0.0046	0.0009
R8S3	33.13	0.06	0.0036	0.0009
R9S3	17.31	0.04	0.0038	0.0009
R10S3	9.77	0.18	0.0014	0.0009
R11S3	29.82	1.52	0.0022	0.0009
R12S1	-3.17	0.00	0.0047	0.0009
R12S2	-0.54	0.02	0.0042	0.0009
R12S3	10.25	0.05	0.0042	0.0009
R13S3	4.44	0.06	0.0030	0.0009

From Table 6, it is observed that the tested discharge base bed load transport equations Schoklitsch (1950) fails to predict for the measured river data. Improvement in prediction is obtained with increase in discharge as shown in yellow colour. However similar trend of prediction is not observed in case of high peak discharge as indicated with pink colour. Thus it is difficult to say that discharge alone plays a significant role in sediment transport. It is also observed that the tested Probabilistic bed load transport equations, Einstein (1950) predicts well for sediment of coarse sand size for the present range of hydraulic parameters.

6. Conclusion

Following conclusions can be made from the field study and analysis of observed measurements:

1. The flow velocity changes considerably with respect to time as the river gets flow due to rainfall in the upper catchment.
2. Highest bed load rate (measured by HS sampler) was observed at 13 m lateral at section A. No bed load movement took place for small velocity of flow.
3. High quantity of bed load is measured even for low velocity conditions indicating the flow of sediment from upper catchment or severe bed erosion from upstream during the monsoon day.
4. The average d_{50} size observed in HS bed load samples at 3, 8 and 13 m from right bank are 2.163 mm, 4.588 mm and 3.893 mm respectively. Overall average d_{50} size is 3.539 mm.
5. Sediments flowing as bed load falls in the sediment classification range of coarse sand to pebbles (0.5-16.0 mm)
6. Large variations in bed load rate are observed at different longitudes across the sections with respect to flow discharge rate.

For the same discharge values, the biggest size that can be moved varies much, indicating other parameters dominance in bed load transport.

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