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Sediment rating curve for the Ganges river

G.M. Tarekul Islam[1] and Shahana Akhter[2]

[1]Institute of Water and Flood Management
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh.
[2]Local Government Engineering Department,
Agargaon, Dhaka 1207, Bangladesh.

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Abstract

In this study, a sediment rating curve for the Ganges river at Hardinge bridge gauge station has been developed by establishing power relations between sediment transport as dependent variable and discharge and unit stream power as independent variables separately. The unit stream power used as independent variable gives an improved curve. The sediment rating curve improves significantly when it is developed by partitioning the data into rising, flood and falling limbs.

Keywords: Sediment, rating curve, Ganges river.

1. Introduction

The relationship between discharge, Q, and sediment transport, S, can be expressed by an average curve. This curve, generally referred to as a sediment rating curve, often represents an exponential function that can be determined either by regression analysis or from a plot of discharge and sediment transport data. Reliability of sediment transport determined from a rating curve depends upon the quantity and quality of data used to define the curve, and whether the data represents the discharge and sediment transport occurring during the period of interest (FAP 24, 1996).

A sediment rating curve assumes a unique relationship between the average flow velocity and the shear stress at river bed (FAP 24, 1996). This unique relationship requires more or less prismatic cross-sections with only one channel in a cross-section of the river. However, in an accelerating flow, deviations may occur relative to a sediment transport rating curve. Several factors can have an effect on the shape, slope and intercept of the rating curve, such as the different seasons, the time lag between the peak sediment concentration and the peak discharge, and the extreme high water events.

Akhter (2004) found that the peak sediment load of the Ganges at Hardinge bridge is generally followed by the peak discharge.

It was demonstrated by Yang (1972) that the sediment transport rate depends on the unit stream power, VS, more than any other hydraulic parameter where V is the average flow velocity and S is the longitudinal bed slope. The unit stream power is defined as the rate of potential energy expenditure per unit weight of water.

Conventional sediment rating curve establishes relationship between ST as dependent variable and Q as independent variable (FAP 24, 1996; Hossain, 1992; CBJET, 1991). Yang (1996) noticed that, with the exception of probabilistic and regression approaches, most sediment transport equations were derived based on the assumption that sediment transport rate or concentration could be determined by a dominant variable. The dominant variables include water discharge, average flow velocity, energy or water surface slope, shear stress, stream power per unit bed area, and unit stream power. In this study, the sediment rating curve for the Ganges river has been developed by considering discharge and unit stream power as independent variables.

2. Previous studies of sediment rating curve for the Ganges river

Sediment rating curve was first used in Bangladesh by the Hydrology Directorate of Bangladesh Water Development Board (BWDB) for the years 1966 and 1967 (FAP 24, 1996). Later, for the hydrological years 1968-69 and 1969-70, sediment rating curves for the suspended coarse sediment were determined by log-log graphs (FAP 24, 1996). In general, rating curves were determined for suspended bed material transport. In some cases, the total suspended sediment transport was considered. Bari (1978) developed the following sediment rating curves for the Ganges.

$$Q_s = 4.33 \times 10^{-7} Q^{2.18} \tag{1}$$

$$Q_T = 1.89 \times 10^{-6} Q^{2.08} \tag{2}$$

$$Q_W = 9.61 \times 10^{-7} Q^{2.08} \tag{3}$$

where, Qs is the suspended sediment load (tons/day), QT is the total sediment load, QW is the wash load and Q is the water discharge.

Hossain (1992) developed an empirical formula for the prediction of the total sediment load (suspended fine and coarse plus bed load transport). His sediment rating curve for the Ganges river based on the data for the period 1980-87 is,

$$S_T = 0.74 Q^{1.48} \tag{4}$$

where, ST = total sediment load (tons/day)

FAP 4 (1993) derived the following suspended sediment rating curve for the Ganges river by regression analysis:

$$S = 4.33 \times 10^{-6} Q^{2.56} \tag{5}$$

It was reported that a single sediment rating curve would not accurately represent the sediment transport under all conditions. The River Survey Project of FAP 24 (1996) analyzed sediment transport data measured by BWDB in two periods, 1966-70 and 1976-88. This separation was based on data consistency, statistical correlation, etc. The sediment rating curve for 1966-70 shows a sediment transport at least 2 times higher than that obtained from the rating curve for 1976-88.

All the previous sediment rating curves were developed by fitting a power relation between water discharge as independent variable and sediment discharge as dependent variable. An important variable, unit stream power, was not considered. The seasonal variations of the dominant variables were also not taken into account.

3. Data used

Data on discharge and sediment loads of the Ganges river at Hardinge bridge station have been collected from the Directorate of Surface Water Hydrology of BWDB. Although the sediment data is available since 1966, the data contains only suspended sand discharge. This means that the sample was not separated into wash load (also called fine fraction) and suspended bed material load (also called sand fraction). The wash load consists of silt and clay fractions. The sand fraction consists of sediment particles larger than 0.063 mm. The sediment load comprises of only suspended load since BWDB does not measure any bed load on regular basis. The sediment data used for this study are for 1983 – 88 and 1992 – 94.

4. Formulation of sediment rating curve

The sediment load data have been plotted against water discharge and unit stream power. The least scattered curve without systematic deviation from a one-to-one correlation between dependent and independent variables has been selected as the sediment rating curve. Thus the sediment rating curve is one of the following two equations:

$$S_T = AQ^B \tag{6}$$

$$S_T = A(VS)^B \tag{7}$$

where, A is the coefficient and B is the exponent.

5. Analysis and discussion

Scattering of plotted data points is determined by the coefficient of determination. The curve having the highest coefficient of determination is taken as the sediment rating curve. Tables 1 and 2 show the equations and the coefficients of determination of the sediment rating curves for different years for discharge and unit stream power used as independent variable respectively. The coefficients and exponents vary within a large extent. This suggests that the rating curve should be updated each year. This is because the Ganges river is very unstable and undergoes erosion and deposition. In some years, sediment discharge shows better correlation with discharge. In other years, the sediment discharge shows better correlation with unit stream power. This suggests that the curve having higher coefficient of determination should be taken as the rating curve for a given year.

Table 1
Sediment rating curve: discharge as independent variable

Year	Sediment rating curve	Coefficient of determination
1983	ST = 1E-06Q2.3231	0.903
1984	ST = 1E-06Q2.3017	0.898
1985	ST = 0.0328Q1.2853	0.750
1986	ST = 0.0004Q1.6741	0.714
1987	ST = 0.3396Q0.9951	0.748
1988	ST = 3.9238Q0.7805	0.410
1992	ST = 4E-05Q2.0174	0.886
1993	ST = 0.0026Q1.5639	0.933
1994	ST = 5E-06Q2.2254	0.961

Table 2
Sediment rating curve: unit stream power as independent variable

Year	Sediment rating curve	Coefficient of determination
1983	ST = 9E+13(VS)3.1456	0.921
1984	ST = 3E+13(VS)3.0134	0.892
1985	ST = 1E+10(VS)1.922	0.759
1986	ST = 3E+11(VS)2.3853	0.662
1987	ST = 2E+08(VS)1.409	0.785
1988	ST = 2E+07(VS)1.0837	0.483
1992	ST = 3E+12(VS)2.6712	0.886
1993	ST = 1E+10(VS)1.9369	0.924
1994	ST = 6E+12(VS)2.7533	0.946

Figures 1 and 2 show the variation in sediment discharge with water discharge and unit stream power by considering data for all years, respectively. The rating curves and the coefficients of determination are summarized in Table 3. The coefficient of determination is higher for unit stream power than discharge. This suggests that the sediment rating curve should be developed by taking unit stream power as independent variable.

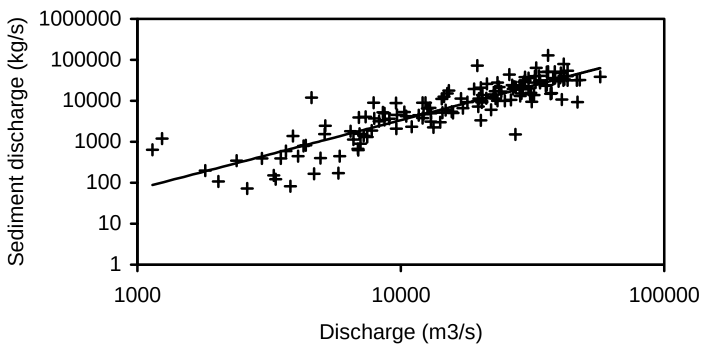

Fig. 1. Sediment rating curve: discharge as independent variable

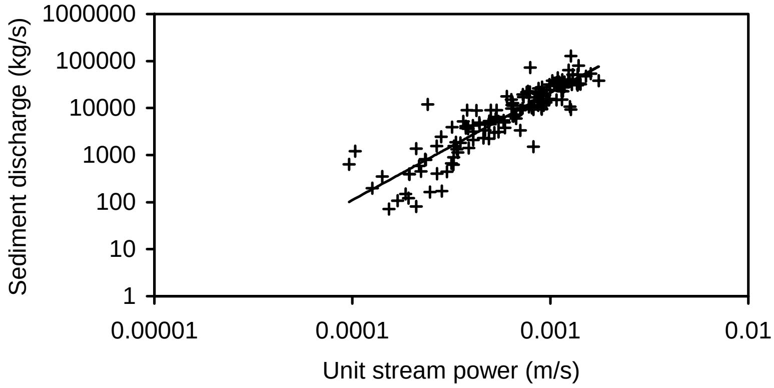

Fig. 2. Sediment rating curve: unit stream power as independent variable

Table 3
Sediment rating curves for different independent variables

Independent Variables	Sediment rating curve	Coefficient of determination
Discharge	ST = 0.0006Q1.681	0.784
Unit stream power	ST = 1E+11(VS)2.282	0.811

The Ganges is a morphologically active river and its cross-sectional geometry changes during flood flow due to erosion, deposition, shifting of bars, etc. The flow and sediment characteristics of the river are influenced by the changes in the geometry and overall resistance to flow. Keeping this in mind, the sediment rating curve for the Ganges has been developed by partitioning the data into three segments of the annual hydrograph viz. the rising limb, flood season and the falling limb. The rising limb represents when the water discharge is below 20,000 m3/s, flood season begins when the water discharge is above 20,000 m3/s and the falling limb represents the period when the water discharge falls below 20,000 m3/s. Table 4 summarizes the different sediment rating curves developed by partitioning the data into different segments for both discharge and unit stream power as independent variables. In each case, the coefficient of determination is higher for unit stream power than discharge as independent variable.

Figure 3 shows the comparison between computed and observed sediment discharge based on rating curve developed by considering discharge as independent variable for all the data. The computed sediment discharge underestimates the observed discharge. Most of the data points lie below 450-line. This suggests that the rating curve developed by considering all the data point together does not give good rating curve. Figure 4 shows the comparison between computed and observed sediment discharge based on rating curve developed by considering discharge as independent variable for partitioning the data into rising, flood and falling limbs. Most of the data points are distributed almost evenly around the 450-line. This suggests that the sediment rating curve developed by partitioning the data gives better results.

Table 4
Sediment rating curves for different independent variables after partitioning the data

Independent Variables	Segment	Sediment rating curve	Coefficient of determination
Discharge	Rising	ST = 0.029(Q)1.282	0.747
	Flood	ST = 0.009(Q)1.430	0.416
	Falling	ST = 1E-06(Q)2.345	0.757
Unit stream power	Rising	ST = 2E+09(VS)1.727	0.791
	Flood	ST = 1E+10(VS)1.892	0.632
	Falling	ST = 3E+14(VS)3.252	0.768

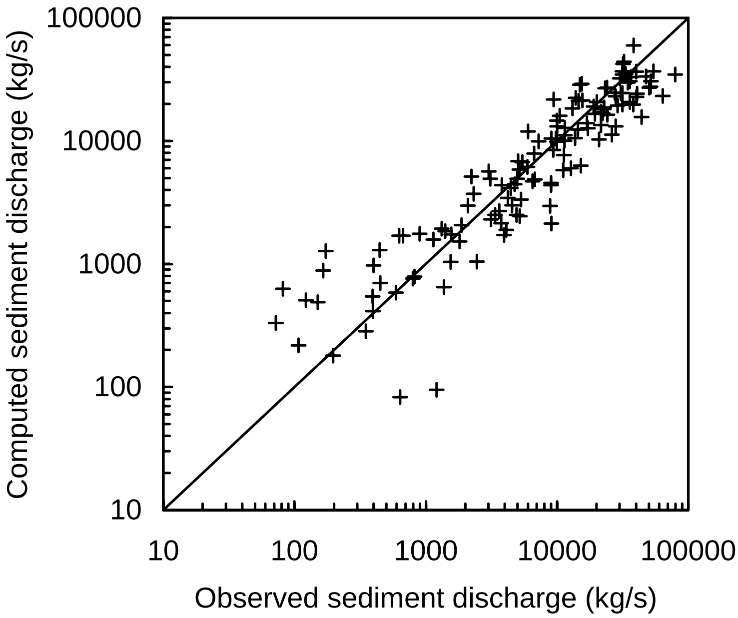

Fig. 3. Comparison between computed and observed sediment discharge based on rating curve developed by considering discharge as independent variable

Figure 5 shows the comparison between computed and observed sediment discharge based on rating curve developed by considering unit stream power as independent variable for all the data. The computed sediment discharge underestimates the observed discharge. Most of the data points lie below 450-line. This suggests that the rating curve developed by considering all the data point together does not give good rating curve. Figure 6 shows the comparison between computed and observed sediment discharge based on rating curve developed by considering unit stream power as independent variable for partitioning the data into rising, flood and falling limbs. Most of the data points are distributed almost evenly around the 450-line. This suggests that the sediment rating curve developed by partitioning the data gives better results. It can be concluded from the above discussion that sediment rating curve when developed by considering unit stream power as independent variable is better than discharge and the curve improves significantly when the data are partitioned into rising, flood and falling limbs.

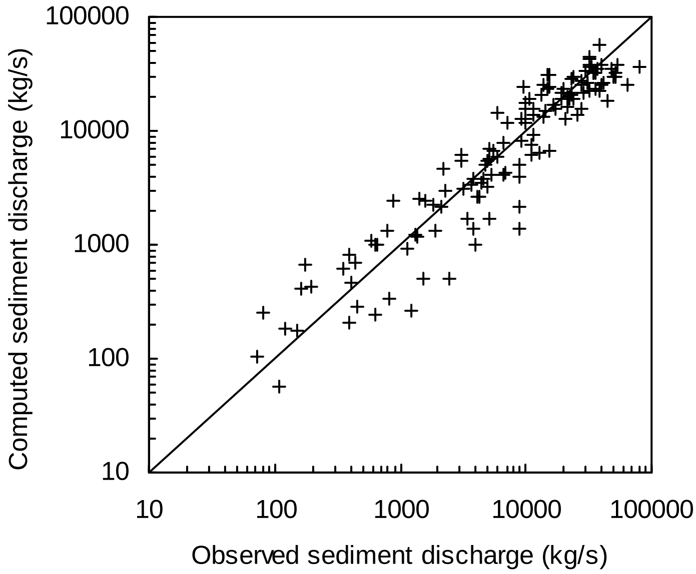

Fig. 4. Comparison between computed and observed sediment discharge based on rating curve developed by considering discharge as independent variable for partitioned data

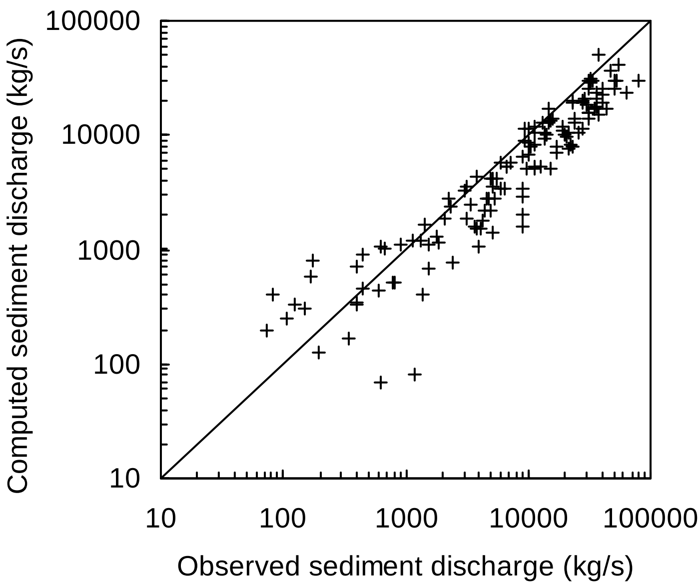

Fig. 5. Comparison between computed and observed sediment discharge based on rating curve developed by considering unit stream power as independent variable

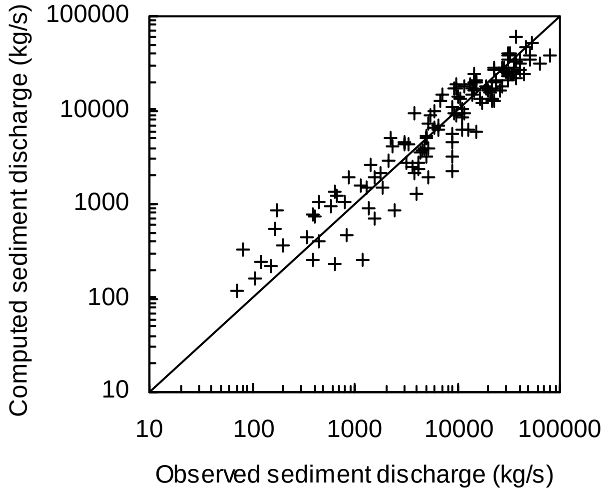

Fig. 6. Comparison between computed and observed sediment discharge based on rating curve developed by considering unit stream power as independent variable for partitioned data

Goodness-of-fit test

The performance of the two methods of deriving sediment rating curve has been analyzed by the goodness of fit test using the following procedures:

$$D_i = \log\left(\frac{\psi_c}{\psi_m}\right) = \log\psi_c - \log\psi_m \tag{8}$$

$$\overline{D}_a = \frac{\sum_{i=1}^{j} D_i}{j} \tag{9}$$

$$\sigma_a = \sqrt{\frac{\sum_{i=1}^{j}\left(D_i - \overline{D}_a\right)^2}{j-1}} \tag{10}$$

where, Di = discrepancy ratio based on logarithm ratio, $\overline{D}_a$ = averaged discrepancy ratio based on logarithm ratio, ψc = computed value, ψm = measured value, σa = standard deviation based on the logarithm ratio.

For a perfect fit, $\overline{D}_a$ = 0 and σa = 0. Comparisons between computed and observed sediment discharge are summarized in Table 5. The sediment rating curve derived with partitioned data is more accurate based on $\overline{D}_a$ and σa. The change of mean discrepancy ratio from -0.171 to -0.009 indicates that the sediment rating curve derived by partitioning the data is better for the Ganges river.

Table 5
Summary of comparisons between computed and observed sediment discharge

Method of deriving sediment rating curve	$\overline{D}_a$	σa
Without partitioning the data	-0.171	0.267
Partitioning the data into rising, flood and falling limbs	-0.009	0.231

6. Conclusions

The sediment rating curve for the Ganges river at Hardinge bridge have been derived by establishing power relations between sediment transport as dependent variable and discharge and unit stream power as independent variables separately. The unit stream power gives a better curve as compared to discharge. The sediment rating curve improves when it is developed by partitioning the data into rising, flood and falling limbs.

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Notations

A = Coefficient of sediment rating curve
B = Exponent of sediment rating curve
Di = Discrepancy ratio based on logarithm ratio
$\overline{D}_a$ = Averaged discrepancy ratio based on logarithm ratio
j = Total number of data used
Q = Water discharge
Qs = Suspended sediment load
QT = Total sediment load
Qw = Wash load
S = Longitudinal bed slope
ST = Total sediment load (ton/day)

V = Average flow velocity
VS = Unit stream power
ψc = Computed value
ψm = Measured value
σa= Standard deviation based on the logarithm ratio