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Roughness Characteristics of Alluvial Rivers of Bangladesh

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Abstract: *The roughness characteristics of alluvial rivers of Bangladesh, in terms of Manning's roughness coefficient n, Chezy's resistance factor C and Darcy-Weisbach friction factor f, seem to be strongly dependent on the river discharge and show a cyclic variation over the year. The roughness is high when the river discharge is low in the months of December to April due to the development of bed forms in the river at low discharges. The roughness is low in the months of July to September when the river discharge is high. At high discharges, the bed forms almost disappear and the river bed becomes plane with a consequent decrease in roughness.*

Keywords: *Alluvial river, Roughness coefficient, Bed forms*

Introduction

The flow boundary of an alluvial river is not fixed, but undergoes changes in the characteristic geometry and dimensions through mutual interaction between the flow and the bed. In rigid boundary open channels, the resistance to flow is due to grain roughness only and a single roughness value for all discharges is considered adequate to describe the resistance to flow. However, the problem of predicting the resistance to flow in alluvial channels is complicated by the fact that the configuration of the bed changes with change in flow conditions. This changing bed condition makes it impossible to describe the resistance to flow in an alluvial river by a single-valued roughness coefficient for a particular river.

The prediction of resistance or roughness characteristics of alluvial rivers is needed for estimating the stage-discharge relationship of the river, for predicting sediment transport from the hydraulic characteristics of the river using the transport formula, for designing irrigation canals in alluvium and for navigation and channel improvement works. Moreover, knowledge of the roughness characteristics of alluvial streams is of great value when dealing with the location of bridges, river training works, flood control works, computation of backwater effect due to bridges, weirs, barrages and other hydraulic structures and confluences and bifurcations in a river channel network, mathematical and physical modeling of flow, prediction of aggradation and degradation due to presence of hydraulic structures and so on.

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The rivers of Bangladesh are alluvial in nature. The three mighty rivers and their tributaries are characterized by variability of flow, sediment transport and channel configuration. Stage, discharge and sediment transport change daily, seasonally and annually. Changes in stage continuously influence scour and fill patterns along the channel bed as well as magnitude of channel roughness.

Khan (1975) determined the roughness coefficients of four rivers, viz. the Kumar, the Gumti, the Halda and the Sangu rivers, of Bangladesh. The River Survey Project (FAP-24) (Delft Hydraulics/DHI, 1996) reported that the bed form roughness is the main component of overall roughness in the Jamuna river. The validity of thé Soil Conservation Service (SCS) method (French, 1986) for estimating the roughness coefficient for the Jamuna river was investigated by the River Survey Project (FAP-24). Alam (1998) investigated the applicability of some alluvial roughness predictors for the Ganges river at the stations Hardinge Bridge and Baruria. Uddin (1999) also investigated the applicability of some roughness predictors for the Gumti and the Kushiyara rivers at the stations Jibanpur and Sherpur, respectively.

The aim of the work presented in this paper has been to determine the roughness characteristics of five alluvial rivers of Bangladesh using the streamflow data collected by Bangladesh Water Development Board (BWDB). Assuming that the flow in the rivers is steady and uniform, the roughness characteristics have been determined in terms of Manning's roughness coefficient n, Chezy's resistance factor C and Darcy-Weisbach friction factor f. The variations of these roughness parameters with river discharge and time of the year have also been considered.

Parameters for Roughness Characteristics of a River

The roughness characteristics of a river can be defined by roughness factors and coefficients, shear stress, shear velocity, roughness height, sediment transport, sediment properties, etc. In the present work, the roughness characteristics of the alluvial rivers are determined by the Manning's roughness coefficient n, the Chezy's resistance factor C and the Darcy-Weisbach friction factor f.

Manning's roughness coefficient n

The Manning's formula for discharge is given by (Chow, 1959; Chaudhry, 1993)

$$Q=\frac{1}{n}AR^{2/3}S^{1/2} \qquad (1)$$

where Q is the discharge (m^3/s), A is the cross-sectional area (m^2), R is the hydraulic radius (m) and S is the slope of the energy line. Rearrangement of Eq. (1) gives the following expression for Manning's roughness coefficient n:

$$n = \frac{AR^{2/3}S^{1/2}}{Q} \tag{2}$$

Chezy's resistance factor C

The Chezy formula for discharge is given by

$$Q = CAR^{1/2}S^{1/2} \tag{3}$$

Rearrangement of Eq. (3) gives the following expression for Chezy's resistance factor C:

$$C = \frac{Q}{AR^{1/2}S^{1/2}} \tag{4}$$

Darcy – Weisbach friction factor f

The Darcy – Weisbach formula for discharge is given by

$$Q = \sqrt{\frac{8g}{f}}AR^{1/2}S^{1/2} \tag{5}$$

where g is the acceleration due to gravity (= 9.81 m/s^2). The Darcy – Weisbach friction factor f is obtained from Eq. (5) as

$$f = \frac{8gA^2RS}{Q^2} \tag{6}$$

Using Eqs.(1), (3) and (5), the following relationships between the roughness parameters n, C and f are obtained:

$$C = \frac{1}{n}R^{\frac{1}{6}} \tag{7}$$

$$\frac{C}{\sqrt{g}} = \sqrt{\frac{8}{f}} \tag{8}$$

$$n = R^{\frac{1}{6}}\sqrt{\frac{f}{8g}} \tag{9}$$

From the above relationships, it is apparent that the Manning's roughness coefficient n and the Darcy-Weishbach friction factor f are directly related to one another, but the Chezy's resistance factor C is inversely related to both n and f, i.e. C decreases with increase in n and f and vice versa. Manning's roughness coefficient n and Darcy-Weisbach friction factor f are direct measures of roughness or resistance, whereas Chezy's C is inversely related to roughness or resistance. So, when the roughness or resistance increases, Manning's n or friction factor f increases, but Chezy's C decreases and vice versa.

Data Collection and Data Analysis

To compute the roughness parameters n, C and f, the discharge, cross-sectional area, width and the slope of the energy line of the river are required. The alluvial rivers of Bangladesh considered in this study are the Jamuna, the Ganges, the Gumti, the Kushiyara and the Dharala. The streamflow data for the Jamuna at the Bahadurabad staton, the Ganges at the Hardinge Bridge and Baruria stations, the Gumti at the Jibanpur station, the Kushiyara at the Sherpur station and the Dharala at the Ferryghat station have been collected from the Hydrology Division, Bangladesh Water Development Board (BWDB). The streamflow data include the discharge, the cross-sectional area and the width. The water surface slopes of the rivers have also been obtained from BWDB. The water surface slope is taken to be equal to the slope of the energy line. The number of days for which streamflow data have been collected, the range of discharge and the water surface slopes for the rivers considered are given in Table 1.

Table 1 Number of days for which streamflow data have been collected, the range of discharge and the water surface slopes for the rivers considered

River	Station	No. of days	Range of discharge(m^3/s)	Water surface slope
Jamuna	Bahadurabad	355	3200 to 75827	0.000063
Ganges	Hardinge Bridge	323	261 to 76000	0.000055
Ganges	Baruria	274	1565 to 107133	0.000040
Gumti	Jibanpur	352	2 to 364	0.000079
Kushiyara	Sherpur	349	43 to 3080	0.000022
Dharala	Ferryghat	246	50 to 640	0.000014

The discharge hydrographs for the rivers Jamuna at Bahadurabad. Ganges at Hardinge Bridge and Baruria and Dharala at Ferryghat are shown in Figs.1. 2 and 3, respectively. The discharge hydrographs for other rivers are more or less similar qualitatively to those presented in these figures. It is apparent that the discharges in the rivers of Bangladesh show a cyclic variation over the year. The river discharge is minimum in the months of December to April where there is very scanty rainfall, starts increasing with the start of monsoon rain in the months of April and May, reaches the maximum in the monsoon months of July to September and then starts decreasing. The discharge in the Jamuna is minimum in February and maximum in July, in the Ganges at Hardinge Bridge is minimum in April and maximum in September and at Baruria is minimum in March and maximum in September, in the Gumti is minimum in March and maximum in August, in the Kushiyara is minimum in January and maximum in August and in the Dharala is minimum in March and maximum in July.

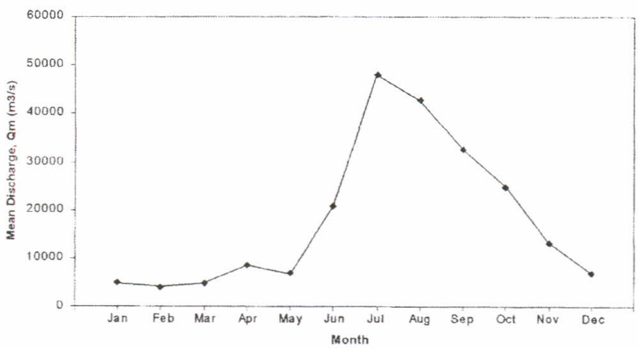

Fig. 1 Discharge hydrograph of the river Jamuna at Bahadurabad

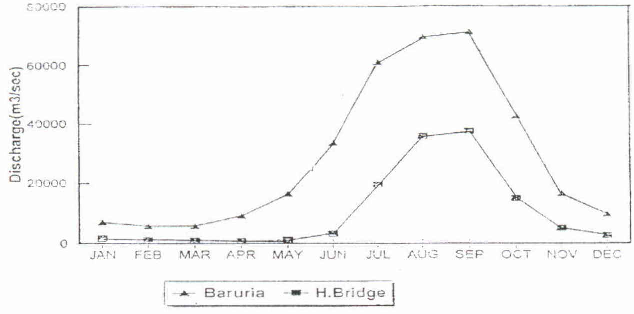

Fig. 2 Discharge hydrographs of the river Ganges at Hardinge bridge and Baruria

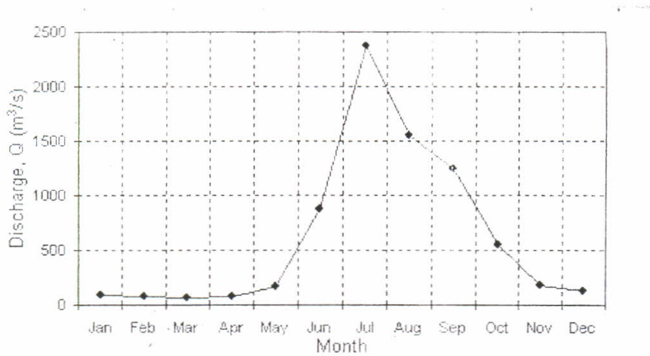

Fig. 3 Discharge hydrograph of the river Dharala at Ferryghat

Results and Discussions

The roughness parameters n, C and f for the five rivers have been computed by the Manning, the Chezy and the Darcy-Weisbach formulas (Eqs. 2, 4 and 6), respectively, using the streamflow data collected from BWDB. The computed minimum and maximum values of n, C and f are given in Table 2. The variations of n, C and f with discharge for the Ganges river are shown in Figs. 4 to 9. The variations of n, C and f with discharge for other rivers are more or less similar to those presented in Figs. 4 to 9.

Table 2 Minimum and maximum values of the roughness parameters n, C and f for the rivers considered

River	Station	Minimum values of				Maximum values of			
		Q (m^3/s)	n	C ($m^{1/2}/s$)	f	Q (m^3/s)	n	C ($m^{1/2}/s$)	f
Jamuna	Bahadurabad	3200	0.011	5.45	0.007	75827	0.237	109.71	2.641
Ganges	Hardinge Bridge	261	0.011	8.88	0.004	76000	0.159	136.03	0.996
Ganges	Baruria	1565	0.004	13.22	0.005	107133	0.080	148.98	1.725
Gumti	Jibanpur	2	0.023	13.40	0.024	364	0.068	57.40	0.437
Kushiyara	Sherpur	43	0.015	11.56	0.008	3080	0.096	96.98	0.587
Dharala	Ferryghat	50	0.012	12.06	0.008	640	0.114	97.87	0.540

The roughness parameters are found to be strongly dependent on the discharge. The Manning's roughness coefficient n is maximum when the river discharge is minimum, owing to the development of bed forms in the river at low discharges. The bed forms in the river, as determined by Alam (1998) and Uddin (1999), are mainly in the lower flow regime, i.e. ripples and dunes. With the increase in discharge, the bed forms gradually disappear and the Manning's roughness coefficient n gradually decreases. With further increase in discharge, the bed forms tends to be removed completely, the river bed tends to be plane and the Manning's roughness coefficient reaches its minimum value (Figs. 4 and 5).

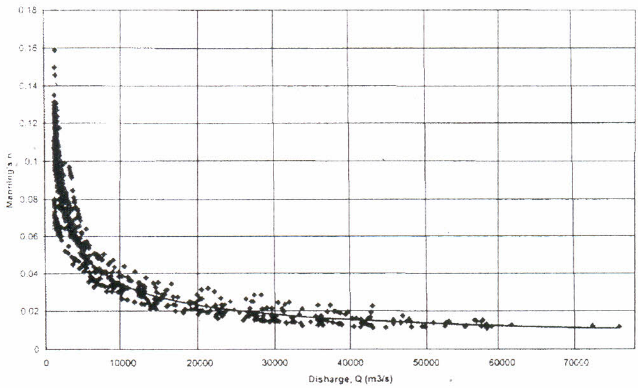

Fig. 4 Variation of Manning's n with discharge of the river Ganges at Hardinge bridge

The Darcy-Weisbach friction factor f also shows a variation similar to that of Manning's roughness coefficient n with discharge, i.e. it decreases with an increase in discharge and vice versa (Figs. 6 and 7).

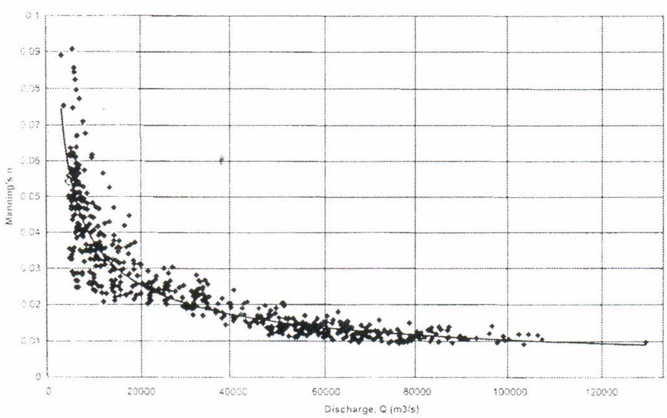

Fig. 5 Variation of Manning's n with discharge of the river Ganges at Baruria

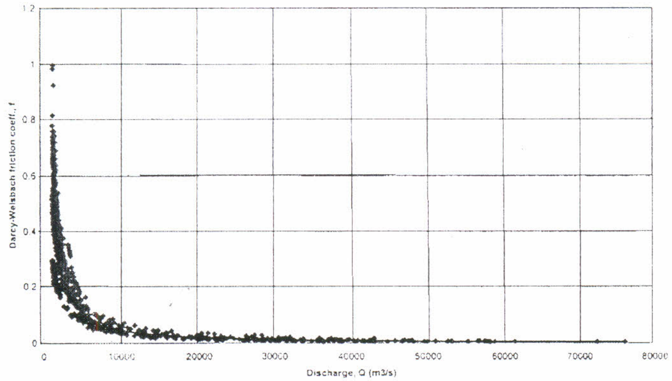

Fig. 6 Variation of Darcy-Weisbach friction factor f with discharge of the river Ganges at Hardinge bridge

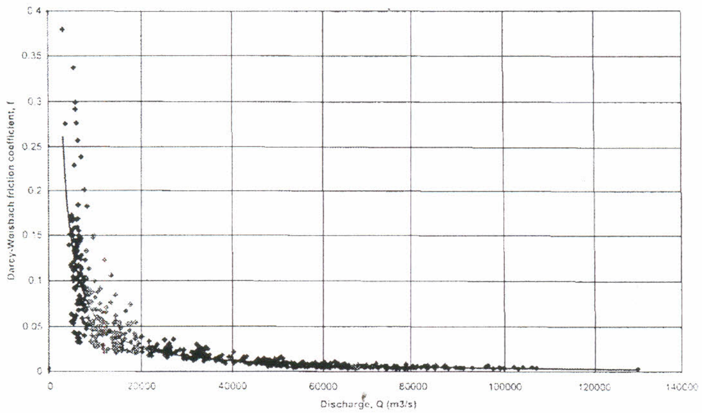

Fig. 7 Variation of Darcy-Weisbach friction factor f with discharge of the river Ganges at Baruria

The Chezy's resistance factor C shows a variation opposite to the variation of either Manning's roughness coefficient n or Darcy-Weisbach friction factor f with discharge, i.e. Chezy's C increases with an increase in discharge, is minimum when the river discharge is minimum and maximum when the discharge is maximum (Figs. 8 and 9).

The computed values of the roughness parameters n, C and f and shown in Figs. 4 to 9 seem to be within reasonable limits (Chow, 1959, Table 5.6 and Fig. 5.5; French, 1986, Table 4.8 and Figs. 4.3 to 4.15).

From Figs. 5 to 9, it is apparent that Manning's n and Darcy-Weisbach frction factor f are inversely related to discharge, whereas Chezy's C is directly related to discharge.

Finally, the variations of mean monthly Manning's n, Chezy's C and the Darcy-Weishbach friction factor f over the year for the Jamuna and Dharala rivers are shown in Figs. 10 and 11, respectively. The Manning's roughness coefficient n, the Chezy's resistance factor C and the Darcy-Weishbach friction factor f tend to show a cyclic variation over the year like the discharge. Both n and f are maximum in the dry season and minimum in the monsoon season. The Chezy's C, on the other hand, is minimum in the dry season and maximum in the monsoon season.

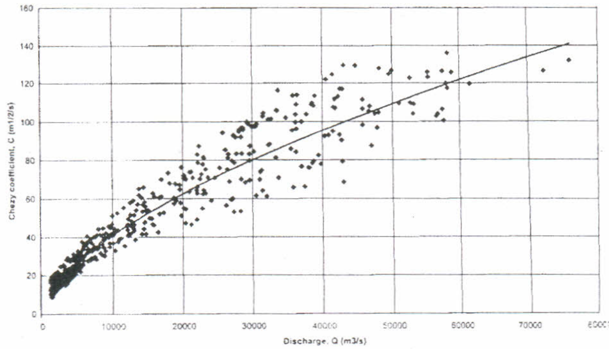

Fig. 8 Variation of Chezy's C with discharge of the river Ganges at Hardinge bridge

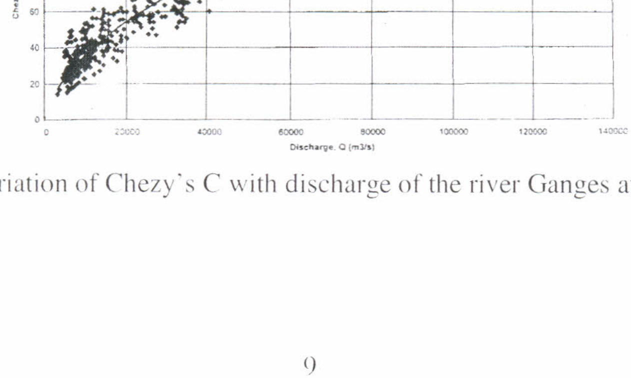

Fig.9 Variation of Chezy's C with discharge of the river Ganges at Baruria

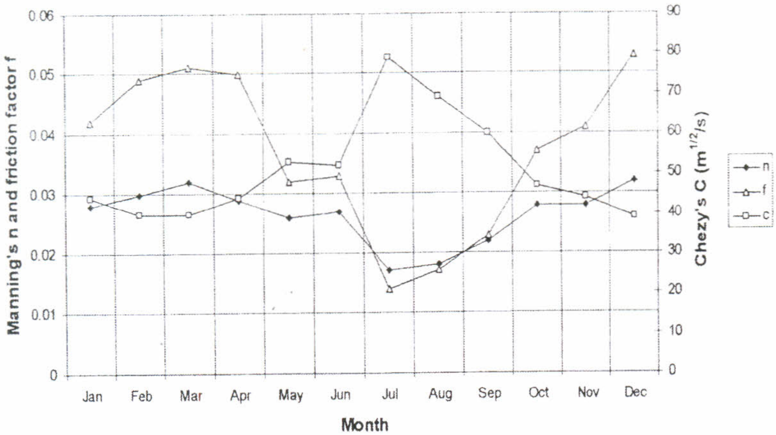

Fig. 10 Mean monthly values of Manning's n, Chezy's C and Darcy-Weisbach friction factor f for the Jamuna river at Bahadurabad

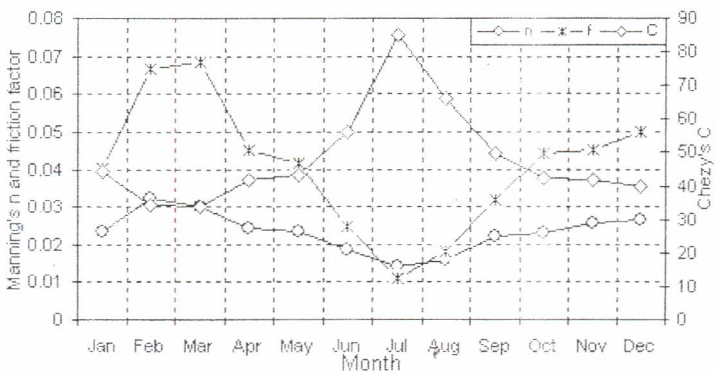

Fig. 11 Mean monthly values of Manning's n, Chezy's C and Darcy-Weisbach friction factor f for the Dharala river at Ferryghat

Figures 1 and 10 jointly indicate that in the Jamuna river, the Manning's n and Darcy-Weisbach friction factor f are maximum and the Chezy's C is minimum in the months of December to March when the river discharge is minimum. On the other hand, the Manning's n and Darcy-Weisbach friction factor f are minimum and the Chezy's C is maximum in the month of July when the river discharge is maximum. Similarly, Figs. 3 and 11 jointly indicate that in the Dharala river, the Manning's n and Darcy-Weisbach friction factor f are maximum and the Chezy's

C is minimum in the months of February when the river discharge is minimum, whereas the Manning's n and Darcy-Weisbach friction factor f are minimum and the Chezy's C is maximum in the month of July when the river discharge is maximum.

The variations of n, C and f over the year for other rivers are more or less similar to those presented in Figs. 10 and 11.

Conclutions

The discharges in the alluvial rivers of Bangladesh tend to show more or less a cyclic variation over the year, start increasing with the start of monsoon rain in the months of April and May, attains the peak level in the monsoon or wet-season months July to September, then start decreasing and finally attains the yearly minimum during the months of December to April. The roughness characteristics of the rivers, which seem to be strongly dependent on the discharge, also show a cyclic variation over the year. The roughness is maximum when the river discharge is low in the months of December to April owing to the development of bed forms (mainly ripples and dunes) in the river. The roughness is minimum in the monsoon or wet-season months of July to September when the discharge is high, the bed forms almost disappear and the river bed becomes plane with a consequent decrease in roughness.

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