

Roughness into the Channel Create the Flood Situation - A Case Study at Lower Reach of Shilabati River Basin, Paschim Medinipur, West Bengal

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Abstract: *Roughness into the channel of streams and rivers determines several important hydraulic parameters must be properly represented in models for estimating water discharge and sediment transport. Hydraulic parameters mainly gradient, hydraulic radius, width, width-depth ratio, wetted perimeter and cross sectional area are considered for analysing the ability of channels to carry discharge but resisting forces are opposing component of this movement. This paper reviews to evaluate the different approaches used to identify the roughness and to understanding of how flow resistance is created by roughness in open channel flows. The Shilabati river basin embraces a portion of the eastern fringe of the Chotonagpur plateau. South west monsoon is the principal source of rainfall in this area. After the heavy storm, the low lying depression in the lower reach of this catchment attracts huge flood water and sediments from it upper catchment, sub-tributaries and larger catchments of neighbouring rivers mainly Damodar, Darakeswar, and Kangsabati. The upper courses are steeper (0.84) and rocky facilitating easy drainage, that gradually concentrates at lower reach as it lost its capacity due to sudden reduction of gradient (Gadghat, 0.08; Bandar, 0.02). In the Shilabati river the cross sectional area changes through time in response to fluctuations in discharge. Channel slopes near these gauging stations are surveyed, that shows continuously decreasing tendency towards lower catchment. Capacity of channel is measured by conveyance of flow. Roughness coefficient value at three gauging station (Banka 0.50, Gadghat near Ghatal 0.82 and at estuary, Banka, 1) measuring by the Manning's equation depicts that the resistance to flow increases steadily at downstream. Channel substrate mainly vegetation and netting also influences the boundary roughness and flow resistance. Friction from sediment load mainly grain roughness are responsible for generating resistance which steadily declines movement and create jamming of water which ultimately leads to flood and water storage situation.*

Keywords: Cross section, Storm, Substrate, Hydraulic, Perimeter, Roughness

I. INTRODUCTION

Most natural and restored waterways are not comprised of simple cross-sectional areas such as rectangles, trapezoids, triangles, or simple curved shapes. Most natural waterways, at a minimum, are composed of a main channel and one or more adjacent flood plains. Such channels are referred to as compound channels since they are made up of more than one of these basic geometric shapes (Kelly, LEED, 2012). The roughness components in vegetated open channels are conceptually divided into three components, which are form roughness, soil grain roughness, and vegetative roughness (Mustafa, 2016). Hydraulic conditions in river channels and floodplain areas are complex because of the existence of numerous sources of flow resistance that contribute to energy losses and influence preferential flow patterns (Simons, 1962). The flow in the natural river is unsteady, fluctuating through time in response to inputs of precipitation to the drainage basin. The flow regimes are fluctuated in seasonal variations of rainfall and the frequency of distributions of flows (Leopold, Wolman, Gordon, 1986). The floodplain is an integral part of the whole river only does the cross-section shape change significantly from not only in its bank shape but also the stream wise pathways for flow alter considerably (Knight and Shiono, 1996). The important hydraulic parameters of the drainage basin are the catchment



shape, size, reach of the channel, width, depth, slope, hydraulic radius of the cross sections etc (Clayton, 2002). The wetted perimeter is the depth of channel boundary that has direct contact with the flow at a given cross section (Bedient, Huber and Vieux, 2008). The water in river channels moves down slope under the influence of gravity which causes to flow. The movement is resisted by frictional forces between the flow and channel boundary and within the flow itself. When water moves down slope it exert a shearing force or shear stress on the channel boundary (Charlton, 2008). Hydraulic characteristics mainly velocity of discharge are measured over the Shilabati river with use of current meter by method of Goudie (1981) and discharge values are obtained by multiplying the cross sectional area with velocity by method of Summerfield (1991) and Kay (1998, Raghunath, 1995 etc). The downstream part of river Shilabati have laid in the lowland with extremely gentle gradient. Abnormal rainfall have entered into channel as a flood way during the summer monsoon or cyclonic storm surge period and ultimately accumulated near the mouth area and remain as a water logging condition up to 10-15 days. The channel under study is dry in upper catchment and carries ephemeral flow only during storm periods but downstream portion is characterised with perennial flow to find the resistance forces create at different hydraulic parameters and to measure how channel roughness control movement of flow and sediment transportation. Resistance occurs due to friction between the flow and channel boundary by various channel substrate. The resistance also provided by vegetation is associated with both the enhancement of structural stability as well as increases in hydraulic roughness. Fish catching practices at regular intervals at the lower course create considerable obstacles to easily pass the flow of water. Resistance of flow occurs due to friction between the flow and channel boundary by various channel substrate. This flow resistance further reduces drainage capacity and helps in water logging.

II. STUDY AREA

The whole Shilabati catchment lies between 22°30'N-23°15'N latitude and 86°40'E-87°45'E longitude (concerned Toposheets no, 73I/12, 73J/16, 73N/1, 73N/5, 73N/6, 73N/9, 73N/10, 73N/11, 73N/2). The lower catchment extends between 22°30'-22°55'N and 87°30'- 87°45'E and faces the fury of flood almost annually. Six main tributaries (Joypanda, Betal, Donai, Tangai, Kubai and Parang) and other 74 small tributaries join the Shilabati River. During storm period these tributaries pour huge amount of runoff and sediments which concentrate at the mouth of river Shilabati and creating flood.

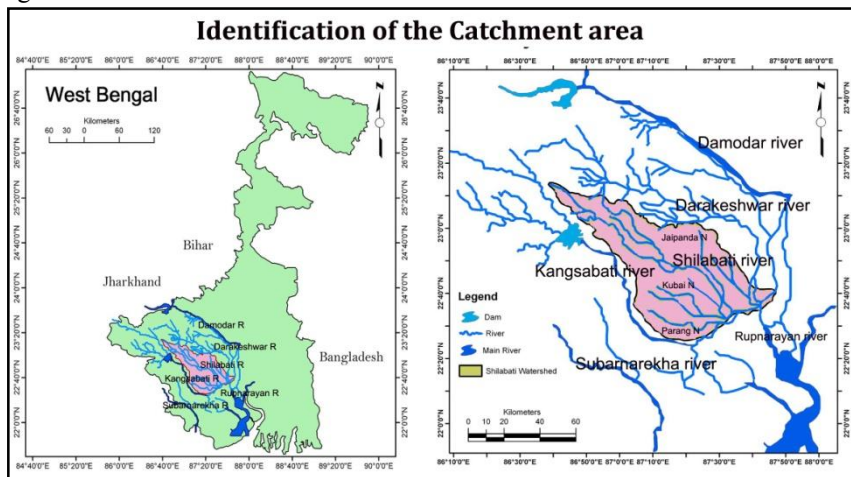


Figure 1: The Study Area

III. METHODOLOGY

Many different methods are also used to identify the roughness of waves through river reaches. Each of the hydraulic variables has been collected from the year wise survey to find out the magnitude of discharge and rainfall occurrence during monsoon period. Hydraulic radius is measured at cross sectional area (m²) / wetted perimeter (m), (The flow in channel is non uniform in lower reach as it does not conform to continuity equation. $Q = A_1V_1 = A_2V_2 = A_3V_3 \dots A_nV_n$.



(www.dot.ca.gov, 2006). Drainage capacity of Channel shows the regiment of engineering intervention for improving channel conveyance which is estimated by the equation $CF = 1/n \cdot A \cdot R^{2/3}$, (Verway, 1994) and Roughness Coefficient is measured by Manning’s equation, $V = 1/n \cdot R^{2/3} \cdot \sqrt{S}$ (Manning, 1890). Grain Roughness is measured by d/D (Charlton, 2008). The conventional methods are used to measure suspended sediments concentration (Morgan, 2005) in discharge during peak flow.

IV. DISCUSSION OF RESULTS

Interrelationship of Velocity, (Depth, Width Ratio) and Discharge

Catchment	Latitude and Longitude of gauge station	Width in m	Depth in m	Gradient	Wetted Perimeter (P) in m	Hydraulic Radius (m)	A=Cross sectional Area of the basin in sq. m.	Width Depth ratio
Upper Catchment	23°7'30"N 86°47' 20"E	36.5	8.4	0.84	55	4.52	288.65	4.35
Middle Catchment	22°51'15"N 87°13'15"E	127	11.6	0.38	323.02	4.47	557.70	10.95
Lower Catchment	22°43'46"N 87°34'31"E	48	14.47	0.142	73	3.11	327	3.32
Banka								
Gadghat	22°37'89"N 87°43'01"E	70	8.38	0.08	209	1.45	416	8.35
Bandar	22°40'26"N 87°46'48"E	92	6.24	0.02	234	1.19	404	14.74

Table 1: Hydraulics variables at different reaches of the channel

Data Source: During Field Survey by the author with Dumpy Level instrument.

Hydraulic parameters mainly gradient, hydraulic radius, width, width-depth ratio, wetted perimeter and cross sectional area are considered for analysing the ability of channels to carry discharge.

Hydraulic radius = cross sectional area (m²) / wetted perimeter (m),.....1, (Raghnath, 1995).

Stations	Latitude/ Longitude	Depth in m (PDL) Preliminary danger level	Velocity m/sec measured by Current Meter.	Cross sectional Area in sq. m	A.V. (Discharge) in cumec
Banka	22°43'46"N 87°34'61"E	14.47	50	327	113.50
Gadghat	22°37'89"N 87°43'01"E	8.38	35	416	106.40
Bandar	22°40'26"N 87°46'48"E	6.24	22	404	61.16

Table 2: The discharge value at PDL in three gauge station

Data Source: (PDL data, from Sub divisional office of Water Way and Irrigation Dept. Ghatal, Paschim Medinipur)

This resistance is controlled by boundary friction that is proportional to width –depth ratio and wetted perimeter. Hydraulic radius is consistently decreased down valley. Width- depth ratio also increases towards estuary that indicates gradual increase of frictional resistance and reduction in conveyance capacity and drainage potential that ultimately leads to flood and water storage situation.

$Q = A_1 V_1 = A_2 V_2 = A_3 V_3 \dots A_n V_n$2, (www.dot.ca.gov, 2006)

At Banka-Gadghat-Bandar segment discharge steadily declines during peak flow when water level touches preliminary danger level. The non- uniformity of flow in this critical section shows that water is stored in between Banka and Gadghat segment due to steady decline in drainage capacity of Channel (table, 2) that shows the regiment of engineering intervention for improving channel conveyance.



Open Channel Hydraulics and Flow Resistance

Stations	Banka	Gadghat	Bandar
Latitude/Longitude	22°43'46"N 87°34'61"E	22°37'89"N 87°43'01"E	22°40'26"N 87°46'48"E
Perimeter(m)	73	209	334
Area in sq.km.(A)	327	416	404
Roughness (R)	0.50	0.82	1
Conveyance of flow, Verway (1994),	16804.71cumec	5974.2cumec	3534.57cumec

Table 3: The general Hydraulic parameters of three gauge stations

Data Source: Data obtained during field survey and calculated by the author

Conveyance of flow is computed as multiplication between the roughness (n), watershed area (A), ratio of cross-sectional area (A) and perimeter (P) of watershed (i.e, hydraulic radius $R=A/P$). The value of conveyance for the conveyance of flow at Banka, Gadghat and Bandar shows a gradual decline of drainage capacity towards lower catchment indicating the condition of water logging.

Conveyance of Flow-(CF): Conveyance of flow is estimated by the equation.

$$CF = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot \sqrt{S} \quad \text{3, (Verway, 1994)}$$

4.1 Roughness Co-Efficient Evaluation

Several equations have been empirically derived for computing the average flow velocity within an open channel. One such equation is the Manning’s equation (Manning, 1890). The mean flow velocity in an open channel are computed as:

$$V = \frac{1}{n} \cdot R^{2/3} \cdot \sqrt{S} \quad \text{4, (Manning, 1890)}$$

where V = Mean velocity in m/s,

n = Manning coefficient of roughness,

S= Channel slope in m/m.

R = Hydraulic Radius, in m = A/WP,

where A = Cross sectional flow area in m², WP = Wetted perimeter, in m.

Gauge Station	Latitude /Longitude	Velocity m/sec measured by Current Meter.	Manning’s coefficient Equation $V = \frac{1}{n} \cdot R^{2/3} \cdot \sqrt{S}$	n= Roughness Coefficient table value	S= Surface Slope.	A= cross sectional Area of the basin, (sq. m)	WP= Perimeter of the basin (m)	Hydraulic Radius (m)
Banka	22°43'46"N 87°34'31"E	50	2.06 m/sec	0.50	0.142	327	73	4.48
Gadghat	22°37'89"N 87°43'01"E	35	0.54m/sec	0.82	0.08	416	209	1.99
Bandar	22°40'26"N 87°46'48"E	22	0.16m/sec	1	0.02	404	334	1.21

Table 4: Increasing resistance towards downstream decreases the flow velocity

Data Source: Velocity data obtained by Current meter during survey.

Manning’s equation is used in this case study. The coefficient of roughness is linked with hydraulic geometry. Roughness coefficient values are calculated from hydraulic parameters of channel at Banka, Gadghat and Bandar. The roughness values steadily increases the resistance to flow.

4.2 Friction from Sediment Load

A. Grain Roughness

Flow resistance increases with the diameter of individual grains. Here depth of flow and size of the particles are the important factors which are expressed in terms of a ratio.

$$d/D \text{-----} 5. \text{ (Charlton, 2008)}$$

where d is the flow depth and D is characteristic grain size index.

Catchment Part	Flow Depth in m (d)	Mean Grain size (Ø), (D)	D/d(mm/m)
Upper Course	14.47	-0.23(2mm)	0.00013
Middle course	8.38	0.23(0.8mm)	0.000095
Lower Course	6.24	1.55(0.2mm)	0.000032

Table 5: Characteristics of sediment grains

Data Source: Grain size data obtained by using Sieve method

This ratio acts as a very significant control on the overall resistance in a channel. Grain roughness is the dominant component of flow resistance at upper catchment in this channel.

Suspended Sediment Analysis at Five points of Study Area.							
Name of Stations	X (Distance in Km)	Average discharge in Cumec during Flood Period	Concentration of suspended sediment (gm/L)	Total water in Litter during Flood Period	(Dissolve Sediments in Gram) from average discharge in cumec during flood period.	Stored Sediments between two corresponding station	
A Shimulia, ---A Point of Upper catchment	0	180.29	3	180290	540870	270	
B Chaitanyapur - -A point of Middle course	10	180.2	3	180200	540600	19200	
C Banka	27.5	173.8	3	173800	521400	129420	
D Gadghat	82.5	130.66	3	130660	391980	151380	
E Bandar	90	80.2	3	80200	240600		

Table 6: The suspended sediment concentration at five points

N.B: Average discharge is calculated at three gauge sites (Banka, Gadghat and Bandar and at two gauge point of upper course and middle course are obtained at through measuring cross sectional area and velocity during flood season.



Fig-2: The sediments filtering method in laboratory
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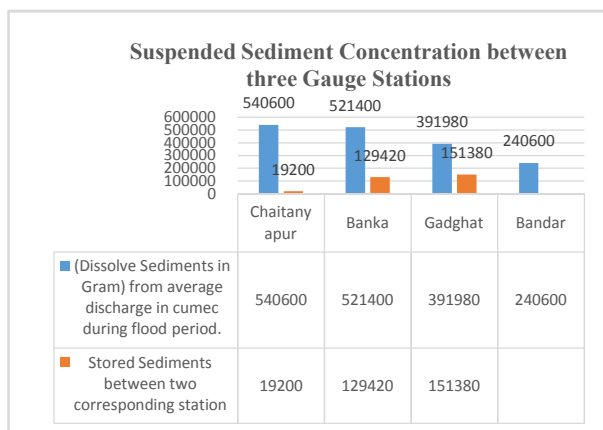


Fig-3.: The storage of suspended sediment at five points.
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Suspended sediment samples are collected from five stations along the longitudinal profile from the thalwage. Water samples are taken at different times to determine the suspended sediment concentration at various discharges over a period of time. This is done using a suspended sediment sampler. The Nozzle samplers are used for taking samples to measure the point integration. Water and sediments enter the intake nozzle and are collected in a sample bottle. Five samples (2liter each) are collected at each of the five sites. Samples volume are taken in 2 liters, sediment concentration is converted into in grams per1000 L (1 m^3) water then the concentration of sediment is calculated in relation to discharge in cumec during flood period. At average of 180.20 cumecs water at Chaitanyapur during peak flood, the weight of sediment load is 540600 gm and stored sediments is 19200 gm. The weight of sediment load is 521400 gm in average 173.80 cumec water at Banka station, stored sediment is 129420gm, the weight of sediment load is 391980 gm and stored sediment is 151380 gm in average 130.66 cumec water at Gadghat gauge station and in average 80.20 cumec at Bandar gauge station the weight of sediments is 240600 gm and stored sediment is highest at Gadghat station near Ghatal. These huge amount of sediments are accumulated at downstream area mainly Ghatal and surroundings. So, flood discharge cannot pass smoothly through the mouth area and create the flood situation.

V. FINDING AND CONCLUSION

The flow hydraulics reveals that channel gradient reduces considerably towards downstream. The upper courses are steeper gradient (0.84) and rocky facilitating easy drainage, that gradually concentrates at lower reach as it lost its capacity due to sudden reduction of gradient (Gadghat, 0.08; Bandar, 0.02). Hydraulic radius also decreases steadily downstream, associated to the increase of width. Width- depth ratios of the channels are 4.35 in the upper reach that becomes 14.74 at Bandar, the estuary. This indicates increasing resistance to flow as the river enters its floodplain at lower reach, creating the condition of water logging. At Banka, the velocity and discharge value at preliminary danger level are 50m/sec and 113 cumec and that reduces to 22m/sec and 61 cumecs at the estuary near Bandar. It indicates considerable decrease of drainage capacity and conveyance of channel that leads to flood. Manning's roughness coefficient exhibits that roughness value towards the mouth is increasing at Banka $n=0.50$ and at Bandar $n=1$) and velocity is decreasing. The increasing roughness creates the obstruction to pass the flowing discharge water and create the flood situation. In channel vegetation and netting also contributes to this increasing resistance to movement of water. The suspended sediment load concentration at lower reach Banka, Gadghat and Bandar are 2.75gm/L, 2.5gm/L and 3.5gm/L respectively where sand and clay particles are accumulated. So jamming of sands and clay particles in lower reach near Ghatal and Bandar insists the accumulation of flood water and create flood situation.

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