Assessment of Sedimentation in Barak River Reach Using HEC-RAS

Bahnisikha Das and B.S. Sil

Abstract Sediment transport study is important in Barak River in the context of river bank erosion, deposition, and water quality management. The initiation of computer technologies has enabled engineers to resolve sediment transport equations through computer simulations. In this study, it is intended to carry out a sediment transport study in the Barak River reach for which the latest version of Hydrologic Engineering Centre-River Analysis System (HEC-RAS) is used. Ackers–White sediment transport equation is used to analyze characteristics of sediment transport. From the analysis of the model, total sediment erosion and deposition were obtained at different cross sections between the study reach. The model is calibrated with the observed data and a statistical performance analysis is done. The result shows that the model is performing well and can describe sediment discharge movement as well as can estimate the amount of sediment deposition and erosion at different sections in the study reach.

1 Introduction

Rivers are the chief resources of water supply used for various purposes. The river is a dynamic system that undergoes continuous changes always. They are affected by various natural and human factors causing remarkable changes to rivers in long run leading to what is known as geomorphologic changes. Thus, the information of river situation such as the erosion and deposition conditions is the chief priorities of the various projects on river. Mismanagement and misuse of a catchment area leads to the contribution of additional sediment load to the river reaches. The high sediment discharge alters the shape and size of the channel and could be dangerous

B. Das (✉) · B.S. Sil
Civil Engineering, NIT Silchar, Silchar, India
e-mail: bahnisikha.das513@gmail.com

depending on where this transport takes place. Moreover, the release of effluents from industries and agricultural practices into the river channel pollutes aquatic system. High amount of sediment in the channel may be destructive for fish habitats and ecosystems. Also, sediment erosion may cause destabilization of the channel resulting in the failure of banks of the channel or the various hydraulic structures located in the channel bed [4], whereas the sediment deposition reduces the channel size thus adding stress to the channel banks and hence raising the water surface elevation level of the channel [8]. Therefore, realistic estimate of sediment transport rates in alluvial channel is essential for a number of water management issues [1].

Barak River is the major river of Barak valley used for numerous purposes. The river rises in Nagaland and passes through the Manipur Hills. It then flows from Lakhipur in the west direction via Cachar region of Assam over a distance of approximately 130 km before entering Bangladesh. The study reach extends from the Annapurna Ghat to Badarpur Ghat which is located toward the downstream end of Barak River covering a distance of approximately 51 km. The width of the river channel appears to be around 150 m and 300 m, respectively. The gradient of the river is less than 0.05 meters per kilometer which is tremendously flat even for a large river [5]. The fall in river water stage between Annapurna Ghat and Badarpur Ghat is approximately 4 m or less. The river is of highly meandering nature that has undergone considerable transformation at various channel locations in Barak valley [6]. The soil formation along the bank consists of a sequence of layers of silty clay, fine sands, and highly plastic clay. The sediment that is transported by the Barak River in considerable amount consists of fine silt and clay particles that are in suspension. The average bankfull discharge of the study area is around 3,800 cubic meters per second. The bank of the channel can resist the moderate flood flow velocities, and hence, most of the bank failures are generally linked with the formation of eddies and scour at sharp bends, or with geotechnical circumstances during falling stages or with seepage occurring into the banks from nearby ponds located along the banks. Sedimentation issues in the Barak River cause increasing pressure on the nearby societies and ecosystems as shifting river course on the one hand is displacing people from its bank and on the other raises doubts on the stability of river course in extreme flood conditions.

The developments of computer in mathematical modeling encouraged its application for analysis and prediction of the changes occurring in the geometry of rivers [7]. The application of a proper computer model to a particular region and its calibration is exclusively important which can simulate the changes in bed and bank elevation during floods in various seasons of year. Numerous mathematical models have been presented by many researchers in this topic on the basis of various assumptions and solutions including: HEC-6, CCHE1D model, CCHE2D model, MIKE11, FLUVIAL, and HEC-RAS model. Some of them became commercial and were used several times in different projects around the world.

1.1 Overview of HEC-RAS Model

HEC-RAS is a hybrid model developed by Hydrologic Engineering Centre, US Army Corps of Engineers. The model is one-dimensional which is utilized for hydraulic analysis of the river channels. The system includes four river analysis components which are steady flow water surface profile computations, unsteady flow simulation, sediment transport computations, and water quality analysis [3]. It uses an iterative method for calculation of water surface profile, and for calculating sediment transport rate, it uses number of semi-theoretical and empirical methods. The computations of sediment transport in the model allow the user to model the dynamic changes in river bed.

HEC-RAS has been present in the public realm for over 15 years and has been peer-reviewed (HEC 2010). It can be downloaded from the HEC Website which is available free of cost and is maintained by the US Army Corps of Engineers. It is also broadly used by numerous government agencies and private firms. However, the model cannot perform two-dimensional analyses for sediment transport and are not capable of predicting changes in the cross sections of river.

2 Methodology and Model Application

The sediment transport model requires a geometry file, steady flow profile, quasi-unsteady flow file, and sediment file to create the conditions similar to the river in HEC-RAS model.

For preparing the geometric data, the cross-sectional data were taken from digital elevation model (DEM) which was obtained from U.S. Geological Survey (USGS) records of satellite images taken with Shuttle Radar Topography Mission (SRTM). The dem is having a spatial resolution of 3 arc-seconds. The cross-sectional data perpendicular to the river course was drawn using HEC-GeoRAS, an extension of Arc GIS software. The geometric data are then imported into HEC-RAS, shown in Fig. 1. The entire study reach was divided into a total of 64 cross sections with an average distance of 0.75 km between each cross section.

To determine the river hydraulics, Manning's roughness coefficient is calibrated in the selected river reach with the steady flow analysis which uses the theory of stream flow energy balance with a known water surface elevation. Then, water surface elevation for each cross section is generated by standard step method which is an iterative procedure of solving the energy equation [2] stated as

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \tag{1}$$

where

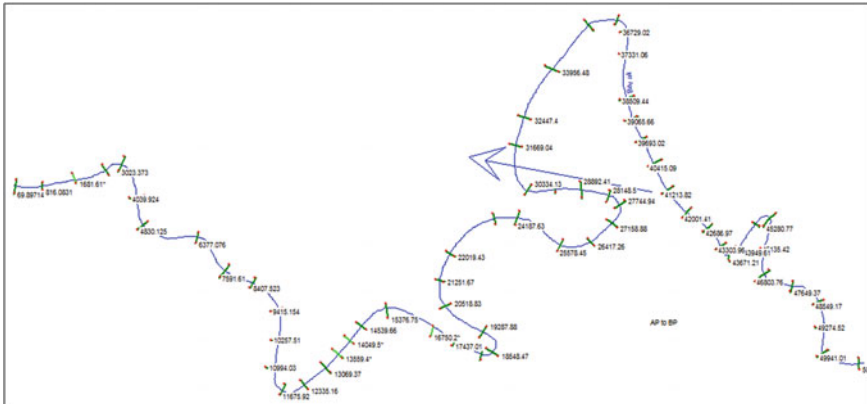Z_1, Z_2 Elevation of the main channel inverts,

Fig. 1 Schematic plan of the study reach in HEC-RAS

Y_1, Y_2 Depth of water at cross sections,
V_1, V_2 Average velocities (total discharge/total flow area),
α_1, α_2 Velocity weighting coefficients,
g Gravitational acceleration,
h_e Energy head loss.

For sediment transport calculations, HEC-RAS uses "quasi-unsteady" flow approach which approximates a continuous hydrograph with a series of discrete steady flow profile. It should be defined in both upstream and downstream of studied boundary conditions of the river. At the upstream cross section (Annapurna Ghat), the boundary condition of *flow series* was utilized where a series of flows were defined at definite time intervals. In quasi-unsteady flow, the variable steps are considered in HEC-RAS model and a 24-h period of time has been considered in this work. The downstream boundary condition at the outlet of the study area (Badarpur Ghat station) is given the option of the *normal depth*. Sediment transport analysis in HEC-RAS model assumes a sediment control volume associated with each cross section. The Exner equation is then solved over the control volume, computing from upstream to downstream as mentioned as follows:

$$(1 - \lambda_p) B \frac{\partial \eta}{\partial t} = -\frac{\partial Q_s}{\partial x} \tag{2}$$

where

η Bed elevation,
B The width of the control volume,
q Volumetric transport rate,
λ_P Bed porosity.

The equation is solved separately by computing a sediment transport capacity for each grain size in the control volume associated with each cross section. If the

capacity is greater than the sediment supply entering the control volume, there is erosion of the bed sediments. If supply surpasses capacity, there is an excess of sediment leading to the deposition of sediment. The size of sediment particles plays an important role in erosion and deposition of sediment in the river; defining the sedimentation part in HEC-RAS, each cross section should have a gradation curve in a discrete bed. For that, samples were collected from Annapurna Ghat station and gradation was done in the laboratory and the bed gradation of the remaining 63 cross sections was interpolated using HEC-RAS tool. The upstream boundary condition was given the option of *Equilibrium Load* in which the volumetric sediment discharge is assumed equal to the transport capacity everywhere in the reach.

3 Results and Discussion

3.1 Hydraulic Calibration of Model

The calibration of calculated data by the model is performed using the observed values at Annapurna Ghat station. The model was run repetitively from 1 June–30 June 2003, by altering Manning's roughness coefficient value at the various cross sections under steady flow analysis in order to get the best value of n. The initial value is obtained from equation given by Cowan

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5 \tag{3}$$

where

n_0 Base value for n for a straight uniform, smooth channel in natural materials,
n_1 Value added to correct for surface irregularities,
n_2 Value for variation in shape and size of channel,
n_3 Value for obstructions,
n_4 Value for vegetation and flow condition,
m_5 Correction factor to account for the meandering of the channel.

From physical interpretation of the values of the various parameters, the n value was obtained as 0.07. The Nash–Sutcliffe efficiency (CE) was used to select the best n value for estimating the water surface elevation of Annapurna Ghat station. However, the model performance was also checked through correlation coefficient (Corr).

The result of calibration is represented in Table 1.

Hence, the best result is obtained with roughness coefficient value as 0.07 same as that obtained from the equation given by Cowan. Hence, the final calibrated value of n was taken as 0.07.

Table 1 Statistical parameters showing the performance of the model with different n values

Statistical parameters	n = 0.07	n = 0.08	n = 0.06
Nash–Sutcliffe efficiency	0.915	0.914	0.856
Correlation coefficient	0.998	0.997	0.996

Table 2 Statistical parameters showing the performance of the model with different sediment transport functions

S. no.	Transport function	Fall velocity	n		Nash–Sutcliffe efficiency	Correlation coefficient	SSE
1	*Ackers–White*	*Report 12*	*0.07*	AP	*0.673*	*0.867*	*47387144460*
				BP	*0.595*	*0.786*	*21551471086*
2	Toffaletti	Report 12	0.07	AP	0.189	0.866	48387144460
				BP	0.591	0.776	21857577900
3	Laursen (Copeland)	Dietrich	0.07	AP	−1.050	0.863	265032006218
				BP	0.064	0.759	44315760821
4	Yang	Van Rijn	0.07	AP	−0.949	0.836	32692646283
				BP	0.207	0.745	22177374373

3.2 Selection of Sediment Transport Function

The second phase of HEC-RAS model calibration was done after calibrating the model hydraulically by running the steady flow analysis. The next step is to evaluate the model for sedimentation calculations. Here, the sediment discharge is used for calibration of the model. The model was run repetitively with different sediment transport functions, which is required for the calculation of sediment transport capacity, and the best transport function was selected which produces the value of sediment discharge close to the observed value at both upstream and downstream cross section. Table 2 displays the comparison of different transport functions and fall velocity method available in HEC-RAS 5 using Nash–Sutcliffe efficiency, correlation coefficient, and sum of square error.

The above table shows that Ackers–White transport function produces better value of the various statistical parameters at both upstream and downstream cross sections as compared to others. Therefore, this transport function is used in the present study for further calculations.

3.3 Prediction of Invert Changes

The invert of a river is an important criterion in geometry of the river cross section to define the potential of erosion or deposition. It undergoes changes during the time affected from river phenomena. The invert change in the model was produced using Ackers–White sediment transport function from Annapurna Ghat to Badarpur
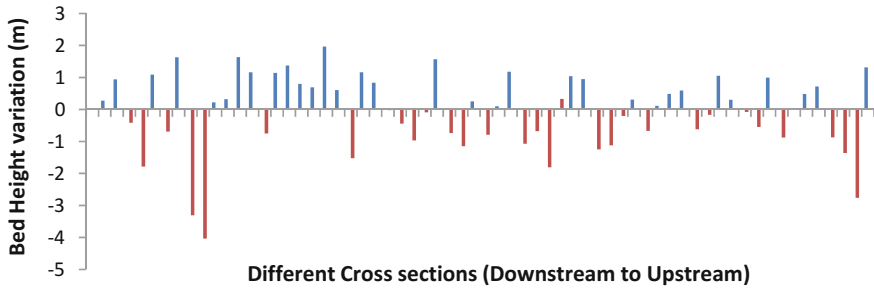
Fig. 2 Prediction of cumulative erosion and deposition of Barak River in the study reach

Ghat station having 64 cross sections from River Station (RS) 50999.31 to River Station (RS) 69.89. The difference between invert change in each cross section and initial bed level will determine the sedimentation. If the invert change is lesser than the initial bed level, then deposition takes place in that particular cross section and vice versa. Figure 2 shows the cumulative value of erosion and deposition of sediment at the various cross sections in the study reach from 1 June to 31 October 2004.

The maximum cumulative depth of erosion in the reach is about 4.04 m occurring at River Station 43949.69 (10th cross section from upstream) and the maximum cumulative depth of deposition is about 1.97 m at River Station 37331.06 (20th cross section from upstream) in wide regions of river as shown in Fig. 2. Because of meandering nature of Barak River, most of the erosion occurs on the concave side and deposition occurs on the convex side of the river bend. By field visit, it is also observed that the simulated erosion and deposition at the various cross sections are approximately same as the practical condition.

4 Conclusion

The present study deals with the simulation of sedimentation condition of the Barak River from Annapurna Ghat to Badarpur Ghat using HEC-RAS. The model was first calibrated for hydraulic conditions of the river, and the Manning's roughness coefficient of 0.07 that gives the best value of Nash–Sutcliffe efficiency (0.92) was considered which was also obtained from the equation given by Cowan. Then, the selection of sediment transport function is performed by calibrating sediment discharge. Ackers–White sediment transport function was found to provide better sedimentation result with Nash–Sutcliffe efficiency of 0.67. Then, channel invert variations were estimated for determination of erosion and deposition at various cross sections. It was found that the model is able to describe the sediment discharge movement as well as can estimate the amount of sediment deposition and erosion at different sections in the study reach. Because of meandering nature of

Barak River, most of the erosion occurs on the concave side and deposition occurs on the convex side of the river bend. It is noteworthy that the sediment transport function of this work has been proposed as more appropriate function not only because it gives better results but since each sediment transport function is based on specific geometric, hydraulic, and sedimentation conditions and it matches well with present study reach. Thus, the geometric, hydraulic, and sedimentation conditions of each sediment transport functions and also the river reach of study are of critical importance in optimized application of these methods.

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