NUMERICAL STUDY TO PREDICT SEDIMENT RUNOFF PROCESS IN THE MATAMUHURI RIVER BASIN, BANGLADESH

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ABSTRACT

Downstream of the Matamuhuri River basin is currently experiencing river bed erosion, bank line shifting, siltation, and flooding due to a huge onrush of sediment-laden water during the monsoon. The present study focuses on prediction of sediment runoff processes in the Matamuhuri Basin using the rainfall runoff inundation model-based sediment transport model called rainfall sediment runoff. The model evaluates the basin-scale sediment production, transportation, bed variation, and sediment sorting. The study basin was simulated for a seven-month wet-dry period in 2020. The model predicted high sediment deposition in the middle part of the basin, where the main channel is flat and has a low sediment carrying capacity. The tributaries and upstream reaches with high slope gradients produce a lot of sediment, among them, three tributaries have higher sediment production (approximately 40% of total) than other tributaries, which implies the effectiveness of check dams for these tributaries. The model also predicts the amount of change in bed erosion at the tributary and deposition at the main channel that can occur if the countermeasures are implemented.

Key Words: Sediment production, Sediment transport, Bed Erosion, Deposition, Countermeasure.

INTRODUCTION

The Matamuhuri River is located in the south-eastern hilly region of Bangladesh. Originating from the Bangladesh-Mayanma border, it flows north-west and eventually falls into the Bay of Bengal. The river has a total basin area and length of approximately 1600km^2 and 150 km respectively. The Bangladesh government formulated a 100-year delta plan for the water sector focusing on economic growth, environmental conservation, and enhanced climate resilience. The Basin is included in one of the six hotspot in delta plan called "Chattogram Hill tracts". This river shapes the agriculture, fisheries, biodiversity, and trades of this region. The Matamuhuri River and most of the tributaries have experienced erosion, siltation, and flooding problems over the years due to a huge onrush of sediment-laden water during monsoons. In addition, human activities such as human settlement, deforestation, hill cutting for construction of road networks, and land preparation for

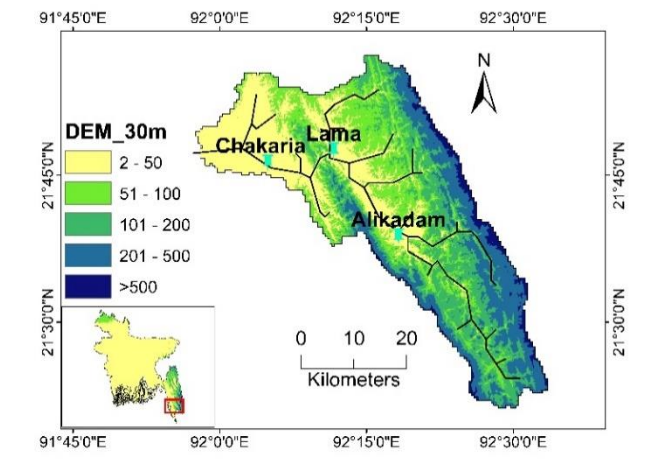

Figure 1. Matamuhuri basin with important locations

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agriculture and brick fields make top soil vulnerable to erosion. Huge siltation leads to decreased conveyance of the river and decreased water availability during the dry season- leading to navigation problems and scarcity of water for industrial use. The local people cultivate the hilly land by plowing and then in the monsoon season, heavy rainfall causes high erosion on the hill slope, causing fast sediment deposition on river bad resulting in low conveyance capacity. Thus, the river decreases its natural conveyance capacity and increases its flood inundation area. Therefore, it is necessary to conduct basin-scale analysis to identify viable ways to address these problems.

This study attempts to predict and evaluate the sediment transport rate, bed variation and sediment sorting along the river course and to develop a plan to reduce the sedimentation rate using structural or non-structural countermeasures. The main challenge of this study was to incorporate the sediment supply from bare land into the computation.

THEORY AND METHODOLOGY

Debris flow, bed load, and suspended load movement through the river channel were all included in typical sediment transport.

It is vital to understand sediment formation, sediment transportation mechanisms, and sedimentation, as well as how human activity intensifies sediment-laden problems. The one-dimensional sediment model rainfall sediment runoff (RSR) was utilized to accomplish these goals. The model was composed of the Rainfall Runoff Innundaton (RRI) model, unit channels and unit slopes,as proposed by Egashira et al.,(2000). The bed load formula from Egashira et al., (1997) and suspended load formula from Harada et al., (2022) were employed in this research. Figure 2 shows the flow chart of the research methods used in this study.

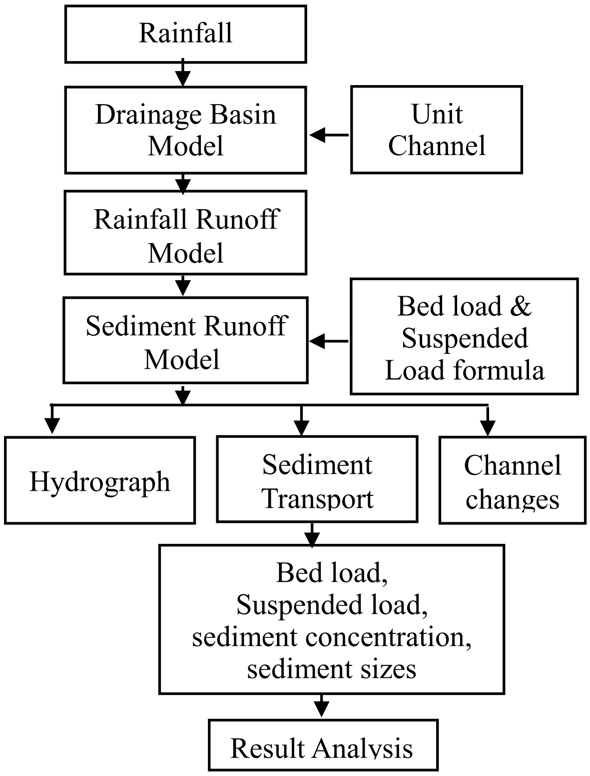

Figure 2. Flow Chart of complete Methodology

Governing equation for sediment

Mass conservation of bed load sediment (equation of bed elevation) is given by the following equation

$$\frac{\partial z_b}{\partial t} + \frac{1}{1-\lambda}\left(\frac{\partial q_{bx}}{\partial x} + \frac{\partial q_{by}}{\partial y} + E - D\right) = 0 \quad (1)$$

where, z_b=river bed elevation, λ=sediment porosity, q_{bx}= bed load rate in the x direction q_{by}= bed load rate in the y direction, E=erosion rate, D= deposition rate.

The critical conditions when the bed load is initiated are critical bed shear stress, non-dimensional critical bed shear stress, and critical shear velocity.

Bed load formula by Egashira et al. (Egashira et al., 1997) is expressed as follows:

$$q_{b^*} = \frac{4}{15}\frac{K_1 K_2}{\sqrt{f_d + f_f}}\tau_*^{\frac{5}{2}}, \text{ where, } \tau_* = \frac{u_*^2}{\left(\frac{\sigma}{\rho}-1\right)gd}, \; u_* = \sqrt{gh\sin\theta} \quad (2)$$

where non dimensional bed load transport rate is q_{b^*} , τ_* is the non-dimensional bed shear stress, K_1 , K_2 , f_d and f_f are specified theoretically, d is the grain size, h is the flow depth and θ is the bed slope.

The equation for suspended sediment erosion rate (Harada et al., 2022) is represented as follows:

$$\frac{W_e}{u} = \frac{K_e}{R_{i*}}, (R_{i*} = \frac{\Delta\rho}{\rho}\frac{gh}{u^2}\ ,\ \ \frac{\Delta\rho}{\rho} = \left(\frac{\sigma}{\rho} - 1\right)\overline{c_s}),\ K_e = 0.0015,\ ,E_{si} = p_i W_e \overline{c_s}\ ,\ E_{si} = p_i \frac{Ku^3}{gh\left(\frac{\sigma}{\rho}-1\right)} \qquad (3)$$

Where W_e is the entrainment velocity, R_{i*} is the Richardson number, $\Delta\rho$ is the difference in the density between the bedload layer and the upper water body layer, $\overline{c_s}$ is the sediment concentration of bed load layer, p_i is the fraction of size class di, h is flow depth, g is gravity acceleration and u is the flow velocity.

When surface flow appears on the slope, suspended sediment is supplied from the slope, according to Equation (3). Additionally, when the slope is not covered by vegetation and turns into bare land as a result of human activities such as deforestation, road construction, and human settlement, the surface roughness of the slope is considered to be less than that in other areas. Considering such a situation, we assumed that the Manning roughness on the bare land was the same as the river bed roughness.

DATA

First, input data were prepared for the RSR model analysis. Second, 30 arc sec data from HydroSHEDS served as the topographic data of the study area to designate the basin. Third, daily ground gauge rainfall data were used for the simulation. We considered the following three cases for this study: Case 1, Sediment production from the river bed; Case 2, Sediment production both from the river bed and slope; and Case 3, Sediment production river bed and slope along with bare land. For Case1 and 2, one type of land use were considered. For case 3, two types of land use were considered, and the second type was bare land based on Google Earth investigation. Human settlements, newly constructed road networks, agricultural land, deforested land and brick fields were considered bare lands where erosion occurs due to formation of gullies on the slope.

In addition to the RRI model input file, a sediment input file was prepared to simulate the RSR model. To consider the sediment supply from both the river bed and slope two sets of non-uniform sediment distribution files were prepared. Several initial grain size distributions (GSDs) were used for the trails and the total yearly sediment volume transported through the outfall per unit basin area and sediment concentration at Lama with observed data of nearby basin were checked. Finally one GSD was selected for the analysis. An additional GSD was used for the slope as shown in Figure 3.

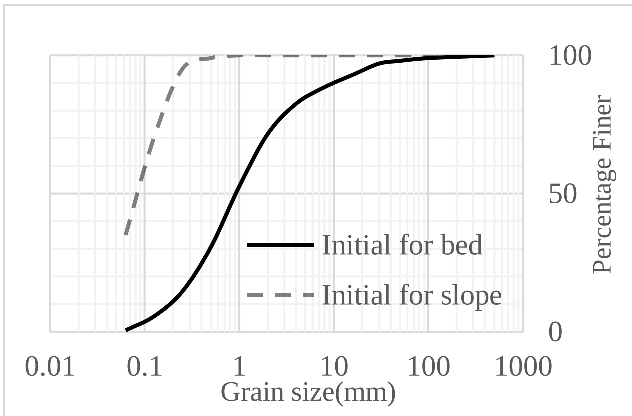

Figure 3. Grain Size Distribution

RESULT AND DISCUSSION

RRI model calibration and validation were performed based on discharge data measured at the Lama Station in 2018 (June to November) and 2020 (June to November) respectively. Calibration and validation were conducted based on the aforementioned steps. The Nash–Sutcliffe model efficiency coefficient values for calibration and validation were found 0.68 and 0.55 respectively.

To understand basin-scale sediment production under different circumstances, three cases were considered as sources of sediment production, Case 1 (river bed), Case 2 (river bed and slope) and Case 3 (river bed and slope with bare land). Approximately 7% and 12% of basin were considered as bare land.

Catchment area and sediment productions

Figure 4 (a) shows the Japanese drainage basin chart. The calculation result agrees with the relationship between the catchment area and the yearly averaged specific discharged sediment. The dots on the chart represent the names of the rivers in Japan plotted based on the sediment discharge. In all three cases in

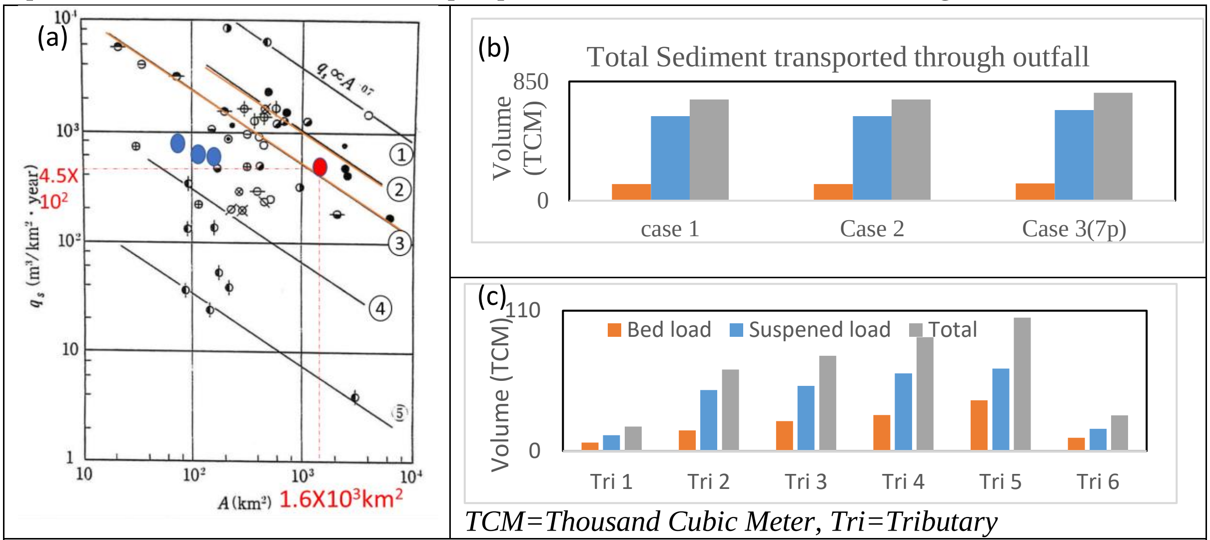

Figure 4. (a) Relation between the catchment area and the yearly averaged specific discharged sediment, (b) Basin total sediment discharge through the outfall and (c) Tributary sediment supply

the study basin, the sediment production was large (between line 2-3) sediment producing river marked with a red dot and for three major tributaries 3,4 and 5 fall under the medium sediment (between line 3-4) producing river marked with blue dot. Among the three major tributaries, tributary 3 has the maximum specific production per unit area. Cases 2 and 3 exhibited similar trends.

Sediment concentration

As the basin lacks sediment concentration data, we compared the sediment concentration of the model output with that of the Sangu River, where field data on sediment concentration are regularly collected.

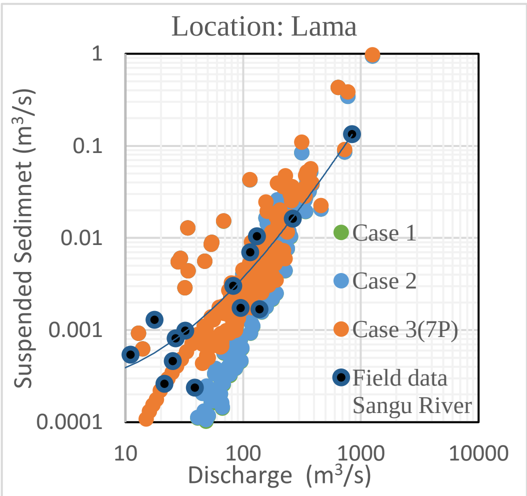

Figure 5: Sediment concentration considering all flood peaks.

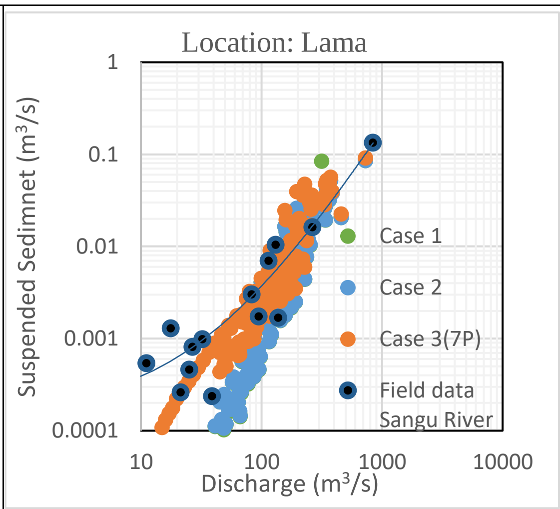

Figure 6: Sediment concentration without 1st flood peak.

The Sangu and Matamuhuri rivers originate from the same geographic location and have similar soil properties, rainfall patterns and land use. The sediment concentration for Case 3 at the Lama is shown in Figure 5. The simulation period up to 1st flood shows higher concentration than later floods, probably due to the effect of the initial condition. Figure 6 shows the concentration without 1st flood, which is a better representation.

Channel bed Variation

Figure 7 shows basin wise erosion and deposition zone on the channel bed. According to model output, most of the tributaries face channel bed erosion where the main channel has depositions. Maximum bed erosion was found to be 0.60m in the upstream reaches and tributaries. Among the main tributaries, Tributaries 3, 4 and 5 had the maximum bed erosion, which can be attributed to the higher slope gradients of these tributaries than others. Among them maximum bed degradation was found on Tributary-3 due to higher rainfall and discharge than tributary-5. Moreover, the middle part of the main channel showed deposition, which increases channel bed level up to a maximum of 0.65 m. For Case 1, 2 and 3, the model showed a similar trend. Deposition in Case 3 was higher than that in Case 1 and 2. At Alikadam, greater sediment deposition (by 4 cm) was observed for Case 3, with 12% bare land, than that for Cases 1 and 2.

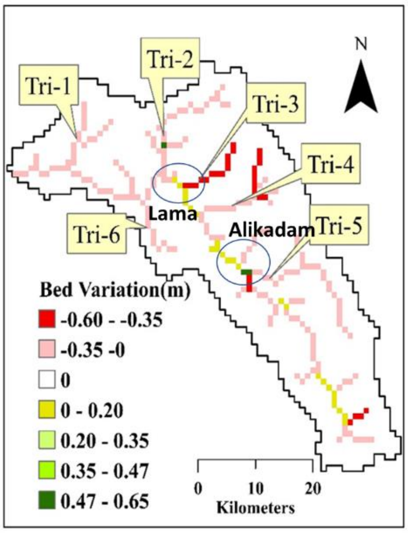

Figure 7. Bed Variation

Lama and Alikadam cities experience sedimentation on the bed with Alikadam showing greater sedimentation than Lama. The Main reason for this is that, the slope at Alikadam is considerably smaller (gradient=0.001) than that at the upstream main channel (gradient=0.004) and Tributary-5 (gradient=0.007). It is also a confluence point of Tributary-5 and the main channel and both of which are currently experiencing bed erosion. Tributary-5 produced 15 % of total sediment volume and the upstream main channel also carried a lot of sediment. These combine sediment which is coming to the Alikadam and loses carrying capacity. As a result, sediment from both bedload and suspended load accumulated here. During flood peaks at Alikadam up to 16 mm size particles gain critical bed shear stress τ_{*c} (Figure-8)

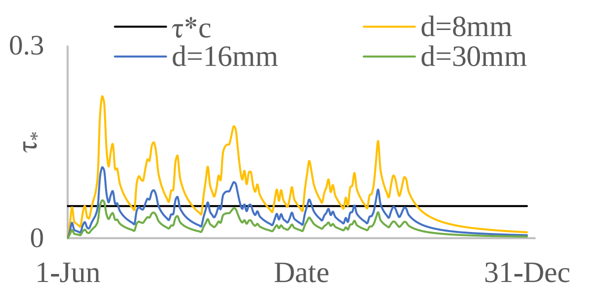

Figure 8. Shear Stress size class i at Alikadam

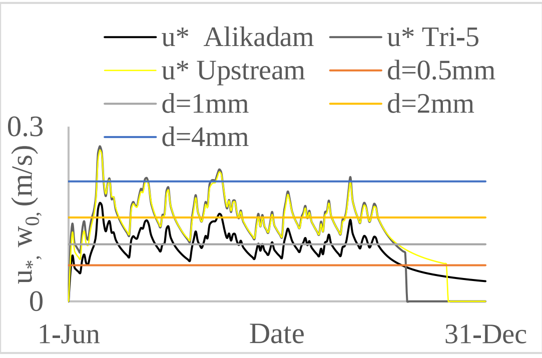

Figure 9. Shear and fall velocity size class i

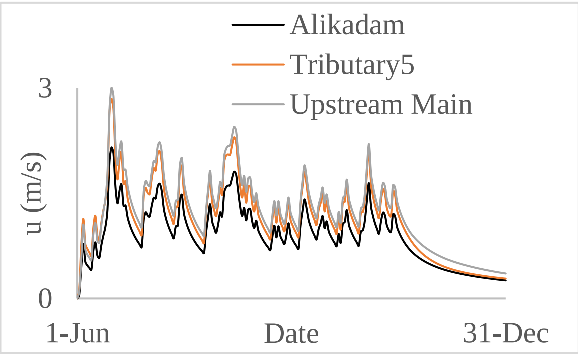

Figure 10. Flow velocity

and up to 2 mm size particles gains shear velocity u_* greater than fall velocity w_0 (Figure 9) to be transported as bed load and suspended load respectively. The erosion rate formula has the functional form u^3 (average flow velocity), as proposed by Harada et al. Therefore, the erosion rate is reduced due to a decreased flow velocity at Alikadam (Figure 10). However, Tributary-5 and the upstream main channel have high flow velocity (Figure 10) indicating a high erosion rate. A similar phenomenon occurred at the city Lama. Therefore, to reduce sediment deposition in these two cities, sediment production at the source needs to be controlled by constructing flow-velocity-reducing structures.

Countermeasures

As sediment deposition on river-beds increases the extent of flooding, it is necessary to control the sediment supply from upstream. Controlling the sediment supply check dam construction on three tributaries (3, 4 and 5), where the supply of sediment is very high, are considered an effective countermeasure. First, the effect of each check dam was analyzed separately. We assumed that the check dam would stop bed load sediment from those tributaries by 70 %. Table 1 and Figure 11 show the bed variation changes in two targeted locations Lama and Alikadam.

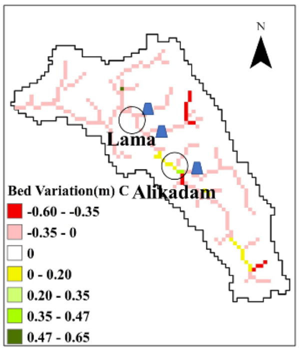

Figure 11. Check dam Effect

Table-1. Construction of check dam

	Outfall			Lama city			Alikadam city		
	Without Check Dam	With Check Dam	Change	Without Check Dam	With Check Dam	Change	Without Check Dam	With Check Dam	Change
Bedload (TCM)	119	115	5	66	62	5	36	34	2
Suspended load(TCM)	602	564	38	250	215	36	118	103	14
Total(TCM)	721	679	42	317	276	41	154	138	16
Bed Variation(m)	**-0.0823**	**-0.0819**	**-0.0004**	**0.1088**	**-0.0239**	**0.1327**	**0.640**	**0.466**	**0.174**

The calculated results showed that the sediment accumulation decreased remarkably (Table-1). In Lama and Alikadam, the previous accumulation of sediment during the simulation period was 0.100m and 0.640m respectively which were reduced to -0.0239 m and 0.466 m respectively. These results indicate that for Lama, the channel capacity is increasing but for Alikadam additional work such as dredging is required to increase the channel capacity.

CONCLUSION AND RECOMMENDATION

The study of the sediment runoff process in three cases provides a better understanding of basin-scale sediment production and transportation. Bare land produces fine particles that increase the concentration and sediment supply. Based on the bare land area 5-10 % additional suspended sediment was found in the simulation which increased sediment accumulation on channel bed and reduced the channel capacity. Check dams on the main tributaries significantly reduced sediment production and accumulation in Lama and Alikadam.

In recent years, due to deforestation and heavy rainfall over a short duration, landslide events have occurred with casualties and injuries but no specific location data are available as there is no responsible authority to keep records of landslide events. However, these landslide events are important because they increase the sediment accumulation rate. Therefore, landslide event incorporation in the basin-scale sediment runoff process is an important issue. Additionally, local scale analysis is necessary to understand channel shifting mechanisms and propose countermeasures.

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