An approach to predict the yearly bank erosion rates of Jamuna River: An application of the correlation of bank shear stress and river discharge

[1]Mahmood Khan, [2] Dr. Mohammad Mostafa Ali
[1]Graduate Student, [2]Associate Professor
[1,2]Department of Water Resources Engineering,
[1,2]Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

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***Abstract* - Hydraulic erosion of river bank is one of the key factors controlling the bank erosion rates. In this study hydraulic bank erosion rate has been quantified with the help of analytical formulae and 2-dimensional numerical model. A 2-dimensional morphological model was developed for the selected reach of Jamuna River using the modeling platform MIKE 21C. After calibrating the erosion trends of Jamuna River for 2012, the model was simulated for hydrologic events with return periods 2.33 year and 100 year to estimate the erosion rates for those events. The erosion rates were used to calculate bank shear stress. Since primary discharge data was not available at different reaches model simulated discharge for different hydrologic events were utilized to correlate it with bank shear stress. This correlation paved a way to estimate bank shear stresses from the river discharges at respective reaches for the hydrological event of 2013, which in turn offered an opportunity to obtain erosion rate for the same event. The erosion rates thus obtained was compared to that revealed by satellite imagery. The outcome of the comparison represents that the erosion rates calculated by the aforementioned approach was very close to the observed ones.**

***Index Terms*- Hydraulic erosion, numerical model, bank shear stress**

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1. Introduction

Stream being a dynamic system changes its course to attain stability. In this continuous process of attainment of stability planform, morphology and other features of streams change to cope with it. The effects of such changes are eventually noticed in planform and channels are adjusted in shape and size to convey the discharge and sediment supplied into the stream. The most common outcome of such adaptation in planform is bank erosion. Stream bank erosion is a dynamic natural geomorphic process that occurs during or soon after floods resulting in meandering of rivers as well as alteration of channel course. Such erosion affects a range of physical, ecological management issues in the fluvial environment. Studies have shown that sediment from stream bank can account for as much as 85% of watershed sediment yields bank retreat rates as high as 1.5 to 110m/year have been documented [1]. In addition to water quality impairment, stream bank retreat impacts flood plain residents, riparian ecosystems, bridges other stream-side structures [2]. Stream bank retreat typically occurs by a combination of three processes sub aerial processes erosion, bank failure and fluvial erosion [3]. Sub-aerial processes are climate-related phenomena that reduce soil strength, inducing direct erosion and making the bank more susceptible to fluvial erosion. The collapse of bank materials due to slope instability is referred to as bank failure. Fluvial or hydraulic bank erosion (hereafter called erosion) is the direct removal of soil particles or aggregates from river banks by the direct erosive action of the flow. Erosion rates can be quantified by the soil critical shear stress (τ_c). the critical shear stress is defined as the stress at which soil detachment begins or condition that initiates soil detachment. If the critical stress is higher than the effective stress, the erosion rate is zero [4]. Theoretically, maintenance of the channel boundary shear stress below τ_c is a requirement for stream bank stability. In general fluvial erosion rates depend on the flow strength physical characteristics (soil erodibility parameters) of the bank materials. It is widely accepted that fluvial erosion rates can be quantified as excess shear stress formula such as

$$\varepsilon = k_d (\tau_a - \tau_c)^a \qquad (1)$$

where ε is the fluvial bank erosion rate (m/s) per unit time per unit area, a is the boundary shear stress applied by the flow, k_d is the erodibility co-efficient, c is the critical shear stress and a is an empirically derived co-efficient which is generally considered to be 1. An empirical relationship [5] between k_d and τ_c is

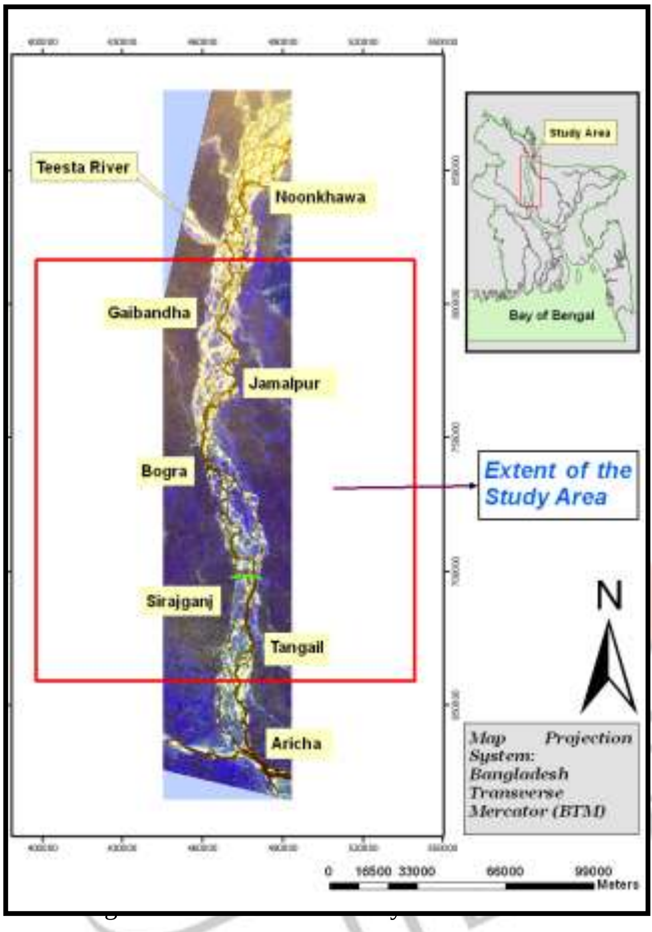
$$k_d = 2.0 \times 10^{-7} \quad (\tau_c^{-0.5})$$

There are several approaches for determining τ_c. Critical shear stress can be determined in flume studies, estimation based on soil parameters such as particle size & soil specific gravity. For non-cohesive soils, Shields' diagram provides estimates of critical shear stress based on particle size using a representative particle diameter & assuming no interaction among the sediment particles.

2. Profile of the Study Area

The lower reach of the Brahmaputra River i.e. about 240km long reach from the international border of Bangladesh to the confluence with the Ganges River is referred to here as the Jamuna River. The distance between the western entry of the river in Bangladesh and the confluence with the Ganges is about 2km longer than the distance between the eastern entry of the river and Aricha. The length of the bank line exposed to erosion is about 265 km along the right bank and 245 km along the left bank. In terms of erodibility, bank materials of the right and left banks have similar characteristics. The Jamuna River is a braided river having a braiding index of 5 to 6. The width of the river varies from 8 to 16 km with a length-averaged width of about 12 km. Both braiding intensity and reach-averaged with of the river have been changing over time [6]

In this study we have focused on 160km reach of Jamuna River from offtake of Teesta River to 70km downstream of Bangabandhu Bridge. In this regard five erosion prone reaches from 5 districts have been identified, 3 of them along right bank while the rest along the left bank. Figure 1.1 depicts the study area.



3. Methodology

A two dimensional model of the study site has been developed using the modeling platform MIKE 21C. The hydrodynamics & morphology of the model was calibrated for the year 2012. Then the model was simulated for hydrological events with return period 2.33 year (flood event-2005), 10 year (flood event-1995) and 100 year (flood event-1998). Utilizing the outcomes of scenario simulations a relationship between τ_a and discharge was established for five erosion prone reaches. The relationship thus obtained was used to calculate the bank erosion rate from the discharge after the passage of hydrological event 2013. Erosion rates for the year 2013 have been calculated from τ_a of the corresponding model simulated discharges indicated by the correlation equation. The calculated erosion rate was compared to the erosion rate depicted by the satellite imagery to evaluate the fitness of the derived relationship.

4. Development of 2-D model

The model setup includes the generation of computational grids, the preparation of the bathymetry, boundary conditions and selection of calibration parameters. Followed by the set up, the model is calibrated with the tuning of hydrodynamic parameters (like Chezy's bed roughness, eddy viscosity etc.), the parameters in the sediment transport magnitude formula e.g., bed load suspended load factors. Figure 4.1 to 4.3 depict the calibration of water level, sediment transport & bank erosion. Then the model has been simulated for different applications runs.

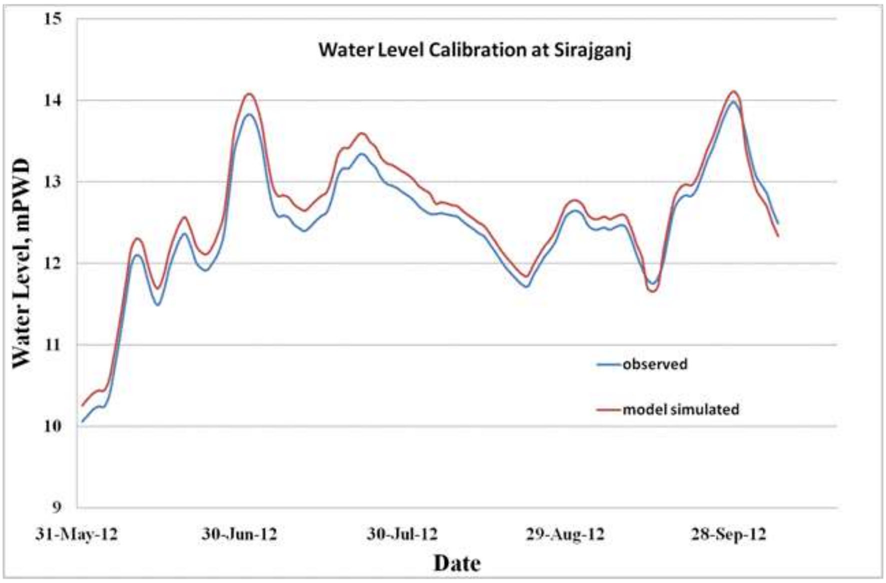


Figure 4.1: Water Level Calibration at Sirajganj Station for the year 2012

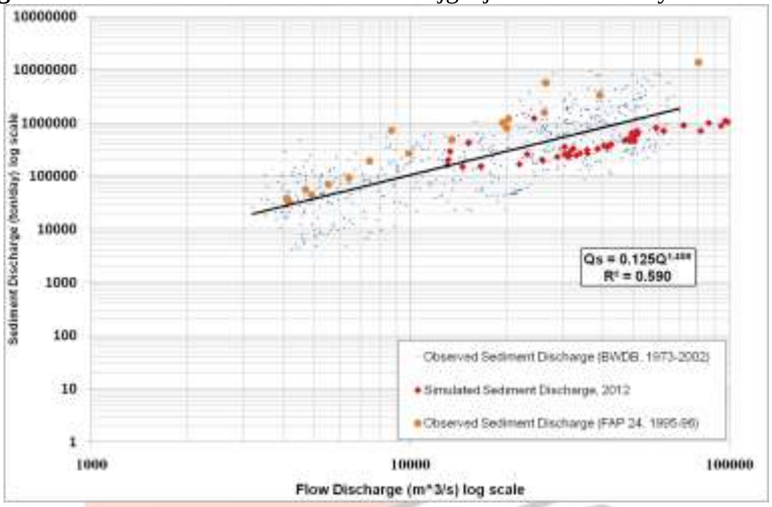
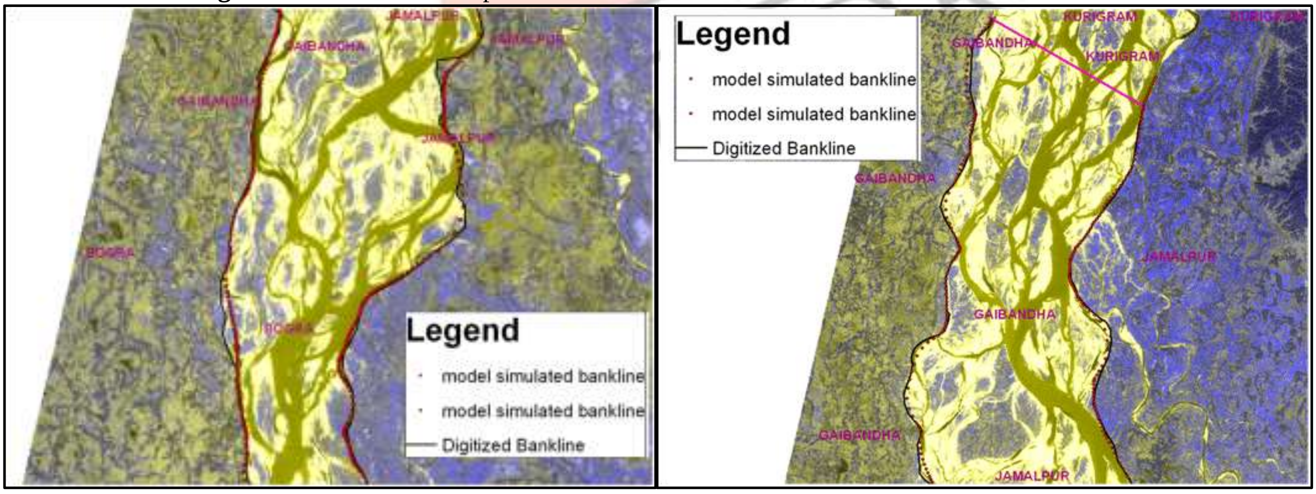


Figure 4.2: Sediment transport rate Calibration at Bahadurabad Station for 2012



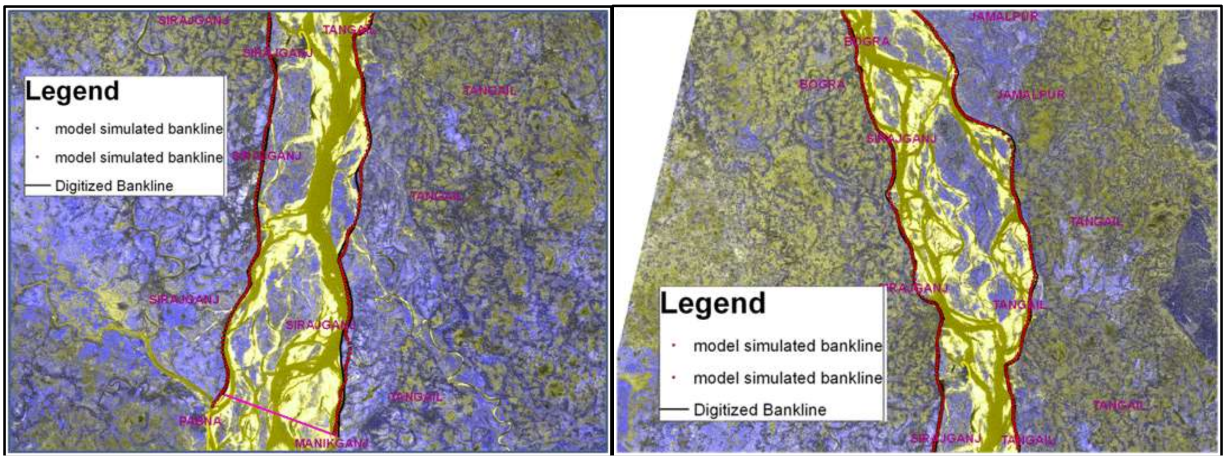
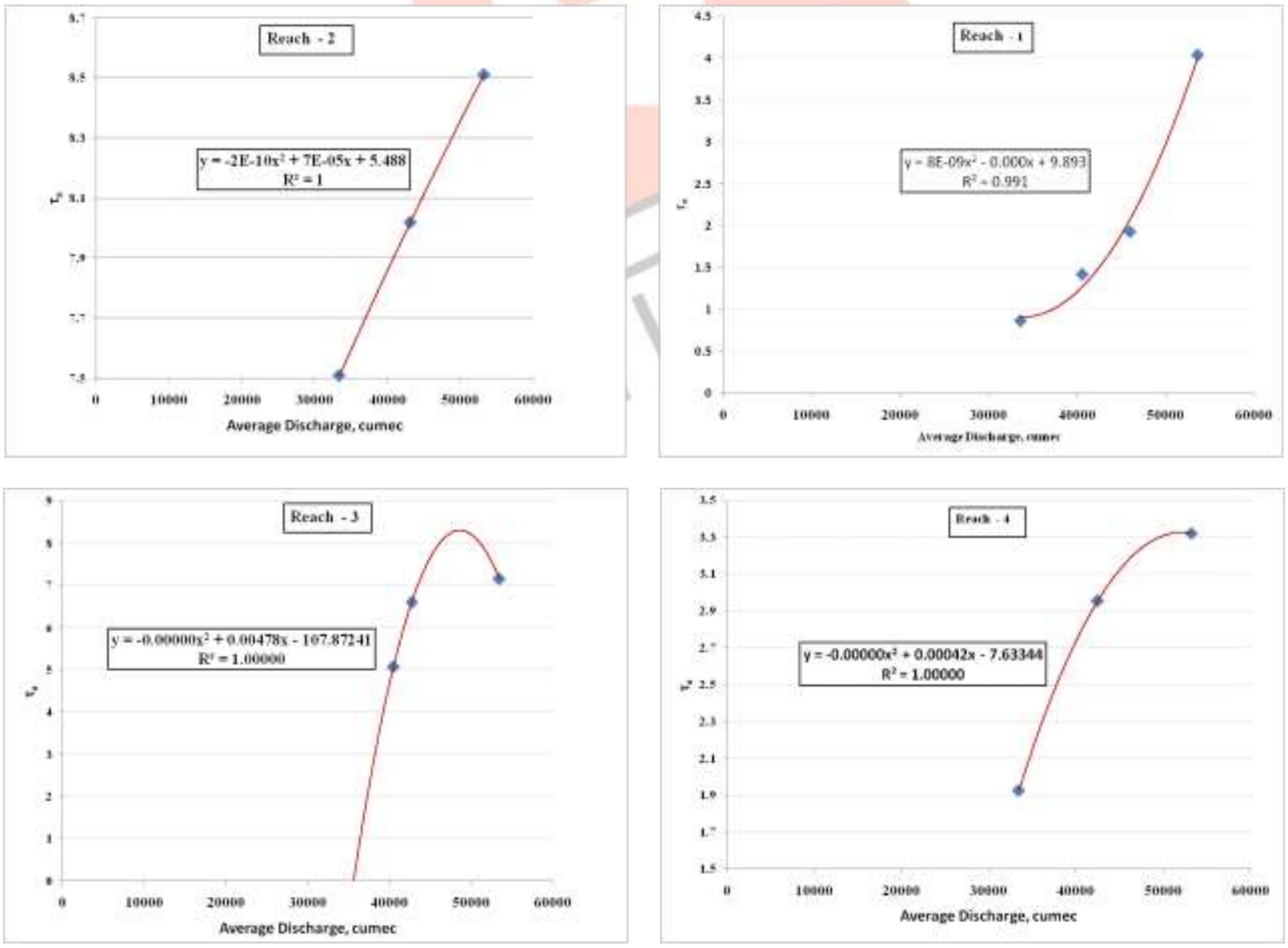


Figure 4.3 Calibration of bank erosion along different reaches

5. Results

The preceding formulae & 2-D model were used to establish relationship between τa and discharge at individual reaches. Since discharge data were not available at the desired reaches model simulated discharges at those reaches were used. Model simulated bank erosion rates for different hydrologic events were utilized to calculate τa for respective hydrological events. The simulated boundary shear stresses were then linked to average flow discharge that prevails over five months (June to October) covering the monsoon season as shown in Figure 5.1. In all cases significant regression relationships were obtained. The best fit polynomial curves depict that simulated boundary shear stress monotonically increases with the average flow discharge.

Furthermore, in addition to the satisfactory correlations between bank shear stress & average flow over the monsoon, it has provided a means to obtain simple bank erosion rate predictions that are linked directly to the flow discharge regime. The above illustrated relationships were next used to derive the erosion rate for the monsoon period of another hydrologic event (2013- flood event) using the developed 2-D model simulated discharge. Using the above illustrated relationships of τa and average flow discharge. The predicted erosion rates th were evaluated by comparing bank erosion rates derived from the correlation with those estimated by remotely sensed imagery. A comparison of predicted versus observed erosion rates has been presented in Figure 5.2. It is evident from the figure that observed & predicted erosion rates fall very close to the 1:1 line for four out of five erosion prone reaches.



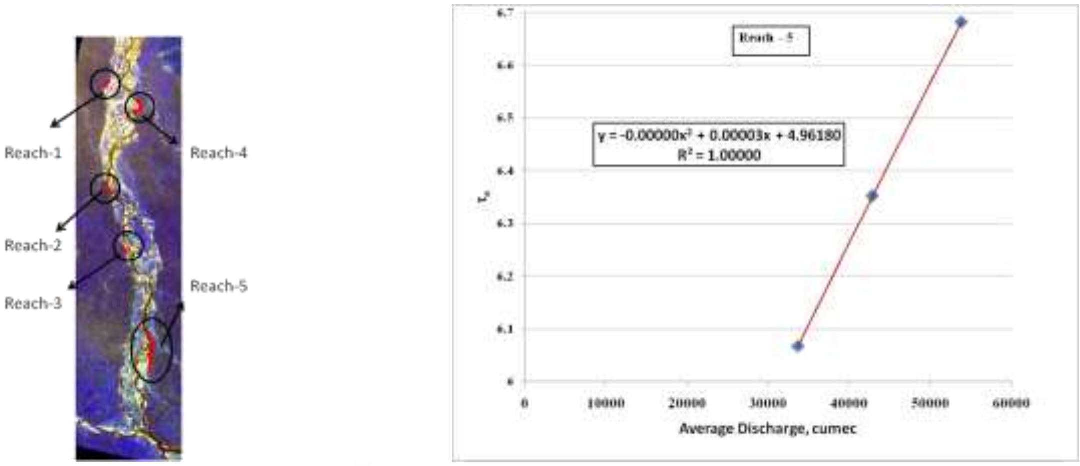


Figure 5.1 Simulated bank shear stresses as a function of average monsoon flow discharge for selected erosion prone reaches

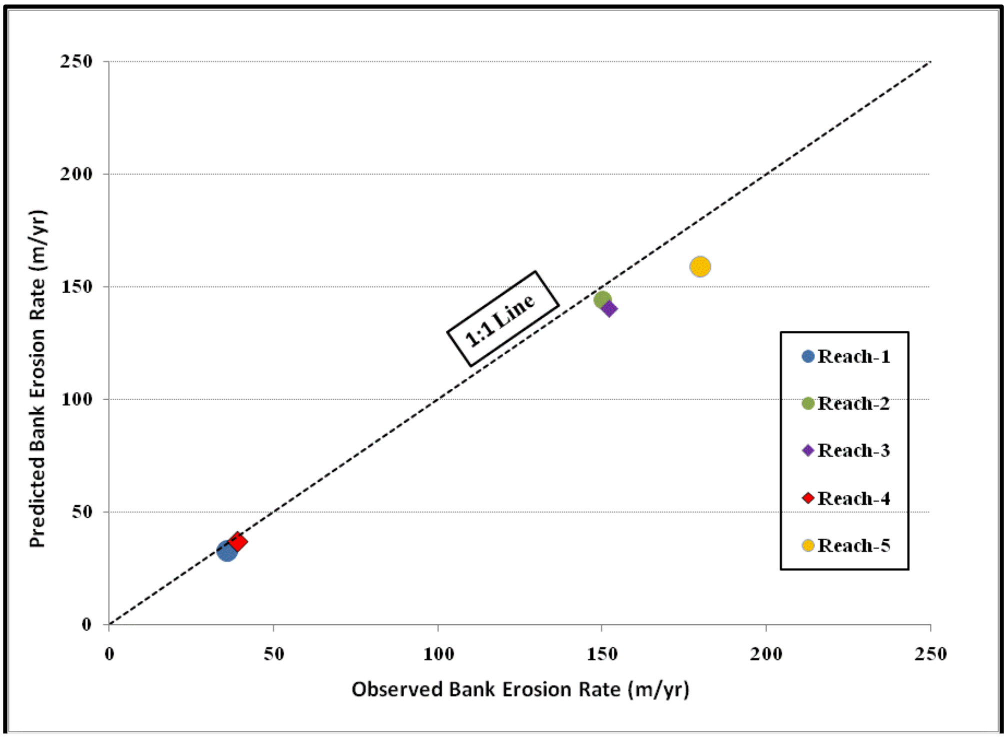


Figure 5.2: Comparison of predicted and observed bank erosion rates at the selected reaches

6. Discussions

It is worth to mention here that the number of data points employed is clearly less than that would be ideal for a comprehensive analysis of performance of the developed correlation. However, there were logistical difficulties involved in collecting the necessary data. A key limiting factor concerns the lack of available satellite imagery or aerial photographs of sufficiently high resolution and at frequent temporal intervals. As such the prediction presented in Figure 5.2 provides only a tentative indication of its acceptability & further work is required to assess its capability across a wide range of river reaches.

7. Conclusions

In this study a combination of analytical approach and numerical model to correlate river discharge & shear stress applied on the river banks due to the erosive actions the flow; applied to non-cohesive riverbanks of Jamuna River. Shear stresses introduced on riverbanks due to the passage of flow have been estimated with the help of model simulated erosion rates. In addition a good correlation between average discharge prevailing throughout the monsoon & bank shear stress paved a way to predict the riverbank erosion rates. This, in turn, has enabled to present such a method of prediction of riverbank erosion rates that do not require complex calculation.

8. Acknowledgements

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9. References

[1] Trimble, S. W., "Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science", 278(5342):pp: 1442-1444, 1997.

[2] ASCE "River Width Adjustment: I.Processes and Mechanisms, Journal of Hydraulic Engineering, 124(9), pp no.- 881-902, 1998.

[3] Lawler D.M., "The impact of scale on channel side sediment supply: A conceptual Model, In effects of scale on interpretation & management of sediment & water quality", IAHS Pub-226, 1995.

[4] Osman, A. M., and C. R. Thorne.. "Riverbank stabilityanalysis": I. Theory. J. Hydraulic Eng.114(2): 134-150, 1998.

[5] Hanson, G. J., and A. Simon. " Erodibility of cohesive streambeds in the loess area of the midwestern USA.", Hydrological Processes15(1), pp- 23-38, 2001.

[6] CEGIS, "Long term erosion rates of Jamuna River", pp-20-25, 2007.