BED FORM AND SIDE BANK EROSION OF PADMA RIVER REACH

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ABSTRACT

Side bank erosion in the curved reach of Padma River is very high at Harirampur area of Manikganj district. Secondary currents and lateral bed slope are important factors for describing bank erosion in curved channels. These two terms act on sediment transportation towards the inner direction. Hence, erosion takes place and sometimes, the bank area is washed away drastically. Present study proposes a bank erosion model and discusses its applicability. The bank erosion model, which is able to evaluates influences of lateral bed slope and secondary currents on sediment transportation, is incorporated into a depth averaged 2-D flow and bed deformation model to compute side bank erosion precisely along the outer banks. Annual bank erosion of Padma River reach is computed and compared with data obtained from Landsat images. The computed results suggest that the proposed model can predict not only side bank erosion but also a channel morphology such as braided streams.

Keywords: Padma River, Curved channel, Secondary current, Bank erosion, Channel morphology

INTRODUCTION

The erosion intensity of Padma river is very high which is second erosion prone river in Bangladesh. Padma river is a braided characteristics which is vulnerable, because channel variation is very active. That is why, it is very difficult to control the flow concentration and predict the channel changes. Sometimes erosion occurs one place and sometimes other place. Such area need to treat carefully. The most erodible place of Padma river is Harirampur area of Manikganj district. Due to severe erosion, bank line was shifting towards the Harirampur upazilla, which migrated in the curved anabranches as morphological change. Secondary current effect as well as lateral bed slope effect exist in curved reach which increases sediment transportation towards the inner direction. For that reason, erosion takes place and the bank area is washed away drastically. Study on mechanism of bank erosion processes in a curved channel is very important to solve the bank erosion problem. Numerical model as a named Morpho2D is proposed by Takebayashi (2009) for bed deformation analysis and it is updated in 2011(Source: Morpho2D Solver Manual). Robin et al. (2016) incorporated their bank erosion model into Takebayashi et. al's model to compute bank erosions which is introduced lateral bed slope effect on straight open channel. Present study proposes a bank erosion model for curved channel and discusses its applicability. This bank erosion model, which is able to evaluates influences of lateral bed slope and secondary currents on sediment transportation, is incorporated into Robin et. al's (2016) model to compute side bank erosion precisely along the outer banks. Annual bank erosion of Padma River reach is computed and compared with data obtained from Landsat images. The computed results suggest that the proposed model can predict not only side bank erosion but also a channel morphology such as braided streams.

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THEORY AND METHODOLOGY

The 2-D depth integrated governing equations are used to compute the flow pattern and river bed variation. Mass conservation equation (Equation of continuity) for water flow

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = 0 \tag{1}$$

Momentum Conservation Equations for water flow

X-component: $$\frac{\partial uh}{\partial t} + \frac{\partial uuh}{\partial x} + \frac{\partial uvh}{\partial y} = -gh\frac{\partial}{\partial x}(h + z_b) - \frac{\tau_x}{\rho} + \frac{1}{\rho}\{\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{\partial}{\partial y}(h\tau_{yx})\} \tag{2}$$

Y-component: $$\frac{\partial vh}{\partial t} + \frac{\partial vuh}{\partial x} + \frac{\partial vvh}{\partial y} = -gh\frac{\partial}{\partial y}(h + z_b) - \frac{\tau_y}{\rho} + \frac{1}{\rho}\{\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{\partial}{\partial x}(h\tau_{xy})\} \tag{3}$$

Mass conservation equation for suspended sediment

$$\frac{\partial h}{\partial t} + \frac{\partial r_1 \bar{c} uh}{\partial x} + \frac{\partial r_1 \bar{c} vh}{\partial y} = \frac{\partial}{\partial x}\left(h\varepsilon_x \frac{\partial \bar{c}}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\varepsilon_y \frac{\partial \bar{c}}{\partial y}\right) + E_i - D_i \tag{4}$$

$$\frac{\partial Z_b}{\partial t} + \frac{1}{1-\lambda}\sum_i \left(\frac{\partial q_{bix}}{\partial x} + \frac{\partial q_{biy}}{\partial y} + E_i - D_i\right) = 0 \tag{5}$$

where, u, v are the velocity components along $x\ and\ y$ directions, h is the depth of flow, τ_x, τ_y are the x and y components of the bed shear stress(τ_b), z_b is bed elevation, τ_{xx}, τ_{yx}, τ_{yy} and τ_{xy} are the Reynolds stresses., ε_x, ε_y are X and Y components of dispersion coefficient (similar to turbulent diffusion coefficient), E_i , D_i are the erosion and deposition rate of sediment for grain size d_i, r_1 is the correction factor, $\partial z_b/\partial t$ is the average bed variation, , q_{bix}, q_{biy} are the bed load transport rate in x and y-direction for grain size d_i, and λ is the porosity of bed sediment.

Lane-Kalinske's (1941) formula for suspended transport rate is expressed as

$$q_{ss} = 5.55P_{mk}[\frac{1}{2}\frac{u_*}{w_0}exp\left(-\frac{w_0}{u_*}\right)]^{1.61} w_0 r_b \tag{6}$$

Rubey's (1933) formula for fall velocity of sediment particle can be expressed as

$$w_0 = -\frac{6\vartheta}{d} + \sqrt{\left(\frac{6\vartheta}{d}\right)^2 + \frac{2}{3}\left(\frac{\sigma}{\rho} - 1\right)gd} \tag{7}$$

where, q_{ss} : Suspended sediment transport rate, P_{mk} : Fraction of sediment size class in bed load layer, ϑ : Kinematic viscosity = 0.01 cm^2/sec

According to steps which are mentioned in Figure 1, whole procedure of present study is mentioned.

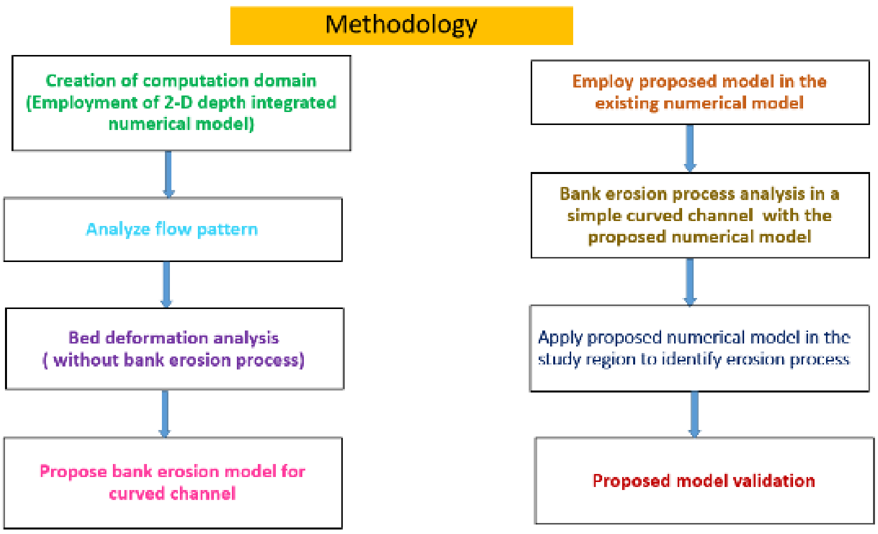
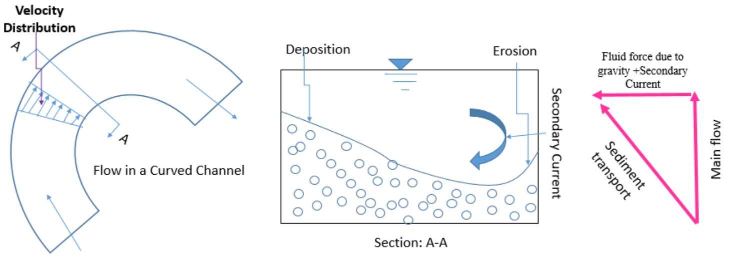


Figure 1. Flow chart of methodology

Bank erosion model for curved channel

When grid size is about 200 m or more, sediment motion along the bank slope can roughly be calculated by the Robin et al. (2016) model. Present study is about curved channel where both lateral bed slope and secondary current effect terms are introduced to evaluate sediment motion along the bank slope precisely. Flow in a curved channel is shown in Figure 2.



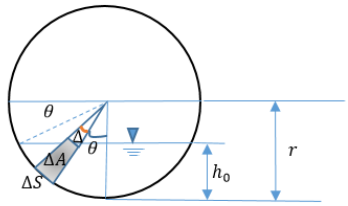
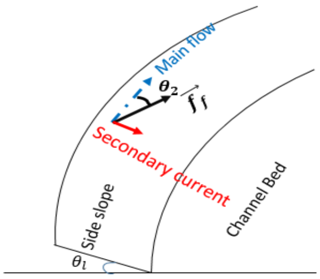


Figure 2. Flow in a curved channel Figure 3. Curved channel section

Estimation of bed shear stress without secondary current effect in terms of area method (Figure 3.)

$$\tau_m = \rho g i_b \left(\frac{1}{2} r - \frac{r - 2h_0 + {h_0}^2/r}{2\cos^2\theta}\right) \tag{8}$$



$\theta_2 \neq 0$

Curved channel half section

Estimation of bed shear stress with secondary current effect, τ_b

$$\tau_b = \tau_m \sqrt{1 + \left(N_* \frac{h}{R}\right)^2} \tag{9}$$

This term is secondary current effect on increase of bed shear stress

Engelund estimated the secondary flow

$$N_* \frac{h}{R} = \tan\theta_2 \qquad (N_* = 7.0 \quad \text{Engelund, 1974}) \tag{10}$$

$$\frac{h_s}{h} = \frac{i_e}{\left(\frac{\sigma}{\rho} - 1\right) c_s \cos\theta_l \tan\emptyset} \cdot \frac{1}{\left(1 - \frac{\tan^2\theta_l}{\tan^2\emptyset}\right)} \cdot \left(\frac{\tan\theta_l}{\tan\emptyset} \tan\theta_2 + \sqrt{1 + \tan^2\theta_2 - \frac{\tan^2\theta_l}{\tan^2\emptyset}}\right) \tag{11}$$

Estimation of bed load transportation by Egashira et. al' s Formula

$$q_{b*} = \frac{4}{15} \frac{K_1^2 K_2}{\sqrt{f_d + f_f}} \tau_*^{5/2} \tag{12}$$

Non-dimensional bed shear stress

$$\tau_* = \frac{\tau_b/\rho}{\left(\frac{\sigma}{\rho} - 1\right) g d} \tag{13}$$

Bed load transport rate, q_b

$$q_b = q_{b*} \sqrt{\left(\frac{\sigma}{\rho} - 1\right) g d^3} \tag{14}$$

$$q_{bx} = \frac{\alpha}{\sqrt{\alpha^2 + \beta^2}} q_b \tag{15}$$

$$q_{by} = \frac{\beta}{\sqrt{\alpha^2 + \beta^2}} q_b \tag{16}$$

Where

$$K_1 = \frac{1}{\cos\theta} \cdot \frac{1}{\tan\emptyset - \tan\theta} = \frac{1}{\tan\emptyset - i_e}$$

$$K_2 = \frac{1}{C_s} \cdot \left\{1 - \frac{h_s}{h}\right\}^{1/2}$$

$$f_d = k_d (1 - e^2) \left(\frac{\sigma}{\rho}\right) C_s^{1/3}$$

$$f_f = k_f (1 - C_s)^{5/3} C_s^{-2/3}$$

Where,

$$\alpha = i_e \ (= i_b)$$

$$\beta = i_b \tan\theta_2 + \left(\frac{\sigma}{\rho} - 1\right) C_s \frac{h_s}{h} \sin\theta_l$$

q_{bx}, q_{by} are the longitudinal and lateral bed load transport rate in which both lateral bed slope and secondary current effect are included. These two terms are incorporated into mass conservation equation of bed sediment (equation no. 5) to evaluate sediment motion along the side bank slope precisely.

DATA

The maximum discharge of Padma river at Mawa gauging station in monsoon and dry period are 116011 m^3/sec, 5500 m^3/sec respectively (Source : FFWC, BWDB). The bankfull discharge range of Padma river is from 75000 m^3/sec to 80000 m^3/sec. Annual average discharge of this river is 30000 m^3/sec (WARPO, 1996). The danger level of Padma River is (+) 6.10 m at Mawa gauging station. Stage-discharge relationship is plotted in Figure 4. This relationship indicates that for discharge range from 80000 m^3/sec to 100000 m^3/sec, water surface elevation crosses the danger level. When water level crosses the danger level, devastating damages occurs.

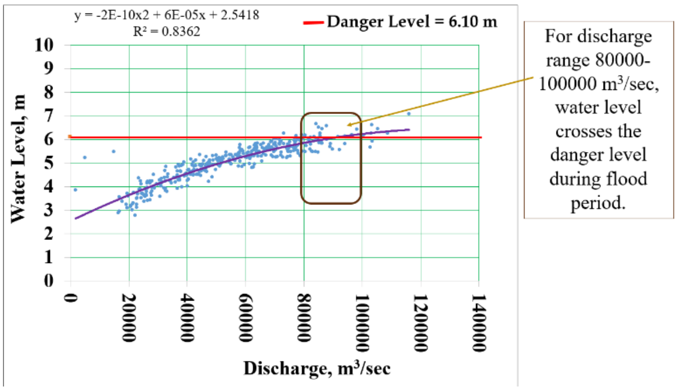


Figure 4. Stage-discharge relationship of Padma River at Mawa point (Source : FFWC, BWDB)

Erosion pattern of the study area

According to ADB technical assistance consultant's report, the cumulative erosion is 8400 m from the period 1973 to 2009 along the left bank of Padma River at Harirampur upazila of Manikganj district. Bank erosion pattern along the left bank of Padma river at Harirampur area is shown in Figure 5.

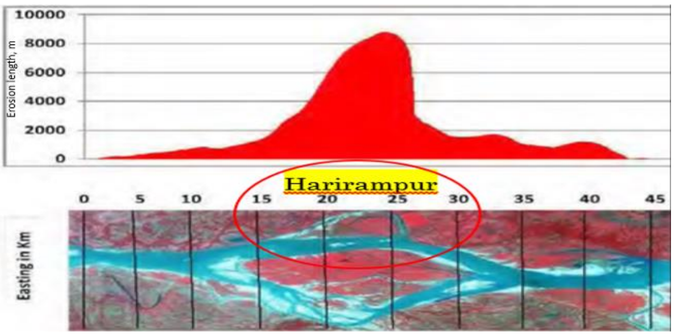


Figure 5. Bank erosion pattern along the left bank of Padma river at Harirampur area (nhc., 2013)

RESULTS AND DISCUSSION

Effects of lateral bed slope and secondary currents on bed shear stress and bed load transportation

Bed shear stress and lateral bed load transport rate are determined by using proposed model. Figure 6 shows that bed shear stress lateral and bed load transport rate are less for case-1 among all cases which is plotted without secondary current effect with respect to lateral bed slope. Results of proposed model from case-2 to case-6 show that bed load movement is increasing in curved channels by the effect of secondary current as compared to straight open channel.

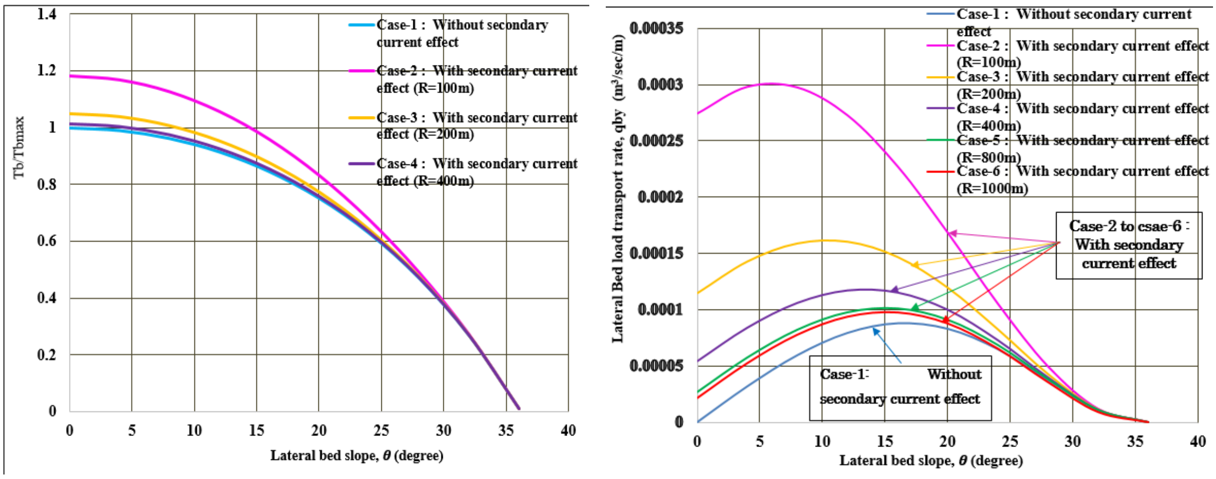


Figure 6. Comparison of different output results of bed shear stress and bed load transportation with and without secondary current effect with respect to lateral bed slope by the proposed model

Output results comparison between the proposed model and an existing model in a simple curved channel

After 3 days computation, existing model shows that right bank has shifted 1m and in proposed model 1.80 m. Here, 0.80 m more erosion occurred in proposed model than existing model, which is shown in Figure 7.

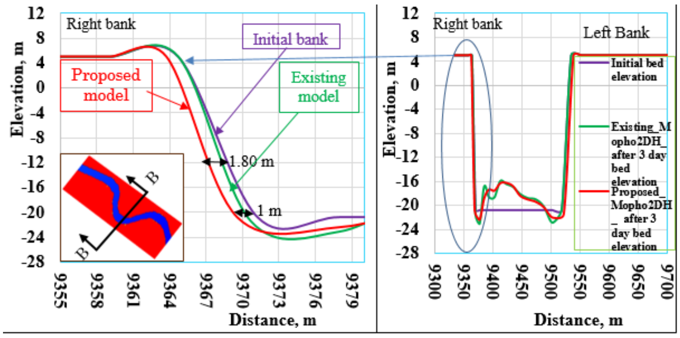


Figure 7. Cross section B-B and grid no. 93 of a simple curved channel

Application of the proposed bank erosion model in the study region

Proposed bank erosion model is applied in the study region to investigate the bed form and side bank erosion of Padma river reach at Harirampur upazilla of Manikganj district. Results obtained after 3, 5, 10 days are summarized in Table 1 which are shown in Figure 8.

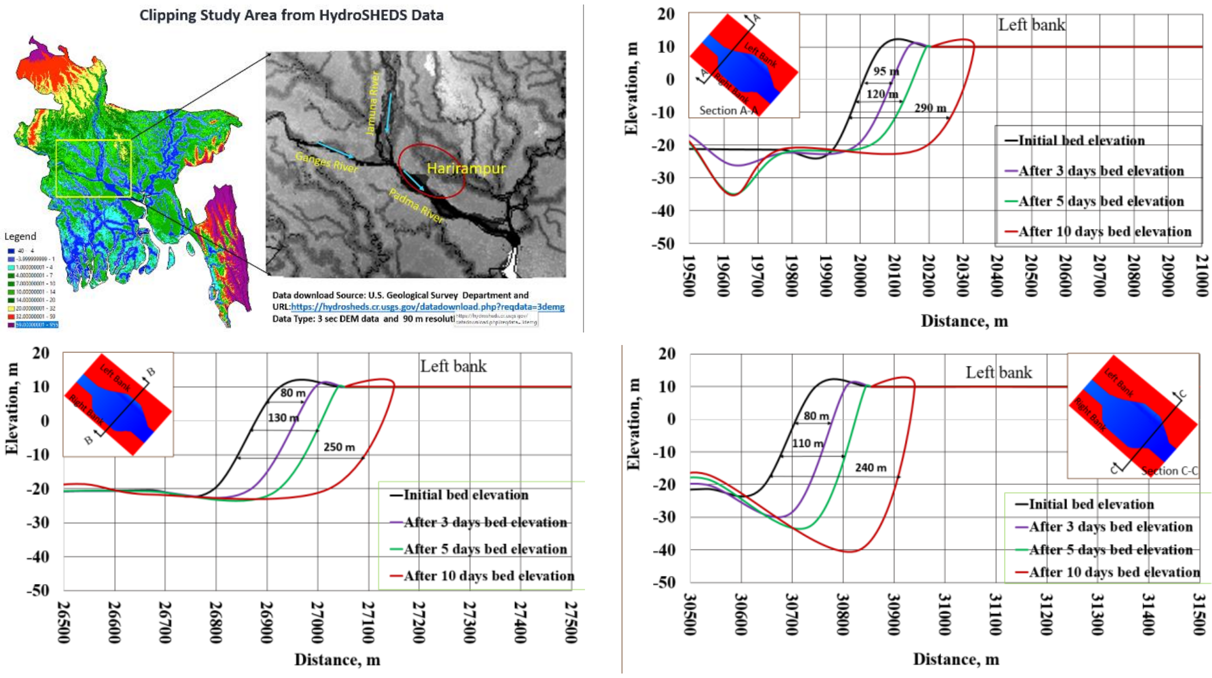


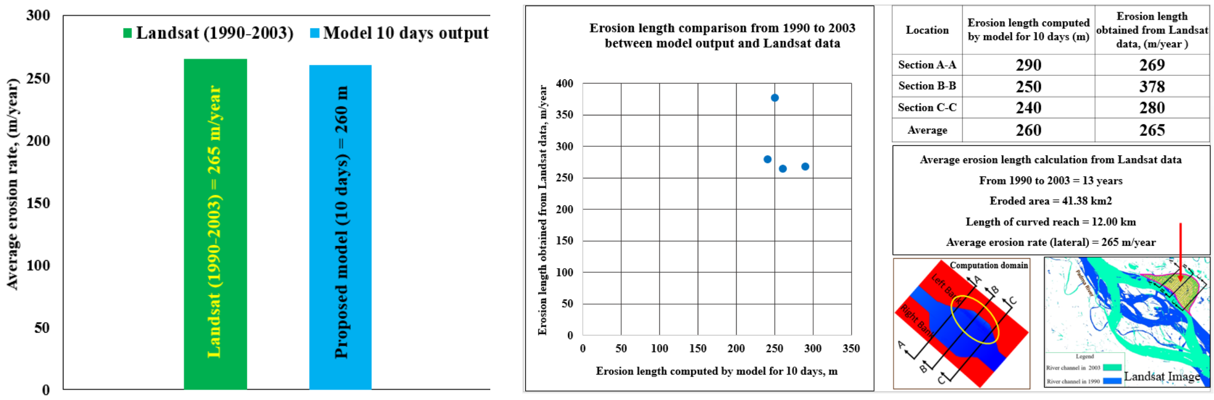
Figure 8. Bed form and bank erosion pattern output of the proposed model at study region

Table 1. Average eroded length estimation from output results

Computation output time (day)	Eroded length at cross section A-A and grid no. 80 (m)	Eroded length at cross section B-B and grid no 120 (m)	Eroded length at cross section C-C and grid no. 150 (m)	Average eroded length in the curved reach (m)
After 3 days	95 m	80 m	80 m	**85 m**
After 5 days	120 m	130 m	110 m	**120 m**
After 10 days	290 m	250 m	240 m	**260 m**

Proposed bank erosion model validation

As computation domain topography is modified nearly similar to the period of 1990 decades. So, in this period of topography is used as initial condition. That is why, validation between proposed model 10 days output and Landsat result during the period 1990-2003 is taken into consideration. Average erosion rate from Landsat data during the period 1990-2003 is 265 m/year which is similar to 10 days proposed model output of 260 m which is shown in Figure 9.



Location	Erosion length computed by model for 10 days (m)	Erosion length obtained from Landsat data, (m/year)
Section A-A	290	269
Section B-B	250	378
Section C-C	240	280
Average	260	265

Average erosion length calculation from Landsat data
From 1990 to 2003 = 13 years
Eroded area = 41.38 km2
Length of curved reach = 12.00 km
Average erosion rate (lateral) = 265 m/year

Figure 9. Erosion rate comparison between proposed model output and Landsat data

CONCLUSION

Bank erosion is a severe problem in Bangladesh. The most erodible place of Padma river is Harirampur area of Manikganj district. Due to severe erosion, bank line was shifting towards the Harirampur upazilla, which migrated in the curved anabranches as morphological change. In a curved reach, there is a secondary current effect as well as lateral bed slope effect, which increase the bed shear stress. For that reason, erosion takes place and washed away the adjacent bank area drastically. Study on mechanism of bank erosion processes in a curved reach is very important to solve that bank erosion problem. Average annual erosion rate from Landsat data during the period 1990-2003 is 265 m/year which is very similar to computed result for 10 days computation. These results suggest that a numerical model developed by Robin et al. (2016) can roughly be calculated secondary current effect, but the proposed model evaluated secondary current effect precisely. So, the improvement through this study is, bed forms and side bank erosion in natural channels can be predicted more precisely by the proposed bank erosion model. This will help us to manage bank erosion properly.

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