STUDY ON THE MORPHOLOGICAL CHARACTERISTICS OF DAWKI-PIYAN RIVER SYSTEM IN BANGLADESH

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ABSTRACT

This study discusses the morphological characteristics of the bifurcation area of the Dawki-Piyan river system in Bangladesh to find out a stable channel planform. First, numerical simulations were conducted to investigate the long-term morphological behavior of the bifurcated area and discharge diversion between two downstream channels. The numerical results show that the diversion ratio of flow discharge changes temporarily due to channel changes together with sandbar deformations. Second, regime relations were derived using continuity conditions for flow discharge and sediment discharge to discuss the stability of a bifurcation system. The derived formulas of regime relations can determine the width of stable channels, which helps us to manage the bifurcation area.

Keywords: channel bifurcation, river morphology, sediment transportation, regime relations, stable channel.

INTRODUCTION

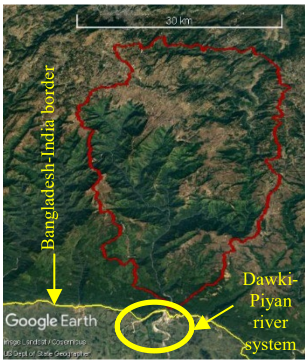

Figure 1: Drainage basin of Dawki-Piyan river

The study area is located in the northeast region of Bangladesh under Meghna Basin, a low-land locally known as “Haor area”. The Om River originates from the Khasia-Jaintapur Hills of India and enters northeastern Bangladesh in Gowainghat Upazilla, where it bifurcates into two rivers; Piyan and Dawki. The bifurcation area of the Dawki –Piyan river system is the focal area of this study. Figure-1 shows the drainage basin of the river system outlined in red color. Total area of the drainage basin is 829 sq. km. The whole drainage area is located under the territory of India. Analysis of historical images shows that the Piyan was more dominant than the Dawki before 1991. However, since 1991, Dawki has become dominant. The upper part of the Piyan experiences excessive sedimentation, which decreases its carrying capacity. As the area is also prone to flash floods, excessive sedimentation of the Piyan River exacerbates the inundation conditions. Sediment mining from riverbeds is another problem in this area. To mitigate existing problems caused by sedimentation, suitable countermeasures must be implemented. The present study aims to generate

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scientific knowledge for mitigating sediment issues in bifurcation regions. First, we investigate the morphological characteristics of the target region by means of numerical simulations. Second, an idea of regime relation is suggested to obtain stable diversion channels.

NUMERICAL EVALUATION OF MORPHOLOGICAL CHANGES

Depth Averaged 2-D Governing Equations for Numerical Model:

The governing equations employed in the numerical model comprise the mass and momentum conservation equations for water flow as well as mass conservation equations for suspended sediment and bed sediment together with a bed-load formula and erosion-deposition formulas of suspended sediment.

The formula proposed by Egashira et al. (1997) was employed for bed load transport rate:

$$q_{b*} = \frac{4}{15}\frac{K_1^2 K_2}{\sqrt{f_d+f_f}}\tau_*^{5/2} \qquad (1)$$

in which K_1, K_2, f_d and f_f are specified theoretically.

The erosion rate is evaluated using entrainment velocity (Harada et al., 2019):

$$E = W_e c_s \qquad (2)$$

in which W_e is the entrainment velocity and c_s is the sediment concentration of bed layer.

The entrainment velocity (W_e) is evaluated by employing the following formula for density stratified flow:

$$\frac{W_e}{V} = \frac{K}{R_{i*}}, \quad \left(R_{i*} = \frac{\Delta\rho}{\rho}\frac{gh}{V^2}\right), K = 1.5 \times 10^{-3} \qquad (3)$$

in which V is the depth averaged velocity defined as $V = \sqrt{u^2 + v^2}$,R_{i*} is the overall Richardson number,$\Delta\rho$ is the density difference between water layer and bed surface layer.

Computational Conditions:

A computational domain was prepared using Nays2DH solver of iRIC software. Owing to the lack of bathymetric data, the Shuttle Radar Topography Mission (SRTM) 30 m DEM data was used to prepare the initial topography of the domain. The grain size distribution was prepared on the basis of image analysis. The total length of computational domain is 3.8 km, maximum width of the domain is 2.15 km and minimum width is 1 km. The total number of grids was 28,476 nos (i=226, j=126).

The boundary conditions were specified as follows. At the upstream boundary constant flow discharge was given, and equilibrium sediment supply was performed for bed load and suspended load. At the downstream end, the corresponding water level obtained from field measurement was employed.

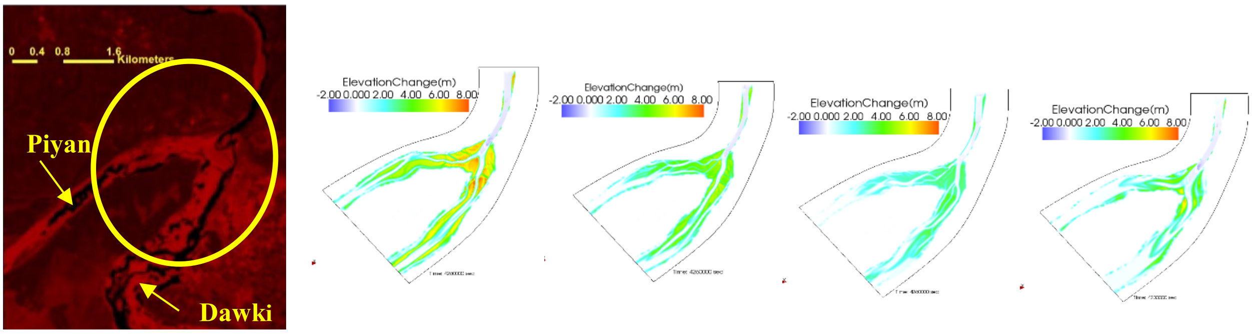
Table-1 shows the computational conditions. The computations were performed for 9 cases for 50 days in each case where the flow discharges were specified referring to observed data from 2007 to 2015, and 2550 m^3/s is the maximum upstream discharge over the period. The grain size distribution was prepared on the basis of image analysis with three different grain size distributions to obtain a better output.

Table-1: Summary of nine (09) cases of numerical simulations

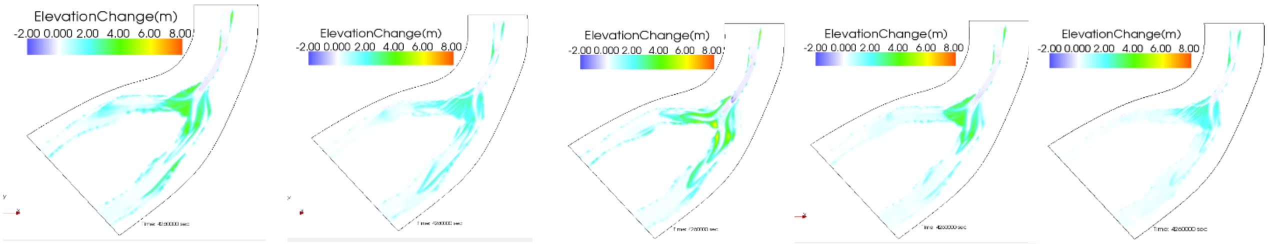
Discharge: Grain Size Distribution:	2550 m^3/s	1470 m^3/s	718 m^3/s
Case-1: d_m= 20.85 mm, d_{50} = 4 mm	**Case-1-1**	**Case-1-2**	**Case-1-3**
Case-2: d_m= 52.12 mm, d_{50} = 14 mm	**Case-2-1**	**Case- 2-2**	**Case-2-3**
Case-3:d_m= 60.81 mm, d_{50} = 18 mm	**Case-3-1**	**Case-3-2**	**Case-3-3**

Results and Discussion

Figure-2 shows the results obtained from 50 days computations on channel morphology for 9 cases, together with the landsat image of the bifurcation area of Dawki-Piyan river (circled in yellow color). The results confirmed that the pattern of sand bar formation and amount of deposition depend on the grain size distribution and discharge. Among the results of 9 cases, Case 1-1 and Case 1-2 reproduce sand bars similar to the Landsat image. However, excessive deposition (more than 8 m) occurred at the bifurcation section in Case 1-1. The grain size was the finest and discharge was the highest in Case 1-1 which causes higher volume of sediment transportation from upstream. Results of all cases confirmed sand bar formation at the bifurcation region.



Landsat image of 2020 *Case-1-1* *Case-1-2* *Case-1-3* *Case-2-1*



Case-2-2 *Case-2-3* *Case-3-1* *Case-3-2* *Case-3-3*

Figure-2: Comparison of sandbars obtained from different simulations with Landsat image of 2020

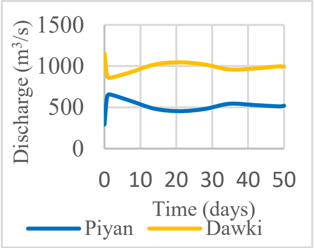


Figure-3: Discharge diversion under Case 1-2

Results of all cases demonstrated that Dawki receives higher discharge (59%-70% of upstream discharge) than Piyan. Such differences in the diversion ratio were observed in actual field. In Figure-3, the temporal change of discharge diversion is illustrated for Case 1-2. According to the results, discharge of Piyan river shows decreasing trend until day-20, after that it starts to increase until day 35 , then again decreases.This phenomenon can be explained by the temporal change of bed elevation in the bifurcation area. Figure-4 shows the temporal changes of the cross section denoted by A-A. As shown in this figure, the elevation of Piyan side of the bifurcation section increases rapidly until day 21 due to high sedimentation, this is a reson of decreased discharge in Piyan within this period. After day-21, a narrow streamline forms (black dotted circle) at Piyan section which causes increasing trend in discharge after day-21 until day-35. After that the main flowpath of Piyan river becomes narrower due to sedimentation (green dotted circle) which may be considered as the reason of decreasing trend of discharge after day-35. This indicates that sedimenation at the bifurcation section plays an important role on flow diversion between the channels.

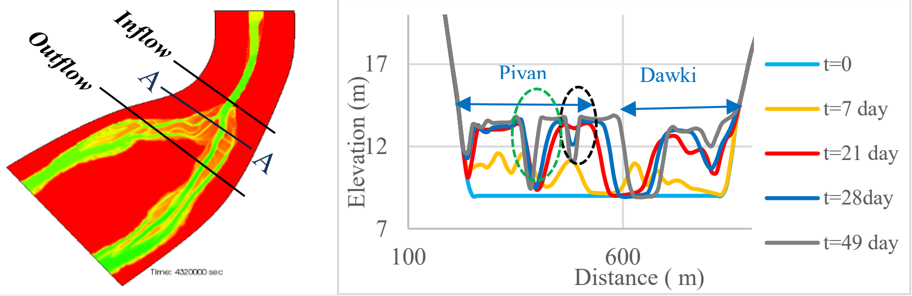


Figure-4: Temporal bed elevation at section A-A (Case-1-2)

Figure-5 shows the inflow and the outflow rate of suspended load and bed load at sections denoted as inflow and outflow in Figure-4. Inflow rate of sediment is always larger than the outflow rate in the bifurcation area that means continuous deposition is taking place in the bifurcation area. Sediment received by the Dawki is higher than that of the Piyan in all cases. Simulation result of case 1-2 shows that 60%-83% of total suspended load and 74% - 95% of total bed load are diverted towards the Dawki.

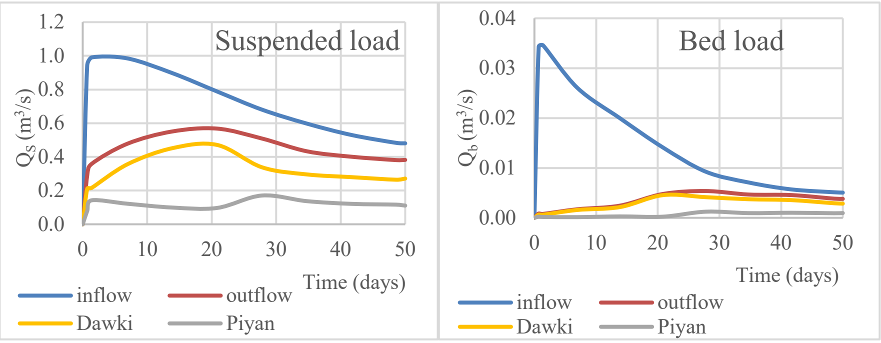


Figure-5: Inflow and outflow rate of sediments at the bifurcation section

REGIME RELATIONS OF BIFURCATED CHANNELS

Derivation of Equations for Regime Relations:

Discussions on regime relations for stable channels help us manage the bifurcated channels. Figure-6 shows the present target channels schematically. Flow discharge and sediment discharge should obey the following continuity conditions.

$$Q_1+Q_2 = Q_0 \quad (4)$$

$$Q_{S1}+Q_{S2}=Q_{S0} \quad (5)$$

in which Q_0, Q_1 and Q_2 are the discharges and Q_{S0}, Q_{S1} and Q_{S2} are the sediment discharges in each channel.

Flow discharge (Q) can be evaluated by Manning's formula assuming a quasi uniform flow as follows:

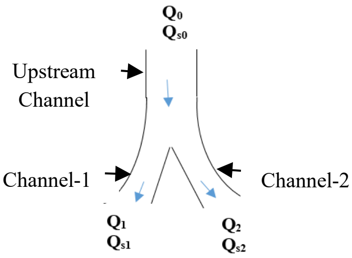


Figure-6: Sketch of the bifurcation area

$$Q = (1/n)I^{1/2}H^{5/3}B \quad (6)$$

in which I is the energy slope, H is the flow depth and B is the flow width.

Employing equation (6), equation (4) is expressed as: $I_1^{1/2}H_1^{5/3}B_1 + I_2^{1/2}H_2^{5/3}B_2 = I_0^{1/2}H_0^{5/3}B_0$

which can be normalized as follows:

$$(I_1/I_0)^{1/2}(H_1/H_0)^{5/3}(B_1/B_0) + (I_2/I_0)^{1/2}(H_2/H_0)^{5/3}(B_2/B_0) = 1 \quad (7)$$

in which suffixes 0, 1 and 2 denote the quantities in the Upstream Channel, Channel-1 and Channel-2 respectively.

Using the definitions such as $B_1/B_0 = b_1$, $B_2/B_0 = b_2$, $H_1/H_0 = h_1$, $H_2/H_0 = h_2$, $I_1/I_0 = i_1$ and $I_2/I_0 = i_2$, equations (7) is expressed as follows:

$$i_1^{1/2}h_1^{5/3}b_1 + i_2^{1/2}h_2^{5/3}b_2 = 1 \quad (8)$$

Regime Relations Based on Dominant Bed-Load:

Employing bed load formula described by $\frac{5}{2}^{\text{th}}$ power of non-dimensional bed shear stress, the sediment discharge can be written as follows:

$$Q_s = Bq = B\sqrt{sgd^3}\,\tau_*^{5/2} \quad (9)$$

in which τ_* is the non-dimensional bed shear stress defined as: $\tau_* = u_*^2/(sgd) = hi/(sd)$

Employing equation (9), equation (5) is expressed as :

$B_1(H_1I_1)^{5/2} + B_2(H_2I_2)^{5/2} = B_0(H_0I_0)^{5/2}$ which is normalized as:

$$(H_1/H_0)^{5/2}(I_1/I_0)^{5/2}(B_1/B_0) + (H_2/H_0)^{5/2}(I_2/I_0)^{5/2}(B_2/B_0) = 1 \quad (10)$$

Using the definitions of b_1, b_2, h_1, h_2, i_1 and i_2, equation (10) is expressed as follows:

$$h_1^{5/2}i_1^{5/2}b_1 + h_2^{5/2}i_2^{5/2}b_2 = 1 \tag{11}$$

Equations (8) and (11) can be called regime relations of bifurcated channels in case of bed load dominant river.

Regime Relations Based on Dominant Suspended Load:

Equilibrium sediment concentration of suspended sediment can be evaluated by:

$$c_e = p_f K\,\frac{c_s}{R_{i*}}\left(\frac{v}{w_{0i}}\right)$$

$$= p_f K\,\frac{v}{w_{0i}}\frac{v^2}{sgh} \qquad \left(K = 0.0015, s = \frac{\sigma}{\rho} - 1\right) \tag{12}$$

in which p_f is the fraction ratio of d_i .

Considering a simple flow field, we put $p_f = 1$. Therefore, the transport ratio of suspended sediment can be expressed as:

$$Q_s = c_e Q \tag{13}$$

in which Q is the flow discharge.

Employing equation (13), equation (12) can be expressed as follows:

$$Q_s = K\,\frac{v^2}{sgh}\left(\frac{v}{w_o}\right)vBh \tag{14}$$

Substituting equation (14), equation (5) can be expressed as:

$$v_1^4 B_1 + v_2^4 B_2 = v_0^4 B_0 \tag{15}$$

Employing $v = (1/n)i^{1/2}h^{2/3}$, equation (15) can be written as:

$$I_1^2 H_1^{8/3} B_1 + I_2^2 H_2^{8/3} B_2 = I_0^2 H_0^{8/3} B_0 \tag{16}$$

Equation (16) can be normalized as:

$$(I_1/I_0)^2 (H_1/H_0)^{8/3} (B_1/B_0) + (I_2/I_0)^2 (H_2/H_0)^{8/3} (B_2/B_0) = 1 \tag{17}$$

Using the definitions of b_1, b_2 , h_1,h_2 , i_1 and i_2, equation (17) is expressed as follows:

$$i_1^2 h_1^{8/3} b_1 + i_2^2 h_2^{8/3} b_2 = 1 \tag{18}$$

Equations (8) and (18) can be called regime relations of bifurcated channels in case of dominant suspended load.

Identification of Stable Width of Bifurcated Channels:

Using the derived equations, the suitable widths of the bifurcated channels are discussed for Dawki-Piyan river system corresponds to the sketch in Figure-6. Figure-7 shows a flowchart of the computation process to identify the channel widths. Generally, *i*i_1 and i_2 are determined naturally by ground topography. After that b_1=1 and $Q_1/Q_0 = 0.45$ are assumed. Then we are able to specify Q_{S1}/Q_{S0} , $h_1, Q_{S2}/Q_{S0}$, b_2 and h_2 corresponding to the assumed value of Q_1/Q_0 and b_1 using equations (8) and (11) for bed load dominant river and using equations (8) and (18), the same can be identified for suspended load dominant river.

The specified channel planform should also satisfy the condition of equal specific energy (*E*) to be stable. Therefore, the specific energy, E_1 and E_2 for Channel-1 and Channel-2 respectively are calculated using the specified b_1, h_1, b_2, h_2 . The similar process is followed assuming b_1= 0.1,0.15, 0.2, 0.3, 0.4, 0.5, 2 & 3 for Q_1/Q_0=0.45 and corresponding E_1 and E_2 are calculated. Then the obtained values of E_1 and E_2 are plotted in a E_1 vs. E_2 graph.

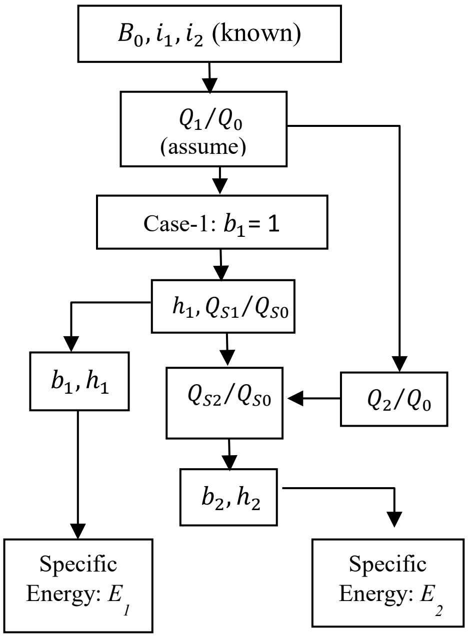


Figure-7: Flow chart of a single case of regime relations for stable channel

Figure-8 shows the graphical plot of E_1 and E_2 for Q_1/Q_0=0.45.Then a smooth line is drawn joining all points. The adjoining line intersects the equal specific energy line at a certain point. This point satisfies the condition of equal specific energy for Channel 1 and Channel 2. Using the values of this point, stable widths of two downstream channels, B_1 and B_2 are calculated.

For dominant bed load case, the calculated stable widths is 24 m and 31 m and for dominant suspended load case, the widths are 33.6 m and 41 m for Channel-1 and Channel-2 respectively.

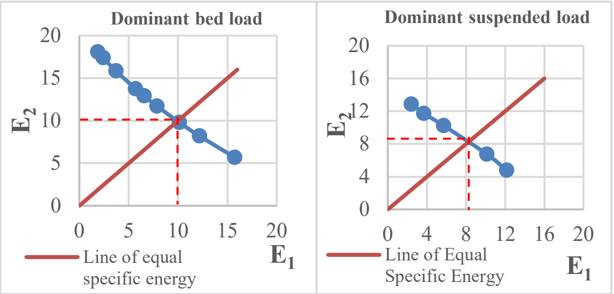


Figure-8: Identification of the Point, E_1=E_2 for Q_1/Q_0=0.45

CONCLUSION AND RECOMMENDATION

The present study discusses the geomorphological characteristics of the bifurcated channel reaches for the Dawki and Piyan rivers based on the numerical computations and regime relations for stable channels, in order to obtain effective information for the channel management. The bed load transport rate formula proposed by Egashira et al. (1997) and a new sediment transport formula proposed by Harada et al. (2019) was applied in the numerical model to reproduce channel morphology and flow pattern. The results obtained from numerical simulations suggest that the model can reproduce the observed sand bar and discharge diversion reasonably well. The results also show that sedimentation at the bifurcation section plays an important role in the discharge diversion between the Dawki and Piyan rivers. Therefore, it is very important to manage the bifurcation area to keep both of the rivers stable. The regime relations are derived for stable bifurcated channels, using the continuity conditions for flow discharge and sediment discharge. They can help us to manage the bifurcation area by determining the flow width of stable channels for both of bed load dominant river and suspended load dominant river. Due to lack of bathymetric data, the slope ratios of the regime relations were calculated on the basis of DEM data. Also, the grain size distribution was prepared on the basis of the image analysis of bed materials. The numerical computations cannot be conducted exactly in response to actual channel conditions. Thus, we are desired to compute channel morphology using much more real conditions which will be provided by field observations. Therefore, the calculated widths of stable channels are not recommended for direct use. On the basis of those field data, the stable width can be calculated as per the idea of regime relations described in this study. Then the existence of stable channels should be checked by numerical simulation and flume experiment before field implementation. In this context, the study presents an opportunity of future work to identify stable channels of a bifurcation system using the idea of regime relations. Sediment mining from river beds is a source of livelihood for the local people in the study area. Therefore, mining cannot be prohibited without providing alternative livelihoods to the local people. As the bifurcation area is experiencing continuous sedimentation, the sediment mining sites can be shifted to the bifurcation area instead of river beds. However, further study is required to identify allowable locations and volume of sediment mining.

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