# PREDICTION OF MORPHOLOGICAL CHANGES IN JAMUNA RIVER NEAR BAHADURABAD AREA

**Md Abu Baker Siddique BHUAYAN** [*] **Supervisor: Dr. Atsuhiro Yorozuya**[**]
**MEE14631**

## ABSTRACT

Rapid morphological changes, especially river bank erosion and mid channel bar deformation are of great concern near Bahadurabad area due to continuous morphological action of Jamuna River. This study estimated an area of around 115 km$^2$ of land which has already been engulfed by the river since 1973 within the study reach. Analysis of satellite image reveals that this area was eroded at an average rate of 2.74 km$^2$/year since 1973, whereas the maximum rate was 6.66 km$^2$/year during the period of 1980 to 1991. A maximum propagation of 2.0 km of sand bar was also identified during 2005 to 2011 by the satellite images. Besides these, numerical prediction showed a maximum velocity as 4.0 m/s. It also showed maximum scoring depth up-to 9.0 m and deposition up-to 15.0 m. The model predicted the vulnerable reaches for bank erosion and flow concentration as well as temporal and spatial distributions of sandbar formation and its deformation. A yearly total sediment transport rate of 324 million cubic meter was identified from the numerical model. The model also showed that the suspended load is dominant over the bed load and that is almost 45 times. The performance of the model was checked based on available observed data and was substantially promising towards predicting the morphological changes. Therefore, it could be emphasized to use this numerical model for the prediction of morphological changes of Jamuna River even for small scale river reach like the present study reach.

**Keywords:** Jamuna River, Prediction, Morphology, Erosion, Accretion.

## INTRODUCTION

The inland landscape of Bangladesh is mainly controlled by the dynamic nature of its mighty rivers. The Jamuna, Padma and Meghna which are the three mightiest river in Bangladesh reshapes its plan-form every year through dynamic channel morphology (Coleman, 1969). This dynamic process poses a great challenge to manage and control the resultant risk and vulnerability of geo-morphological hazards within the riverine corridor (Gares *et al.,* 1994). Fundamentally, these rivers respond to natural processes and their inevitable alteration of shapes provides all the changes of river valley shape. The driving forces and factors of these rivers are so huge and diverse that even a single season could produce a significant morphological changes. Sometimes these processes reach to such an extent that they impede normal activities and pose great threat to local and national economy and disrupt social structure within the riverine corridor (Blitz, 2014). Therefore, it demands utmost consciousness and consideration from national point of view to take proper strategy and management plan. The impact of river morphological changes has strong influence over social and economic conditions. The effects of rapid bank line shifting and deformation of char lands have serious detrimental socio-environmental issues. Although the number of casualties could be less with respect to huge assets and property loss, but the social impacts are enormous. People suffer from losing their valuables, agricultural lands and homesteads every year. In this respect, they not only lost their assets but also become rootless and deprived of family ties and social bondage. For this reason, utmost attention is needed to manage and to reduce the impacts of such river morphological hazards. Both structural and non-structural measures are important from the engineering and management point of view. Therefore, this study aims to facilitate the soft measures identifying a rational method for predicting spatial and temporal morphological changes of Jamuna River to reduce human sufferings and consequent socio-economic and environmental losses.

---

[*] Sub-Divisional Engineer, Bangladesh Water Development Board, Bangladesh.

[**] Associate professor, International Centre for Water Hazard and Risk Management (ICHARM), PWRI, Japan.

## METHODOLOGY AND APPROACH

This study covers both Geographical Information System (GIS) using remotely sensed satellite image data and mathematical technique through numerical simulation to analyze and to predict morphological changes of Jamuna River within the study area. Landsat satellite images of low flow period (February & March) were used for GIS analysis and for numerical analysis, 2D numerical model was used. Several morphological phenomenon like erosion-accretion, sandbar formation, deformation and migration and local bend migration were studied through GIS and Remote Sensing (RS) technology. This technique could be very useful for monitoring temporal and spatial changes of river morphology. Analyzing satellite images could provide significant information to investigate the behavior of the river for morphological changes (Klaassen & Masselink, 1992; Sarker & Thorne, 2009).

For a numerical prediction of temporal and spatial change of river morphology within the study reach mathematical model proposed by Takebayashi *et al.* (2003) was employed to reproduce the process of formation, deformation and migration of sandbars and also bank line shifting. The model was setup for generating computational grid system. All the computational, initial and boundary conditions were incorporated within the model for the simulation purpose. To generate computational grid and assigning elevation data into each nodal point Shuttle Radar Topographic Mission (SRTM)'s Digital Elevation Model (DEM) was used in this study. The model used depth integrated continuity equation for flow in Cartesian coordinate system considering the seepage flow which is as follows,

$$\Lambda\frac{\partial z}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hv)}{\partial y}+\frac{\partial(h_g u_g)}{\partial x}+\frac{\partial(h_g v_g)}{\partial y}=0 \tag{1}$$

The depth integrated momentum conservation equations for flow in Cartesian coordinate system in x and y-directions are as follows,

$$\frac{\partial(hu)}{\partial t}+\frac{\partial(hu^2)}{\partial x}+\frac{\partial(huv)}{\partial y}=-gh\frac{\partial(h+z_b)}{\partial x}-\frac{\tau_x}{\rho}+\frac{\partial(h\sigma_{xx})}{\partial x}+\frac{\partial(h\tau_{xx})}{\partial y}-\frac{F_{vx}}{\rho} \tag{2}$$

$$\frac{\partial(hv)}{\partial t}+\frac{\partial(huv)}{\partial x}+\frac{\partial(hv^2)}{\partial y}=-gh\frac{\partial(h+z_b)}{\partial y}-\frac{\tau_y}{\rho}+\frac{\partial(h\tau_{xy})}{\partial x}+\frac{\partial(h\sigma_{yy})}{\partial y}-\frac{F_{vy}}{\rho} \tag{3}$$

where, $u$ and $v$ are the depth average flow velocity along x-direction and y-direction, respectively, $h$ is depth of flow, $u_g$ and $v_g$ are depth average seepage flow velocity along x-direction and y-direction, respectively, $z$ is water surface elevation, $\rho$ is density of water, $\tau_x$ and $\tau_y$ are shear stress in the x-direction and y-direction, respectively, $\tau_b$ is bed shear stress, $z_b$ is bed elevation, $\lambda$ is porosity of soil, $F_{vx}$ and $F_{vy}$ are vegetation drag force along x-direction and y-direction, respectively. The soil porosity represented by the parameter $\Lambda$ is 1 When, $z \geqq z_b$ and $\Lambda = \lambda$ when, $z < z_b$. Bed load discharge was calculated by Ashida and Michiue's equation as follows,

$$q_{bk}=17\frac{\rho u_{*_e}^2}{(\rho_s-\rho)g}\left(1-\sqrt{K_c}\frac{u_{*ck}}{u_*}\right)\left(1-K_c\frac{u_{*ck}^2}{u_*^2}\right)f_{bk}r_b \tag{4}$$

where, $\rho_s$ is the sediment density. $u_*$ is friction velocity, $u_{*_e}$ is the effective friction velocity, $u_{*_{ck}}$ is critical friction velocity of sediment size class $k$, $K_c$ is is the modification function of the effect of the local bed slope on the sediment transport, $f_{bk}$ is the concentration of bed load of size class $k$ in the bed load layer, $r_b$ is the function of the exchange layer thickness. The equilibrium concentration of the suspended load at reference level ($c_{sbek}$) was calculated by Lane & Kalinske's equation as follows,

$$c_{sbek}=5.55\left(\frac{1}{2}\frac{u_*}{w_{fk}}\exp\left(-\frac{w_{fk}}{u_*}\right)\right)^{1.61}f_{bk}r_b \tag{5}$$

where, $w_{fk}$ is settling velocity of suspended sediment.

The depth averaged concentration of suspended sediment of size class $k$ is evaluated by the following continuity equation of suspended sediment in Cartesian coordinate system.

$$\frac{\partial ch}{\partial t}+\frac{\partial uch}{\partial x}+\frac{\partial vch}{\partial x}=\epsilon_x\frac{\partial^2 ch}{\partial x^2}+\epsilon_y\frac{\partial^2 ch}{\partial y^2}+E-D \tag{6}$$

where, $c$ is depth the depth-average sediment concentration and $\epsilon_x$ and $\epsilon_y$ are components of dispersion coefficient. $E$ and $D$ are erosion and deposition rate of sediment.

Continuum equation of bed sediment for horizontal two dimensional field in Cartesian coordinate system is as follows,

$$\frac{\partial}{\partial t}(c_b E_b) + (1-\lambda)\frac{\partial z_b}{\partial t} + \frac{\partial q_{bx}}{\partial x} + \frac{\partial q_{by}}{\partial y} + E - D = 0 \tag{7}$$

where, $E_b$ is the bed load layer thickness, $c_b$ is the depth averaged concentration of bed load, $q_{bx}$ and $q_{by}$ are bed load transport in x and y-directions, respectively.

## RESULTS AND DISCUSSION

### (A) Analysis of morphological changes using satellite images

River bank shifting happens very frequently and rapidly along the left bank of the study reach in Jamuna River. Figure 1 shows the temporal movement of left bank and resultant decadal erosion and accretion and their rates from 1973 to 2015 and also overall eroded and accreted land from 1973 to 2015. From this analysis it was found that from 1973 to 1980 the resultant erosion amount is 26.22 km$^2$ (erosion: 43.38 km$^2$, accretion: 17.16 km$^2$) and from 2000 to 2010 the resultant erosion amount is 35.93 km$^2$ (erosion: 49.68 km$^2$, accretion: 13.75 km$^2$). So, during this time period erosional process was dominant engulfing a huge amount of land into the river. Most of the accretion happened during the period 1991 to 2000. During this period the erosion amount was 46.47 km$^2$ and accretion amount was 66.08 km$^2$. The resultant accretion amount was 19.61 km$^2$. The average rate of erosion was 2.74 km$^2$/year since 1973, but the maximum rate was 6.66 km$^2$/year during the period of 1980 to 1991.

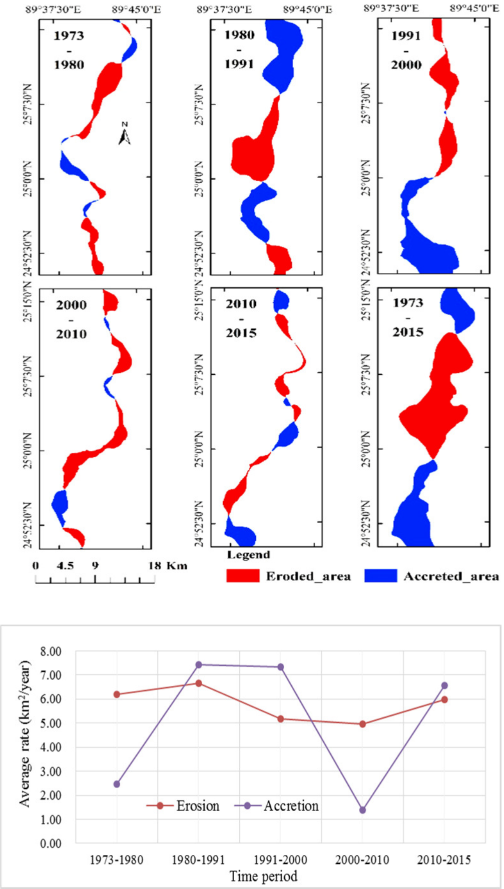
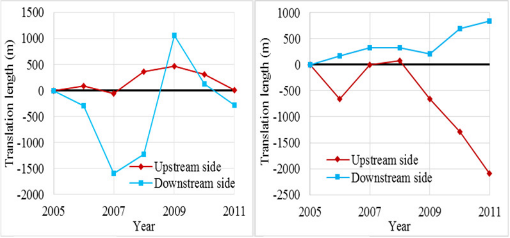


Figure 1 Temporal movement of left bank of Jamuna River

#### *Sandbar migration*

The migration pattern of sand bars in terms of magnitude and the variability of this movement in time and space is analyzed in this study to identify the plan form changes of the river within the study reach. Figure 2 shows the results of such analysis. The figure shows a maximum downstream propagation of 2090 m for target sandbar_2 during 2005 to 2011.



**(a)** sandbar_1 **(a)** sandbar_2

Figure 2 Sandbar migration rate.

#### *Bank erosion process in channel bends*

Satellite images utilized to investigate river bank erosion on the left bank of the study reach through channel bends. Satellite images from 2005 to 2011 were used to find the temporal shifting of bank line in curved area. A simple approach was adopted to investigate local bank erosion rate using the following variables.

$$E \propto f\left(\frac{1}{R},\frac{W}{R},\theta,\frac{\theta}{W},\frac{\theta}{R},\dots\dots\dots\right)$$

where, $E$ is bank erosion rate, $R$ is average radius, $W$ is average width, $\theta$ is average angle of attack of flow to the bank line with respect to relative position of adjacent sandbars in a curved channel portion.

The results for bend migration is presented in Figure 3, which shows appreciable effect on the local bank erosion rate while considering the product of curvature and angle of attack ($R^2 = 0.73$).

## (B) Results of numerical simulation and discussion

The transport rate of bed load and suspended load derived from model output are presented in Figure 4. Based on these data, it is observed from the linear regression that the transport rate of suspended load is almost 45 times larger than the bed load and that Jamuna River is very much suspended sediment load dominated river. Most of its morphological features are largely influenced by the suspended load rather than bed load.

### *Variability of sediment transport of the river*

The model can estimate total sediment transport temporally and spatially, which is shown in Figure 5. The figure shows predicted temporal total sediment discharge at km. 2.5, km. 25, km. 37 and km.49. Table 1 shows the seasonal variable sediment transport rates.

### *Non-Dimensional suspended load vs relative fall velocity ($W_f/U_*$)*

The model output shows the non-equilibrium sediment transport condition of Jamuna River. In Figure 6, plotted points are scattered due to these non-equilibrium condition and effect of upstream reach shear velocity.

### *Prediction of sandbars formation, deformation, channel formation and bank erosion*

The model can predict meso-scale bed forms and channel plan forms controlled by sediment transport. Formation, deformation and migration of sandbar take place actively in braided river. Figure 7 shows some of these features and its temporal and spatial changes derived from simulation of the numerical model at T=0, 3 months, 6 months and 9 months.

In Figure 7, several colored ellipsoidal areas are figured out to identify some meso-scale bed changes

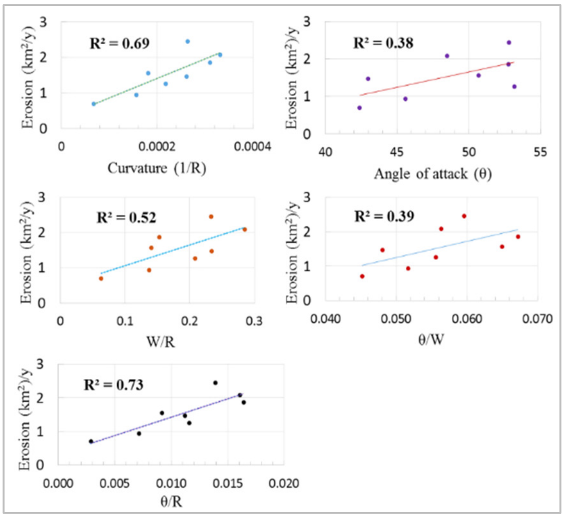


Figure 3 Governing factors for local bend migration.

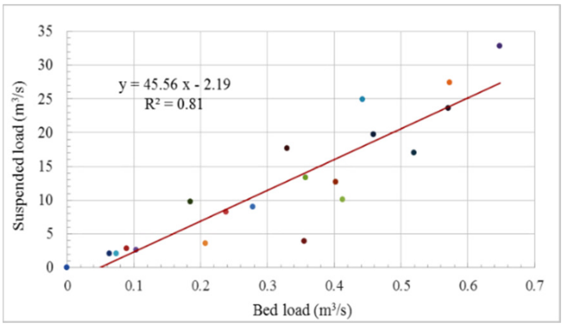


Figure 4 Relationship of suspended load and bed load of Jamuna River.

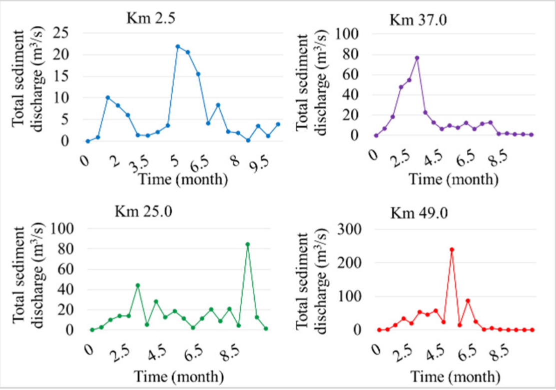


Figure 5 Temporal and spatial distribution of total sediment transport rate.

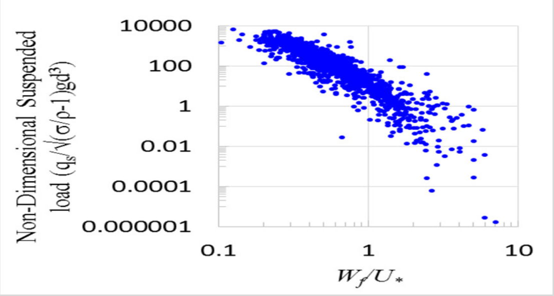


Figure 6 Non-dimensional suspended load with relative fall velocity ($W_f/U_*$).

Table 1 Seasonal variability of sediment transport rate.

| Month | 01-Mar-2000 | 01-Apr-2000 | 15-Apr-2000 | 01-May-2000 | 15-May-2000 | 01-Jun-2000 | 15-Jun-2000 | 01-Jul-2000 | 15-Jul-2000 | 01-Aug-2000 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bed load (m3/s) | 0.000 | 0.089 | 0.357 | 0.648 | 0.442 | 0.573 | 0.459 | 0.330 | 0.184 | 0.570 |
| Suspended load (m3/s) | 0.021 | 2.885 | 13.32 | 32.84 | 24.940 | 27.46 | 19.73 | 17.66 | 9.813 | 23.62 |

| Month | 15-Aug-2000 | 01-Sep-2000 | 15-Sep-2000 | 01-Oct-2000 | 15-Oct-2000 | 01-Nov-2000 | 15-Nov-2000 | 01-Dec-2000 | 15-Dec-2000 | 01-Jan-2001 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bed load (m3/s) | 0.520 | 0.403 | 0.278 | 0.239 | 0.413 | 0.104 | 0.074 | 0.207 | 0.063 | 0.355 |
| Suspended load (m3/s) | 17.049 | 12.740 | 8.959 | 8.208 | 10.041 | 2.604 | 2.107 | 3.569 | 2.108 | 3.884 |

of the study reach. Among the selected areas, the red colored ellipse shows the formation and deformation of sand bars, blue colored ellipse shows the migration of sand bar, the green color ellipse shows the formation of new channels through the sand bars and the purple colored ellipse shows bank erosion prone region. Based on these results, it can be emphasized that the model is reasonable enough to predict such meso-scale changes in the braided river.

Figure 8 shows the predicted spatially distributed velocity field after one month. The maximum velocity found from the simulation is 4.0 m/s, which is in accord with other researchers findings for the same river (Uddin & Basak, 2012).

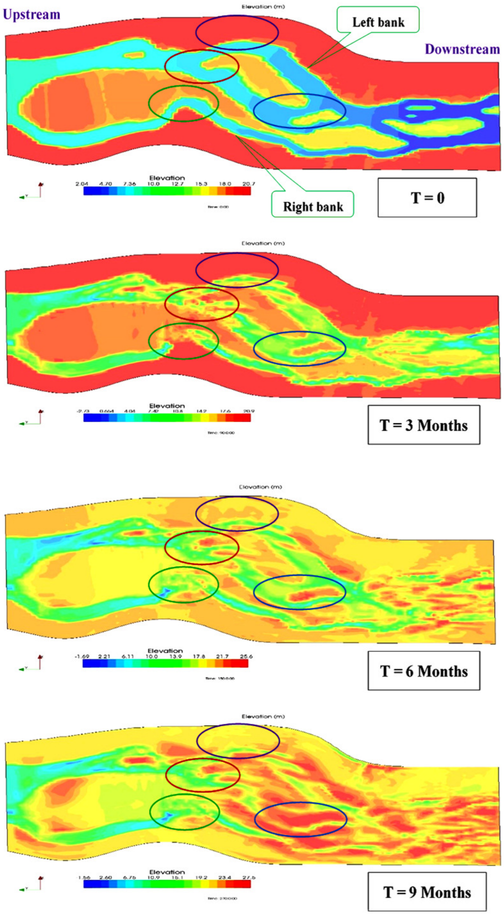


Figure 7 Model outputs, showing the temporal changes of sandbar formation, deformation and migration with localized bank erosion.

## CONCLUSION AND RECOMMENDATION

The analysis of plan data shows erosion vulnerability of the left bank of study area. The decadal variation of erosion and accretion rate shows a periodic feature of increase and decrease of their extent. Besides this, a maximum downstream propagation of sandbar up-to 2090 m was observed. Reasonable effects of curvature and angle of attack on the erosion rate in curved channels were found. Numerical simulation revealed sediment transportation process and its influences on bed variations due to sandbar formations and migrations. It also showed maximum scoring depth up-to 9.0 m and deposition up-to 15.0 m. The model predicted the vulnerable reaches for bank erosion and flow concentration. Besides this, it showed a yearly total sediment transport of 324 million cubic meter within the study reach.

The temporal and spatial distributions of morphological features can be reproduced by the present numerical model. The predicted morphological changes which substantially represent the actual river morphology, justifies the numerical model for its predicting capability even in a small river reach like the present study area. As some simplifications was considered in this study while using numerical model due to scarcity of field measured data, further study could be conducted incorporating the non-uniform sediment size, spatial distribution of channel roughness, bank line soil properties, seepage and pore water pressure in the river bank into the model and taking adequately field measured elevation and sediment data to investigate the overall impact on river morphological changes.

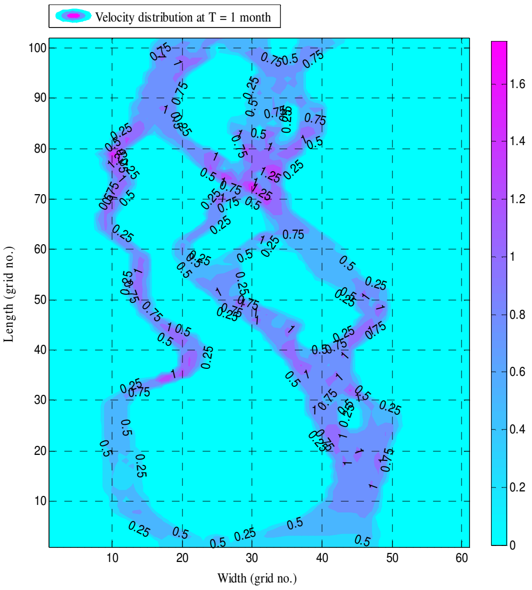


Figure 8 Predicted flow velocity (m/s) distribution field.

## ACKNOWLEDGEMENT

With the blessing of almighty Allah, I would like to show my utmost gratitude to my supervisors Assoc. Prof. Atsuhiro Yorozuya and Prof. Shinji Egashira for their precious guidance and advice for my thesis. I would also like to show my gratitude to Japan International Cooperation Agency (JICA), International Centre for Water Hazard and Risk Management (ICHARM), National Graduate Institute for Policy Studies (GRIPS), Bangladesh Water Development Board (BWDB) and Government of Bangladesh (GoB) for their great support to attend this Water-related Disaster Management Course (2014-2015). I would also like to share my heartiest feelings with Mr. Robin Kumar Biswas and Muhammad Masood, Phd. Student, ICHARM for his enthusiastic support for my thesis work. Finally, I would like to express my love and affection to my mother and all my family members, other relatives, friends and colleagues for their continuous moral support and encouragement for this thesis work.

## REFERENCES

Blitz, Brad K. (2014). Location Security and Environmental-Induced Displacement: a Case Study of the Riverine Islands in Bangladesh. *Refuge: Canada's Journal on Refugees, 29*(2).

Coleman, James M. (1969). Brahmaputra River: channel processes and sedimentation. *Sedimentary Geology, 3*(2), 129-239.

Gares, Paul A, Sherman, Douglas J, & Nordstrom, Karl F. (1994). Geomorphology and natural hazards. *Geomorphology, 10*(1), 1-18.

Klaassen, Gerrit J, & Masselink, Gerd. (1992). *Planform changes of a braided river with fine sand as bed and bank material.*

Kovacs, Agnes, & Parker, Gary. (1994). A new vectorial bedload formulation and its application to the time evolution of straight river channels. *Journal of fluid Mechanics, 267*, 153-183.

Sarker, Maminul Haque, & Thorne, Colin R. (2009). Morphological response of the Brahmaputra–Padma–Lower Meghna river system to the Assam earthquake of 1950. *Braided Rivers: Process, Deposits, Ecology and Management (Special Publication 36 of the IAS), 21*, 289.

Takebayashi, H., Egashira, S. and Okabe, T. (2003). Braided streams formed on bed with non-uniform sediment. *Proc. 3rd IAHR Symposium on River, Coastal and Estuarine Morphodynamics*, pp. 787-798.