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Significance of deep-channel dynamics at Lower Jamuna bifurcation

S. Giri & G. Donchyts
Deltares, Delft, The Netherlands

A. Thompson
Northwest Hydraulic Consultants, Edmonton, Canada

E. Mosselman
Deltares and Delft University of Technology, Delft, The Netherlands

J. Alam
Bangladesh Water Development Board, Dhaka, Bangladesh

ABSTRACT: We present an explorative hydraulic and morphological analysis of a major bifurcation of the Lower Jamuna in Bangladesh based on satellite images, ground data and morphological modelling. We used Aqua Monitor to process multispectral satellite images to estimate the spatiotemporal extent of morphological processes and alterations. The tool is found to be quite effective for on-the-fly analysis of large-scale changes of such a dynamic river bifurcation. Furthermore, we analyzed the dynamics of the deep channels at the bifurcation based on bathymetry measurements. We also simulated the morphological changes using numerical modelling. Our study reveals the importance of deep-channel dynamics at the bifurcation. This regards branches with highly erodible bed and banks under large variations in upstream flow and morphological conditions including human interventions. The focus on deep channels is a key change of perspective as numerical modelling of large rivers usually focuses on sandbar dynamics. Understanding and predicting the deep-channel dynamics is important to identify present and future vulnerable areas and prioritize measures and adaptation. The analysis highlights the complexity of the system which can be quantified but is difficult to replicate and predict due to the large natural and human-induced uncertainties involved. It appears that the morphological behavior of such a large bifurcation does not fully comply with assumptions and guidelines that are mainly applicable to idealized and smaller bifurcations under relatively milder flow and morphological conditions. We present partial results as a preview of a more complete paper currently under preparation.

1 INTRODUCTION

Understanding and predicting the dynamic behavior of river bifurcations is important for assessing the hydraulic and morphological evolution and stability of the connected channels and anabranches. This becomes a concern when there are important areas, settlements and infrastructures along the banks of the channels as well as on islands and floodplains. The evolution of the Lower Jamuna in Bangladesh is an example.

The study of major bifurcations is an essential part of the river stabilization plan within the scope of the Flood and Riverbank Erosion Risk Management Investment Program (FRERMIP) (ADB, 2014). This is study is related to a Lower Jamuna reach with a major bifurcation, located at about 17 km downstream of the Jamuna bridge (Figure 1). Within the scope of this paper, we present some evidence of large morphological changes at the major bifurcation,

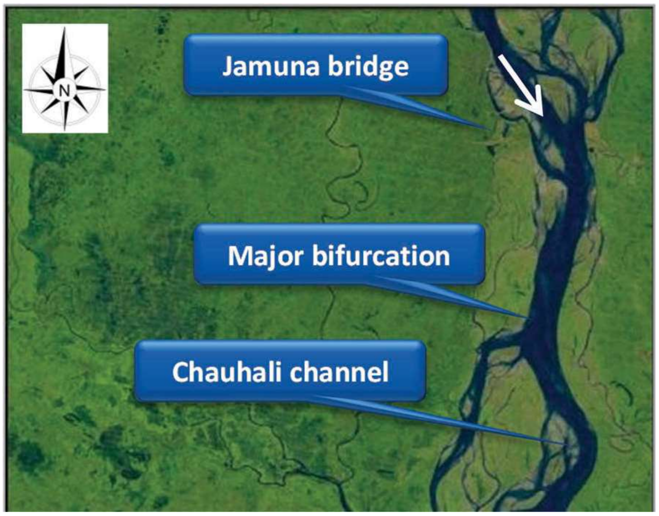


Figure 1. Lower Jamuna reach with major bifurcation (Google earth image).

particularly detection of deep-channel dynamics based on a rapid analysis of ground data and satellite images (using Aqua Monitor). Additionally, we present some preliminary results of numerical modelling. We present partial results as a preview of a more complete paper currently under preparation.

2 UNDERSTANDING DEEP-CHANNEL DYNAMICS

2.1 *A key change of perspective*

A deep channel in a large river system is a micro- or meso-scale (spatial scale), usually shorter-term (time scale) and recurring morphological feature (such as thalweg, anabranches, long bend scour). They are morphologically active during almost all flow periods and are very unstable, triggering bed and bank erosion as well as channel shifting. Therefore, it is important to detect and predict their dynamic behavior, interaction with banks, islands and sandbars for improvement and adaptive management of large rivers (e.g. river stabilization, land/floodplain management, inland navigation). One of our previous works has revealed the problems associated with deep-channel dynamics in various large river systems in South Asia, demonstrating why they are important (Giri et al., 2019). The focus on deep-channel dynamics is a return to the original perspective on understanding the behavior of the Brahmaputra-Jamuna and other large rivers (Jagers, 2001, 2003) as most numerical studies of large rivers usually focus on sandbar dynamics.

2.2 *On river bifurcation studies*

Several studies have been carried out on river bifurcation since long. These studies provide fundamental insights into hydraulic and morphodynamic behavior as well as guidelines for (quasi) stable bifurcations, anabranches and distributary offtakes. However, most of past findings and guidelines do not always comply with the bifurcation and anabranches in a large and extremely dynamic river system like the Brahmaputra-Jamuna. An overview about river bifurcation has been presented in ISPMC (2016) and Bertoldi (2004). Among some previous works, Kleinhans et al. (2008) is noticeable, in which they found that bifurcation dynamics are dominated by gradient differences, upstream bends, width to depth ratios of the upstream approach channel, which determines the bar pattern, sediment sorting, local bank irregularities, bank erosion and accretion as well as scour holes or vortex bars just downstream from the bifurcation. Kleinhans et al. studied meandering rivers with a width of 500 m. Their model tests concluded that counteracting effects, such as an upstream bend and a downstream gradient can offset each other and create a stable bifurcation. One of the main conclusions was that the transverse slope at a bifurcation can influence the sediment division because the gravitational effects can counteract the shear stress resulting from the flow velocities. This effect does not play a large role in rivers with large width to depth ratios, such as the Brahmaputra-Jamuna (Mosselman, 2018). Edmonds & Slingerland (2008) addressed why asymmetrical bifurcations are more common in nature. Their numerical modelling results found that in a fine-grained cohesive bifurcation the dominant mechanism of sediment division between the downstream branches is the variation in bed levels, causing non-uniform surface elevation at the entrance of the two branch channels. This study urged that asymmetrical bifurcations were more common in nature because perturbations, such as alternating side bars, river meandering, floods or planform advantages, cause asymmetry between the branches. Once a bifurcation becomes unsymmetrical, the non-uniform water surface topography and the effect of the bed ramp on the flow field provide feedbacks that keep asymmetrical bifurcations dynamically stable. Schuurman & Kleinhans (2015) used schematic models to study the evolution of bar dynamics and bifurcations in braided, sand-bed rivers. The study found that cross-bar channelization, caused by water level differences between parallel branches, is the most frequent cause of the instigation of bifurcations. Furthermore, the study found that bifurcation closure was not dominated by one specific process. The bar movement was determined to have a notable influence on branch closure, particularly bar-tail limb expansion in minor branches and bar merging. The study revealed that bar-tail limbs are useful for predicting the dominant flow direction and large angle asymmetry that may lead to the closure of a branch. Lama & Kurki (2016) combined experimental and numerical investigations to assess the effect of alternating bars in the approach channel. The study showed that a pool zone in front of a branch entrance increased the quantity of sediment entering into this branch as opposed to a shallower area. These studies, with the exception of Schuurman & Kleinhans (2015), have looked at bifurcations, found in narrow, meandering rivers.

In large and erodible rivers like the Lower Jamuna, understanding the dynamics of deep channels is found to be important given the fact that they control the discharge distribution during, particularly during medium and lower flows. Moreover, their formation and migration, which is much faster and severe than sandbars, may lead to bifurcation instability due to large erosion (bed and banks) in the approach channel and branches. This also hampers river functions as well as management efforts. Consequently, in this study, we attempted to detect and understand behavior of the deep channels in a large river bifurcation.

2.3 *Ground data analysis*

There were some regular measurements at the bifurcation. The bathymetry measurement data are of different resolution; therefore, we plot them without interpolation (Figure 2). Analysis of these data reveals the dynamics of deep channels at the bifurcation, particularly at the upstream reach and branches, that can be outlined as follows:

- In 2011 and 2012, there was one main approaching deep channel upstream of the bifurcation, which was propagating towards the left channel with a meandering pattern. Such meandering pattern of deep channel, which propagated towards to a bend at the left branch, making the bank vulnerable to erosion (that eventually eroded in 2015).
- In 2016, there were two deep channels upstream, apparently due to formation of a mid-channel bar (as a result of capital dredging and channel diversion upstream leading to large erosion and transport downstream). The formation of two deep channels led to the erosion of both banks immediately upstream of the bifurcation expanding the width from about 2.4 km to 3 km particularly during 2016-2018.
- The deep-channel curvature became sharper in 2016 that caused erosion along the bank of the central island right after the bifurcation point (at the left branch). About 800 m of bank erosion occurred along the island during 2015-2018 (see Figure 2).

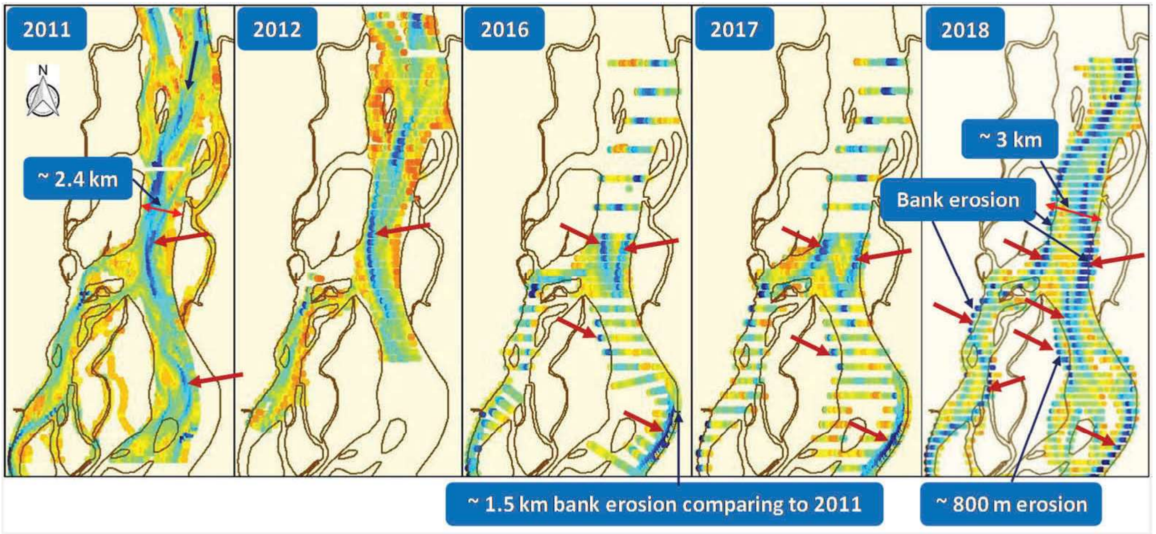


Figure 2. Bathymetry measurement at the bifurcation and branches (dark blue dots indicate deep channels, while yellow to red dots indicate shallower areas with sandbars), illustrating widening of upstream channel and bank erosion at the left branch due to deep-channel formation and migration (brown arrows indicate some of the deep channels).

- The dynamics of deep channels along the bend in the left branch resulted in large bank erosion at Chauhali bend (about 1.5 km during 2015-2016). It is evident from the data that a deep channel was present at this bend already in 2011, which could be one of the triggers for the bank erosion in later years in combination with the upstream intervention leading to changed deep-channel dynamics. The bank was protected in 2016, so local deep erosion along the protected bank is visible in the bathymetry data of 2016 -2018.
- The bathymetry of 2018 shows strong development of deep channels at the upstream reach and both branches making banks and island more vulnerable to erosion.
- The right branch has survived the significant morphological changes in upstream reach during 2011-2016 apparently due to the formation of a deep channel near the upstream right bank that allows some discharge (about 20%-25%) towards the right branch during low flow. However, the 2018 bathymetry evinces the migration of a deep channel towards this branch and its further development with a strong meandering pattern along the branch hitting the bank leading to bank erosion and stability problems to existing protection measures (indicated in bathymetry plot of 2018 in Figure 2).

It must be emphasized that the regular measurement and observation of deep channels are useful to understand their behavior. This is also helpful to predict their (short-term) behavior which is necessary for planning and adaptation of river management efforts.

2.4 *Image analysis using Aqua Monitor*

Analysis of satellite images was made based on a recent advanced image processing technique, referred to as Aqua Monitor, developed at Deltares (Donchyts et al., 2016) to assess the medium- (last 15-30 years) and short-term (last 1-5 years) large scale changes, which mainly includes erosion and accretion of river banks, large sandbars and islands. The formation of new deep channels are not captured by Aqua Monitor (unless they are formed along the sandbars) as they are usually under the water surface.

The changes in wet and dry areas (interpreted as spatial and temporal variation of accretion and erosion) were quantified by detecting the changes in water bodies using multispectral satellite imagery based on number of steps, which enable automated calculation of changing water surface area using both cloud-free and partially cloud-free images (Donchyts, 2016). Advantages of the method are: (i) high frequency images with improved processing and analysis, (ii) automated processing like extraction of geometry and topology, (iii) robust and accurate method of water body detection and delineation, (iv) estimation of temporal changes in water surface area, and (v) monitoring and estimation of accretion and erosion (spatial and temporal variation, but not the volume).

The analysis process was automated and developed an interactive tool ‘Aqua Monitor’ (http://aquamonitor.deltares.nl/). The Aqua Monitor establishes water-land and land-water occurrence on-the-fly by estimating the MNDWI spectral index values and performing trend analysis for these MNDWI values over both user-selected periods. To decrease noise for the high latitudes, all Landsat images acquired during night time are excluded. Additionally, we apply a topographic mask based on Height Above the Nearest Drainage (HAND) to decrease the noise in the hilly areas, occurring due to mismatches between sun elevation and azimuth parameters in both periods. All pixels representing mountain hills (HAND > 150 m) are excluded. The final estimation of the surface area (land to water and water to land) is obtained by including pixels where significant slope changes were observed. The threshold was found empirically. The Google Earth Engine backend of the Aqua Monitor prepares all computations and visualizations on-the-fly (Donchyts, 2016).

The results and analysis of short-term morphological changes are briefly outlined as follows:

- Figure 3 shows the large-scale morphological changes at the bifurcation and branches during last 30 years, which has been split over two different period of 15 years. The result shows that there was a large erosion trend during first 15 years, while there was accretion trend during last 15 years. It is to be noted that the major bifurcation started to form already in 1992 (based on Landsat image). The reason for such a large change is the Jamuna Bridge, however the bridge effectively impacted on the river from 1996 onwards when the west guide bund was completed.
- The result shows that significant accretion occurred mostly along the right channels during last 15 years (2000-2015). This might be attributed to the increase in upstream supply and stabilization of upstream reach after the construction of Jamuna bridge. This can also be partly due to long-term effect of Ganges confluence downstream (not shown in the figure), particularly given that fact that accretion has been occurring along the right channel (as Ganges flows from the right side).
- This accretion trend during last 15 years (2000-2015) seems to have been causing bank erosion in both channels due to formation of deep channels, particularly this is more

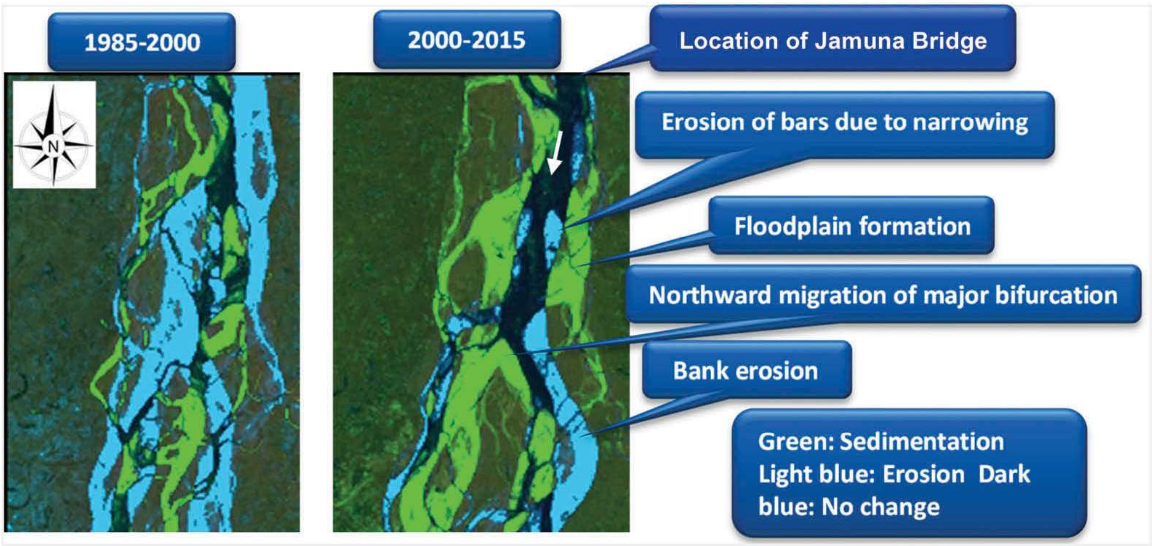


Figure 3. Changes in morphology at the bifurcation in last 30 years, separated in two different periods of 15 years, quantified by using Aqua Monitor.

pronounced in the left channel. The Aqua Monitor result replicates well the formation of new floodplains at both side and stabilization of the narrow straight channel between the upstream bridge and the bifurcation (see the left plot of Figure 3) after the construction of the bridge (in 1996).

- The results on shorter-term morphological changes at the upstream reach between the bridge and the bifurcation as well as at both branches is depicted in Figure 4. It must be emphasized that dredging activities was carried out in dry period of 2012 near the bridge. As a result, a new deep channel developed upstream of the Jamuna bridge, thereby leading to active morphological development at the reach downstream (as shown in the left plot of Figure 4). Consequently, formation of sandbars seems to be leading to bank erosion and widening of the channel in the reach between the bridge and the bifurcation as particularly the mid-channel bar pushes the deep channels towards the both banks. Such changes in upstream morphological condition might cause bifurcation instability in future in case the banks are not well protected.
- The morphological changes during later period, i.e. 2014-2018 show further erosion of banks and formation of deep channels in both branches (see right plot of Figure 4). Although some of the deep channels near the island and the bend partly silted up again during 2016 flood.
- The changes also show formation of a large sandbars in the left branch (between the bend and the island) as a result of sediment supply caused by the large bank erosion at the bend. This sandbar appears to have been partly eroded during 2016 flood with formation of cut off/deep channels through the bar (see right plot of Figure 4).
- The morphology at the entrance of the right channel has also been changed during past few years. The discharge distribution does not appear to have been changed drastically so far (less than 5% during lower flows). It must be noted that deep-channel patterns at the bifurcation (e.g. curvature) appear to have a major impact on discharge distribution and could even be more important than the planform shape and alignment, particularly for medium- and lower flows that are important for river erosion management and stabilization. Further detailed study about this aspect is in progress.

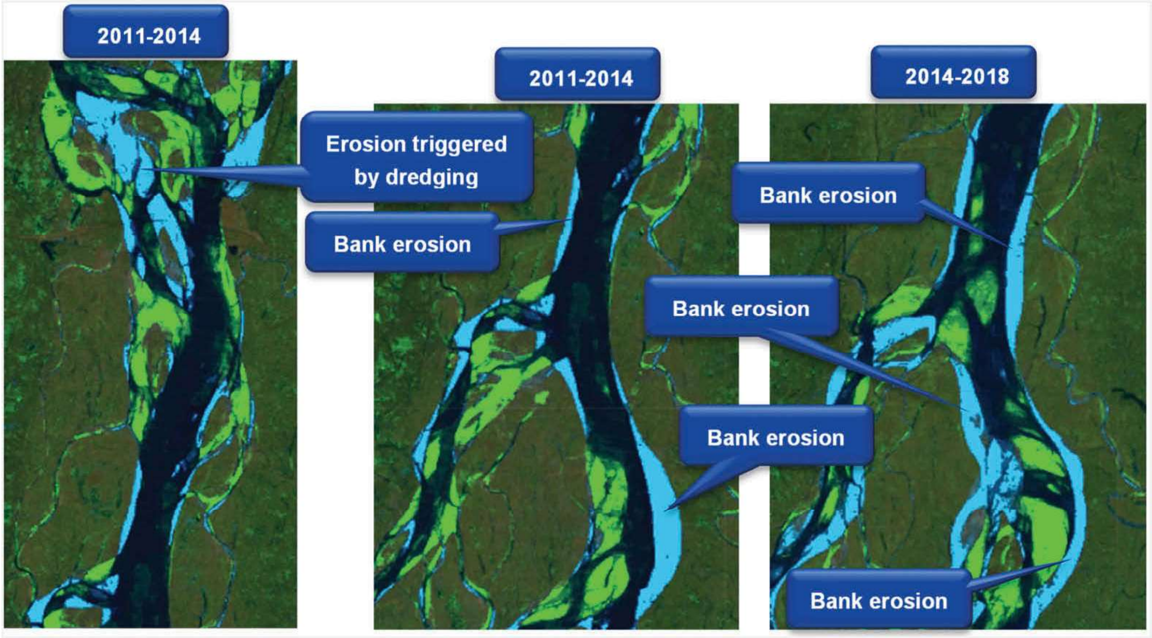


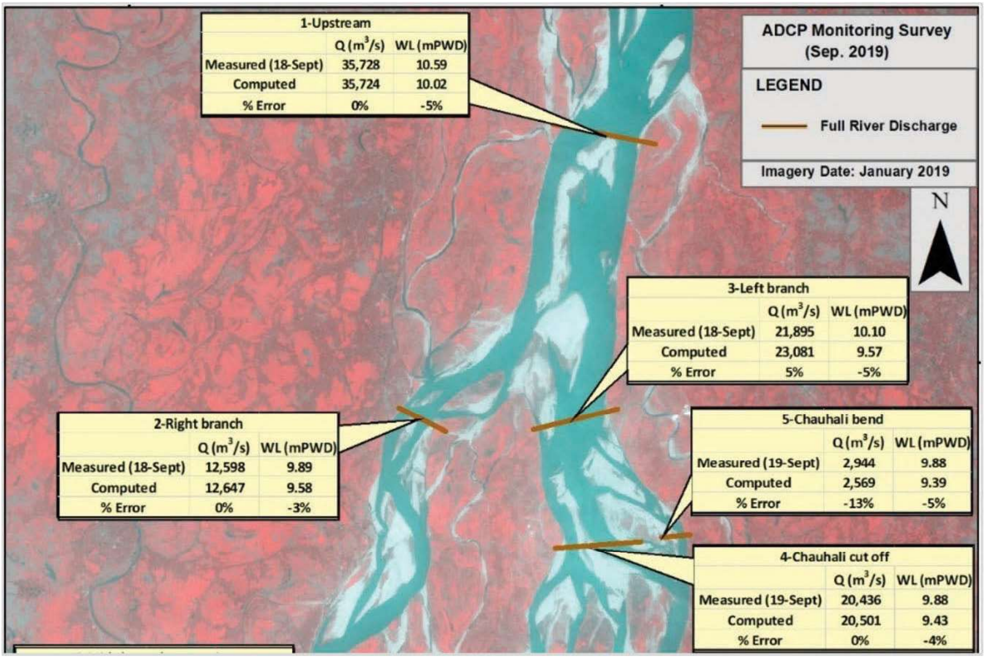
Figure 4. Large erosion triggered by the dredging forming new deep channel during 2011-2014 (left plot), resulting bank erosion during downstream reach with bifurcation and branches during the same period (middle plot) and further erosion and formation of deep channels at the branches.

The result of Aqua Monitor is found to be consistent with the ground observation and data. The tool is useful for quick assessment of spatial and temporal changes of large- and meso-scale morphological features of large and dynamic rivers.

2.5 *Numerical modelling of deep channels*

A depth-averaged morphological model, namely Delft3D, was used. Mathematical formulations and relationships have not been presented here as the approach is well-known from the literatures on fluid dynamics and sediment transport theories and practices, and also mentioned in Delft3D reference manual. A user-defined general sediment transport formula was selected which approximately represents the FAP formula. This transport formula was specifically developed for the Jamuna (Delft Hydraulics & DHI, 1996). The sediment is uniform (with median grain size of 0.15 mm). Other details can be found in Giri et al. (2019).

We present here only some preliminary results as the work is in progress. Figure 5-7 show the results of hydrodynamic simulations and comparison with measurements. The result is not perfect but acceptable as a first outcome for such a large and dynamic system. Figure 8 shows an example of morphological modelling of deep-channel formation and migration. More detailed study with further improvement is in progress.



1-Upstream	$Q (m^3/s)$	WL (mPWD)
Measured (18-Sept)	35,728	10.59
Computed	35,724	10.02
% Error	0%	-5%

2-Right branch	$Q (m^3/s)$	WL (mPWD)
Measured (18-Sept)	12,598	9.89
Computed	12,647	9.58
% Error	0%	-3%

3-Left branch	$Q (m^3/s)$	WL (mPWD)
Measured (18-Sept)	21,895	10.10
Computed	23,081	9.57
% Error	5%	-5%

4-Chauhali cut off	$Q (m^3/s)$	WL (mPWD)
Measured (19-Sept)	20,436	9.88
Computed	20,501	9.43
% Error	0%	-4%

5-Chauhali bend	$Q (m^3/s)$	WL (mPWD)
Measured (19-Sept)	2,944	9.88
Computed	2,569	9.39
% Error	-13%	-5%

Figure 5. Comparing measured and simulated instantaneous discharges.

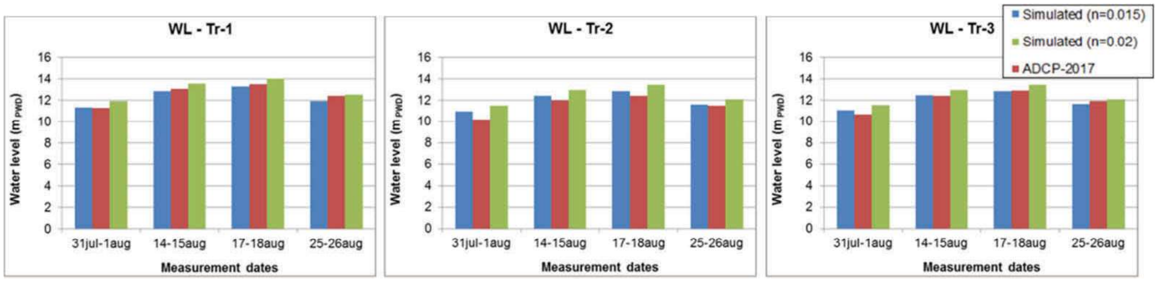


Figure 6. Comparing measured and simulated instantaneous water levels upstream of the bifurcation (left plot), at the right branch (middle plot) and at the left branch (right plot).

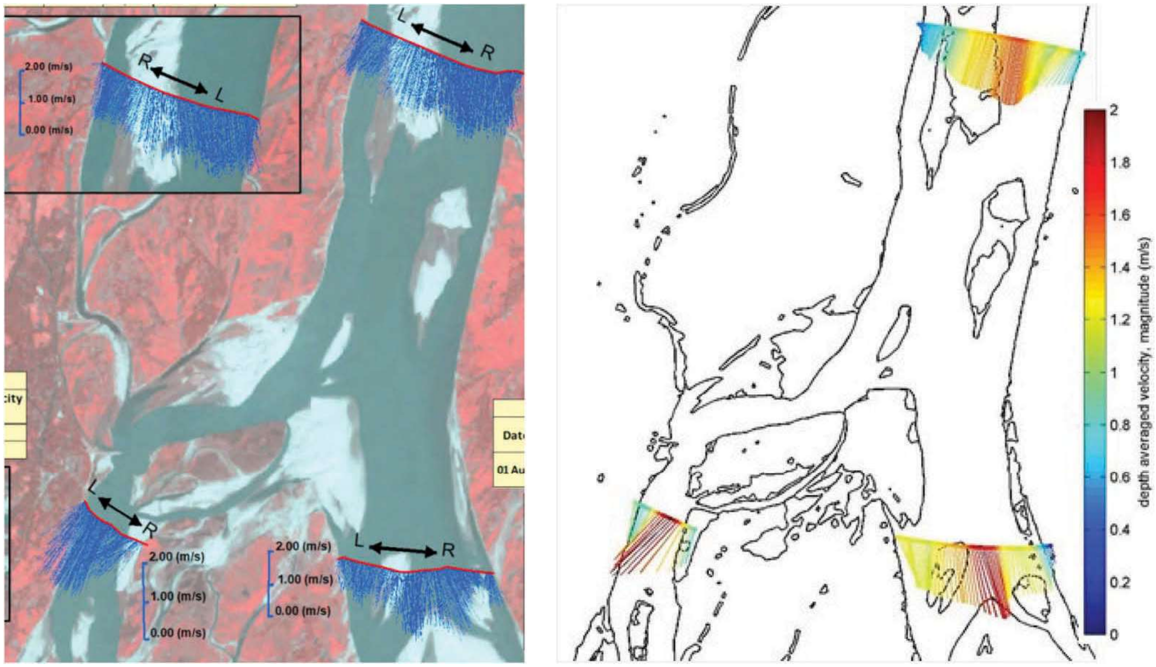


Figure 7. Measured using ADCP (left) and simulated (right) depth-averaged flow velocity vectors (Q = 40510 m^3/s).

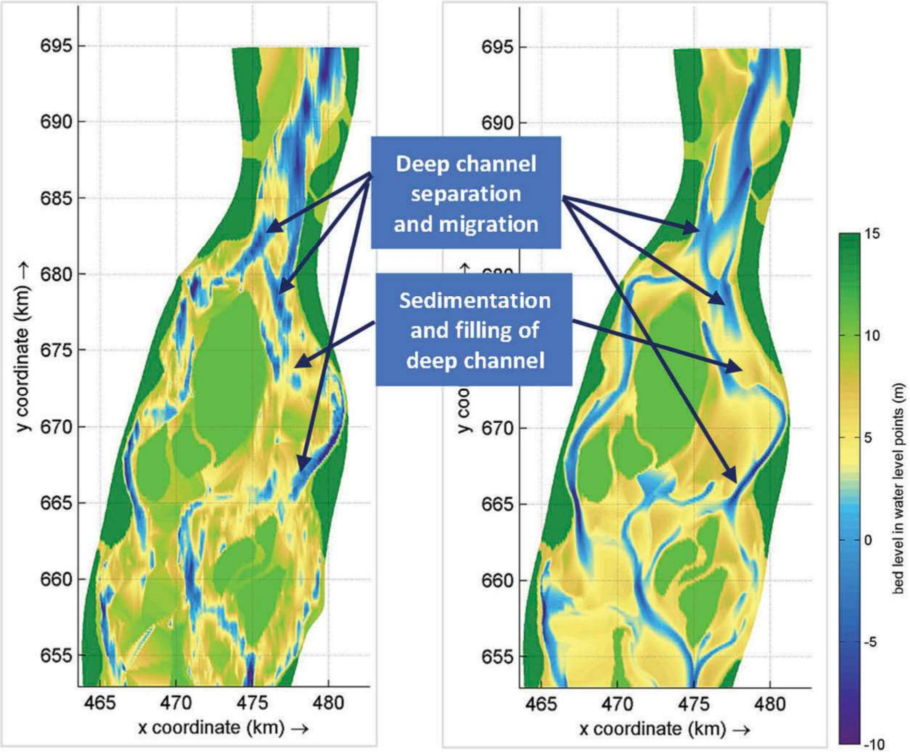


Figure 8. Morphological simulation of bed level changes with a focus on deep-channel dynamics (left plot: observation, right plot: simulation).

3 CONCLUDING REMARKS

This study demonstrates the importance of deep channels at the bifurcation and branches in a large river system with highly erodible bed and banks. Particularly, understanding and predicting the dynamics of deep channels is important to identify present and future vulnerable areas, and to prioritize and adapt river management efforts. The analysis highlights the complexity of the system which is possible to quantify, but difficult to replicate and predict due to high uncertainties involved. A combination of ground measurement, image processing techniques and modelling is useful to understand and predict at least the short-term behaviour of deep channels that is important for planning and adaptation of river management efforts in large and dynamic rivers. It appears that hydraulic and morphodynamic behaviour of such a large bifurcation does not fully comply with assumptions and guidelines that are mainly applicable to idealized and smaller bifurcations under relatively milder hydraulic and morphological conditions. More studies will be carried out to further improve our analysis and to support our first conclusions.

Our future work shall include (but will not be limited to): (i) continuation of field monitoring, image analysis as well as detailed and improved modelling; (ii) making specific links to the adaptive approach for river stabilization and management, majorly depending on forecasting, particularly shorter-term; (iii) deriving a new formulation for a "Deep-Channel Index (DCI)" that could be based on depth evolution, quantity and direction of deep channels, and other parameters.

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