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Assessment of long term evolution of morphodynamics of the Kalni-Kushiyara River system in Bangladesh using one dimensional morphological model

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Abstract

Application of the one-dimensional morphological modelling serves the purposes of gaining understanding of sediment transport phenomena and the morphological behavior in-terms of trend in long term bed level changes. Two dimensional and three dimensional mathematical model is suitable for the interpretation of local phenomena due to its big computation time and large extent of data requirement where one dimensional morphological model can be applied for the general understanding of river system in long run river morphodynamics. Thus the results from 1D model should be taken as indicative rather considering its quantitative outputs. In this study, 1D morphological model is developed for Kalni-Kushiyara river system which is one of the class III navigation route of Bangladesh. And the model is calibrated with observed suspended sediment concentration and vertical stability with assessment of FAP6 study. This study shows upstream reaches of the Kalni-Kushiyara river system are likely to be under combined effect of erosion and deposition in some alternative reaches while lower reaches (basically Kalni River) are mostly under deposition process in the bed which is allied with FAP6 study. This study also reveals the suitability of sediment transport equation for the Kalni-Kushiyara river system. And over all this study depicts the applicability of 1D morphological model for the assessment of long term morphodynamics of the river where an indicative solution could be achieved with limited set of data and less computation time.

Keywords: Hydrological model, hydrodynamic model, morphological model, NERM sediment transport model.

1. Introduction

Channel morphodynamics refers to the study of interaction and adjustment of the channel bed and bank with the fluid hydrodynamic process. River morphology is dependent on the longitudinal slope, channel conveyance, off take of sediment load, sediment transport rate, mean diameter of the sediment, particle settling velocity and incipient motion demonstrated by Kadi *et al.* 2015. Lateral stability of the stream are assessed by the horizontal shifting of the river conceptualize from the historical maps and images. And the vertical stability is made primarily by comparing historical cross-section of the river at identical location stated by FAP6 1994 and FAP6 1998.

Kalni-Kushiyara river system is class III navigation route introduced by the Bangladesh Inland Water Transport Master Plan (BIWTMAS) in 1989 shown in Figure 1. In class III route, indicated draft is 1.5 m which is seasonal in nature and is not feasible to maintain higher least available draft (LAD) throughout the year. In Bangladesh, class three routes are 32% in entire length of the navigation route where Kalni-Kushiyara river system is 13.4% of the class III route. Statistics shows passenger fare and freight cost for different modes, inland water transport is comparatively cheaper than other transport such as railway and roadway. Navigability of streams in Bangladesh is deteriorating due to the natural & morphological processes along with the withdrawal of water during dry season stated in Mishra and Hussain 2012.

Fig. 1. Bangladesh inland navigation route (Source: BIWTA).

Mathematical model is helpful for solving and addressing the problem of bridge construction, pipelines, river dredging, reservoir silting problem, etc. In several researches done by past few decades, 2D and 3D mathematical models for sediment transportation have been developed and used for the prediction of river regime and river bed deformation stated in Jilani and

Hashemi 2012; Chollet and Cunge 1980; Hinwood *et al.* 2015. Detail level of bathymetry data are needed prior to develop the model even the computation time for the model is very high. Thus it needs more costs and time for the evolution of long term river morphodynamics study using 2D and 3D dimensional model. MIKE 11 is a 1-D mathematical modelling tool developed by Danish Hydraulic Institute (DHI water & environment). For this study model version 2012 has been used to develop the models. The hydrological model in MIKE 11 is called NAM model which can be characterized as a deterministic, lumped, conceptual model with moderate input data requirements. The MIKE 11 hydrodynamic module (HD) uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as super critical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Basic equations used are Saint Venant Equations stated in DHI 2014.

The non-cohesive sediment transport module (NST) can be simulated in two modes- one is explicit mode (sediment transport) another is morphological mode. The explicit mode is used to apply where significant morphological changes are unlikely to occur and in this mode output is required from the hydrodynamic module (HD) in terms of discharge, water levels, cross-sectional area and hydraulic radius both in time and space. There is no feedback from the sediment transport calculations to the HD module and the results are in the form of volume transport rates. In the morphological mode, sediment transport is calculated in tandem with the HD module. The feedback from the sediment transport calculations to the HD is achieved through solution of the sediment continuity equation and through the updating of the bed resistance and the following sediment transport. Results are in the form of sediment transport rates, bed level changes and resistance number. The morphological model updates the bed level due to erosion or deposition using the continuity equation for sediment transport. There are five different assumptions for the bed level updating in MIKE 11 NST module where default setup is method 4. And method4 here considers the deposition and erosion is uniformly distributed over the entire cross-section. There are different sediment transport equations for the simulation of sediment transport and morphology module in MIKE 11 such as Ackers and White, Engelund and Hansen, Smart and Jaeggi, Engelund and Fredsoe, Van Rijn, Meyer Peter and Muller, etc.

However, one dimensional morphological model needs comparatively less data and time to simulate though it has limitation of overlooking bend scour. But for long term simulation it is convenient to get sediment transport and bed level change as an indicative solution for the planning process referred by Nones *et al.* 2015. Thus it is helpful for decision maker and planners for the long term planning relevant to river restoration. The one-dimensional sediment transport model has been developed in this study for the Kalni-Kushiyara River system using MIKE 11 software package. The developed model has been calibrated with observed water level, rated discharge and sediment concentration data. Thus the model is applied to assess the long term erosion and deposition pattern along the longitudinal profile of the river reach which is compared with the assessment of the FAP6 study.

2. Location of the study

Location of the study concentrates to the Kalni-Kushiyara river system which originates from Barak River in India and passes through Sylhet, Moulvibazar and Habiganj district of Bangladesh. These districts are situated in the North-East region of Bangladesh which is under floodplain of one of major Meghna River basin. The topography of the area is irregular which is falling from the piedmont hills near India with gentle sloping plain in the boarder to the haor depression. Haor is termed as large bowl shaped depression area where a perennial beel located inside the haor. During pre-monsoon and monsoon flash and riverine flood water enters to the haor area and river gets again the recession of flood water during the post monsoon stated in IWM, 2007 and IWM, 2009. Again upstream part of the Kalni-Kushiyara river system passes through the physiographic sub-region of Sylhet high plains & Sylhet hills including Meghalaya foothills-Tila ranges where the downstream part of the river system falls under the haor basin demonstrated by Rashid 1991. Figure 2 shows the Kalni-Kushiyara river system in the northeast region of Bangladesh.

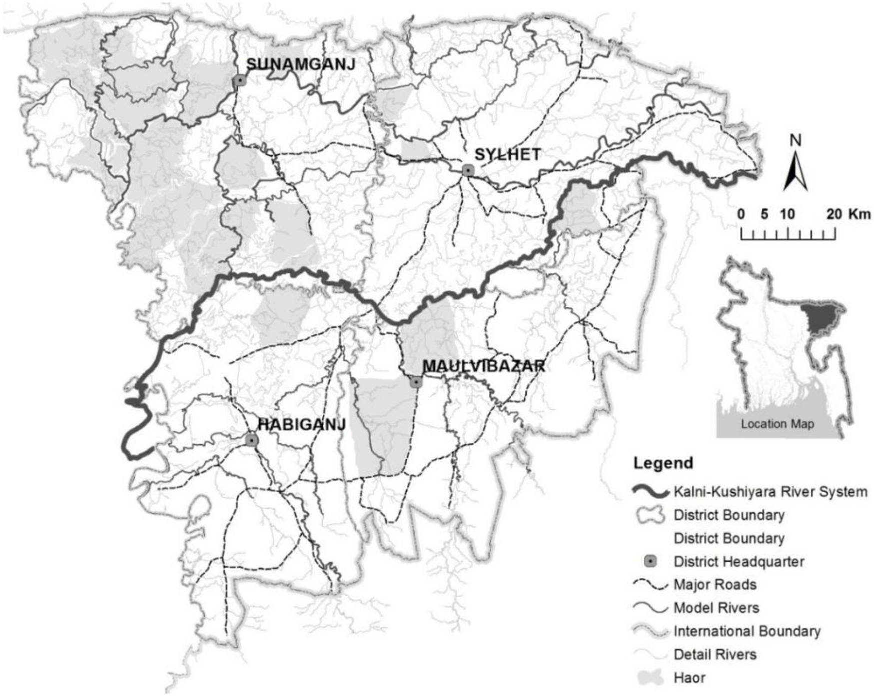

Fig. 2. Kalni-Kushiyara River system in northeast region of Bangladesh.

3. Methodology and data collection

Relevant project reports and publications have been reviewed to develop the study methodology. Mathematical modeling technique has been applied to conduct this study. Danish Hydraulic Institute (DHI water & environment) developed one dimensional (1-D) modelling tool MIKE11 has been used. Model input data have been collected from various secondary data sources. The models have been developed for continuous 15 years of historical data starting from 1992 and calibrated for the years 2005 to 2007 based on recent data availability. Finally the model results have been analyzed to calculate net changes in longitudinal profile on basis of erosion and deposition on river bed. The methodological flowchart of the whole study is shown in Figure 3. Prior to develop the mathematical model, historical hydro-meteorological, topographic and sediment data has been collected from several secondary sources such as Bangladesh Water Development Board (BWDB), Institute of Water Modelling (IWM) and from review of previous relevant reports and journals. Secondary sources data include rainfall, evaporation, water level, discharge, river cross-sections, suspended sediment concentration and sediment grain size distribution. The important river reaches along with their status of cross-sections in the model is described in the Table 1.

4. Mathematical model development

The 1-D models have been developed using 2012 version of MIKE11 modelling software under three sequential stages. The hydrologic and hydrodynamic models have been truncated from IWM developed North East Region Model (NERM).

4.1 IWM developed NERM

The North-East Regional Model (NERM) has been developed in early 1991 under the Surface Water Simulation Modelling Program Phase-II (SWSMP II). After development of the regional model, it has been routinely updated and validated by Institute of Water Modelling (IWM). The NERM model has been covered an area of about 24,265 square kilometer where it receives external inflows of about 20,311 square kilometer from India. There are 38 nos. of sub-catchments are considered in hydrological component of the model which is shown in Figure 4.

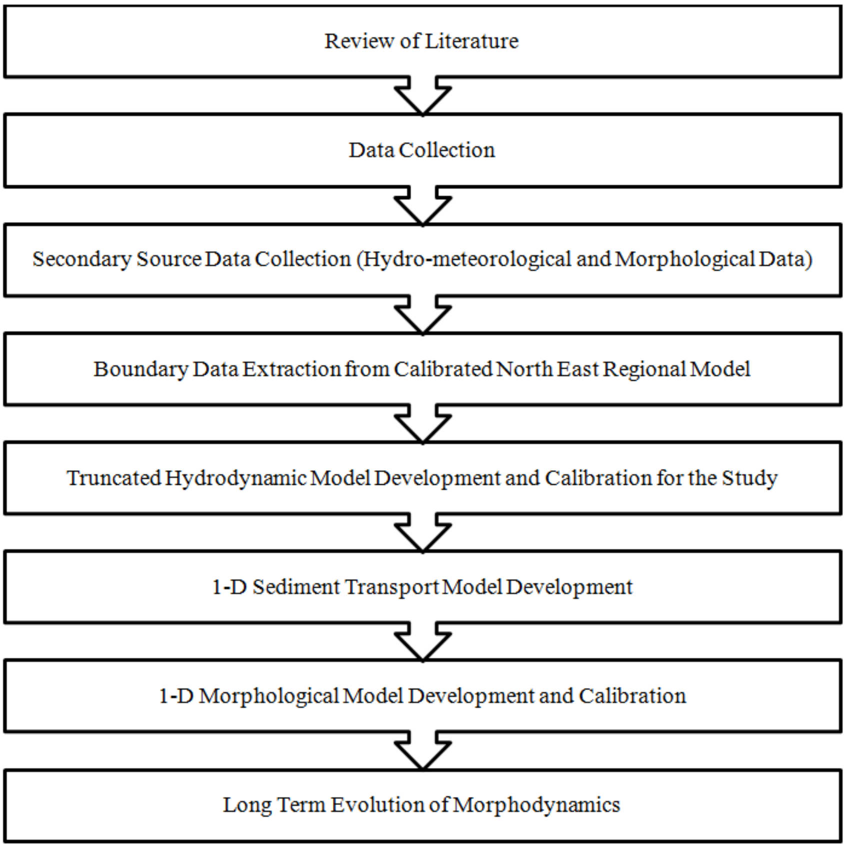

Fig. 3. Overall methodological flowchart of the study.

Table 1
Cross-section survey status in 1D morphological model

3	Reach (Chainage: km)	Survey year
Upper Kushiyara	0 to 45	2013
Kushiyara	0 to 135.5	2013
Kalni	0 to 72	2012

Approximately 3500 km length of river reaches with 1200 nos. of cross-sections have been comprised the hydrodynamic component of the model stated in IWM 2007 and IWM 2009. Figure 5 shows the schematized river in NERM model.

4.2 Hydrologic and hydrodynamic modelling of the study

Truncated model has been developed from calibrated North East Regional Model (NERM). Schematized river in the truncated model is shown in Figure 6. The upstream boundary for the model is being considered the rated discharge at Amalshid where downstream boundary is water level extracted from the calibrated NERM model. In the NERM regional model detail of major rivers, minor rivers, floodplains and haors are schematized. But in truncated model developed for the study, all of those links with floodplains, haors and minor rivers are considered as 'point inflow' boundary and their boundary data are also extracted from NERM historical simulation.

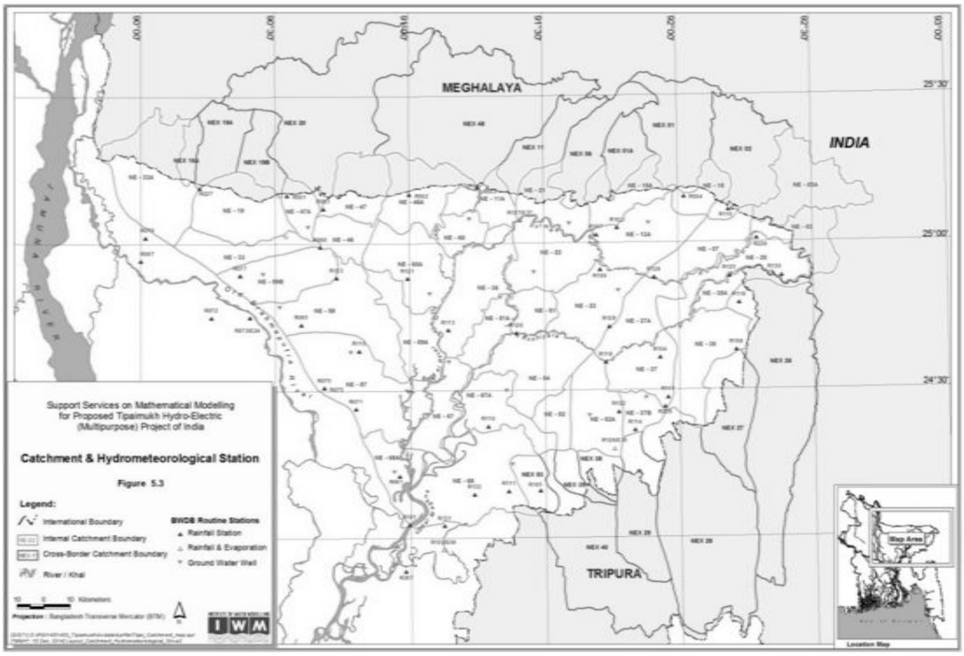

Fig. 4. Sub-catchments and hydro-meteorological station in NERM model (Source: IWM).

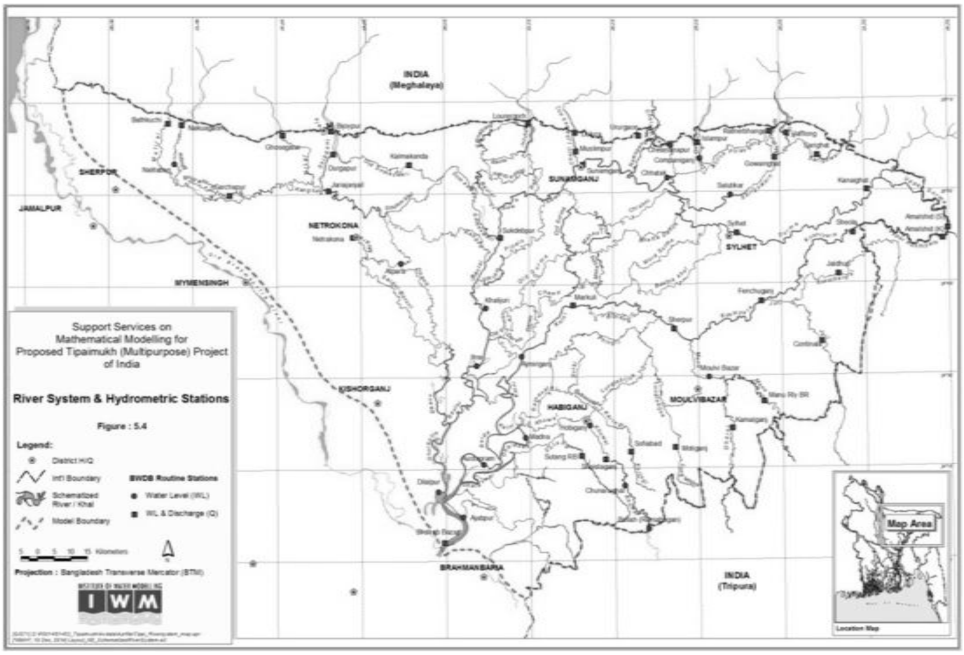

Fig. 5. Schematized river systems and hydrometric station in NERM model area (Source: IWM).

Developed truncated model result has been compared with observed water level and rated discharge at several locations such as Amalshid, Sheola, Fenchuganj and Sherpur. Sample of calibration plot at Sheola station is shown in Figure 7 and Figure 8. Calibrated hydrodynamic model is pre-requisite for the further proceed to the development of sediment transport and morphological model.

Fig. 6. Schematized river for the truncated hydrodynamic model.

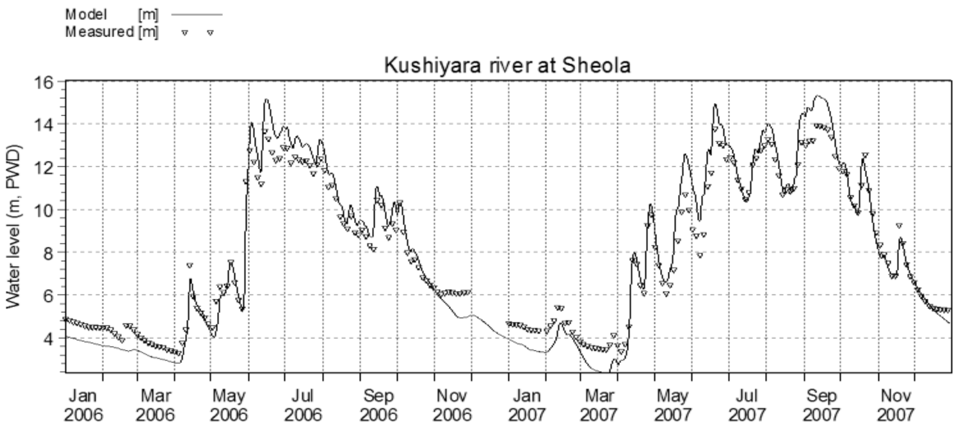

Fig. 7. The water level comparison plotting at Sheola station on the Kushiyara River.

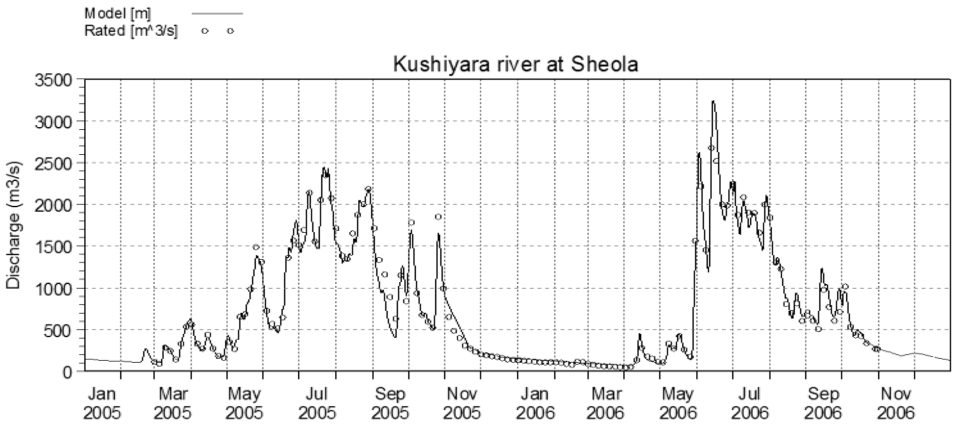

Fig. 8. The discharge comparison plotting at Sheola station on the Kushiyara River.

4.3 *Sediment transport modelling*

The non-cohesive sediment transport model has been developed and used to evaluate the sediment transport rate and accumulated sediment transport data. The model has been run using a number of grain sizes (D_{50}) representing grain size fractions of individual reaches of Kalni-Kushiyara River system shown in Figure 9.

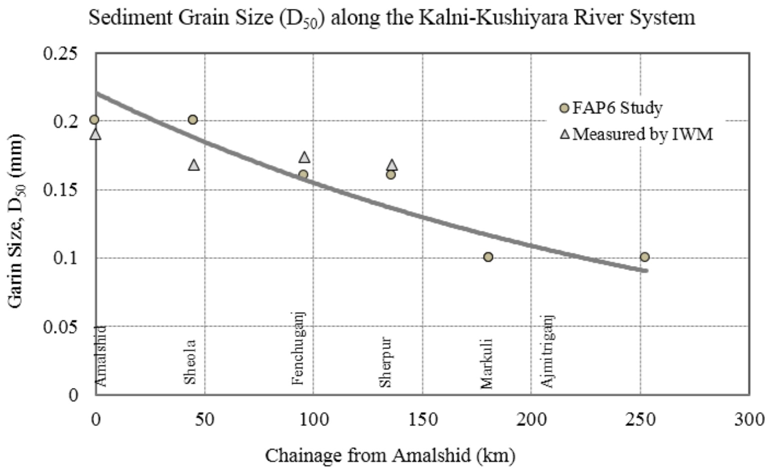

Fig. 9. The median grain size distribution (d_{50}) of bed material samples.

Sediment boundary data is not needed to assign during explicit mode simulation. For the morphology module simulation, boundary sediment data near the Amalshid location is extracted from the explicit simulation result and the downstream sediment boundary is considered as morphological equilibrium i.e. no net scouring or deposition as represented by zero rate of sediment transport.

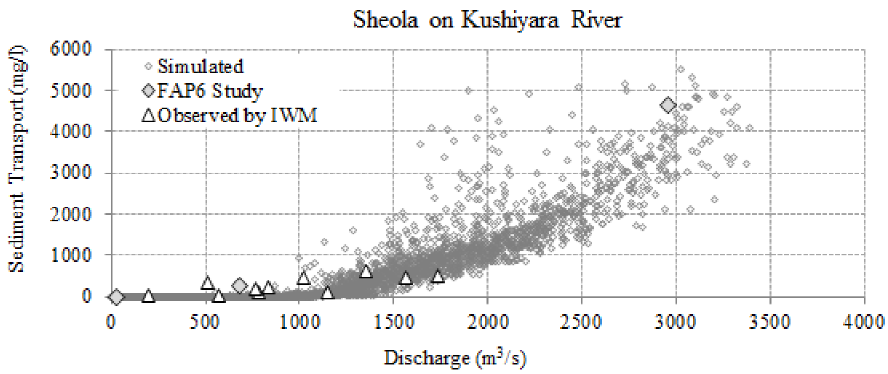

Fig. 10. Plot showing agreement of measured and model simulated concentration at Sheola of the Kushiryara River.

4.4 *Sediment transport and morphological modelling*

The developed 1-Dimensional morphological model has been simulated for the long period of 15 years from 1992 to 2006 based on the availability of boundary data. The model run was carried out using several sediment transport formula such as Van Rijn, Engelund Fredso, Ackers White, and Engelund Hansen etc available in non-cohesive sediment transport (NST) module of MIKE11 packages. The sediment transport using Engelund Fredso sediment transport formula shows the good agreement with observed sediment transport data collected from secondary source for Sheola and Sherpur station shown in Figure 10 and Figure 11.

5. Results and discussion

The Kalni-Kushiyara river system maintains a dynamic equilibrium condition. The trend of bed level changes (sedimentation and erosion pattern) along the Kalni-Kushiyara River system is shown in Figure 12. From the figure it is clear that the Upper Kushiyara reach of the system shows both deposition and erosion scenarios. First 15 kilometer of this reach shows deposition whereas the rest of the part shows erosion. The rage of bed level change varies from -1.8 m to 2.3 m. The middle portion of the system is Kushiyara reach which displays erosion in first 15 kilometers then very minor combination of erosion and deposition in middle 75 kilometers and a sharp deposition is observed in the last 40 kilometers. The range of bed level change fluctuates between -1.9 m and 2.4 m. The last portion of the Kalni-Kushiyara river system is Kalni reach which shows a very high deposition over the whole length of the river except last 2 kilometers. The highest change of bed level in this reach is 4 m but in most parts of this reach bed level changes are over 2 m.

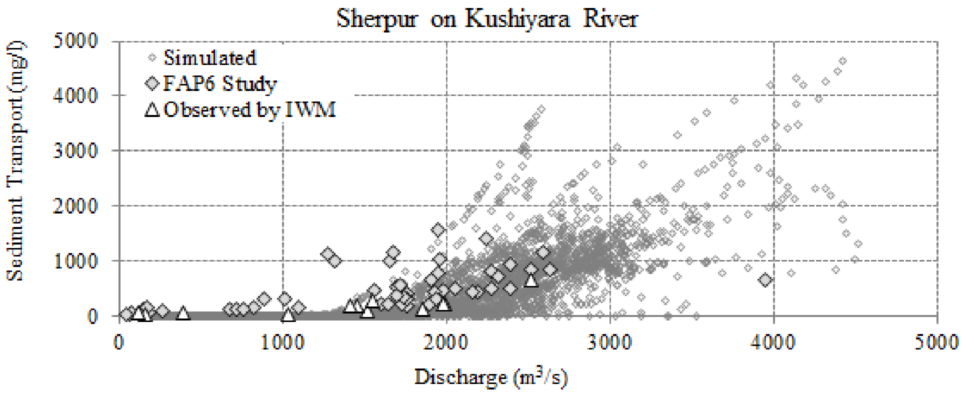

Fig. 11. Plot showing agreement of measured and model simulated concentration at Sherpur of the Kushiyara River.

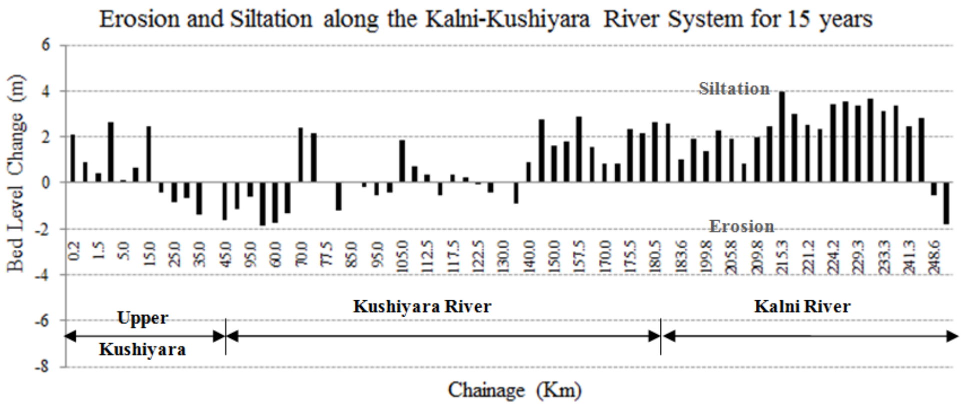

Fig. 12. Bed level changes along the Kalni-Kushiyara River system.

6. Conclusions and recommendations

Erosion tendency is observed in the upper reaches whereas deposition is observed in the lower reaches. Upstream reaches of the Kalni-Kushiyara river system are likely to be under combined effect of erosion and deposition in some alternative reaches while lower reaches (basically Kalni River) are mostly under deposition process in the bed. FAP6 (1998) study reveals that from the location Amalshid to Markuli, the river system is degrading and from Markuli to the end of reach is aggrading which is also relevant to this study finding.

The 1D morphological model of the Kalni-Kushiyara river system has been developed with limited sediment data and information, and thus the results should be taken as indicative rather considering its quantitative outputs. This model has estimated satisfactorily the overall sediment transport rates and predicted the morphological changes in-terms of bed level changes, which could be reasonably explained by physically based features. It should be mentioned that the one-dimensional morphological models generally have limitations. Nevertheless, the results are useful in investigating the response of a river system to large changes in the flow regime. The present development of the morphological model would be useful in planning activities such as assessment of trend of relatively sensitive morphological features, any intervention made in the river like dredging and sediment trap.

References

Chollet, J. P. and Cunge, J. A. (1980). "Simulation of unsteady flow in alluvial streams", Appl. Math. Modelling, Volume 4, 234-244.

DHI, (2014). A modelling system for rivers and channels, Danish Hydraulic Institute (DHI), Reference Manual

FAP6 (1994). Flood Action Plan, Northeast regional water management project, Specialist study, River sedimentation and morphology, Final report. SNC Lavalin International Northwest Hydraulic Consultants, Flood Plan Coordination Organization, Bangladesh Water Development Board. Government of the People's Republic of Bangladesh.

FAP6 (1998). Flood Action Plan FAP6, Northeast regional water management project, Kalni-Kushiyara river management project feasibility study, Annex A: Sedimentation and morphology, Final report. SNC Lavalin International Northwest Hydraulic Consultants, Flood Plan Coordination Organization, Bangladesh Water Development Board. Government of the People's Republic of Bangladesh.

Hinwood, J. B., Gould, O. and McLean, E.J. (2015). "A one-dimensional tidal river morphological model", http://www.mssanz.org.au/modsim05/papers/hinwood.pdf, (accessed on February, 2015)

IWM. (2007). Mathematical modelling along with the hydrological studies and terrestrial survey under the haor rehabilitation scheme, Final report, Main report, Institute of Water Modelling (IWM), Client: Bangladesh Water Development Board, Flood Plan Ministry of Water Resources, Government of the People's Republic of Bangladesh.

IWM. (2009). Flash flood forecasting in northeast region of Bangladesh, Flash flood forecast technology for disaster preparedness in Bangladesh, Institute of Water Modelling (IWM), Client: USAID, CARE and ADPC.

Jilani, A. N. and Hashemi, S. U. (2012). "Numerical investigations on bed sediment transportation using SPH method", Scientia Iranica A, 20 (2), 294-299.

Kadi, K. E., Lapuszek, M., Matyas, A. L., Paquier, A. and Piwowarczyk-Ogorek , J. (2015). "One dimensional sediment transport models: application to Raba river", *http://www.impact-project.net/publications/wp4_pub8.pdf, (accessed on February, 2015).*

Mishra, D. K. and Hussain, S. M. (2012). "Situation analysis on inland navigation. Ecosystems for Life: A Bangladesh-India Initiative", International Union for Conservation of Nature (IUCN)

Nones, M., Silvio, G. D., Guerrero, M. and Pastorello, L. (2015). "1-D long term simulation of the Paraná River morphodynamics in the light of climate variability", file:///D:/Research/AHK/River_Flow_2012_paper_Nones_review.pdf, (accessed on February, 2015).

Rashid, H. E. (1991). Geography of Bangladesh, second revised edition, University press limited, Red Crescent building, 114, Motijheel C/A, Dhaka.