ID: WRE 036

APPLICATION OF 1D MODEL TOWARDS ESTABLISHING FLOW PATTERNS FOR THE SOUTHWEST COASTAL REGIONS OF BANGLADESH

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ABSTRACT

Around one-fourth of the population of Bangladesh live in coastal regions where water plays an important role in socio-economic and livelihood developments. The southwest region is known as the zone of vulnerabilities because the combination of natural and man-made hazards, such as, storm surge, cyclones, floods, water logging, water and soil salinity, risks from climate change, etc., have adversely affected lives and livelihoods of the region. It is necessary to conduct biophysical modelling to understand the underlying processes, which lead towards assessment of coastal vulnerabilities. Hydrodynamic modelling is used to assist quantifying the flows, sediment and salt loads carried by the coastal river systems. To simulate numerical hydrodynamic models, discharge data at the lateral boundaries of the model domain is required. Nevertheless, discharge measurement station in the coastal region is not available. The only available hydrologic data are water level stations data measured by Bangladesh Water Development Board. Therefore, HEC-RAS is very important for generating discharge data of the coastal rivers. HEC-RAS is designed to perform 1D hydraulic calculation. With a geo-referenced modelling of river channel networks, it can be used for assessing the river flow. In this regards, this study has made an attempt to establish a real river network of the southwest region of Bangladesh using 1D model HEC-RAS for flow analysis.Coefficient of determination (R2) between observed and modelled water level has been found as 0.98, 0.97,0.99,0.85,0.84,0.61,0.92 and 0.88 at Kamarkhali, Goalunda Transit, Gorai Railway Bridge, Mawa, Bagerhat, Kabirajpur, Gournadi and Khulna respectively. However, except three locations, NSE for all locations have been found greater than 0.5 that indicate simulated water level are close to observed mean. Another statistical parameter (RMSE) has been analyzed to find the error between simulated and observed water level. Most of the stations have shown good result according to this statistical parameter.

Keywords: Hydrodynamic Model, Flood Simulation, HEC-RAS, Nash Sutcliffe Efficiency, Coastal Region.

INTRODUCTION

Natural and man-made hazards, such as, storm surge, cyclones, floods, erosion, high arsenic content in groundwater, water logging, earthquake, water and soil salinity, various forms of pollution, risks from climate change, etc., have adversely affected lives and livelihoods of the south west region of Bangladesh, where one-fourth of the population of this country reside. Water, in this region, plays a significant role in both socio-economic and livelihood developments. The discharge measurement data is unavailable for the stations in the coastal region. Although the water level data is available on those locations which have been measured by BWDB (Bangladesh Water Development Board). The objective is to calibrate the channel roughness coefficient (Manning's 'n' value) for the rivers in this region using 1D hydrodynamic modelling, HEC-RAS. HEC-RAS is an open source software which is user friendly, designed to perform one dimensional hydraulic calculation (HEC-RAS, 2010). HEC-

RAS can be used for assessing the river flow of the coastal zone with a geo-referenced modelling of river channel networks.

Depending upon the variation in channel characteristic along the flow, the channel roughness shows variations along the river. HEC-RAS has been extensively used all over the world to develop hydraulic model by calibrating the channel roughness for different rivers (Patro et al., 2009; Usul and Burak, 2006; Vijay et al., 2007 and Lal,1995). Single channel roughness value, using optimization method, has been estimated for open channel flow by taking the boundary condition as constraints (Ramesh et al., 1997). Channel roughness has been calibrated for Mahanadi River, India (Parhi et al., 2012) and for Lower Tapi River, India (Timbadiya et al., 2011) using HEC-RAS model. Once calibrated, the model can be utilized for flood inundation mapping and flood forecasting mapping of the southwest region which will enable the concerning authorities to take necessary precautions to save lives and properties therein. It can also be used for coupling with other models which may enable us to understand the other river dynamics involved.

METHODOLOGY AND DATA

The real river networks of the southwest region of Bangladesh have been selected as a study area of this study as shown in Fig. 1. The major rivers of this region are the Ganges, the Padma and the Lower Meghna and others river are the Arialkhan, the Gorai, the Kaliganga, the Chandana, the Kumar, the Sitalakhya, the Madhumati, the Bhairab, the Pussur, the Bishkhali, the Tentulia, the Baleswar and the Burishwar etc. Firstly, the whole river networks of southwest region have been digitized in the Google Earth software. The river networks that are obtained as KML files from the Google Earth, have been converted into shape files using the ArcGIS software. The river name, reach and junctions have been assigned along the south-west river network using HEC-GeoRAS extension. The corrected networks have been imported in HEC-RAS software. In HEC-RAS, data of all the cross sections which have been collected from BWDB (Bangladesh Water Development Board) have been set up for the whole river network of the southwest region.

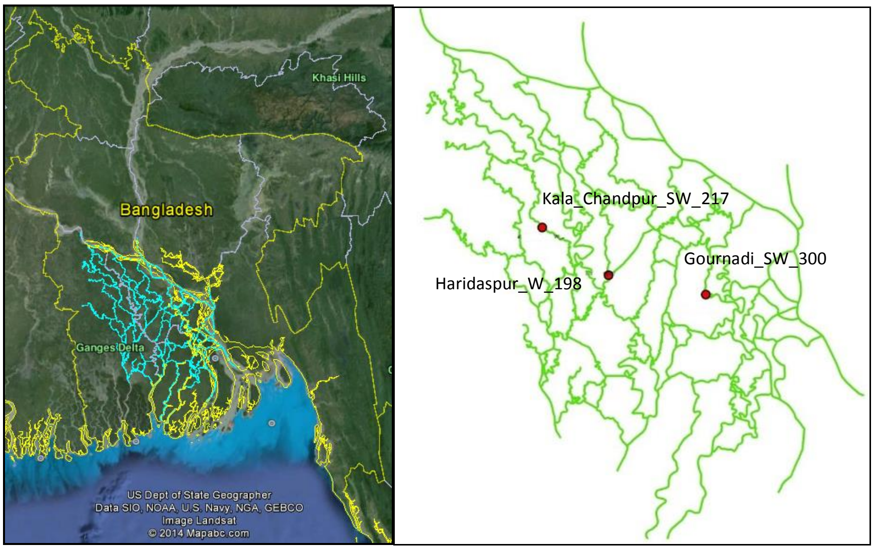

Figure 1: The southwest river network of Bangladesh (left side) and Three gauge station used for calibration (right side)

Boundary conditions are applied to define the inflows and outflows at the model boundary. Boundary fluxes are expressed in terms of mass and momentum exchanges. For hydrodynamic modeling, the boundary conditions are commonly specified at inflow and outflow elements of the model domain. Numerically, three types of boundary conditions are identified: Dirichlet condition (specified head boundary), Neumann condition (specified flow boundary), and Cauchy condition (head-dependent flow boundary). The Cauchy boundary condition that is also called mixed boundary condition relates heads to flows at the outflow elements. The flow is computed based on the difference between specified heads outside the model domain as supplied by the user, and the computed heads at the boundary elements (Alemseged and Rientjes, 2007).The boundary condition of the HEC-RAS model has been established from the observed upstream discharge data obtained from Hardinge Bridge station at the Ganges, the Bahadurabad station at the Jamuna, and Bhairab Bazar station at the Upper Meghna have been selected as flow hydrograph data and water level data obtained from Shahabaz, Tentulia, Buriswar, Bishkhali, Baleswar and Mongla stations have been selected as stage hydrography. The data concerning the floods for years 1998 have been used for calibration of Manning's roughness coefficient, "n".Three gauging stations, Kala Chandpur, Haridaspur and Gournadi have been chosen to perform the calibration of roughness coefficient (Manning's "n") of the corresponding channels. The stations have been pointed out in figure 1. Finally, the model has been simulated for six-month hydrograph and as an unsteady flow and four months has been used as warm period which is necessary to stabilize model.

Model Description

In the present study, unsteady, gradually varied flow simulation model i.e. HEC-RAS, which is dependent on finite difference solutions of the Saint-Venant equations (Equations (1)-(2)), has been used to simulate the flood in the South West river network of Bangladesh.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA\frac{\partial H}{\partial x} + gA\left(S_0 - S_f\right) = 0 \tag{2}$$

Here A = cross-sectional area normal to the flow; Q =discharge; g = acceleration due to gravity; H = elevation of the water surface above a specified datum, also called stage; S_0 = bed slope; Sf = energy slope; t = temporal coordinate and x = longitudinal coordinate. Equations (1) and (2) are solved using the well known four-point implicit box finite difference scheme (HEC-RAS, 2010). This numerical scheme has been shown to be completely non dissipative but marginally stable when run in a semi-implicit form, which corresponds to weighting factor (θ) of 0.6 for the unsteady flow simulation. In HEC-RAS, a default θ is 1, however, it allows the users to specify any value between 0.6 to 1. The box finite difference scheme is limited to its ability to handle transitions between subcritical and supercritical flow, since a different solution algorithm is required for different flow conditions. The said limitation is overcome in HEC-RAS by employing a mixed-flow routine to patch solution in sub reaches (HEC-RAS, 2010).

RESULT AND DISCUSSION

In the present study, an effort has been made to calibrate the HEC-RAS model through setting Manning's roughness coefficient ('n')_ for as a single value for each channel in the network using aforesaid data. Subsequently, different 'n' values have been chosen for each network to justify their adequacy for simulation of flood in the river reaches. Model has been calibrated for floods of year 1998. Nash and Sutcliffe Efficiency (NSE) test has been used for comparison of simulated flow hydrograph with the observed flow hydrograph for various Manning's "n" as used by Moriasi et al., 2007. Cofficient of determination(R^2) describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al.,2001). R^2 have been yielded ranging from 0.6 to 0.9 which are acceptable. Table 1 presents a summary of the statistical parameters used in this study.

Table 1: Statistical parameter of the model.

Statistical parameter	Coefficient of Determination (R^2)
Locations	Model evulation(1998)
Gouranadi Station	0.79
Haridaspur Station	0.89
Kala Chandpur Station	0.75

The comparison between observed and simulated stage hydrograph at Haridaspur,Gournadiand Kala Chandpur gauging stations for the flood year 1998 is shown in Fig.3. Visual interpretation from all hydrograph shows that peak flow of simulated discharge are overestimated the observed discharge. But the pattern of simulated hydrograph at all locations are similar to the observed pattern. Both Haridaspur and Kala Chandpur stations have shown higher stage than observed during pre-monsoon although Gournadi station represents quite close to the observed stage. From June to mid September, the difference of simulated stage and observed stage is maintained by one meter at Haridaspur station, 0.02m at Gournadi station and 0.3m at Kala Chandpur station. After moonson period, the stage difference between simulated and observed at Haridaspur are higher than at Gournadi and Kala Chandpur stations. After setting model and modifing the Mannings "n" value, the model still have shown bias because the datum of cross-sections are not correct in many locations. Moreover, many cross section of the southwest are not updated according to the present bathymetry of the river.

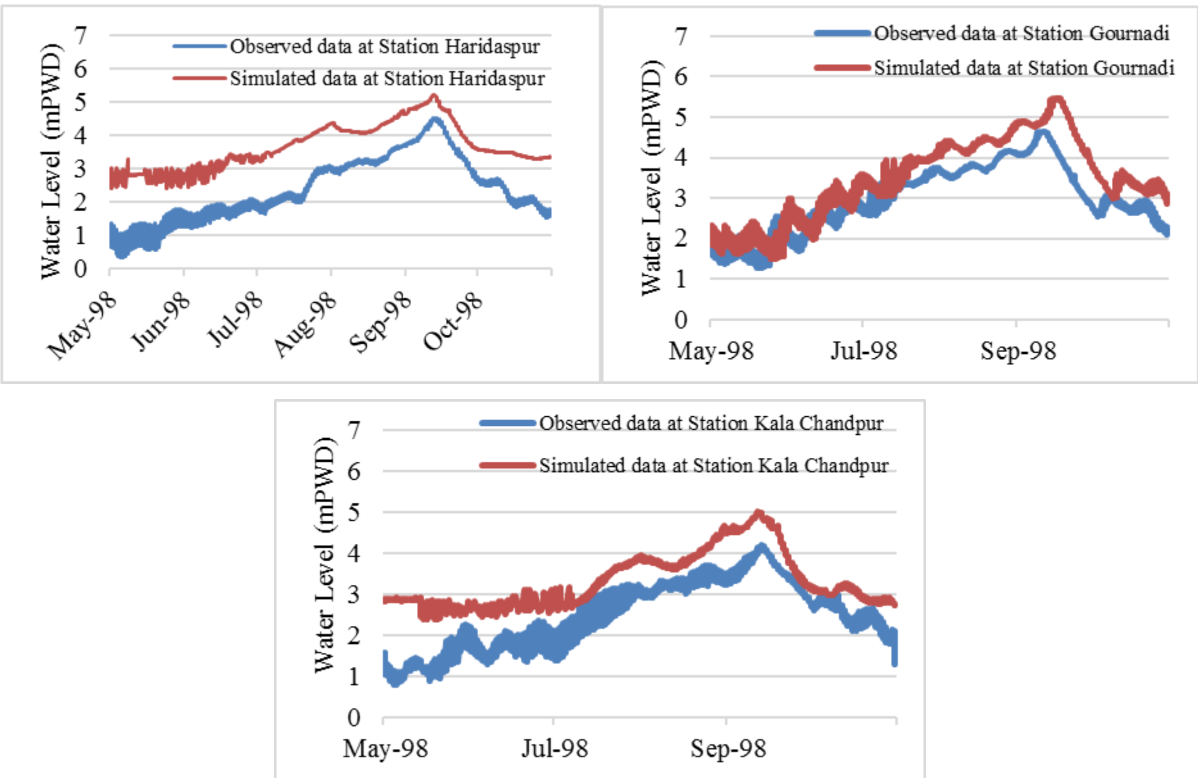

Figure 3: Observed and simulated stage hydrograph at Haridaspur,Gournadi and Kala Chandpur stations.

CONCLUSION

1D model for South-west region of Bangladesh is very important for flood mapping and coupling with 2D costal model. So, to set up and calibrate model is first step for futre impacr study. On the basis of simulation carried out for the river network on the southwest region of Bangladesh following findings can be summarized:

1. Manning's roughness co-efficient of 0.02 can provide better calibration for the rivers..

2. Performance of calibrated and validated model has been assessed through determining the coefficients of determination (R^2) between simulated and observed water level. A close agreement is seen between the simulated and observed water level at station Haridaspur, Gournadi and Kala Chandpur.

3. There needs further modification of the datum of the cross-sections due to subsidence occured in the southwest coastal belt.

ACKNOWLEDGMENTS

This research leading to these results has received from the collaborative project "High-End cLimate Impacts and eXtremes (HELIX)" implemented by Bangladesh University of Engineering and Technology (BUET) and the Exeter University, UK funded by European Union.

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