A STUDY ON HYDRODYNAMIC AND SHORT TERM FLASH FLOOD ANALYSIS OF SURMA RIVER USING DELFT3D MODEL

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ABSTRACT

Surma is a mountainous river, originating at Manipur hills of India enters Bangladesh through Sylhet district. Due to its location near the foothills of Himalaya, this region has a large rate of precipitation. As a result, the river causes frequent flash flood during early monsoon causing a significant change in peak flow. Being sudden and violent in nature, flash flood causes massive destruction in the agricultural productions, transports, navigations and valuable properties. This concerns for a better understanding of Surma River and its flash Flood. The selected reach is almost 85km and spans from Surma Transit at u/s to Sunamganj at d/s. Different hydrodynamic characteristics such as variation in water level, velocity, discharge and flash flood analysis due to peak flow change at the Chhatak transit for the year 2000 are assessed. The result output shows, maximum water level and discharge of Surma River is obtained during the monsoon. The velocity is also high during this period. During the winter, discharge and velocity are almost zero. Flash Flood analysis of Surma River shows rapid change in water level and flow during the month of April, 2000 with respect to flood level. Due to its development on a short time, the changes in water level and discharge will show its devastating impact. Overall, Hydrodynamic analysis will help to understand the characteristics and features of Surma River and Flash Flood analysis will shows its development and occurrence period in Surma River along with impacts.

Keywords: *Characteristics, surma river, delft3d, hydrodynamic*

1. INTRODUCTION

Surma is a trans-boundary, Meandering and Perennial River. The Barak River being originated at Manipur hills of India, enters Bangladesh through hilly regions of Sylhet as Surma River at the North-East Region (Alam, 2007). Due to its location near foothills of Himalayas, this region has a large rate of precipitation. During early monsoon, heavy precipitation water channeling through streams or narrow gullies causes congestion. As a result, frequent Flash flood occurs within a very short time causing a significant change in peak flow (Jong, 2004). As flash flood is sudden and violent, Surma River has developed a lot of devastating flash floods causing major problems. Sudden occurrences of Flash Flood always cause massive destruction of croplands. Usually after heavy downpour, flash flood overflows banks with restrictions in transport and navigations. It also has a devastating impact as it takes only minutes or hours to develop, even sometimes comes without any warning. Flash flood may carry sediments with big sized stones, boulders along river channels changing size, shape and location of the channel. As a result, Sedimentation may occur as high as 4-5 m, creating serious obstructions for water flow navigation in the north eastern region (BWDB, 2014). So, regular Hydrodynamic and Flash Flood analyses of these rivers are crying need of the day. For this reason, a research on Hydrodynamic and Flash flood analyses of Surma River are performed in this thesis. The paper covers different Hydrodynamic characteristics and features of Surma River and as well as also Flash Flood analysis for a better understanding to this prospect.

The Specific Objectives of the Study are:

- ✓ To Setup a Surma River model using Delft3D for a length of 85Km.
- ✓ To perform Calibration and Validation of the river model.
- ✓ To perform a Short term analysis on Peak Flow change due to Flash flood.

2. THEORY AND METHODOLOGY

The solution to a hydrodynamic problem typically involves calculating various properties of the fluid, such as flow velocity, discharge, pressure, density, and temperature, as functions of space and time (Sarfaraz, 2013).

Hydrodynamic study is based on a number of equations. These are shortly described below from User Manuals Delft Hydraulics, 2005a:

4.1 Momentum Equation

The equations of fluid motion expressing conservation of mass (baryon number), Momentum, and energy are called the Euler equations.Using the mass conservation equation, the momentum conservation equation is often written in the form of the Euler equation,

$$\frac{\partial v}{\partial t} + (v.\nabla)\, v = -\frac{1}{\rho} \nabla P - g \tag{1}$$

Where, $\frac{\partial v}{\partial t} + (v.\nabla)\, v$ is the co-moving time derivative of the velocity vector with respect to time.

4.2 Viscosity: Navier-Stokes

The introduction of a viscosity term, which converts macroscopic motion in the velocity field v into microscopic motion (internal energy), is due to Navier and Stokes, so this form of the equations is named for them.
Momentum with viscosity terms, in tensor form (Landau & Lifshitz - 1959),

$$\rho\left(\frac{\partial v_i}{\partial t} + v_k \frac{\partial v_i}{\partial x_k}\right) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_k}\left\{\eta\left(\frac{\partial v_i}{\partial x_k} + \frac{\partial v_k vk}{\partial x_i} - \frac{2}{3}\delta_{ik}\frac{\partial v_l}{\partial x_l}\right)\right\} + \frac{\partial}{\partial x_i}\left(\zeta \frac{\partial v_l}{\partial x_l}\right) \tag{2}$$

Writing Equation (3.5) in a vector form,

$$\rho\left[\frac{\partial v}{\partial t} + (v.\nabla)v\right] = -\nabla P + \eta\nabla^2 v + \left(\zeta + \frac{1}{3}\eta\right)\nabla(\nabla.v) \tag{3}$$

4.3 Equation of Continuity

The equation of continuity is,

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0 \tag{4}$$

4.4 Flash Flood

A flash flood is a rapid flooding of geomorphic low-lying areas: washes, rivers, dry lakes and basins. It may be caused by heavy rain associated with a severe thunderstorm, hurricane, tropical storm, or melt water from ice or snow flowing over ice sheets or snowfields. Flash floods may occur after the collapse of a natural ice or debris dam, or a human structure such as a man-made dam. Flash floods are distinguished from a regular flood by a timescale of less than six hours (BWDB, 2014).

3. METHODOLOGY

According to user Manual delft3D-quickin 2005b, major portion of this research work is accomplished with Delft3D. But before that, it requires no of works to pre-process data. For Surma River, water level, discharge and cross-section data are collected and analysed. Then using cross-sections, a bathymetry is developed in Delft3D. Then a model is simulated using discharge data at u/s and water level at d/s in Delft3D. After calibration and validation, model was ready for a hydrodynamic analysis. Finally, a flash flood analysis is performed based on curves developed using water level and discharge data.

3.1 Study Area Selection

Study area has been selected as Surma River for reach length of 85km and spans from Sylhet transit at the upstream and Sunamganj at the downstream. The observation area selected for the study is Chhatak area (Figure 1).

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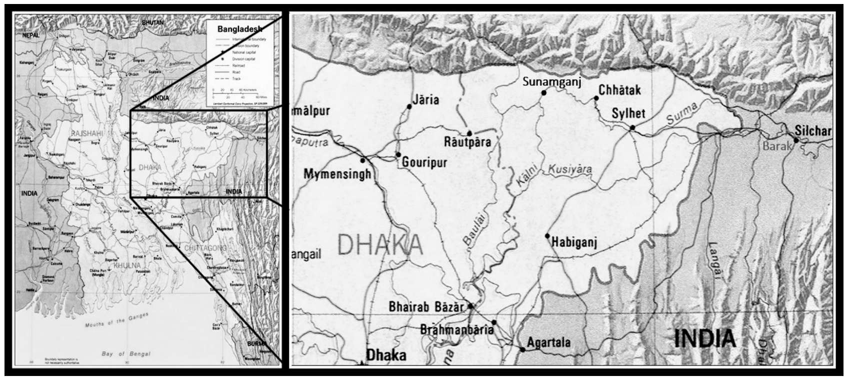


Figure 1: Location of Surma River (Wikipedia Surma River)

3.2 Data Collection

To setup a Hydrodynamic model, we need WL, cross-section and discharge data. We collected all these necessary data of Surma River for different time period and stations. Data collected for the setup of hydrodynamic model of Surma River are shown in Table 1.

Table 1: Data Collection

DATA	LOCATION	PERIOD	SOURCE
Bathymetry	Station ID: RMS-1 to RMS-20	2000	WARPO
U/S discharge	Sylhet (SW-267)	2000	WARPO
Water Level	Sunamganj (SW-269)	2000	WARPO

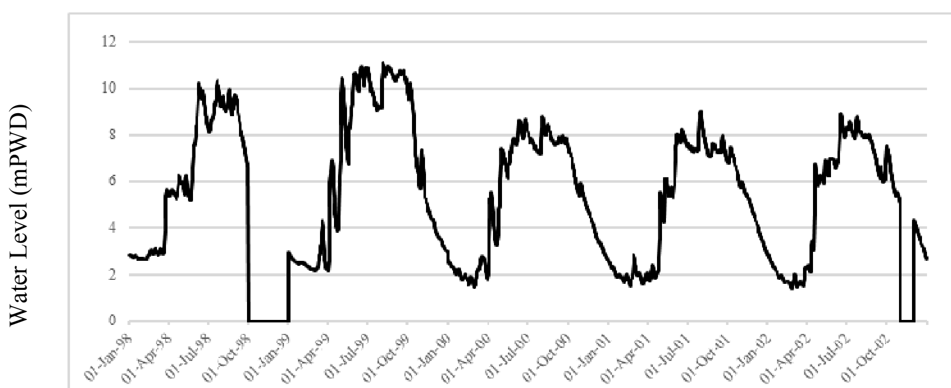
A shape file along latitude-longitude of Cross-sections in BTM is also collected from WARPO. The time period of data selected for model is 2000. The area of study ranges from Sylhet (SW-267) at U/S to Sunamganj (SW-269) at D/S, a reach length of 85Km. Model observations are performed at Chhatak (SW-268).

3.3 Data Analysis

Graphs of Water Level and Discharge data are plotted versus Time for different years and for the selected year of research. These graphs help to understand the data over past years and also helps in selecting the year of research.

3.3.1 Water Level Graphs

Observed data is plotted in graph as Water Level vs Time for years 1998 to 2002.



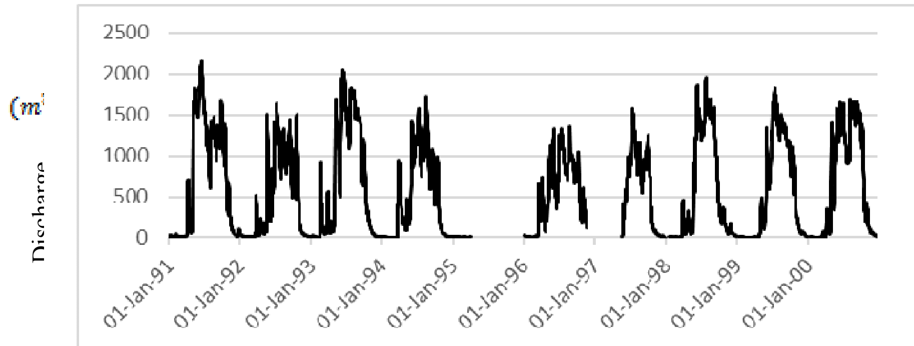
Time Series (01-Jan-1998 to 31-Dec-2002)

Figure 2: Water Level vs Time (1998 to 2002)

Figure 2 shows that, some water level data are missing for few months. During the monsoon period (May-October), water Level is as high as 11m. During the winter (November-February), water Level is very low and below 1m. Water level of year 2000 is selected for the development of Hydrodynamic model of Surma Rivers.

3.3.2 Discharge Graphs

Observed data is plotted in graph as Discharge vs Time for years 1991 to 2000.



Time Series (01-Jan-91 to 19-Dec-2000)

Figure 3: Discharge vs Time (1991 to 2000)

Figure 3 shows that, some discharge data are missing for few months. During the monsoon period (May-October), peak flow occurs and is almost 2000 m^3/s. During the winter (November-February), flow is almost zero. Discharge of year 2000 is selected for the development of Hydrodynamic model of Surma Rivers.

3.3.3 Data Selection

After graphical analysis of water level and discharge data against time, data for model simulation are selected. Selected data for Hydrodynamic modeling are shown in Table 2:

Table 2: Data Selection

TYPE OF DATA	PERIOD
Data for Calibration	1 May, 2000 to 31 May, 2000
Data for Validation	1 May, 2001 to 31 May, 2001
Data for Model Simulation	1 Jan, 2000 to 31 Dec, 2000
Data for Flash Flood Analysis	1 Mar, 2000 to 31 May, 2000

3.3.4 Preparation of XYZ Input File

At first, the shape file of cross-section stations with BTM co-ordinates are added in ArcGIS. Left and right banks are drawn with shape files to find left and right bank co-ordinates in ArcGIS. Left and right bank stations for each cross-section are joined and interpolated with distance from cross-section data in ArcGIS using xtools pro. Latitude and Longitude in BTM co-ordinates and River Level data are exported to Excel as XYZ values for three files as left bank, right Bank and cross-sections. XYZ values from excel are copied to text file and saved as xyz file type, also known as delft3D input file.

3.4 Bathymetry Setup

Bathymetry is a setup to provide underwater depth of the river bed. A well simulation of model largely depends on the accuracy of the bathymetry setup.

3.4.1 Land boundary Setup

In Delft3D GRID, left bank, right bank and cross-sections xyz files are imported as sample files in QUICKIN of Delft3D. Selecting Polygon in QUICKIN, boundary Lines are drawn along the left & right Banks stations. The boundary lines drawn in model are then exported to save the Land boundary file (Figure 4).

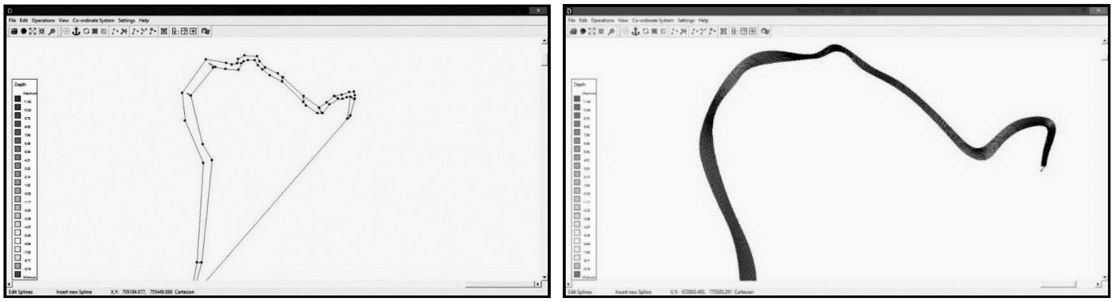


Figure 4: Land boundary Setup and Grid Formation

3.4.2 Grid Setup

Importing Land boundary in RGFGRID, splines are drawn along boundary lines and across cross-sections. After balanced spline formation, splines are converted to grid. Depending on shape of the river reach and grid formed, refinement factors M and N are provided. Grid is refined few times to form a smooth grid all over the river reach. Grids are orthogonalised for few times for well-functioning of model and better grid formation in square shape. A triangular interpolation is performed to fill the missing values of model with interpolated values in the grid.

3.4.3 Depth file setup

Internal diffusion and Smoothing is performed several times to ensure smoothness of the bathymetry. Missing depth values in the grid are filled with a known average depth 999. Then, the depth file is exported as bathymetry.

3.5 Flow Model Setup

Flow model setup completes the simulation of the model and will find simulated data of the specified time period.

3.5.1 Initial Conditions setup

Model name and necessary descriptions are provided in the FLOW input. Grid file with its enclosure, previously prepared in the bathymetry, is opened in the Grid parameter and Depth file is also opened in the Bathymetry of DOMAIN. Reference date, Simulation start-stop time are provided with specified format in the TIME FRAME.
Time Step for data analysis is also provided along with local time zone in GMT. Initial water level for the observed area is provided in INITIAL CONDITIONS from the observed data.

3.5.2 Boundary Conditions

Upstream and downstream cross-sections are selected from the visualization area in BOUNDARIES. Total discharge at the U/S and water level at the D/S with time series is selected and saved as bnd & bct file. Discharge and water level data are provided editing the bct file in the notepad.

3.5.3 Model Simulation

Constants, Roughness and viscosity values are provided here. Manning's n is selected as 0.025 for this model. Observation points are selected over the study area for data comparisons and calibration.

Table 3: Hydrodynamic parameters

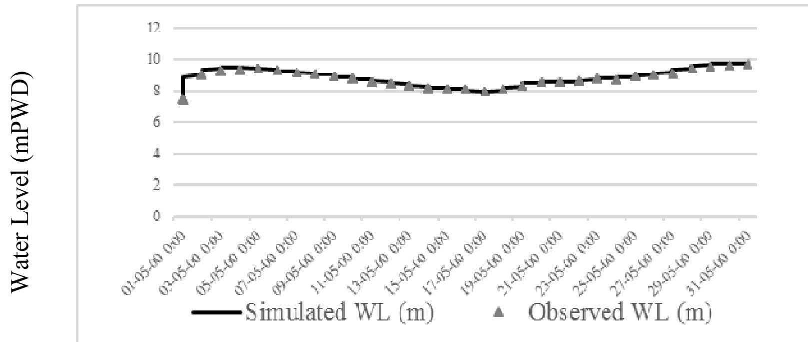
Physical Parameters	Value
Gravity	9.81 m/s^2
Water density	1000 kg/m^3
Roughness, n	0.025
Horizontal eddy viscosity	1 m^2/s

Time series for study output is provided in this step. Then, the model is simulated with START.

4. RESULTS AND DISCUSSIONS

4.1 Calibration Results

Calibration shows acceptance of simulated model confirming similar data is produced by the model as in real life. After complete model simulation, simulated results are stored in trih-Surma.dat. It shows Waterlevel data for different observation points and our observation station is Chhatak (SW 268) for calibration. We set SI unit and file type as CSV. Then we export WL of simulated data to a Excel file. Actual observed data for Chhatak (SW 268) is also imported in Excel file. A graph is generated which shows comparison between the observed and simulated data. We accept the model calibration as both graphs generated are almost same (Figure 5).

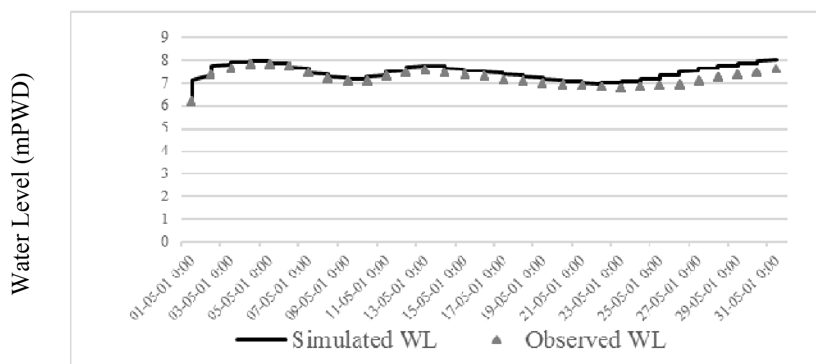


Time Series (01-May-00 to 31-May-2000)

Figure 5: Calibrated Water Level vs Time Graph

4.2 Validation Results

Validation shows the acceptance of simulated model also for different time periods. Validation of our model is performed by comparing graphs of Waterlevel vs Time for the simulated model and actual data for May, 2001. For validation, a new time period is selected, in our study it is May, 2001. Discharge at upstream and WL at downstream for the time period specified is provided and a new model is simulated. After model simulated, WL data are extracted from QUICKIN as a csv file for Chhatak station (SW 268). Actual Observed data of Chhatak (SW 268) for the time period May, 2001 are also collected and inserted in Excel file. After both observed and simulated WL data of Chhatak (SW 268) for May, 2001 are collected, Water Level vs Time graphs are generated for both the case. Validation is accepted when both the graphs generated are almost same (Figure 6).



Time Series (01-May-00 to 31-May-2000)

Figure 6: Validated Water Level vs Time Graph

4.3 Hydrodynamic Analysis and Results

Hydrodynamic analysis deals with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them. After calibration and validation of WL data, model is prepared for year 2000. Accordingly, discharge data at U/S Sylhet (SW 267) and water level data at D/S Sunamganj (SW 269) are selected for year 2000. After all input, model is simulated again for analysis of full year 2000. After model simulation, simulated results stored in trih-surma.dat file is opened in QUICKIN. Simulated results for Station

Chhatak (SW 268) are generated for water level, depth avg. velocity and depth avg. acceleration. All data generated are exported as csv file to store in Excel.

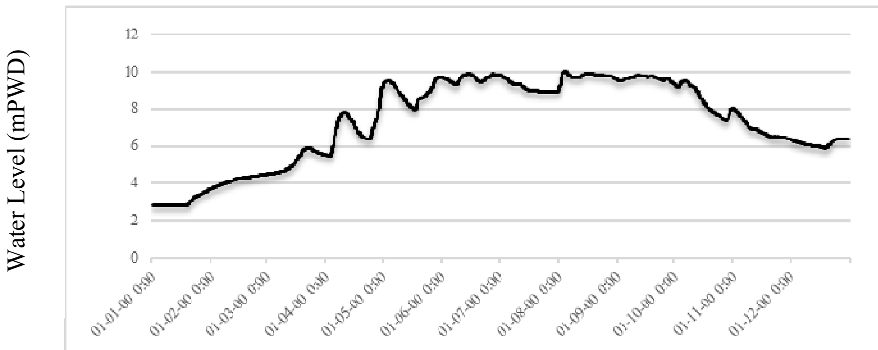
4.3.1 Water level results

The results obtained from model simulation for water level are analyzed in excel as following outputs in Table 4:

Table 4: Water level Results

Type	Maximum (mPWD)	Minimum (mPWD)	Average (mPWD)
Water Level	10	2.8	7.34

From simulated results, a graph of Water Level in mPWD against Time for year 2000 is plotted.



Time Series (01-Jan-00 to 31-Dec-2000)

Figure 7: Simulated WL vs Time (2000)

Figure 7 graph shows change of WL in Chhatak Station (SW 268) for year 2000. Graph shows WL is high during the month of June to August. Maximum WL is as high as 10 mPWD. WL is Low during the month of November to January. Minimum WL is as low as 2.8 mPWD.

4.3.2 Velocity Results

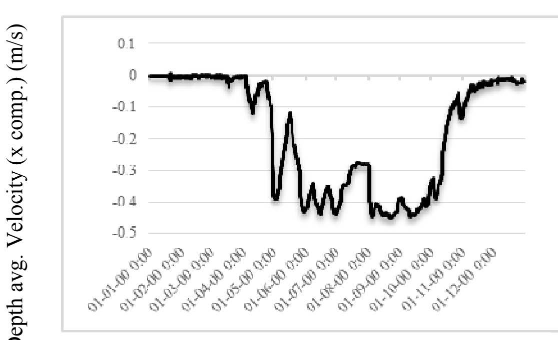
The results obtained from model simulation for velocity are analyzed in excel as outputs in Table 5:

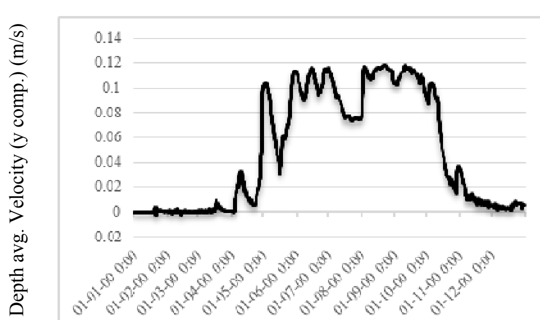
Table 5: Velocity Results

Type	Maximum (m/s)	Minimum (m/s)	Average (m/s)
x-component Depth average Velocity	0.01	-0.45	-0.18
y-component Depth average Velocity	0.12	0	0.05
Depth average Velocity	0.46	0	0.19

4.3.3 Depth averaged Velocity Graphs

Graphs of x and y components of depth average velocity in m/s against Time for year 2000 is plotted from simulated results.



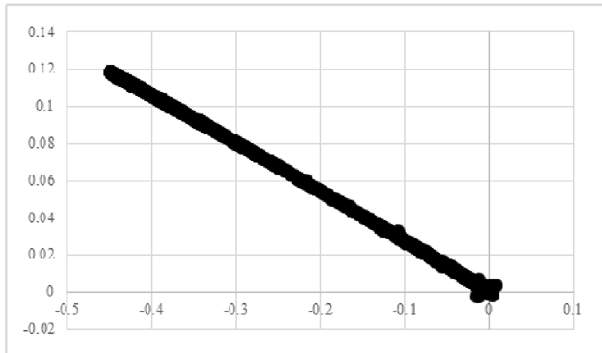


Time Series (01-Jan-00 to 31-Dec-2000)

Time Series (01-Jan-00 to 31-Dec-2000)

Figure 8: Depth Average Velocity vs Time

Depth avg. Velocity (y comp.) (m/s)



Depth avg. Velocity (x component) (m/s)

Figure 9: Depth avg. Velocity (y component) vs Depth avg. Velocity (x component)

4.3.4 Observations

Figure 8a shows change of depth average velocity (x comp.) against time in the horizontal direction of flow. Velocity over the time is zero initially then it rapidly decreases at April. It continuously remains negative during April to September. During October it rapidly increases again to become zero. So, velocity in x-direction is minimum during monsoon as -0.44 m/s. Velocity is maximum again during winter and almost equals to zero.

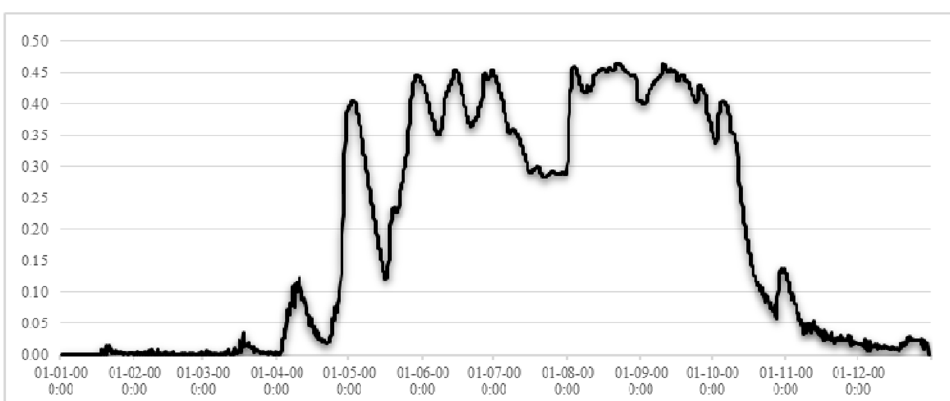
Figure 8b shows change of depth average velocity (y comp.) against time in the vertical direction of flow. Velocity is high during April to September. During t October it decreases again to become zero. So, velocity in y-direction is maximum during the monsoon as 0.12 m/s. Velocity is minimum during the winter and almost equals to zero.

Figure 9 shows change of depth average velocity in the vertical direction against horizontal direction of flow. Graph shows that the decrease in x component of depth average velocity causes increase in the y component of depth average velocity. Graph shows at initial condition, both x and y component of velocity is zero. For minimum value of x component of depth average velocity as -0.44 m/s, the maximum value of y component of depth average velocity as 0.12 m/s.

4.3.5 Average Velocity vs Time

A graph of average velocity in m/s against Time for year 2000 is plotted from simulated results.

Avg. Velocity (m/s)



Time Series (01-Jan-00 to 31-Dec-2000)

Figure 10: Average Velocity vs Time

4.3.6 Observations

Figure 10 shows change of average velocity against time in direction of flow. Avg. velocity over time period is zero initially then it rapidly increases at the month of April. It continuously remains high during the period of April to September. During October it rapidly decreases again to become zero. So, Avg. velocity in y-direction is as high as 0.46 m/s during Monsoon. Average velocity is minimum during the winter and almost equals to zero.

4.3.7 Discharge Results

The results obtained from model simulation for velocity is analyzed in excel as outputs in Table 6:

Table 6: Discharge Results

Type	Maximum (m^3/s)	Minimum (m^3/s)	Average (m^3/s)
x-component Depth average Discharge	1.45	-169.9	-66.3
y-component Depth average Discharge	56.22	-2.37	22.5
Depth average Discharge	178.9	0	70.1
Instantaneous Discharge	1675	0	637

4.3.8 Depth averaged Discharge (x component) vs Time

A graph of x component of depth average discharge in m^3/s against Time for year 2000 is plotted from simulated results.

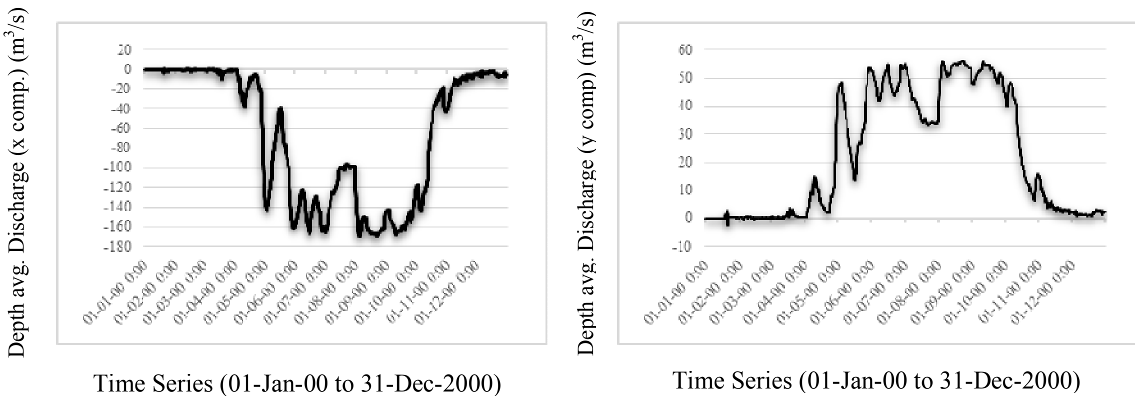


Figure 11: Depth averaged Discharge vs Time

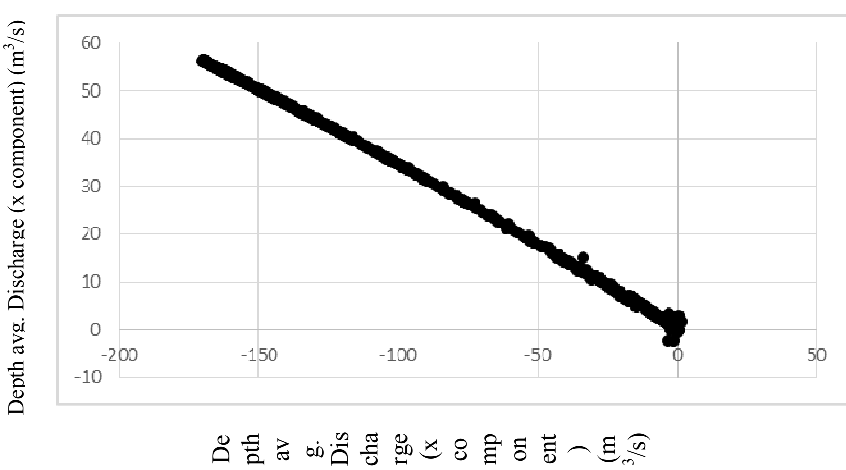


Figure 12: Depth avg. Discharge (y component) vs Depth avg. Discharge (x component)

4.3.9 Observations

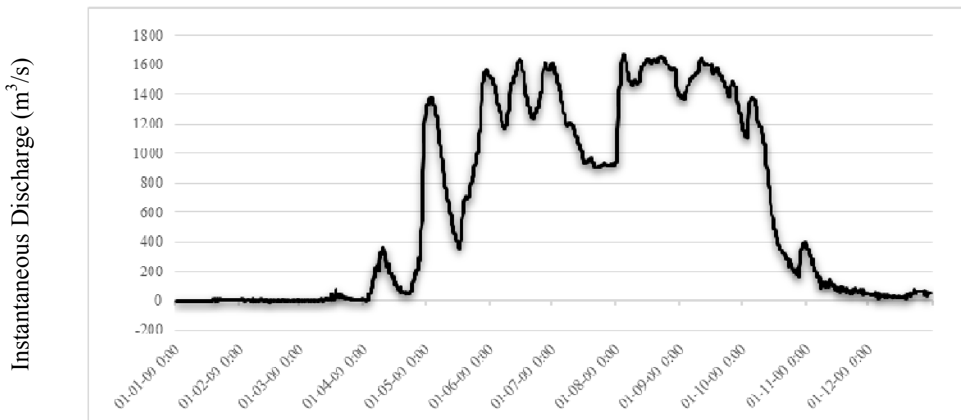
Figure 11a shows change of depth average discharge against time in the horizontal direction of flow. Depth average discharge over the time period is zero initially then it rapidly decreases at the month of April. It continuously remains negative during the period of April to September. During the month of October it rapidly increases again to become zero. So, depth average discharge in x-direction is minimum during the monsoon and is as low as -170 m^3/s. Depth average velocity is maximum in x-direction during the winter and almost equals to zero.

Figure 11b shows change of depth average discharge against time in the vertical direction of flow. Depth average discharge over the time period is zero initially then it rapidly increase at the month of April. It continuously remains high during the period of April to September. During the month of October it rapidly decreases again to become zero. So, depth average discharge in y-direction is maximum during the monsoon and is as high as 56 m^3/s. Depth average discharge is minimum in y-direction during the winter and almost equals to zero.

Figure 12 shows change of depth average discharge in the vertical direction against horizontal direction of flow. Graph shows that the decrease in x component of depth average discharge causes increase in the y component of depth average discharge. Graph shows at initial condition, both x and y component of discharge is zero. For minimum value of x component of depth average discharge as -170 m^3/s, the maximum value of y component of depth average velocity as 56 m^3/s.

4.3.10 Hydrograph (2000)

A graph of instantaneous discharge in m^3/s against Time for year 2000 is plotted from simulated results for developing a hydrograph.



Time Series (01-Jan-00 to 31-Dec-2000)

Figure 13: Hydrograph (2000)

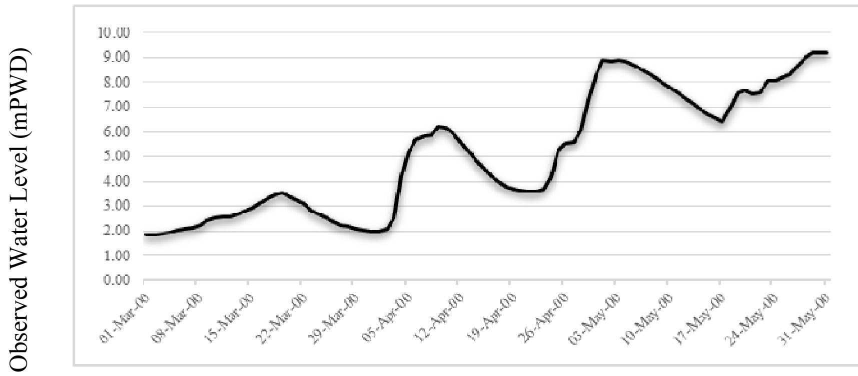
4.3.11 Observations

Figure 13 shows change of instantaneous discharge against time in the direction of flow. Instantaneous discharge over the time period is zero initially then it rapidly increase at the month of April. It continuously remains high during the period of April to September. During the month of October it rapidly decreases again to become zero. So, instantaneous discharge is maximum during the monsoon and is as high as 1657 m^3/s. Instantaneous discharge is minimum in during the winter and almost equals to zero.

4.4 Flash Flood Analysis Results

4.4.1 Water level vs Time (Mar to May 2000)

From simulated results, a graph of Water Level in mPWD against Time for Mar-May 2000 is plotted.



Time Series (01-Mar-00 to 31-Map-2000)

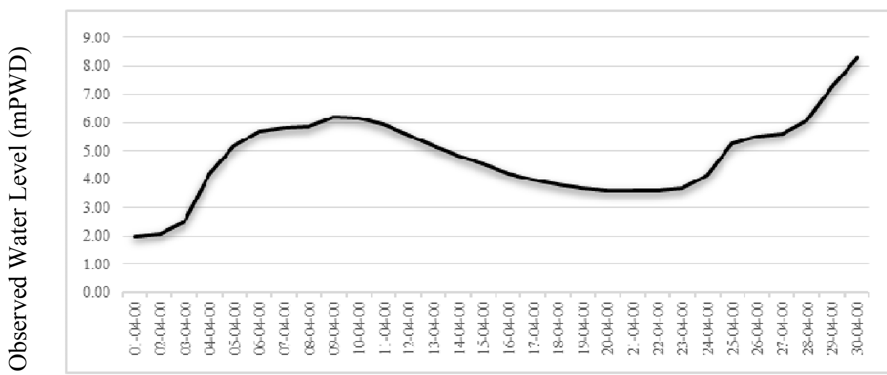
Figure 14: Water level vs Time (Mar to May 2000)

4.4.2 Observations

Figure 14 shows change of WL for the month of Mar to May 2000. Graph shows WL rises rapidly during the month of April. In April, 1st water level rise is from 2.1m to 5.2 m and 2nd water level rise is from 3.7 m to 8.9 m. During the 1st rise all lakes and reservoir gets filled with water and creates a situation for flash flood. During 2nd rise WL rises upto 8.9 m at Chhatak where danger water level in 7.5m. When such WL rise overcomes danger level within a short time, flash flood occurs.

4.4.3 Water level vs Time (Apr 2000)

From simulated results, a graph of Water Level in mPWD against Time for April 2000 is plotted.



Time Series (01-Apr-00 to 30-Apr-2000)

Figure 15: Water level vs Time (Apr 2000)

4.4.4 Observations

Figure 15 shows change of WL for April 2000. In April, 1st water level rise is from 2.1m at 3 April to 5.2 m at 5 April. 2nd water level rise is from 5.6 m at 27 April to 8.3 m at 29 April. During the 1st rise all lakes and reservoir gets filled with water and during 2nd rise WL rises upto 8.9 m at Chhatak. Danger WL in this region is 7.5 m, so WL rises above such level rapidly during late of April and Flash Flood occurs.

4.4.5 Discharge vs Time (Apr 2000)

A graph of instantaneous discharge in m^3/s against Time for April 2000 is plotted from simulated results.

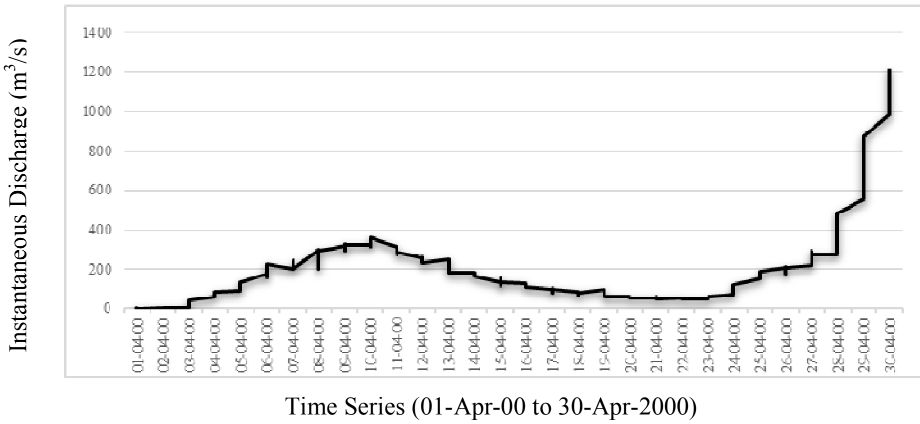


Figure 16: Instantaneous discharge vs Time (Apr 2000)

4.4.6 Observations

Figure 16 shows change of instantaneous discharge against time April 2000. In April, 1st discharge increase is from 4m^3/s at 3 April to 97 m^3/s at 5 April**.** During 2nd rise discharges increases from 221 m^3/s at 27 April to 878 m^3/s. at 29 April**.** During the rise of flow all lakes and reservoir gets filled with water and creates a situation for flash flood. Such rapid increase in discharge in a very short time of 2 days develops flash flood.

5. Conclusions of the Study

The summary of the findings of present study are as follows:

- It is observed that in Surma River, the water level in the Chhatak area rises rapidly during the month of April. Water level remains high during the period of Monsoon from April to September. Water level again decreases rapidly during the month of October and remains low during the period of winter from November to March.
- In this Chhatak area, the depth average flow in the horizontal direction is low during the monsoon and almost zero during the winter period. Again, the depth average flow in the vertical direction is high during the monsoon and almost zero during the winter. So, when the change in horizontal flow is downward graded during the monsoon, the change in vertical flow is upward graded during winter.
- As a whole, the instantaneous discharge in the Surma River at Chhatak area is high during the monsoon period due to heavy precipitation in the area and is low during the winter season. The discharge increases suddenly and rapidly in this area during the month of April and decreases during the month of October.
- The depth average velocity in the horizontal direction is low during the monsoon and almost zero during the winter period. Again, the depth average velocity in the vertical direction is high during the monsoon and almost zero during the winter. As a result, when the change of velocity in horizontal direction is decreasing during the monsoon, the change of velocity in vertical direction is increasing during winter.
- It is observed that, during the month of March to April in the Chhatak area of Surma River water level is upward graded. But the rapid change in water level occurs during the month of April. Within few hours or days, water level rise 2 m to 5 m. Such rapid rise in water level causes flash flood during April.
- The discharge of the river is also upward graded during the month on April in this Chhatak area. The discharge also increases rapidly 100 m^3/s to 500 m^3/s within few hours or days. Such rapid change in discharge happens due to heavy precipitation during the early monsoon.
- Sudden and rapid change in water level and discharge during early April fills all lakes, reservoirs and river with water. As a result, during the late April, any rapid change in water level and discharge causes flash flood in the Chhatak and Sylhet district.
- For a high level of change in water level and discharge in the Surma River, flash flood developed in the Chhatak and Sylhet area causes a devastating impact. Even a flash flood of few meters can destroy a vast croplands, causes disruption in transport and destruction of valuable properties.

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