Effects of Coastal Phenomena on the 1998 Flood

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Abstract

The water level during the 1998 flood was unusually high in the lower Meghna, which is the single outlet for the drainage of flood flow in Bangladesh. Using data generated by a finite element model in two-dimensional space as well as observed tide level data, effects of some coastal phenomena on the flood flow have been studied. The unusual high water level in the lower Meghna was mainly due to obstruction to the very large flood discharge by the unexpectedly large spring tide flow from the opposite direction. The monsoon wind can cause a maximum wind set-up of around 25 cm, which may reduce the velocity of flow by about 29%. The study does not indicate presence of earthquake-generated tsunamis in the coastal region during the 1998 flood.

INTRODUCTION

There was unusually high water level in the Lower Meghna during the 1998 flood. It was remarked in the bulletin of the Flood Forecasting and Warning Center of Bangladesh Water Development Board (BWDB) that there was abnormal tide. A total of 14 tidal gage stations (Fig.1) were considered to investigate the abnormal tidal behavior, if any, which might have been responsible for the unusually high water level at Lower Meghna. Two stations belong to the Mongla Port Authority while the rest to the Bangladesh Inland Water Transport Authority (BIWTA). Besides 1998, data of 1992 and 1988 floods were also used. The flood in 1992 was an average flood while the 1988 flood was second biggest after 1998 flood with respect to magnitude and duration. The expected tidal levels calculated by harmonic analysis were used from the Tide Tables of BIWTA for comparing with observed data. Some results are presented here.

In the months of May, June and August 1998, several earthquakes occurred in the Bay of Bengal close to the Nicobar Island of India (Web Page, USGS), the most severe one occurring near the island (7.329N, 94.277E) on the 10th of August at around 3:50 pm BST with a magnitude of 5.8 in the Richter Scale. The present study investigated if that particular earthquake generated any tsunami and/or had any influence along the coastline of Bangladesh using a two-dimensional hydrodynamic model of water circulation in the Bay of Bengal.

Monsoon wind speed in the Bay of Bengal varies between 5 to 15 m/s. When this monsoon wind blows over the sea surface, apart from the creation of waves (superimposed on the tidal waves), the shear stress at the sea surface causes a rise or surge in water level. Amplitude of surges will only be small in deep water but will become magnified on account of the shoaling effect on entering shallow water. The two-dimensional finite element model has been applied also to study the monsoon wind set-up along the coast of Bangladesh.

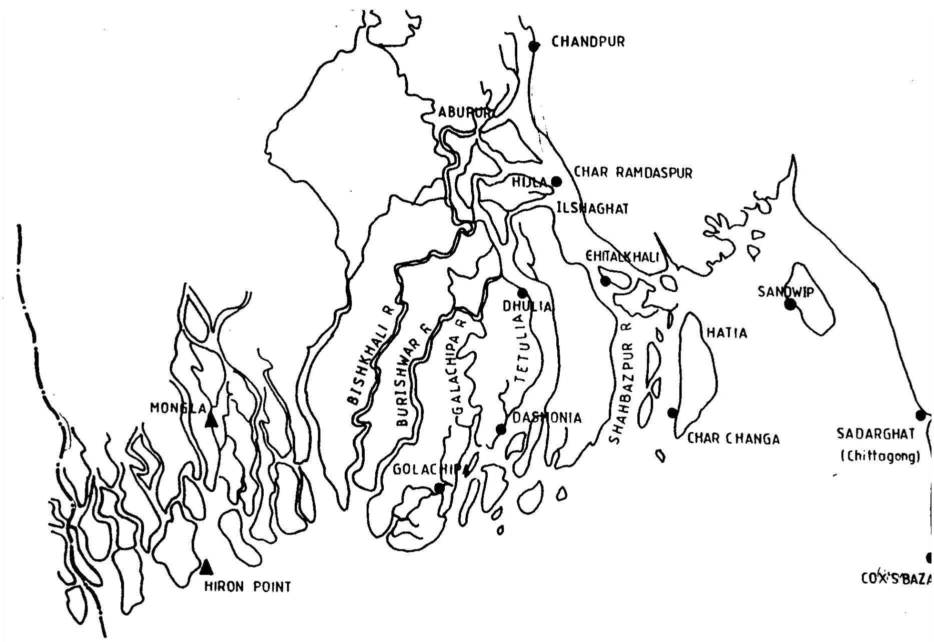

Figure 1: Locations of tidal gage stations

INVESTIGATION OF THE TIDAL BEHAVIOR

Tidal Characteristics

The outlet channels that carry the upland fresh water flow to the Bay of Bengal include Biskhali, Buriswar, Lohalia, Tetulia, Shahbazpur and Hatia channels (Fig.1). The major distributary system includes the Tetulia, the Shahbazpur and the Hatia channels; the Shahbazpur channel being the main flow-carrying river. Tide along the Bangladesh coast originates in the Indian Ocean and approaches the coast of Bangladesh approximately from the south, arriving at the Hiron point and at Cox's Bazar at about the same time. The tide along the coast is semi-diurnal having an average period of 12 hours and 25 minutes. However, funnel shaped coastal geometry and uneven bottom topography results in distortion of tides at some places. The tide has some daily inequality in high water levels varying between 0.0 m and 0.6 m. Spring-neap tide cycle is about a fortnight and during this cycle the tidal period varies because of the phase inequality. There is considerable variation from neap to spring tides. There is also seasonal variation of the mean sea level that has a direct causal effect on the tidal range.

Was There Abnormal Tide?

The water level at Lower Meghna was unusually high (much more than 100-year flood). The question is whether it was due to any abnormal behavior of tides as suggested by the Flood Forecasting and Warning Center of BWDB. A simplified approach was adopted which involved study of hydraulic characteristics along two spatial directions (Fig.2): (i) section 1-3-2 along the coastal belt, and (ii) section 3-4-5 from the river mouth towards upstream in the estuary. Any suspected abnormality in tidal behavior in the estuary must have manifestation of the same along the coastline.

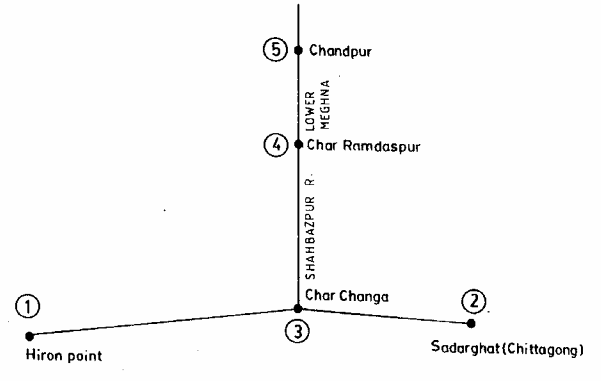

Figure 2: Simplified schematization of tidal network

Figures 3 and 4 show the observed tidal levels along with the expected tidal levels obtained by harmonic analysis along the two selected sections for the month of August of 1998. Evidently, the observed tidal levels matched very well with the expected levels along the coastal belt (Fig.3), whereas the difference between the two got increasingly pronounced upward in the estuary (Fig.4). Similar phenomenon was observed in the months of July and September, and also in the monsoon months of 1992 and 1988 (Haque et al., 1999). The possibility of the presence of any abnormal behavior upstream causing extremely high water level seems to be remote.

The unusually high water level in the Lower Meghna resulted from the interaction between flood waves and spring-neap tidal cycle. The entire flood flow from the upstream drains to the Bay of Bengal through the single outlet of the Lower Meghna. On the other hand, there is an inflow of huge volume of tidal water from opposite direction during rising tide from the Bay of Bengal. The Lower Meghna is the meeting point of upland fresh water flow and tidal flow (Fig.1). During 1998 monsoon, four large flood waves passed Bangladesh in succession, each one coming before the river level could recede. As a result, there was continuous flow of large volume of water for more than two months to the Lower Meghna. This flow was obstructed by the very large spring tides from the opposite direction that resulted in building up of a very large water depth. In other years, the duration of flood wave was short and there was time for recession of flow after a flood or between two flood waves.

INVESTIGATION OF TSUNAMI GENERATION

Physics Behind the Formation of Tsunami

'Tsunami' is a series of waves of extremely long wavelength and long period generated in a body of water by a disturbance, primarily the earthquakes in oceanic and coastal regions. As the tsunami crosses the deep ocean, its length from crest to crest may be hundred kilometers or more, and its height from crest to trough only a few meter or less. They cannot be felt aboard ships nor they can be seen from the air in the open ocean. Upon entering the shoaling water of coastline, the wave velocity diminishes and the wave height increases resulting in building up of a large tsunami exceeding 30 m in height strikes with devastating force.

In the deepest oceans, the tsunami behaves as shallow water waves because of long wave length traveling in speed exceeding several hundred kilometers per hour. The water depth to wave length ratio gets very small and waves move at a speed equal to the square root of the product of the acceleration of gravity and water depth. For example, if the typical water depth is 4000 m, a tsunami travels over a speed of 700 km/hr. A tsunami will lose little energy as it propagates, as the rate at which a wave loses its energy is inversely related to its wavelength. Hence in very deep ocean, a tsunami will travel great distances at high speeds with limited energy loss. As it propagates into the shallower water near the coast, its speed diminishes as the depth of water decreases, but the change of total energy of the tsunami remains constant meaning that the height of the wave grows. Because of this, a tsunami may appear as a series of rapidly rising or falling waves. The terminal wave height will depend on the travel path of the waves, the coastal configuration and the offshore topography.

Numerical Simulation

A numerical model has been developed to study whether the earthquake which occurred near the Nicobar Island (7.329N, 94.277E) at around 3:50pm BST on the 10th of August 1998 with a magnitude of 5.8 generated any tsunami along the coastline of Bangladesh. The model developed is a two-dimensional horizontal plane finite element model where the basic equations are the conservation of mass and momentum in two space dimensions. They are:

$$\frac{\partial \zeta}{\partial t} + H\frac{\partial \overline{U}}{\partial x} + H\frac{\partial \overline{V}}{\partial y} = 0$$

$$\frac{\partial \overline{U}}{\partial t} + \overline{U}\frac{\partial \overline{U}}{\partial x} + \overline{V}\frac{\partial \overline{U}}{\partial y} = -g\frac{\partial \zeta}{\partial x} + \frac{\partial}{\partial x}(-\overline{uu}) + \frac{\partial}{\partial y}(-\overline{uv}) - \frac{\tau_{bx}}{\rho H}$$

$$\frac{\partial \overline{V}}{\partial t} + \overline{U}\frac{\partial \overline{V}}{\partial x} + \overline{V}\frac{\partial \overline{V}}{\partial y} = -g\frac{\partial \zeta}{\partial y} + \frac{\partial}{\partial x}(-\overline{uv}) + \frac{\partial}{\partial y}(-\overline{vv}) - \frac{\tau_{by}}{\rho H}$$

In the above equations, velocity $(\overline{U}, \overline{V})$, Reynolds stresses $(\overline{uu}, \overline{uv}, \overline{vv})$ are depth averaged quantities, τ_{bx} and τ_{by} are the bottom shear stresses, ζ is the surface elevation above the datum, H is the total water depth and ρ is the water density. The pressure gradient term has been evaluated using the hydrostatic pressure assumption. Bottom shear stress in the second and third equations arises due to vertical integration of Reynolds shear stress terms. These stresses have been evaluated by assuming velocity profile to be logarithmic and using a uniform flow approximation. Unknown correlations appearing in the second and third equations are closed using second order closure level of turbulence. Finite elements are used for the spatial discretization and a three level semi-implicit time scheme has been used for the time discretization.

The model has been applied in a region of the Bay of Bengal spanning more than 3000 km in east-western and more than 2000 km in north-southern directions. In the schematized model domain western boundary covers coastlines of Srilanka and India, northern boundary covers coastlines of India and Bangladesh, eastern boundary covers coastlines of Myanmar, Thailand and Malayasia, and the southern boundary covers coastline of Indonesia and open sea.

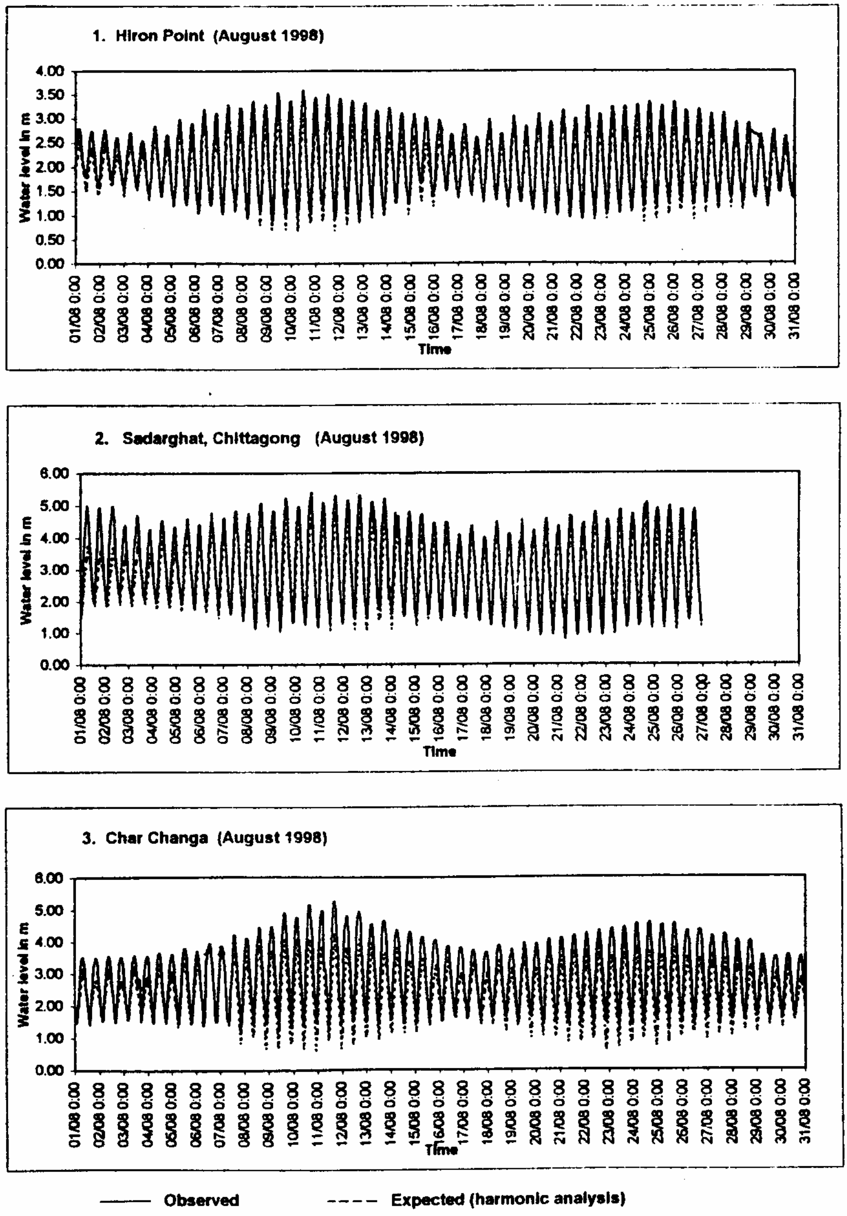

Figure 3: Observed and expected tidal levels along the coastal belt (section 1-3-2) in August 1998

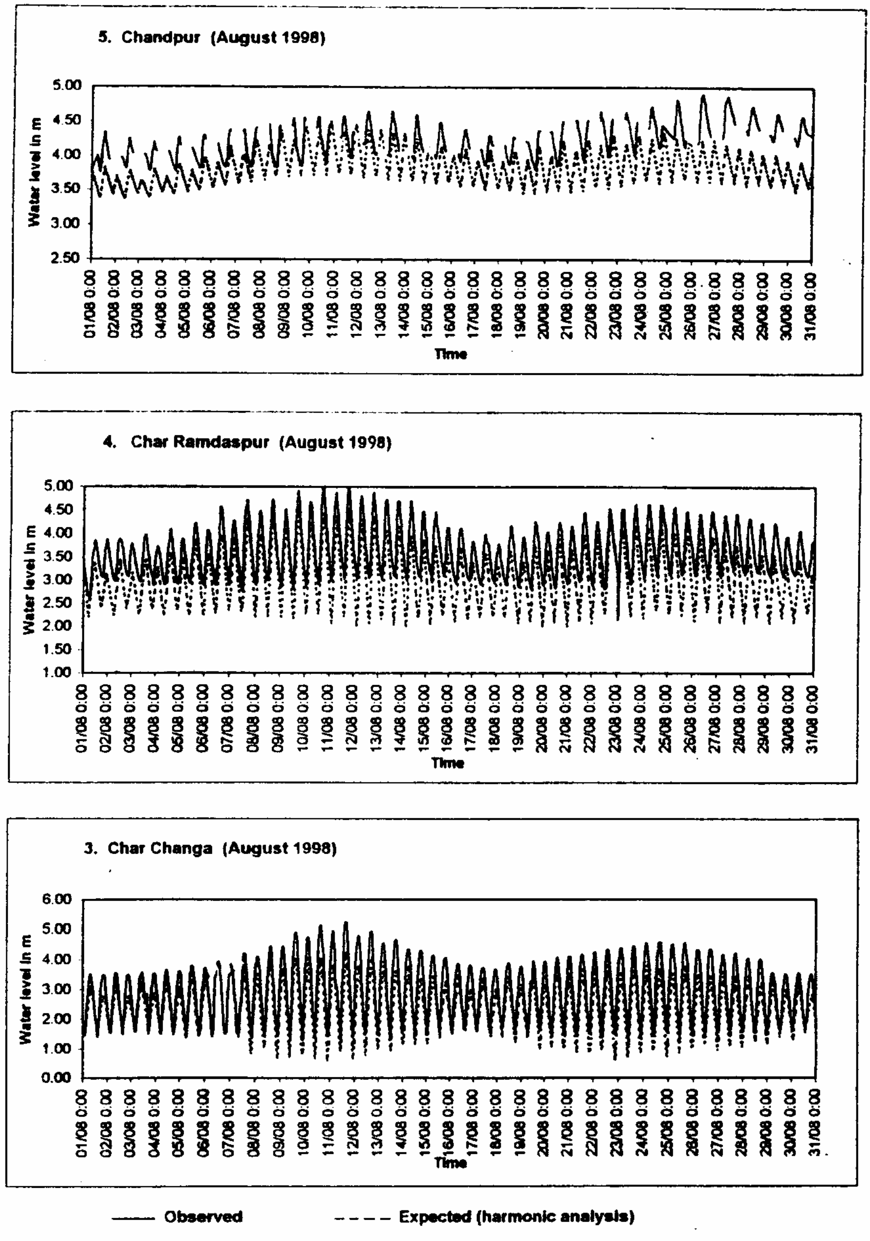

Figure 4: Observed and expected tidal levels from the coast towards upstream along the esturary (section 3-4-5) in August 1998

Model simulations for the sea surface elevation on August 10, 1998 at 4:00pm, 4:30 pm, 5:00 pm and 9:00 pm (approximately 10 minutes, 40 minutes, one hour and 5 hours after the occurrence of earthquake) were generated (Haque et al., 1999). It was seen that after 10 minutes, the tsunami wave reached the coast of Andaman Island from the north-west direction, the coast of Thailand from the eastern direction and the coast of Indonesia from the southern direction. It did not propagate much in the western direction because of the presence of Andaman Island. After 40 minutes (at 4:30pm), the wave propagation continued, but it did not amplify significantly near the Coast of Nicobar Island, Andaman Island, Thailand and Indonesia. The possibility of the wave reaching near the coast of Bangladesh at this time seems to be a rare possibility, and approximately after 1 hour it could be completely ruled out. Approximately after 5 hours (around 9:00pm), the sea surface came to the original position. Vector plot of tsunami propagation direction at 4:00 pm, 4:30pm, 5:00 pm and 9:00 pm (Haque et al., 1999) indicates that the tsunamis started propagating in almost all directions from its origin 10 minutes after the earthquake. After 40 minutes and approximately 1 hour, the tsunamis were never directed towards the coast of Bangladesh. Approximately after 5 hours, the waves were completely dissipated.

Alternative Scenario

Historical evidence showed that earthquake also occurred in the deep sea near the Andaman Island (Webpage, NOAA). Model has been applied to study the probable tsunami generation for this case assuming the epicenter to be near the Andaman Island (10.67N, 93.19E), a location close to which most of the earthquakes occurred in the past (Webpage, USGS). Probable sea surface elevations for a hypothetical large earthquake for this situation were evaluated and the vector plots of tsunami propagation direction were plotted (Haque et al., 1999). It was seen that within 10 minutes of the occurrence of earthquake, waves are initially reflected at the Coast of Andaman Island and propagate towards the south-westerly and north-westerly directions. Unlike the previous case (epicentre close to the Nicober Island), the tsunami did not reach the coast of Indonesia and Thailand. Within 40 minutes of its generation the wave traveled a long distance mainly in the deep ocean, but still remained far away from the coast of Bangladesh. After approximately 1 hour, the tsunami with an insignificant magnitude reached the west coast of Srilanka and India, but the coast of Bangladesh was completely free from any attack. After approximately 5 hours from its generation, waves were dissipated and the sea surface came to its original position.

Measured data

Tidal gage station records, if there is any tsunami, should generally indicate an upward swell followed by a rapid drawdown. After that there should be a series of waves with a period varying from a minute to an hour (Webpage, USGS). A comparison of measured water levels and expected tidal levels (from the Tide Tables of BIWTA) from August 9-12, 1998, at six tidal gage stations along the coast (Hiron Point, Galachipa, Char Changa, Sandwip, Sadar Ghat and Cox's Bazar), situated from west to east, showed that the measured data qualitatively do not show any abnormality compared to the expected behavior (Haque et al., 1999). Quantitatively, the measured values do not show any rapid swell or drawdown or any sign of series of waves indicative of a tsunami.

EFFECT OF MONSOON WIND

Model for Wind Set-up

Due to monsoon wind, seawater movement is basically horizontal. In this case, the previously used two-dimensional finite element model in a horizontal plane has been applied. The wind-generated waves were not incorporated in the model. Only the wind induced shear stress was considered. The wind influence was assumed constant over the flow field. A time series of wind velocity components could be incorporated in case of wind varying with time. The transfer of momentum of wind energy to water body is achieved as a shear stress acting on the water surface and is calculated using a square law.

The schematized model domain covers an area consisting of the western coast of India, the coastline of Bangladesh and eastern coast of Myanmar. East-west and north-south boundaries of the model span about 1000 km and 500 km, respectively. The model domain has been discretized into linear elements. Tidal variation of water level has been specified at the southern ocean boundary. These tidal elevations are calculated from the tidal constants for Baruva (India) and Searl Point (Myanmar). The constants were taken from the Admiralty Tide Tables. In intermediate locations, a linear interpolation for the tidal constituents has been made.

Simulated Sea Surface Elevation

Model simulations of sea surface elevations for different wind speeds when southern sea boundary is at LW and HW have been developed (Haque et al., 1999). As expected the LW and HW at the sea boundary are not propagated instantly towards the coast. When wind blows over the sea surface, sea level starts rising, particularly near the coast. Although the effective wind stress is the same on deep and shallow water, the funneling shape and shallowness of the Bay near the coast causes sea level to rise particularly near the coast than the deep ocean. The effect is more pronounced with the increase of wind speed. Rise of sea level due to monsoon wind set-up is particularly significant near the coast of Bangladesh and partly near the Indian coast. But this effect is nearly absent along the coast of Myanmar.

Longitudinal profiles of water level along the Bangladesh coast for different wind speed when sea boundary is at HW and LW show that as the stronger winds blow over the sea, water level rises along the coast. Table 1 shows numerical values of this water level rise. On average, a monsoon wind speed of 10 m/s over the sea raises the water level along the coast by 11cm. The average sea level may rise upto 25 cm, 46 cm and 74 cm if the monsoon winds blow with a speed of 15 m/s, 20 m/s and 25 m/s, respectively. It may be recalled here that monsoon wind speed in the Bay of Bengal varies between 5 to 15 m/s. So this monsoon set-up may result a rise of sea level along the Bangladesh coast upto a maximum 25 cm above the normal astronomical tide that may reduce the velocity of flow by about 29%.

Table 1: Water level Rise along the coast of Bangladesh when sea boundary is at HW and LW

Distance from Hiron Point	Water Level Rise (m) due to wind speed of							
	10 m/s		15 m/s		20 m/s		25 m/s	
(km)	HW	LW	HW	LW	HW	LW	HW	LW
0	0.08	0.07	0.19	0.16	0.35	0.31	0.59	0.50
57	0.09	0.08	0.21	0.20	0.40	0.37	0.65	0.59
99	0.10	0.09	0.24	0.22	0.44	0.41	0.71	0.65
148	0.11	0.11	0.26	0.26	0.47	0.48	0.76	0.76
180	0.11	0.12	0.25	0.28	0.46	0.51	0.74	0.81
211	0.11	0.13	0.25	0.30	0.46	0.54	0.73	0.85
245	0.12	0.14	0.27	0.33	0.49	0.60	0.77	0.94
285	0.12	0.16	0.28	0.36	0.50	0.66	0.79	1.03
Average	0.11		0.25		0.46		0.74	

CONCLUSIONS

The unusually high water level in the Lower Meghna during the 1998 flood resulted from the continuous flow of large volume of water for more than two months coupled with the obstruction by spring tides from the Bay of Bengal. The earthquakes that occurred near the Nicobar Island in the Indian Ocean in 1998 did not cause any tsunami along the Bangladesh coast. Even had there been any earthquake near Andaman Island, the tsunami would not have reached the Bangladesh coast. The monsoon wind set-up may result a rise of sea level along the Bangladesh coast upto a maximum 25 cm above the normal astronomical tide that may reduce the velocity of flow by about 29%.

REFERENCES

Haque, A., Salehin, M. and Chowdhury, J. U. (1999), Effect of Coastal Phenomenon on 1998 Flood, BUET