Some Aspects Of Sensitivity Of Water Level Associated With Tropical Storms Along The Meghna Estuary In Bangladesh

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SUMMARY

The coastal belt of Bangladesh is frequently lashed by tropical storms along with surges causing heavy loss of life and property. Specially, the Meghna estuary is a highly affected region in the coastal belt. In this paper a vertically integrated tide and surge interaction model, using shallow water equations, is applied to investigate some aspects of sensitivity of water level associated with tropical storms along the Meghna river estuary in Bangladesh. In order to incorporate the major islands and bending of the coast line properly in the model, a fine mesh numerical scheme (inner scheme) for the estuary is nested into a coarse mesh scheme (outer scheme) which extends from the coast of Bangladesh up to 15° N lat. of the Bay of Bengal. The outer scheme is completely independent whereas, along the open boundaries of the inner scheme the parameters like velocity and elevation are prescribed from those obtained in the outer scheme in each time step of the solution process. Appropriate tidal condition is generated in the estuary by applying tidal forcing through the southern boundary of the outer scheme. For tide and surge interaction purpose a circulatory system, representative of a tropical storm, is introduced in the previously generated tidal oscillation. Using this model sensitivity of water level w.r.t. intensity and route of some hypothetical storms are tested. Sensitivity w.r.t curving coast has also been tested. It is found that the water level is highly sensitive to these factors. Moreover morphological changes are going on due to huge discharge of sediments through the Meghna river and due to complex tidal phenomenon within the estuary. Model shows that the morphological changes also influence the surge intensity.

1. INTRODUCTION

Among all the natural calamities, a tropical storm along with surge is the most devastating one along the coast of Bangladesh. Meghna estuarine area is the most affected region in the coastal belt. Extreme bending of the coast line, shallowness of water, off-shore islands, huge discharge through the Meghna river, low lying islands and coastal regions make the estuary favorable for high surge. Besides these, the head Bay of Bengal is a large tidal range (difference between high and low tide) area. Among the tidal constituents, M2 and S2 due to attractions of the moon and the sun respectively are predominant in the estuary. Since the astronomical tidal oscillation is a continuous process in the sea, it becomes the initial dynamical condition in tide-surge interaction phenomena. The water level due to tide-surge interaction becomes significantly higher if the storm approaches the coast during high spring tide.

A considerable number of works on modelling of surge generation have so far been done for the coast of Bangladesh. Mention may be made of Das et al(1974), Johns & Ali(1980), Dube et al (1985,1986) Sinha et al(1986), Roy(1985,1993). Out of them Das et al(1974), Johns & Ali(1980) and Roy(1993) considered tide and surge interaction phenomena but none of them, except Roy(1993), incorporated the off-shore islands in the modelling process. The model of Roy(1993) consists of two numerical schemes viz. the outer and inner schemes. The outer coarse mesh scheme extends from the Bangladesh coast up to 15 degree N lat. (Fig.1). On the other hand, the inner fine mesh scheme covers the estuary only (Fig.2). The fine mesh is considered in order to incorporate the off-shore islands in the estuary. In this paper the model of Roy(1993) is used to investigate the sensitivity of water level along the Meghna estuary due to some factors which influence the surge response. In this paper water levels are shown above PWD (Public Works Datum) which is approximately 0.6 m below the MSL (Mean Sea Level) in the estuary.

2. BASIC EQUATIONS

Considering the displaced position of the free surface as $Z=\zeta(x,y,t)$ and the position of the sea floor as $Z=-h(x,y)$, the vertically integrated equations are

$$\zeta_t + U_x + V_y = 0 \qquad (1)$$

$$U_t + (uU)_x + (vU)_y - fV = - g(\zeta+h)\zeta_x + \tau_1/\rho - C_f U(u^2+v^2)^{1/2}/(\zeta+h) \qquad (2)$$

$$V_t + (uV)_x + (vV)_y + fU = - g(\zeta+h)\zeta_y + \tau_2/\rho - C_f V(u^2+v^2)^{1/2}/(\zeta+h) \qquad (3)$$

where (u,v) are vertically integrated components of Reynold's averaged velocity, $(U,V)=(\zeta+h)(u,v)$, f=Corioli's parameter (τ_1,τ_2)=components of surface stress, C_f=friction coefficient
Wind field is derived from the empirical formula given by Jelesnianski(1965)

$$V_a = V_0 (r/R)^{3/2} \quad \text{for } r \le R$$
$$\quad = V_0 (R/r)^{1/2} \quad \text{for } r > R$$

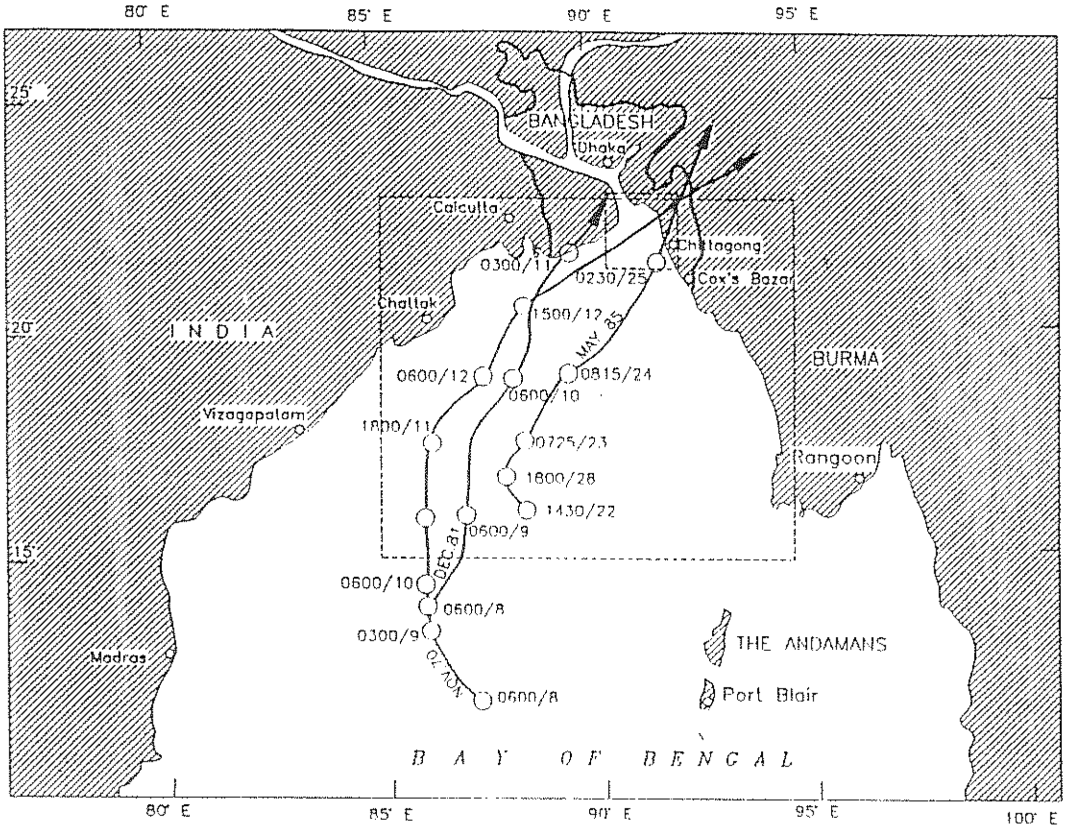

Fig. 1. Boundaries of the outer scheme and routes of three chosen storms.

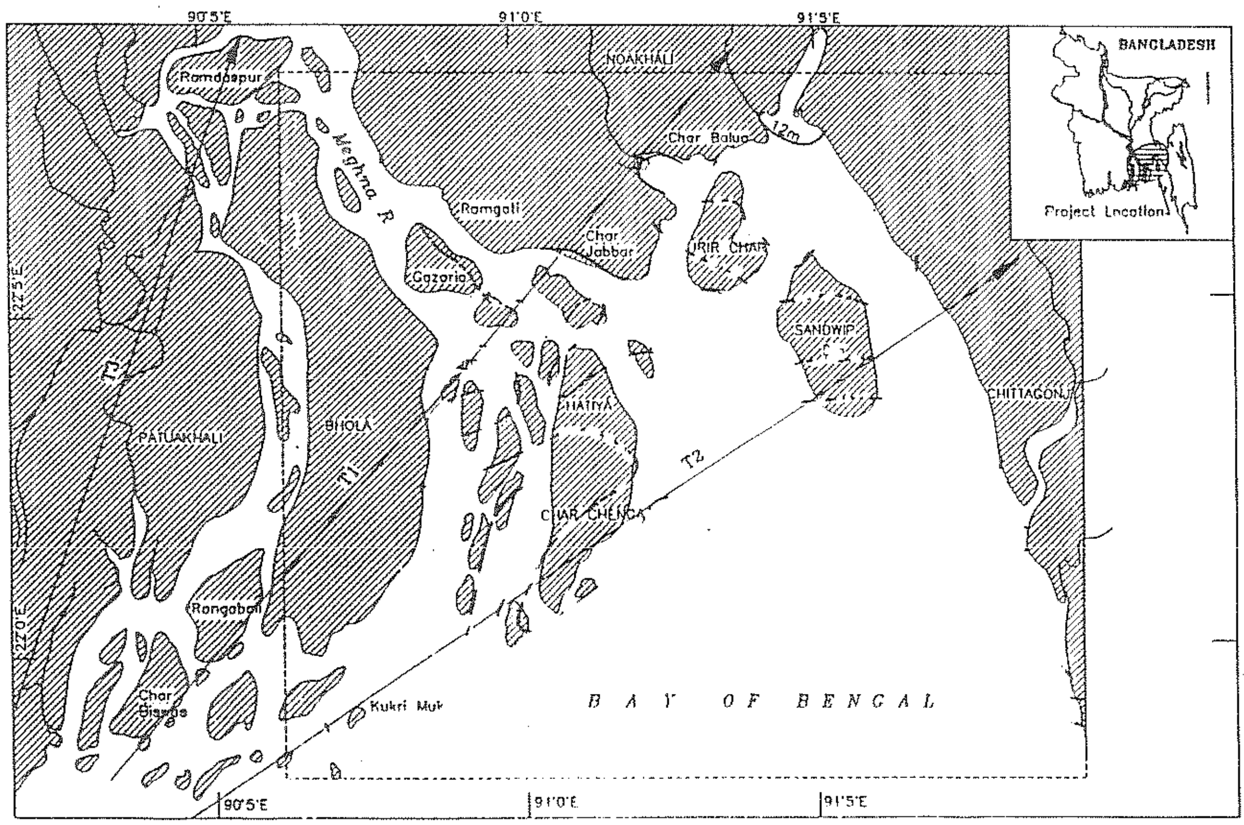

Fig. 2. Boundaries of the inner scheme and three routes of the hypothetical storms

where V_0 is the maximum sustained wind at radial distance R from the eye.
Radial and tangential components of wind stress are derived by $(\tau_r, \tau_\theta) = C_D \rho_a V_a^2 (-\sin\delta, \cos\delta)$ where C_D, ρ_a and δ are respectively drag coefficient, air density and inflow angle. The inflow angle as a function of r is taken according to Johns et al (1985) and Overland (1975). Then τ_1 and τ_2 are derived from τ_r and τ_θ.

3. SET-UP OF NESTED SCHEMES

In order to include the major islands of the estuary in the numerical scheme, the mesh size should be small whereas this is unnecessary away from the estuary. Considering the above fact, a high resolution numerical scheme (inner scheme) with mesh sizes δx =1388.75 m and δy =1288.76 m is nested into a coarse resolution bigger scheme (outer scheme) with mesh sizes δx =22.2 km and δy =21.0 km. The outer scheme covers the area between 15° N to 22° 48′ N and 85° E to 94° 36′ E (Fig.1). The inner scheme covers the area between 21° 49′ 30″ N to 22° 51′ 45″ N and 90° 38′ 15″ E to 91° 54′ 45″ E (Fig.2). The inner scheme includes only the estuary where the river discharge and off-shore islands are incorporated. The outer scheme also includes the estuary but without incorporating them.

Both the schemes have the same dynamical equations with different boundary conditions. The outer one is completely independent. On the other hand, along the open boundaries of the inner scheme the parameters ζ, u, v are prescribed from those obtained in the outer scheme in each time step of the solution process. Along the north-west corner of the inner scheme the effect of river discharge is incorporated through

$$u_b = u + Q/\{(\zeta+h)B\} \qquad (4)$$

where Q and B are river discharge and breadth of the river. According to Johns et al (1985), the boundary conditions at west (85° E), east (94° 36′ E) and south (15° N) boundaries of the outer model are respectively

$$v + (g/h)^{1/2}\zeta = 0 \qquad (5)$$

$$v - (g/h)^{1/2}\zeta = 0 \qquad (6)$$

$$u - (g/h)^{1/2}\zeta = -2(g/h)^{1/2} a \sin\{(2\pi t)/T+\Phi\} \qquad (7)$$

where a and Φ denote respectively the prescribed amplitude and phase of the tidal forcing and T is the period. At the closed boundaries the normal components of the depth-mean current are taken as zero.

The governing equations along with boundary conditions are solved by conditionally stable explicit finite difference scheme using staggered grid. The closed boundaries have been approximated by lines following the grid lines. The time step is chosen in such a way that the CFL criterion of stability is satisfied in the numerical scheme.

4. SENSITIVITY TEST

The details of model calibration and verification are given in Roy(1993). The initial values of a and φ in (7) are prescribed following McCammon and Wunsch (1977). Through calibration a and Φ of (7), friction coefficient C_f etc. are adjusted. The model is then verified with time series of observed water level data of three chosen storms, the paths of which are shown in Fig.1. For tide and surge interaction purpose a representative tidal response in the basin is generated by prescribing appropriate values of a, Φ and T in (7) along the southern open sea boundary of the outer scheme. Though the period of oscillation in the estuary is not exactly constant, the mean period is always found to be approximately 12.4 hrs. which is of M2 constituent. Accordingly T is chosen to be 12.4 hrs. For sensitivity test three hypothetical storms with maximum wind speed 223 km/hr, (62 m/s), 235 km/hr (65 m/s) and 252 km/hr (70 m/s) respectively are considered along tracks T1, T2 and T3 for each of them (Fig.2). It should be mentioned that outside the estuary the track of each of them lie along that of Nov. 1970 storm as shown in Fig.1. Each of the above storms is introduced in such a stage of the initially generated tidal oscillation that, it (storm) reaches the coast during high tide along the estuary.

Fig.3 depicts the water levels, corresponding to the hypothetical storms mentioned above at Chittagong, North Sandwip and Ramgati. It is evident from the figure that, for each route the intensity of surge at each location increases with the intensity of storm. Again, it may be observed that, Chittagong lies at the right of each track, North Sandwip lies between T1 & T2 and Ramgati lies between T3 & T1 (Fig.2). It is seen from the Fig. 3(b) that at North Sandwip the surge levels from highest to lowest are obtained according to the routes T1, T3 and T2 respectively for each storm intensity. Sandwip is to the right of T1 & T3 and to the left of T2. Computational results indicate that the surge response is higher to the right of the route. It is natural to obtain highest surge for T1 as it is nearer to Sandwip. But the response to T2 is lower than that of T3 though T2 is nearer to Sandwip than T3, because Sandwip is to right of T3. Similar analysis may be made for the responses of other two locations. Thus the estuary will be more affected if a storm crosses the coast to the left of the estuary.

Fig.4 gives the contours of peak water levels along the coastal belt of the estuary from west to east. It is evident from the figure that intensity of water level increases with the increasing intensity of the storm for each route. On the other hand, for the route T1 the highest peak is near Feni river and then sharply decreases towards the east. In fact, near Feni river the bending of the coast line is maximum and towards the right (east) the coast is almost straight (Fig.2). Similar picture is seen for the route T3. But for T2 the surge response is comparatively less through out the estuary, because most of the region is to the left of T2. This figure clearly explains the sensitivity of water level due to route also.

Finally, test is done for morphological changes on the estuary. In fact, morphological changes are going on due to huge transport of sediments through the Meghna river and due to complex tidal phenomena within the estuary. It is expected that in course of time Sandwip, Urir Char and Char Jabbar will be linked up through accretion of land (Fig.2). Computation is done with this modification of territory. It is found that except near Feni river, there is over all increase of intensity of water level within the estuary. Hence any morphological changes in the estuary will also influence the surge intensity.

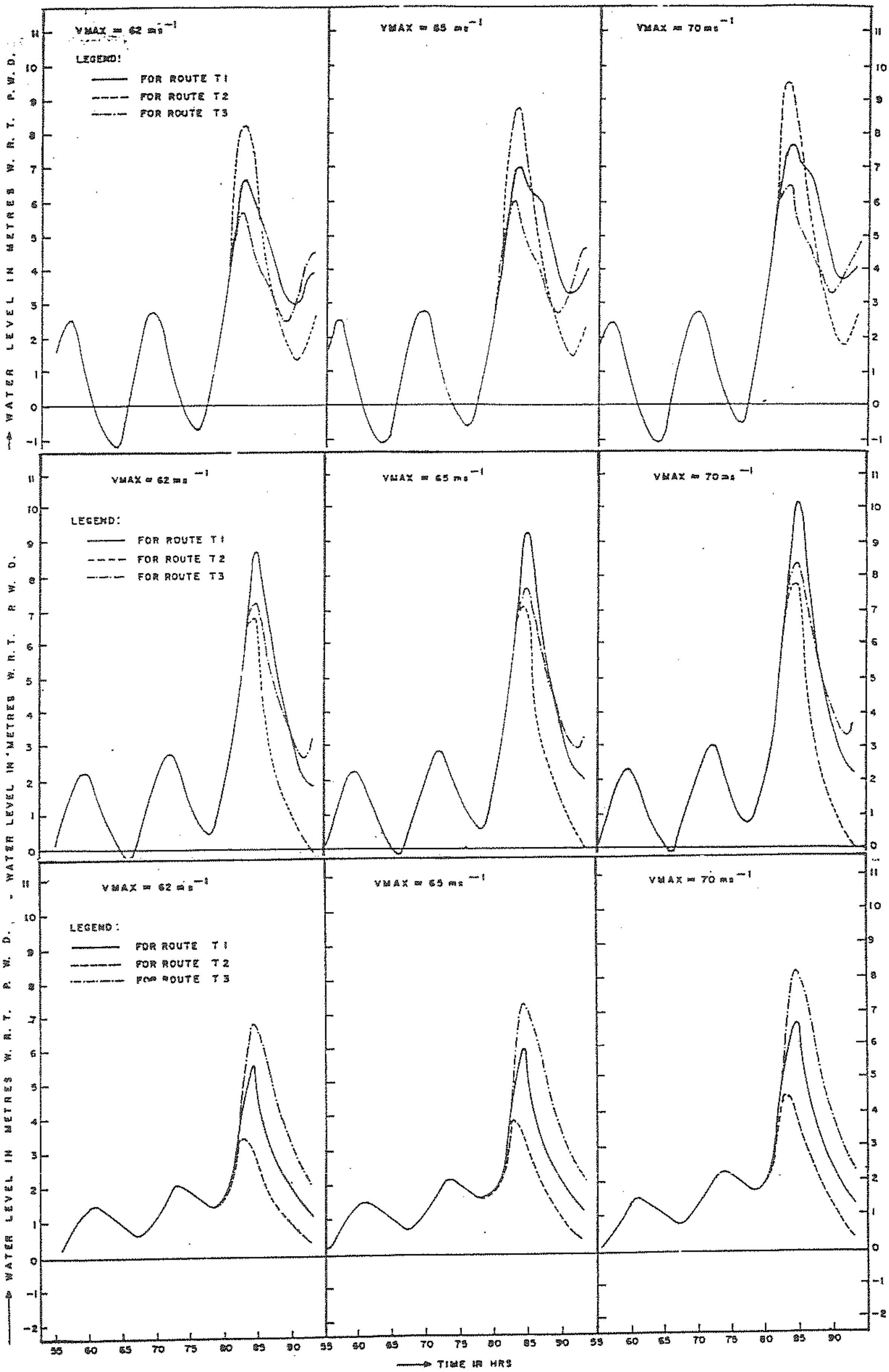

Fig. 3. Water levels w. r. t. routes and intensities at (a) Chittagong, (b) North Sandwip and (c) Ramgati

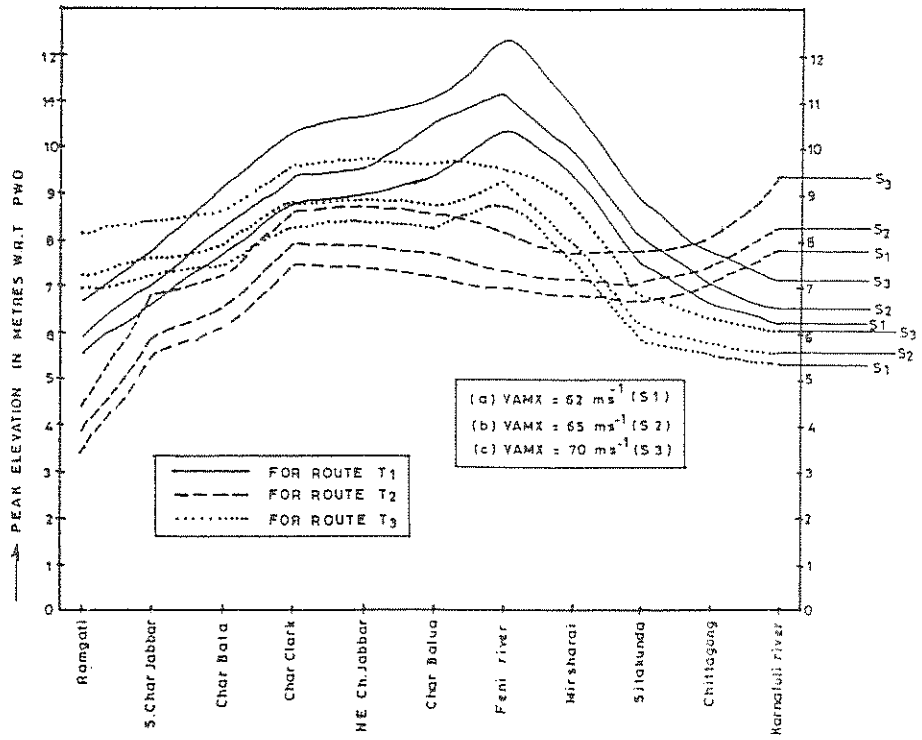

Fig. 4. Peak water levels at the coastal boundary of the Meghna estuary w. r. t. intensity and route.

5.CONCLUSION

This paper gives a clear understanding regarding the sensivity of water level associated with tropical storm in the Meghna estuary. The outcome of this study can be utilized in practical forecasting purpose.

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