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A description of tidal propagation in Hooghly estuary using numerical and analytical solutions

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ABSTRACT

A tidal propagation characteristic of Hooghly estuary is presented using numerical (ADCIRC) and analytical models (Friedrichs and Aubrey, 1994) along with observations. The analytical model is based on Friedrichs and Aubrey (1994) that simplifies the governing hydrodynamic equations greatly by retaining only those terms that are significant without losing the overall understanding of the propagation process. The analytical model is compared with corresponding 2-D depth averaged numerical (ADCIRC) model that retains all non-linear terms. The assumptions for simplification are found to be reasonable in the light of close agreement among analytical, numerical models and observations. A plan-form geometrical characteristic as well as hydrodynamic variable of the Hooghly has been compared with that of Delaware estuary for corroborating similar tidal propagation process. **The Hooghly estuary has flood dominant asymmetric tidal propagation and a positive amplitude growth factor (μ)**. The observed tidal celerity (phase speed) on an average is slightly more than frictionless celerity. Using the conventions of Toffolon et al. (2006), **Hooghly can be classified into 'strongly convergent – strongly dissipative' estuary**. From the results it can be construed that the estuary is yet to stabilise and reach its equilibrium morphology. It can be close to its equilibrium as very little amplification (0.1 m) is noticed in the predominant semi-diurnal constituent M_2 over 78 km (barely 7%) in the estuary. The parameters of width variation (γ) and the ratio between friction and inertia (χ) have been used to define the marginal condition for amplification. The relative position of Hooghly in terms of marginal condition is consistent with similar set of estuaries elsewhere that have been grouped using the above parameters.

1. Introduction

For general understanding of the estuarine processes and possible engineering intervention, it is imperative to be in a position to describe the tidal propagation so that the hydrodynamics, sedimentation and morphology can be predicted with a reasonable certainty. The study of tidal propagation in shallow waters and confined water bodies like estuary is rendered complicated due to the effects of geometry and local settings that obscure the relationship between the forcing functions and resulting hydrodynamics. Analytical solutions are mathematically elegant and may offer generalised connectivity between the forcing parameters and the propagation characteristics. It must be noted that analytical solutions require significant simplifications from real field conditions and often become too complicated and unwieldy to be of any effective engineering utility. On the other hand, the numerical solutions can more closely reproduce the natural behavior in a simulation for case specific manner but it precludes generalisation. Classical approach in analytical models where the processes are sought to be described from first principles and retain all components has given way to simplified approaches where few components are eliminated depending on their importance and their contribution to overall solution. For example in the 1-D analytical model of governing equations, it has been found that the contribution of advective acceleration term is insignificant when compared to that of friction term to the overall process. It indicates that acceleration term can safely be omitted to significantly simplify the model without compromising the overall understanding of the process (Friedrichs and Aubrey, 1994).

A numerical simulation using ADvanced CIRCulation (ADCIRC) model provided solutions of elevation, currents and harmonics over the model domain. Following the approach of Friedrichs and Aubrey (1994), a 1-D analytical solution was obtained to examine the behavior of few representative parameters like predominant constituent (M_2), its over-tide (M_4), phase lag between elevation and current (φ) and celerity (c) along estuary. Combining the information obtained through

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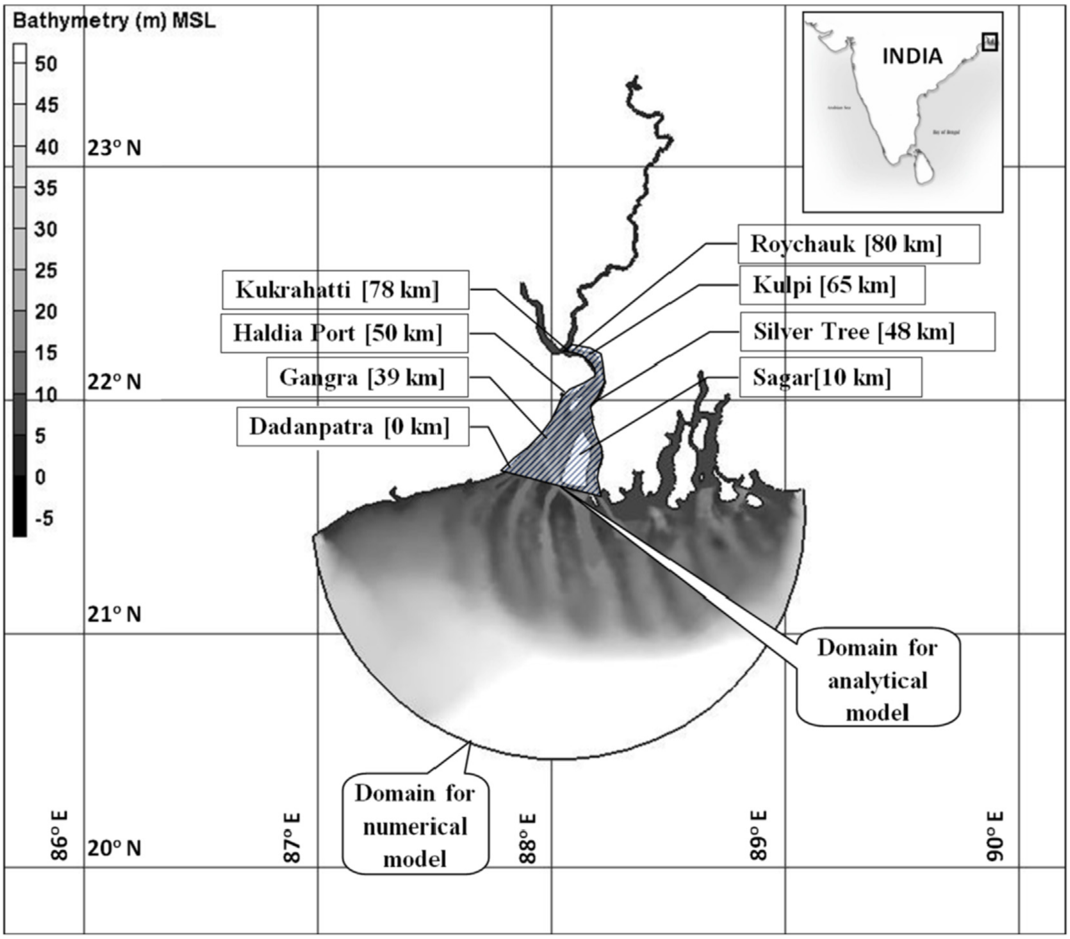

Fig. 1. Location map of Hooghly estuary.

above three steps, an effort is made in this study to classify the tidal propagation in Hooghly estuary. Using the conventions of Toffolon et al. (2006), the marginal condition for tidal amplification pertaining to Hooghly is evaluated.

2. Background of the study area

Hooghly estuary is situated in the western end of the vast Ganga-Brahmaputra delta (Fig. 1). The estuary is connected to two rivers (Bhagirathi and Roopnarayan) on the north that mainly discharge monsoon floods. The estuary is very important in the region as it provides access to two major ports which in turn serve a vast hinterland comprising many eastern and north eastern states of India (Kolkata Dock System, 22º32′N and 88º18′E, Haldia dock complex, 22º02′N and 88º06′E.). Due to the very gentle gradients in the river and flat nature of topography, any major change in tidal hydrodynamics will lead to flooding or lateral shift of the river course. It has been reported (Sinha et al., 1997) that sea level rise can affect the circulation pattern within the estuary significantly. The morphology of estuary is still evolving to reach equilibrium and portions of water ways require substantial maintenance effort by the ports of Haldia and Kolkata for shipping purpose (Sivakholundu et al. (2009)).

The estuary portion under study lies between latitudes 21º30′N and 22º12′N and longitudes between 87º42′E and 88º15′E. It is a typical alluvial estuary shaped mainly by hydrodynamic factors with no geological constraints. In Hooghly, the tidal effect is felt up to about 300 km from the open sea (McDowel and O'Connor, 1977). The funnel shaped main channel ends at about 80 km from sea and the convergence of channel further upstream is negligible. In general the bathymetry is very shallow with an average depth of about 6 m below mean sea level. Due to shallow depths and large tidal range, the estuary is characterized by braided channels, tidal flats and large intertidal region (Fig. 1). The alluvial bed is conducive for frequently shifting channels redistributing the flow accompanied by shoal formation as well as eroding banks. Two main channels are formed on eastern and western edges of the estuary separated by shoals and islands. The western channel called Jellingham is mainly flood dominated while the eastern channel called Rangafala channel is ebb dominant. The depths in the flood channel in the vicinity of study site are of the order of 8–10 m, whereas for equivalent portion on ebb channel is deeper by about 2 m. This confirms the general conventions that ebb channels are deeper than flood channels and also flood channels have a tendency to become shallower progressively.

As a part of morphological evolution, the flood dominant western channel is progressively becoming shallower from its earlier condition. According to port records, the Jellingham channel was naturally maintaining a depth of about 9 m (w.r.t Mean Sea Level) during 1970s when the new port of Haldia was developed as an augmentation to Kolkata Port. For maintaining the navigation in Hooghly estuary, Kolkata Port Trust continues to carry out one of the massive maintenance dredging in the country to the tune of 20 Mm^3/year. Despite such dredging efforts, the maintained depth at Jellingham channel has seen progressive drop in the availability of navigable depth which is reduced to about 7.3 m during the year 2002.

The bathymetry on the southern side (open sea) of estuary is characterized by tidal flats, braided channels and shallow patches called sandheads that extend about 80 km to a depth of 30 m (Fig. 1). The sandheads define the navigation route for shipping to enter into the

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