ROLE OF MANGROVE BIOMASS IN NUMERICAL WAVE MODELS FOR REDUCING COASTAL VULNERABILITY IN THE ESTUARIES OF INDIAN SUNDARBANS

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Abstract: The Indian Sundarbans at the apex of Bay of Bengal is exposed to several vulnerabilities associated with climate change which primarily include sea level rise, salinification, cyclonic depressions, tidal surges, wave actions and erosions. Mangroves are widely distributed in all the islands of Indian Sundarbans, whose biomass and branching are functions of salinity and substratum characteristics. They act as the line of defense against these vulnerabilities. Salinity plays a crucial role in regulating the mangrove characteristics preferably the biomass. The present paper is a first order analysis on the role of dominant mangroves in reducing wave related vulnerabilities along two major estuaries of Indian Sundarbans namely the Hooghly estuary and the Matla estuary, which have significantly contrasting salinities. The biomass and growth of mangrove along the Hooghly estuarine complex is relatively higher compared to the mangroves thriving along the mudflats of Matla estuary. In this paper, the wave attenuation potential of four dominant mangrove species have been studied for these two major estuaries considering the relevant input parameters in two seasons namely monsoon (in the month of July, 2018) and postmonsoon (in the month of November 2018).

Keywords: Wave attenuation; Salinity; Mangroves; Biomass; Indian Sundarbans.

I. INTRODUCTION

Indian Sundarban Biosphere Reserve (SBR) with an area of 9630 sq km is a mangrove dominated World Heritage Site at the apex of Bay of Bengal. The area experiences a sea level rise of 3.14 mm/year, whose vulnerability is considerably reduced by the abundance and biomass of mangroves. The Indian Sundarbans sustains 34 true Mangrove species [2], which exhibit variable growth due to variation in salinity [11, 1, 3, 4, 5, 7, 8, 9, 10, 6]. The variation in salinity and features of intertidal mudflats greatly affect the growth, pneumatophore density and branching of mangroves [2]. It has also been documented that the ecosystem services of mangroves is regulated by abiotic parameters. The role of mangroves in attenuating waves is still a grey area preferably when the species specificity is considered. The islands of Sundarbans are highly dynamic and are exposed to cyclonic depressions associated with tidal surges and wave actions.

Tropical cyclones (TCs) are one of the most devastating natural hazards associated with strong winds and heavy rainfall. The Indian coasts are significantly vulnerable to this damaging natural catastrophes causing loss of life and property. The third-generation spectral ocean wave models such as WAM [12], WAVEWATCH III [13], and SWAN [14, 15] are run with global numerical weather prediction model surface winds to produce significant wave height forecasts. However, the resolution of the global weather models is often insufficient to capture the steep wind gradients associated with TCs. Tolman developed a two-way nested approach for wave modelling [16]. He presented a mosaic or multi-grid approach to wind wave modeling. The approach is implemented in the WAVEWATCH III wind wave model [17] which is run operationally at the National Centers for Environmental Prediction of USA. Wave and circulation models have been limited by their spectral, spatial and temporal resolution. This limitation can be overcome by nesting structured meshes, to enhance resolution in specific regions by employing meshes with progressively finer scales. Relatively fine nearshore wave models, such as STWAVE and SWAN, can be nested inside relatively coarse deep water wave models, such as WAM and WaveWatch III. SWAN has been used extensively to simulate waves in shallow water and it has been converted to run on unstructured meshes [22]. Researchers integrated the unstructured mesh SWAN model and the ADCIRC model, which is known as the SWAN+ADCIRC mode [21]. The SWAN component develops the offshore and nearshore waves, and the ADCIRC component develops the hydrodynamics and storm surge. Numerical modelers used WRF, WAM, SWAN and ADCIRC to couple and simulate a severe cyclonic storm Thane that developed in the Bay of Bengal during December 2011 [18]. The significant wave heights measured along satellite tracks by three satellites viz; ENVISAT, JASON-1 and JASON-2, as well *in-situ* near-shore buoy observation off Pondicherry was used for comparison with model results. The study signifies the importance of coupled parallel ADCIRC+SWAN model for operational needs during extreme events in the North Indian Ocean. Oceanographers implemented a coupled wave + surge hydrodynamic modeling system (ADCIRC+SWAN) to simulate storm surge, still water level elevation and wave induced setup associated with 'Phailin', a very severe cyclonic storm that made landfall in the Odisha State, east coast of India, during October, 2013 [20].

Researchers also used the Simulating WAves Nearshore (SWAN) model with unstructured grids and the ADvanced CIRCulation (ADCIRC) model to study the hydrodynamic response in the Gulf of Maine during the Patriot's Day storm of 2007 [19].

In this study the SWAN model is used with vegetation and mud input to evaluate the wave attenuation along the Indian Sundarbans. The major inputs in running SWAN model are wind speed, depth, mud layer, density of the tree, height of the tree, diameter of the tree etc. The present study considers the major mangroves floral species (*Sonneratia apetala, Avicennia marina, Avicennia alba* and *Avicennia officinalis*) in two separate estuaries namely Hooghly and Matla having contrasting salinities. This work is the first attempt to evaluate the species-wise attenuation of waves using SWAN model on the basis of real time data that have been collected from the mangrove ecosystem of Indian Sundarbans during 2018.

II. MATERIALS AND METHOD

In the coastal region, mangrove vegetation has the ability to attenuate waves which are generated by severe storms and tidal surges. SWAN model helps to determine the effect/impact of vegetation on the wave height. Thus this model is a powerful tool to evaluate the attenuation of waves by mangroves or any other coastal vegetation. This model consists of an energy dissipated term due to vegetation. The dissipated energy is subtracted from the incoming wave energy, which results in less wave energy behind the vegetation span thus resulting in the lowering of the wave height. The vegetation is considered as cylindrical obstacles and the vegetation properties as height, width, density, drag-coefficient are used to determine the magnitude of dissipation term.

The SWAN model is simulated with real time *in situ* collected data for four dominant mangrove species (*Sonneratia apetala, Avicennia marina, Avicennia alba* and *Avicennia officinalis*) along the Hooghly and the Matla estuaries. Average salinity in the Hooghly estuary is around 15 psu, whereas in the Matla estuary the average salinity is 22 psu. The Hooghly estuary is hyposaline because of the Farakka Barrage discharge whereas the Matla estuary is hypersaline because of the siltation in the head region blocking the input of fresh water in the estuarine stretch.

The input data includes height of the tree, diameter of the tree (diameter at breast height as per the standard protocol), mud thickness and bulk density as real time data for the months of July and November, 2018 representing the monsoon and postmonsoon seasons respectively. It is observed that *Sonneratia apetala* is adapted to low saline environment (range 5 psu to 15 psu), whereas *Avicennia marina, Avicennia alba* and *Avicennia officinalis* prefer hyper saline condition (greater than 20 psu as observed in the inshore waters of central Indian Sundarbans).

GEBCO (https://www.bodc.ac.uk/) gridded data with spatial resolution 30 seconds (0.008333 degree) has been used to generate the bathymetry for the study area (longitude from 88.0°E to 89.5°E and latitude from 21.0°N to 22.5°N). For the SWAN simulations the above bathymetry and constant wind fields have been given as model inputs. A course SWAN run is also performed for the Indian Ocean region to generate the boundary conditions. The significant wave heights (SWH) generated are compared for the Hooghly ($88^0 08'$ E, $21^0 38'$ N) and Matla ($88^0 44'$ E, $21^0 53'$ N) estuaries separetely.

III. RESULTS AND DISCUSSION

In this paper the impact on wave attenuation, by four dominant mangrove species (*Sonneratia apetala, Avicennia marina, Avicennia alba* and *Avicennia officinalis*) thriving in different salinity zones of Indian Sundarbans is analysed. In this work two major estuaries have been considered, namely the Hooghly and the Matla having contrasting salinities. The mangrove vegetation along the Hooghly estuary has relatively more biomass owing to congenial environment with a mean salinity of 15 psu. On contrary, Matla has relatively low mangrove biomass because of high salinity (mean salinity is 25 psu). The present research aims to evaluate the role of vegetation (preferably biomass of vegetation) in attenuating the waves generated in the estuarine stretches of the Hooghly and Matla. The SWAN model is simulated for the months of July and November representing the monsoon and postmonsoon seasons with real time data namely height of the tree, diameter of the tree, mud thickness and bulk density. Separate experiments are conducted (species-wise) for Hooghly and Matla estuaries. Figure 1 presents the bathymetry of the study area (longitude from 88.0°E to 89.5°E and latitude from 21.0°N to 22.5°N) generated from GEBCO gridded data having 30 second or 0.008333 degree spatial resolution. The minimum depth is -13.0 meter and maximum depth is 728 meter.

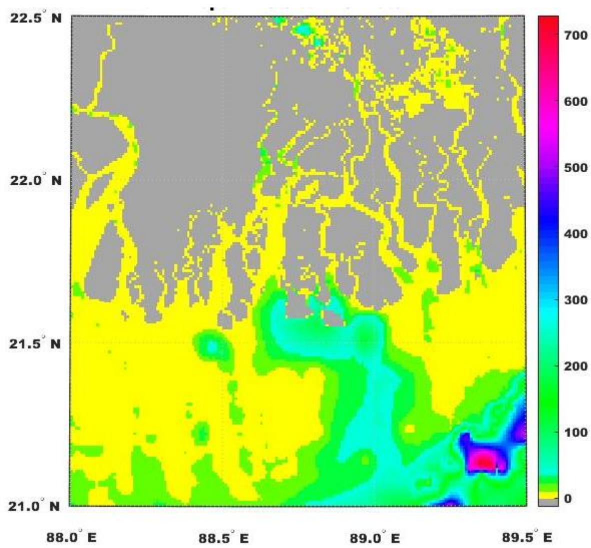

Figure 1. Bathymetry from GEBCO gridded 30 second (0.008333 degree) data

Species-wise the SWAN model is simulated with real time collected vegetation and mud data and average wind. It is observed that mangrove floral species showed better attenuation in the Hooghly estuary during July 2018 compared to the Matla estuary (Figures 2 and 3). Table 1 highlights the model computed SWH for the month of July.

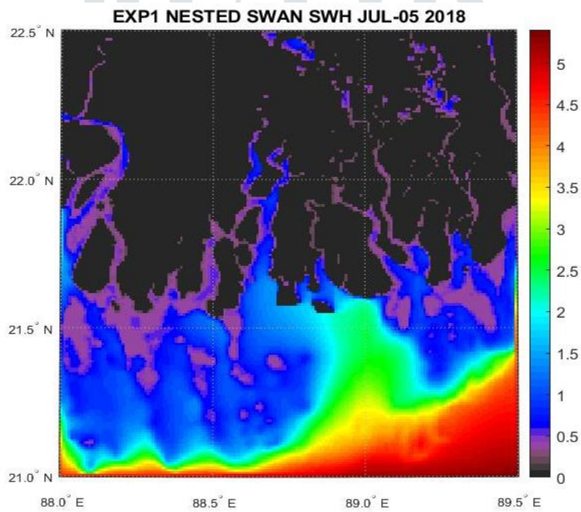

Figure 2. SWAN simulation with vegetation input for Hooghly estuary on 5th July 2018

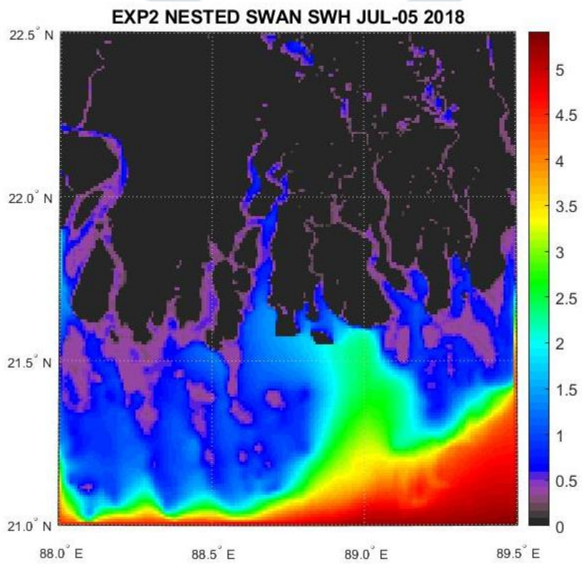

Figure 3. SWAN simulation with vegetation input for Matla estuary on 5th July 2018

Table 1 Model computed SWH for July 2018

Hooghly (depth: 3.3165m) (88°08′ E, 21°38′ N)		SWH meter	Matla (depth: 12.0842m) (88°44′ E, 21°53′ N)		SWH meter
EXP 1	*Sonneratia apetala*	0.46	EXP2	*Sonneratia apetala*	1.08
EXP3	*Avicennia marina*	0.46	EXP4	*Avicennia marina*	1.08
EXP5	*Avicennia officinalis*	0.46	EXP6	*Avicennia officinalis*	1.08
EXP7	*Avicennia alba*	0.46	EXP8	*Avicennia alba*	1.08

The attenuation decreased in the month of November which is a postmonsoon month in the study area (Figures 4 and 5). During this month the wave height is very less compared to the monsoon season [4, 8, 9]. Table 2 gives the model computed SWH for the month of November.

In July mangroves showed maximum attenuation and the wave height has been reduced by 57% compared to November when the attenuation was 31%.

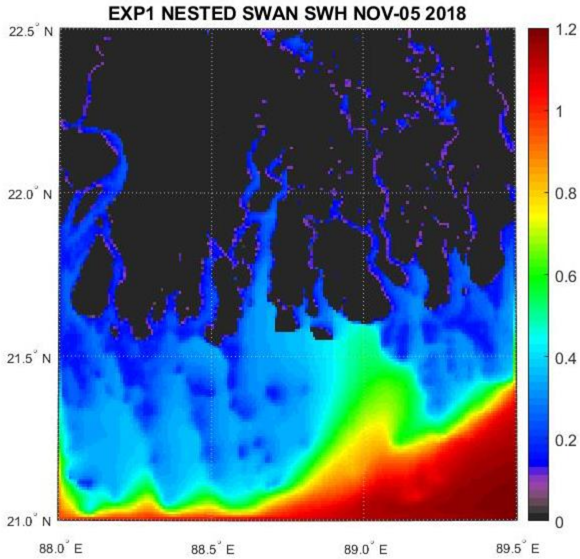

Figure 4. SWAN simulation with vegetation input for Hooghly estuary on 5th November 2018

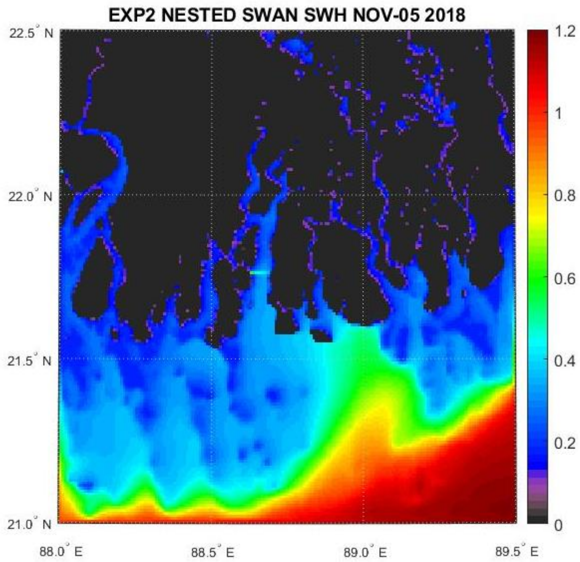

Figure 5. SWAN simulation with vegetation input for Matla estuary on 5th November 2018

Table 2 Model computed SWH for November 2018

Hooghly (depth: 3.3165m) (88°08′ E, $21^{0}38'$ N)		SWH meter	Matla (depth: 12.0842m) (88°44′ E, $21^{0}53'$ N)		SWH meter
EXP 1	*Sonneratia apetala*	0.22	EXP2	*Sonneratia apetala*	0.32
EXP3	*Avicennia marina*	0.22	EXP4	*Avicennia marina*	0.32
EXP5	*Avicennia officinalis*	0.22	EXP6	*Avicennia officinalis*	0.32
EXP7	*Avicennia alba*	0.22	EXP8	*Avicennia alba*	0.32

IV. CONCLUSION

Sundarban is a cyclone prone zone associated with disaster due to wave actions and tidal surges. The present result depicts that mangroves can act as bio-shields against the massive wave actions which otherwise may destroy the island villages and damage lives and properties. It is observed that the wave height has been reduced in the Hooghly estuarine stretch by 31% in November and 57% in July compared to the wave height of Matla estuary. There is no species-wise variation in attenuating waves in both the estuaries, or in other words all the four selected species (*Sonneratia apetala, Avicennia marina, Avicennia officinalis* and *Avicennia alba*) have uniform regulatory impact in the domain of wave attenuation. The reduction of wave height in the Hooghly estuary points towards the role of stilt roots, pneumatophores and biomass of the mangrove species in attenuating waves. The biomass of mangrove vegetation in the Matla estuary is comparatively low due to which the wave attenuating efficiency is relatively low. The wave attenuation potential of mangrove species is thus directly proportional to the biomass of the species. The model simulations also highlighted that during the monsoon season the mangrove vegetation has greater ability to attenuate waves compared to the postmonsoon season.

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