Research Paper

RESEARCH ON BOTTOM MORPHOLOGY AND LITHODYNAMIC PROCESSES IN THE COASTAL AREA BY USING NUMERICAL MODEL: CASE STUDIES OF CAN GIO AND CUA LAP, SOUTHERN VIETNAM

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ABSTRACT

A numerical model to simulate Litho-dynamic processes and bottom morphology at the coastal area such as the flow, sediment transport and bed changes under the effects of tides, waves and winds have been suggested. The model is based on the system of Reynolds equation coupled with sediment transport and bed load continuity equation. There are three verification cases of the model: verification of the tide-induced current, the wave-induced current and the sediment transportation., The results from the model are good in accordance with the analytical solution. The model is then applied to the coastal zone of Can Gio mangrove forest and Cua Lap estuary (South East of Vietnam). As a result, the trend of sediment accretion and erosion in these two areas are qualitatively in agreement with satellite observation and practical measurement.

Keywords: *The numerical model, Litho-dynamicprocesses, Sediment transportation, Eccretion and erosion.*

1. Introduction

Hydrodynamic in estuaries coastal zone has a direct impact on the societal issues such as coastal engineering, environmental protection, and recreation. Waves, current, sediment transport, and morphology are important processes within coastal and estuaries setting, so accurate predictions of waves, currents, and sediment transport plays a key role in solving estuary and coastal problems, especially those related to bedded morphological evolution. Waves and currents mobilize and transport sediment, and gradients in the transport cause deposition or erosion, affecting the local topology. Therefore, understanding of hydrodynamic regime in the coastal zone and simulating its potential changes over the years are important information to support coastal management plan toward sustainability. A coastal morphodynamic modeling is the best way to convert scientific information to practical application and to improve communication between scientists and managers or practitioners.

The model has been developed by the authors since 2004. It is used to simulate simultaneously the flow due to wave, wind, and tide and combined with sediment transport and bed level changes in the coastal and estuary area. The model has been verified with some analytical solutions and applied for the real cases in some coastal and estuary areas such as Can Gio coastal area and Cua Lap estuary area.

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2. Material and methods

2.1 Governing equations

The adopted model is a 2D surface where Ox and Oy represent the length and the width of the study area. The model is based on the system of four governing equations as follows:

Reynolds equations

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv = -g\frac{\partial \varsigma}{\partial x}+\frac{\tau_{Sx,wind}-\tau_{Sx,w}}{\rho(h+\varsigma)} - \frac{\tau_{bx}}{\rho(h+\varsigma)}+A\nabla^2\bar{u} \quad (1)$$

$$\frac{\partial \varsigma}{\partial t}+\frac{\partial[(h+\varsigma)\bar{v}]}{\partial x}+\frac{\partial[(h+\varsigma)\bar{v}]}{\partial y}=0 \quad (2)$$

Continuity equation

$$\frac{\partial \varsigma}{\partial t}+\frac{\partial[(h+\varsigma)\overline{u}]}{\partial x}+\frac{\partial[(h+\varsigma)\bar{v}]}{\partial y}=0 \quad (3)$$

Suspended sediment transport equation

$$\frac{\partial C}{\partial t}+\gamma_V\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right) = \frac{1}{H}\frac{\partial}{\partial y}(HK_x\frac{\partial C}{\partial y}\left(HK_y\frac{\partial C}{\partial y}\right)+\frac{S}{H} \quad (4)$$

Bed load continuity equation

$$\frac{\partial h}{\partial t}=\frac{1}{1-\varepsilon_p}\left[S+\frac{\partial}{\partial x}\left(HK_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(HK_y\frac{\partial C}{\partial y}\right) + \frac{\partial q_{bx}}{\partial x}+\frac{\partial q_{by}}{\partial y}\right] \quad (5)$$

where A is Horizontal viscosity coefficient [m^2/s]; u,v arethe depth-averaged horizontal velocity components in x, y direction[m/s]; C is thedepth-averaged concentration of suspended load [kg/m^3]; h isthe static depth from the still water surface to the bed[m]; ς is thefluctuation of water surface [m]; S is thedeposition or degradation of grain [kg/m^2s]; $H = \varsigma + h$; with H is defined by static depth h and fluctuation ς illustrated in figure 1[m].

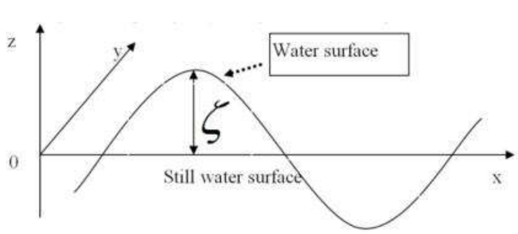

Fig. 1. Initial static level

2.2 Computational method

A numerical code based on finite difference method was built to solve the governing system of equations above with variables u, z, v, and C. In the paper, a visual basic is used to build the model. The scheme ADI (Alternating Direction Implicit) is used to solve the system of converted algebraic equations. Computational grid for the governing system of equations is shown in figure 2. The main concept of the ADI method is to split the finite difference equations into two, one with the x-derivative and the next with the y-derivative, both taken implicitly (Douglas, 1955). The system of equations involved is symmetric and tri-diagonal (banded with bandwidth 3), and is typically solved using tri-diagonal matrix algorithm. It can be shown that the method is unconditionally stable and second order in time and space (Douglas, 1955).

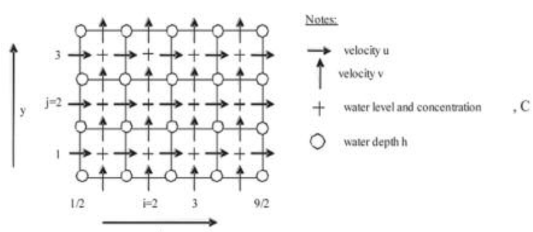

Fig. 2. Computational grid for the governing system of equations

3. Result and discussion

3.1 Verification of the model

There are three verifications: Verification of the tide-induced current, verification of the wave-induced current and verification of sediment transportation.

• Verification of the tide-induced current: Analytical solution for water level and velocity of a wave transmitted in a narrow frictionless channel to the end of the channel and reflect totally (G. Airy, 1845). Figure 3 is the result of the water level at the middle of the channel, blue line stands for the simulation results and the pink one stands for the analytical solutions. The figure shows that there is a good agreement between 2 results.

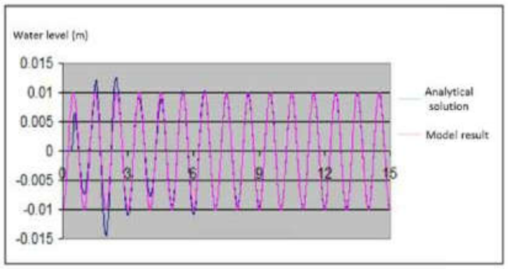

Fig. 3. Water level at the middle of the channel

•Verification of the wave-induced current: the results are presented in figure 4.a and 4.b. The calculated results from the model show that the wave-induced current occurs strongly in the surfzone. The maximal value of velocity V of 0.67 m/s and direction of current are parallel to the shoreline. Compared to the analytical solution (the maximal value of velocity V of 0.64 m/s), a good agreement is observed.

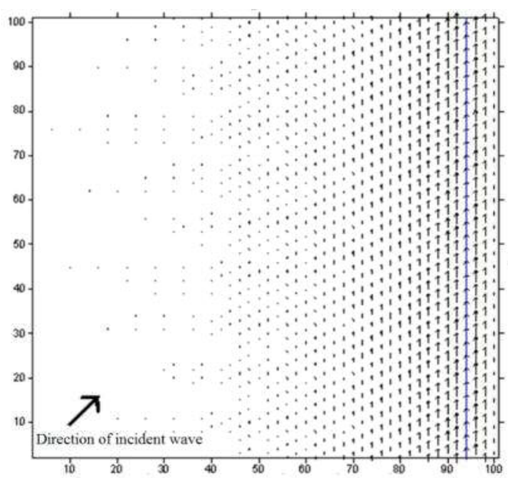

Fig. 4. (a) Alongshore current along the uniform beach computed by the model (angle of incident wave 45^0)

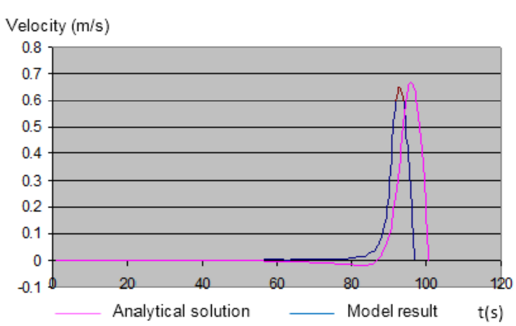

Fig. 4. (b) Velocity in x-direction across the beach.

The above figure represents the vector of the alongshore current. Meanwhile, the below figure shows the velocity values along the x-direction, the comparison between our method and analytical solution.

• Verification of sediment transportation: The simulated results are presented in the form of contour levels at times. The results from the model are good in accordance with the analytical solution. This confirms the reliability of the sediment transport model and the possibility to apply in practice.

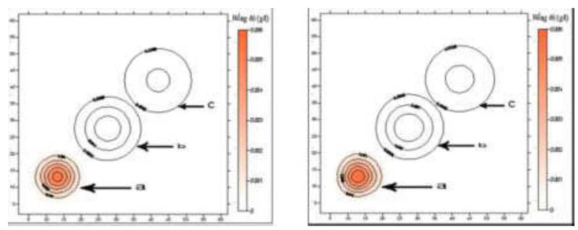

Fig. 5. Comparison of simulated result (left) and analytical solution (right) after (a) 1 hour (b) 3 hours;(c) 5 hours.

3.2 Can Gio coastal area

Can Gio coastal area is located in South of Vietnam (figure 6). The obtained data from our model are evaluated based on the satellite date presented in Vinh and Deguchi (2004).

Fig. 6. Location of Can Gio coastal zone and study area

Simulation results shown in figure 7 illustrate the bed changes of Can Gio coast after 3-month calculation. The agreement between the results by our current modeling approach and satellite data confirms the reliability of the suggested model. In other words, satellite data are served as the validation base for our mathematical model.

Moreover, while satellite data just provides the information on certain local zones at a fixed time of measurement, modeling approach can describe at different series of time, in the past, in the presence and even in the future (predicting and forecasting roles).

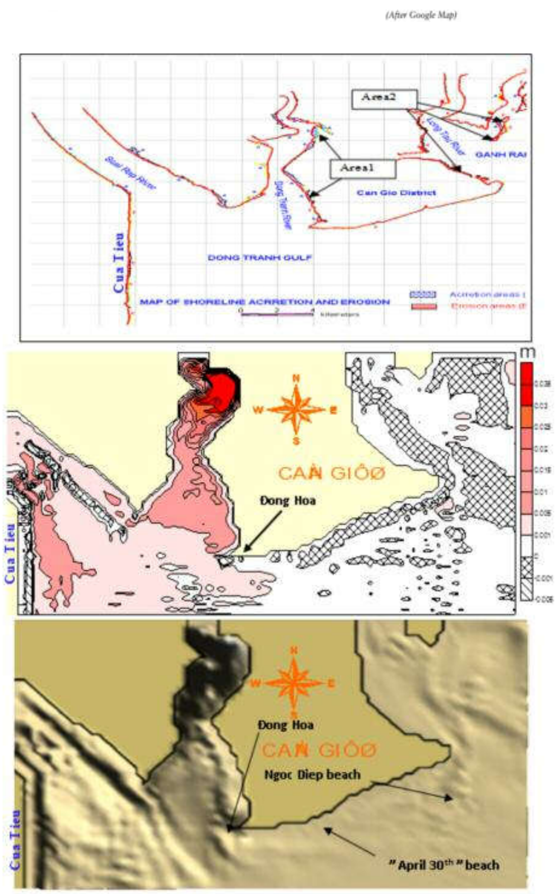

Fig. 7. The bottom topography changes at the Can Gio Coast

It's noted that satellite database (from GIS and remote sensing technology), especially multi-temporal and multi-sensing data provide useful information for coastal monitoring, while the numerical models are now the essential tool for monitoring the changes of near-shore topography, in the shoreline and riverbanks, and offer benefits over the satellite observations.

Figure 7 shows the bottom topography changes at the Can Gio Coast. Where figure 7(a) is results of accretion and erosion location by remote sensing and satellite photo, from 1992 to 2003, figure 7(b) and 7(c) is simulation results after 90 days of calculation (The hatched positions are the erosion zone and the positions which red color changes from light to dark are the accretion zone in (b) and 3D illustration in (c))

This general trend of accretion and erosion in the study area (figure 7) of Can Gio coast obtained from the model corresponds fairly well to the results from the satellite picture presented in Vinh and Deguchi (2004).

3.3 Cua Lap estuary area

Cua Lap estuary is located at the coastal strip from Vung Tau province to Binh Chau province, Vietnam. The shoreline runs from Northeast to Southwest with two cliffs: Nghinh Phong cape and Ky Van cape. This area is strongly influenced by the East Sea tidal regime.

Fig. 8. Location of Cua Lap estuary and study area

The bottom topographic data was obtained from the Cua Lap storm shelter (2009) and the Vung Tau coastal both tomography map (reprinted 1993), with mesh: 340 x 220, $\Delta x = \Delta y = 50$ m.

Simulation results in Northeast monsoon: The results of bed changes are presented in figure 9. In this figure, the color scale from pale orange to dark orange is standing for increasing of erosion. In this area, the velocity is quite high so it generates a force weathering the bottom layer, causing the erosion phenomena in the narrow passage of the river. This area is eroded 4 to 8 cm in depth.In the B area, the current in this season are mainly directed from Cua Lap to Vung Tau, so this area mainly received the sediment from Cua Lap given. Additionally, reducing the gradient of the current velocities due to the friction with the bank that makes the sediment settle in this area. Therefore, the accretion process in this area is mainly. The C area occurs alternately the processes of deposition and erosion. Overall, the level of deposition is larger than the level of erosion so the deposition occurs mainly in this area. In the D area, the calculated results show that the deposition occurs near Cua Lap estuary. The other area occurs mainly the erosion because these areas are not provided the sediment from the river to compensate the amount of sediment lost due to erosion.

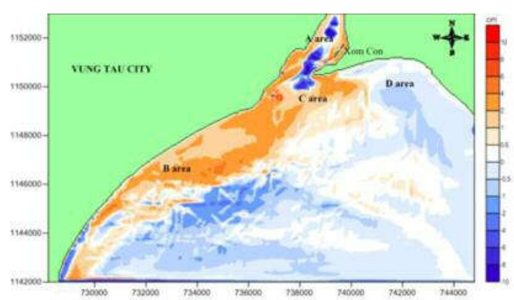

Fig. 9. Bed level change in the Northeast monsoon after 3-month simulated

Simulation results in Southwest monsoon: The deposition and erosion area in the Southwest monsoon are shown in figure 10.In the A area, there are two erosion areas. One is in the narrow passage of Cua Lap River, the other bends according to Xom Con. At the areas of both side bank, decreasing the gradient of the current velocity due to friction make the suspended sediment settling. Therefore, the deposition occurs mainly in these areas. In the B area, due to the influence of southwest wind and wave coming from Southwest, the sediment cannot move to this area. Therefore, the amounts of sediment lost that are not compensate. The erosion is dominant. In the C area, similarly in the northeast monsoon, the area takes place alternately the processes of erosion and deposition. In general, the deposition prevails. In the D area, the deposition is dominant. It is explained that the bottom friction makes reducing the gradient of the current so that the sediment settles in the Xom Con.

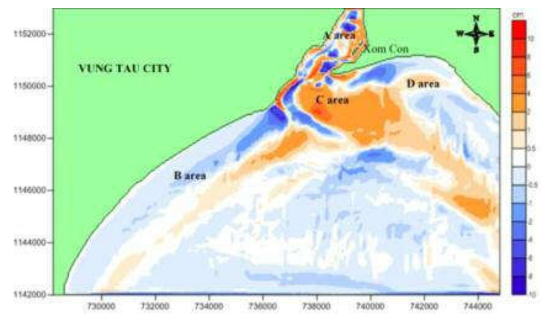

Fig. 10. Bed level changes in the Southwest monsoon after 3-month simulated

The results of bed level change in the Northeast monsoon and Southwest monsoon were compared with the previous research of Sub-Institute of Physics (2000). There are a good agreement in A and C area. In the Thuy Van – Vung Tau area (A area), it happed erosion in Southwest monsoon and deposition in Northeast monsoon. Besides that, the sand dune in front of the estuary (C area) occurred erosion in Northeast monsoon and deposition in Southwest monsoon.

4. Conclusion

The two-dimensional model simulating the current under the influence of the combination of tides, waves, and winds has been developed. The verification of the model shows that the simulated results of the wave-induced current and the tide-induced current area good accordance with the analytical solutions.

The model is applied to simulate water movement, sediment transport, accretion and erosion in Can Gio coastal area and Cua Lap estuary in the Northeast monsoon and Southwest monsoon. The model performs well in reflecting the actually occurring water movements, sediment transport, deposition, and erosion.

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