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Research article

Bottom morphology in Hau estuaries under influences of sediment reduction and climate variation

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ABSTRACT

The erosion and accretion processes happening in the Mekong Delta under the influences of sediment reduction and climate variability have been challenging we are facing. The aim of the study was to simulate the bottom morphology under the influence of river currents and tides in Hau Estuary during the flood season, according to 3 scenarios: the baseline scenario in 2017; the scenario of sea-level rise of 73 cm; and the scenario of reducing sediment 30% in the upper Mekong river by using MIKE 21 FM. Calibration and validation results for hydraulic module (i.e. Water level and flow rate), and sediment transport module (i.e. Suspended sediment concentration) are positively evaluated with data from the Dai Ngai and Tran De hydrologic stations. Thus, the use of the MIKE models is reasonable for simulating and evaluating erosion and accretion trends for all three scenarios. The results show that the erosion and accretion processes are consistent with the velocity distribution of the flow; the accretion trend prevailed over the erosion trend in Hau Estuary. The maximum velocity was distributed in the river bed at the upstream islet bank, with a maximum erosion level of 0.3m. While the accretion occurs primarily along the bank of the islet and on both sides of the river mouth, with the largest extent at the Dinh An Estuary is 0.24m. For the scenario of sea-level rise and reducing sediment, the trends of accretion and erosion did not change much compared to the baseline scenario in 2017. With the sea-level rise scenario, the value of erosion will be decreased, and deposition value will be recorded an increase in the estuary. Regarding the reducing sediment scenario, the islet upstream will be eroded more than the scenario in 2017, on the contrary; the accretion of the river mouth will be reduced.

Key words: Bed change, sediment transport, MIKE 21, erosion and deposition, sea-level rise

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INTRODUCTION

Coastal and estuaries areas are very important to socio-economic development because of their rare resources. However, human activities and climate change issues have caused direct and indirect changes, affecting the hydrodynamic regime and morphological changes (along the coast and seabed) in the coastal areas present. Specifically, sea-level rise (SLR) not only increases flood and inundation risk in low-lying areas but also affects variable sediment regimes in the lower sections of estuaries, increasing the lack of providing sand to the coast leads to a direct increase in coastal erosion. According to the fourth assessment report of the Intergovernmental Panel on Coastal Climate Change, during the past 100 years, the average sea level has risen from 10 to 25 cm. Therefore, the SLR level will also have a huge impact on the long-term coastal morphology [1].

Although many natural causes alter the morphology of the shoreline, most of the effects are due to human intervention in sediment transport and a reduction in sediment supply. In recent times, the presence of dams on the upper Mekong has caused a shortage of sediment downstream, increasing erosion rates and reducing accretion in estuaries. A typical example is that after the Manwan dam in China came into operation in 1993, the sediment volume downstream significantly reduced. Although it was compensated with sediment from other catchment parts downstream, the observed data showed that the average sediment content at Tan Chau, Chau Doc, Can Tho, My Thuan stations decreased by 20 - 30% [2].

Thus, the factor of SLR and changes in sediment transport from large rivers will cause long-standing stable coastal morphology. Specifically, causing the process of fluctuating topography of the bottom, which can cause bottom erosion and shore collapse, leading to increasingly complicated coastal erosion consequences, greatly affecting the marine ecological environment, threatening life in many residential areas, causing damage to coastal constructions.

Soc Trang is a coastal province in the Mekong Delta, located downstream of the Hau River flowing into the East Sea at two estuaries Dinh An and Tran De, with a coastline of 72 km (Department of Natural Resources and Environment of Soc Trang in 2011). Here, due to

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the impact of the exploitation of resources, exploitation of mangrove forests for aquaculture, construction of coastal works, ... along with the effects of climate change, the situation of erosion of the coastline has complicated developments[3,4]. As of February 2020, Soc Trang province had 4 landslides with a total length of 6372 m, of which the erosion of ring dikes in Don Bien Phong An Thanh 3, Cu Lao Dung district was 4222 m; the break of sea dike, section passing Lai Hoa commune, Vinh Chau town was 1600 m[5].

In this study, the MIKE 21 FM model is applied to simulate and evaluate the bottom morphology in Hau Estuary, according to the scenarios in 2017; SLR of 73 cm; and reducing sediment 30%. The achieved results are a premise for the planning of coastal estuarine management.

MATERIAL AND METHODS

Applying mathematical model - MIKE 21 FM model developed by Danish Hydraulic Institute, is the main method in this study. In the Mike 21 FM model, flow process and sediment transport are calculated based on the momentum and continuity equations, as well as the sediment transport function which is cover stream function and bottom change relied on the gradient of sediment and the continuous bottom sediment equation[6,7].

Data acquisition

Study Area

The study area is expanded to include: from Can Tho hydrological station on Hau river to the coastal area of Tra Vinh and Soc Trang provinces with a coastline of 100 km and the distance from the coast to the offshore 60 km, in which topography, boundaries and hydrological stations for calculation in the model as shown in Figure 1.

To simulate relatively accurately the coastal bottom topography, unstructured mesh suitable for complex coastal terrain is selected. Mesh for the model is set up in Mesh Generator with 21145 elements and 11229 nodes. The distance between the nodes in the offshore area is 400 m, the estuary area is 200 m, the area in the river is 100 m.

Shoreline and bathymetry's data

For the shoreline, data was established in 2017 on the Google Earth software and digitized using ArcGIS software. The bathymetry data in 2010 was provided by Bay N (2017-2021)[8].

Hydraulic model boundary data

Upstream boundary: The hourly discharge data in 2012 and 2017 at the Can Tho hydrological station (Hau river) were collected at Southern Regional Hydrometeorological Center (SRHC);

Downstream boundaries: Boundary 1 (near the mouth of the Cung Hau river - Tra Vinh province); Boundary 2 (to the boundary of Bac Lieu province) and Boundary 3 have been taken from Tide Predictions of Heights in MIKE 21 Toolbox;

In addition, the hourly water levels data were collected at SRHC in 2012 and 2017 in two hydrology stations of Tran De and Dai Ngai will be using for model calibration and validation.

Sediment transport model data

Suspended sediment concentration (SSC): Data were collected at SRHC each day in 2012 and 2017 at Can Tho station, used as model input conditions. In Dai Ngai and Tran De station, it's extracted from Bay N (2017-2021)[8] and used for model calibration/ validation.

Geological data and grain size fractions: refer to the documentation and use from the Research topic by[9].

Wind data

Wind data used in the topic are average wind speed for many years (constant) and prevailing wind direction with four main months (January, April, July, October) at Soc Trang station from 1980 - 2010 was a reference from Vietnam's Atlas.

Model setting

The methodological framework in this study is described in Figure 2.

Modeling scenarios.

To simulate the bottom morphology during the flood season from July to November for the study area, under the impact of factors such as reducing sediment and sea-level rise, three scenarios were built, including:

SC1: Baseline scenario – Simulation of the hydraulic regime and sediment transport in 2017.

SC2: SLR 73 cm – Simulation with SLR is 73 centimeters (refer to Climate change and sea-level rise scenarios for Viet Nam were released by the Ministry of Natural Resources and Environment in 2016 and choose SLR under RCP8.5 scenario).

SC3: Reducing sediment – Simulation with reducing sediment by 30% in the upper Mekong River[10].

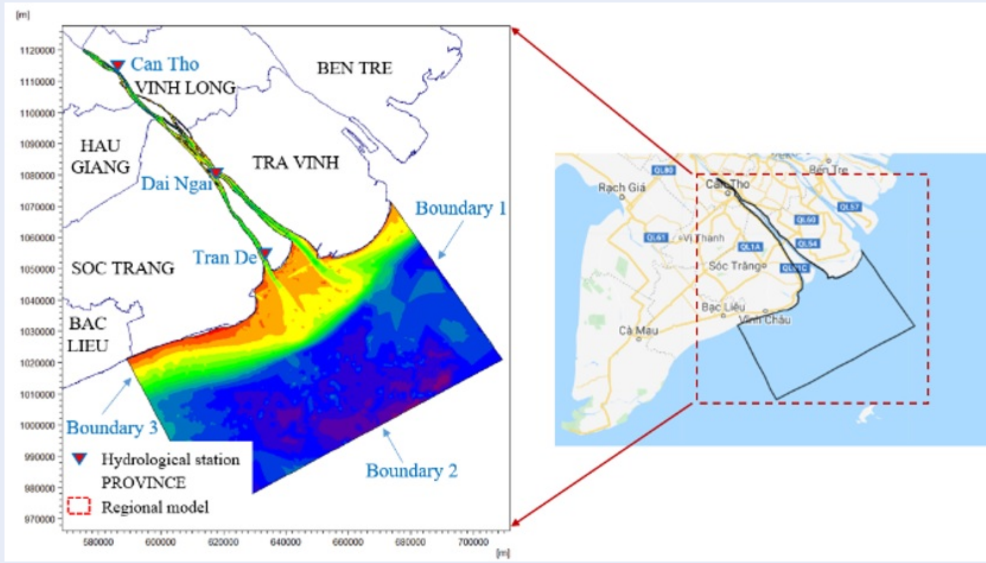

Figure 1: Study Area.

RESULTS AND DISCUSSION

Model calibration/ validation.

The hydrodynamic and mud transport models were firstly calibrated with observation data of water level and extraction data from [9] of the flow velocity and SSC from October 1, 2012, to October 30, 2012. Subsequently, the model was validated at the same time in 2017. Hydrological stations used for model calibration/ validation are presented in Figure 1.

The model Mike 21 FM HD with Manning number may be used as calibration parameters in the modeling. For MT model was calibrated by adjusting the critical shear stress for deposition τ_{cd} (N/m^2); the erosion coefficient E (kg/m^2/s); the critical shear stress for erosion τ_{ce} (N/m^2) and the bed roughness k_n (m).

The model performance was assessed using statistical indices [11], including: (1) Nash-Sutcliffe Efficiency (NSE) and Correlation coefficient (R^2) used for assessing the model performance in the flow simulation, and (2) percent bias (PBias) used for assessing the model performance in the simulation of suspended sediment.

The calibration and verification results of water level, flow velocity, and total SSC are presented in Table 1 and Table 2.

The hydraulic model was calibrated with NSE and R^2 ratios given good results (NSE>0.7 and R^2>0.75 for all stations). However, the velocity results performance evaluated as satisfactory with NSE>0.50 at Dai Ngai station and still had a good correlation (NSE>0.79 and R^2>0.80) in the remaining time. The sediment transport model was calibrated by the mean error in the condition that the values are less than 10% for each station. So that, the hydraulic and sediment transport models were reasonable to simulate and to evaluate the trend of erosion for this study.

Hence, the input parameters of the hydraulic and sediment model will be established after the calibration and validation process are:

MIKE 21 FM HD: Manning coefficient values ranging from 20 to 45 (m$^{1/3}$/s).

MIKE 21 FM MT:

- **Constant settling velocity** (m/s): w_s = 2.5 x 10^{-5} (clay), w_s = 0.001 (silt), w_s = 0.02 (fine sand). **Grain size fractions** (mm): 0.005 (clay), 0.0275 (silt), 0.15 (fine sand). **Water column parameter**: The critical shear stress for deposition: τ_{cd} = 0.1 N/m^2. **Bed parameters**: the erosion coefficient: E = 2x10^{-6} (kg/m^2/s); The critical shear stress for erosion: τ_{ce} = 0.25 N/m^2; Bed roughness (m): k_n = 0.0001.

Flow simulation results and bottom morphology.

After calibration, the model has applied to simulate for four months of the flood season in 2017. The calculated area is divided into two segments for analysis including Seg.1 is from the top of the islet to estuaries, Seg.2 from the estuary to the sea at a depth of 6 meters, and the area does not consider the location along the shore. The results analysis area is shown in Figure 3.

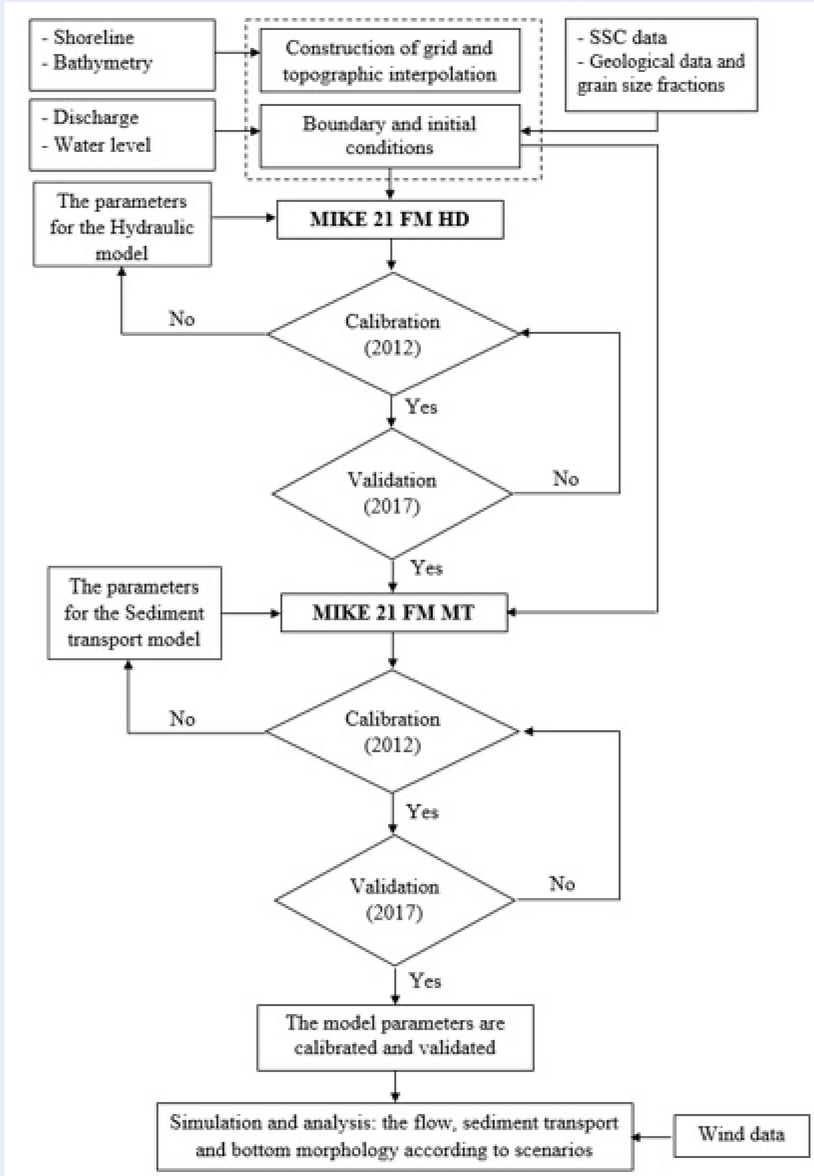

Figure 2: The schematic framework of research methodology.

Table 1: The water level and flow velocity results of calibration and validation at various stations.

Stations		Calibration (2012)		Validation (2017)	
		NSE	R2	NSE	R2
Dai Ngai	Water level	0.50	0.90	0.78	0.88
Tran De		0.86	0.91	0.87	0,92
Dai Ngai	Velocity	0.52	0.93	0.54	0.92
Tran De		0.90	0.94	0.85	0.87

Table 2: The total SSC results of calibration and validation at various stations in the study area

Stations	Calibration (2012)	Validation (2017)
	PBias (%)	
Dai Ngai	0.11	0.60
Tran De	0.78	1.52

Results of the simulation of the current direction and velocity field are shown at the time of the strongest ebb current and the strongest flood current. For velocity results, the color scale from dark to light is standing for the velocity value from large to small.

Total bed thickness change after 4 months simulations in 03 scenarios was presented below representative for deposition process with the scale from light to dark-blue color shows the level of accretion from less to much, the red scale from dark to light shows the rate of erosion from more to less.

Current field

a) Flood current

The velocity distribution in Seg.1 (Figure 4a) during the flood current shows that the tidal current is influenced by the flow in the river: The inlet tidal current velocity is quite small from 0.2 – 0.3 m/s. Meanwhile, at the top of the islet, the flow velocity from upstream is strong, so the impact on the shoreline is from 0.5 – 0.7 m/s. Out to the middle of the islet, the tidal currents and the river flow interact with each other, so the velocity tends to be eliminated, fluctuating in the range 0.01 – 0.05 m/s.

In Seg.2 (Figure 4b), the common velocity of the whole area is about 0.1 – 0.35 m/s: Nearshore velocity fluctuates below 0.1 m/s. Midstream of the two estuaries, the velocity was greater from 0.3 – 0.5 m/s, because of the considerable riverbed depth.

b) Ebb current

The velocity distribution in Seg.1 (Figure 5a) during the ebb current shows that the value of the whole area is in the range of 0.5 – 0.8 m/s, of which the maximum speed reached 1.0 – 1.4 m/s at branch 2 and was distributed in midstream of riverbed at the top of the islet. Because of small islets at the top of branch 1, the flow axis was dispersed and more likely to move toward branch 2. In addition, at branch 1, the highest velocity at the top of the small islet is 1.03 m/s (circled position) and at the narrow passage is 1.02 m/s.

In Seg.2 (Figure 5b), the velocity of distribution in the whole area is about 0.1 – 0.4 m/s, in which: the area close to the shore, the speed is not high, below 0.1 m/s. The midstream in two estuaries (Dinh An and Tran De) has a higher value compared to the whole region (from 0.7 – 0.8 m/s) and reaches the highest velocity of 0.82 m/s and 0.85 m/s corresponding, due to the influence of topography.

In general, from calculation results, the velocity distribution from the islet to the Hau river mouth during flood current is mostly similar to that of the ebb current, but the value is smaller. It can be seen that, during the flood season with large discharge, the flow velocity distribution clearly shows the dominance of the river flow from upstream. In addition, the flow tends to distribute and reach the highest velocity in the river bed at the islet's crest and midstream in two estuaries of Dinh An and Tran De. Terrain depth also affects the flow rate.

Bottom morphology

a) Baseline scenario

The result of bed level change (Figure 6a) shows that the accretion trend occurred mainly in the area along the riverbank (about 0.05 – 0.1 m). Due to the large upstream discharge, the flow velocity in the river is strong and tends to move to branch 2. Therefore, the high-velocity distribution made the crest of the islet more eroded in the middle of the river bed, with levels up to 0.3 m.

In Figure 6b, the estuary area has an accretion trend mainly in the middle of the islet's shore and along two sides of the river mouth, with the level from 0.03 – 0.13 m, in which the highest accretion along Tran De and Dinh An is 0.14 m and 0.24 m corresponding. Furthermore, in the middle of Dinh An estuary, erosion occurred with a rather small level of about 0.02 – 0.03 m.

b) Sea level rise scenario

The bed level change under the SLR 73 cm scenario from Figure 7 shows that the result is similar to that in the baseline scenario, but tends to be more accretion and less erosion.

In Seg.1 (Figure 7a), the accretion trend appears more with the average level from 0.02 – 0.03 m, and the largest level of 0.16 m in the area along the riverbank. Erosion trend still occurs at the top of the islet in the middle of the riverbed due to strong flow velocity, with a rate of 0.05 – 0.16 m.

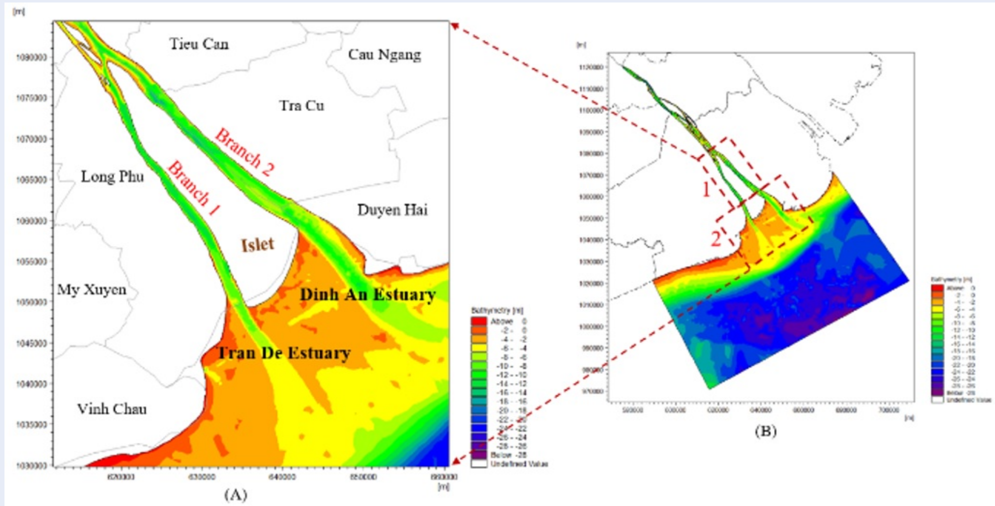

Figure 3: Results analysis area (A: detail areas used to present results, B: limits the simulation area to 2 segments).

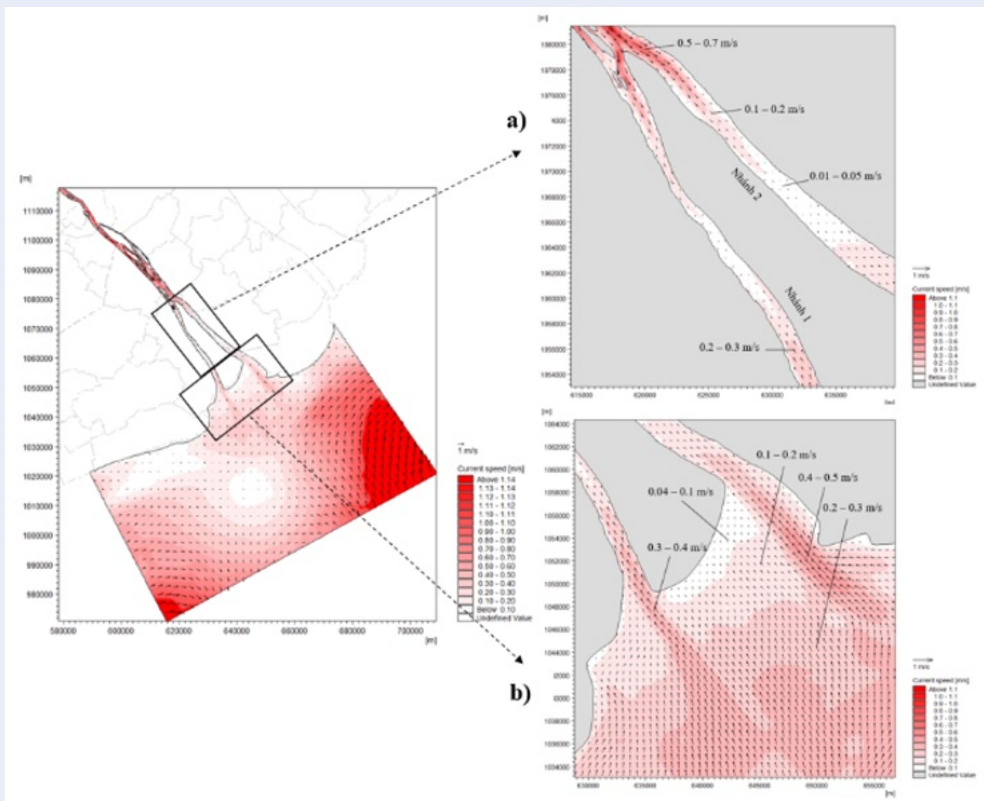

Figure 4: Current speed during flood current.

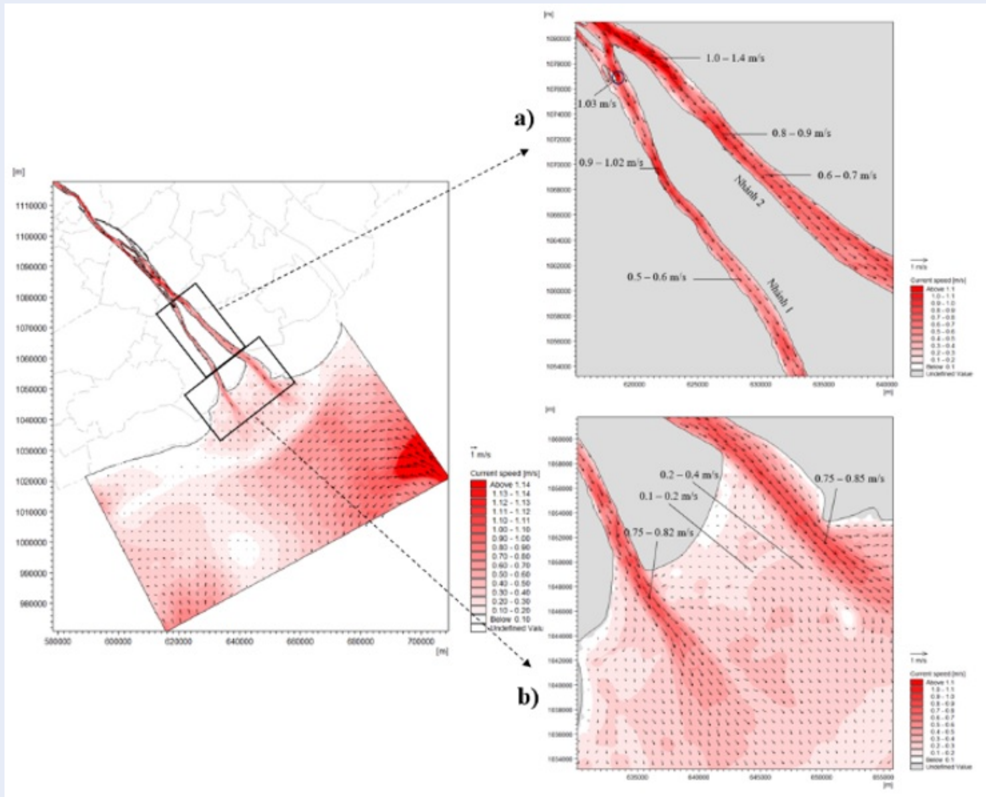

Figure 5: Current speed during ebb current.

In Seg.2 (Figure 7b), the accretion trend is dominant with levels from 0.01 – 0.03 m in two river branches, and in the middle of the islet's shore, the level is up to 0.17 m. In addition, along the shores of Tran De and Dinh An estuaries, the highest accretion rate of 0.19 m and 0.35 m corresponding.

c) Reducing sediment scenario in the upper Mekong river

The bed level change under the reducing 30% of sediment scenario from Figure 8 shows that the result is similar to that in the baseline scenario, but tends to be more erosion and less accretion.

In Seg.1 (Figure 8a), showing clearly the erosion trend at the tip of the islet in the middle of the riverbed between 0.1 – 0.5 m. Besides, the accretion trend is much along the banks of the two branches with the level from 0.03 – 0.1 m.

In Seg.2 (Figure 8b), the accretion trend still appears mainly in the middle of the islet's shore between 0.04 – 0.1 m. In which, the highest level was 0,1 m and 0,7 m corresponded with along the estuaries of Tran De and Dinh An rivers.

In summary, the calculated results of bottom morphology in 03 scenarios are quite consistent with the results of the calculation of flow and the accretion trend prevailed over the erosion trend in Hau Estuary, this is consistent with Trung *et al.* (2014)[3]. Thereby, it can be seen that the sediment transport process is strongly influenced by the river flow from upstream. For the baseline scenario, due to the large discharge from upstream, so the flow velocity is stronger and provides more sediment. The highest velocity is distributed at the tip of the islet and causes erosion along the flow axis in the middle of the riverbed with the largest level being 0.15 m; Out to the coastal area, the flow velocity concentrates mainly in midstream of Tran De and Dinh An estuaries, with little impact on the shore, so the level of accretion shows much along with the river mouth and middle of the islet's shore; Especially, the most accreting area along with the Dinh An estuary with a level of 0.24 m.

CONCLUSIONS

By using the mathematical modeling method, specifically the MIKE 21 FM model with HD and MT modules, the authors applied the model to simulate the hydrodynamic regime and alluvial convey in Hau Estuary in Soc Trang province. From there, it is possible to

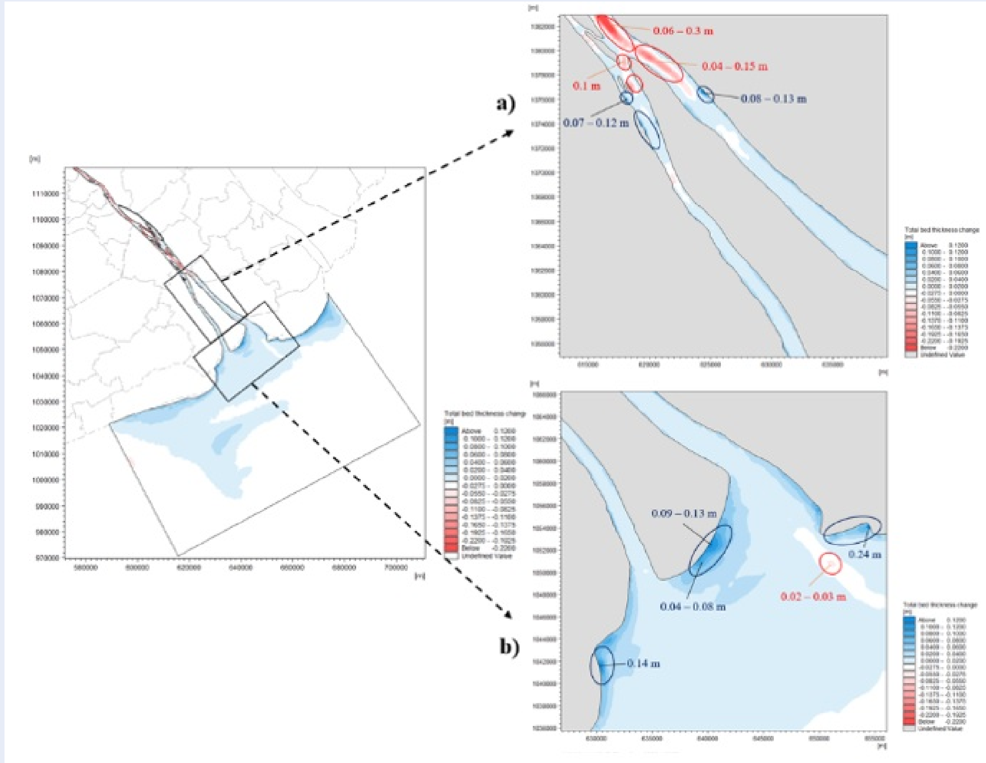

Figure 6: Bed level change in Hau Estuary after 4 months of flood season – SC1.

analyze the bed level change according to the scenarios. The results of hydraulic and sediment transport verification show a good correlation at Dai Ngai and Tran De stations, ensuring the reliability to simulate the bottom morphology in flood season. The bed level change under the scenario of SLR 73 cm and reduction of sediment by 30% in the Mekong River does not change much when compared with the baseline scenario, only showing an increasing or decreasing trend of accretion and erosion.

From the simulation results, SLR increases the level of accretion in the estuary area; In the river, it reduces erosion at the tip of the islet. For example, for the coastal area of the Mekong estuary, Vu *et al.* evaluated the effect of SLR on the bottom topography through cross-section at estuaries [12]. The results show that the SLR slightly reduces the erosion rate in the coastal area outside the Co Chien, Cung Hau, and Tran De estuaries: In the area outside the Tran De estuary, the water level rise is a factor increasing accretion speed at the alluvial ground at the river mouth, limiting sediment flow from the continent to move out to the sea, but focusing on moving and depositing at the mouths.

As for the effect of the lack of sediment in the upstream Mekong due to the construction of structures, the erosion rate increased at the top of the islet lead to the accretion decreased in the area along the banks of two estuaries and middle of the islet. This trend is completely understandable because the Mekong Delta has begun to be deposited with alluvium from the Mekong River, originating from river and swamp deposits [10].

COMPETING OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptualization: T.T.K., N.T.B.; Methodology, T.T.K., N.K.P., N.T.B.; Software: T.T.K., T.N.Q.N., N.T.T.M.; Validation: T.T.K., T.N.Q.N., N.T.T.M.; Formal analysis: T.T.K., N.T.T.M.; Investigation: T.T.K.; Resources: T.T.K., N.T.B.; Data curation: N.T.B., T.T.K, T.N.Q.N.; Writing–original draft preparation: T.T.K., N.T.T.M.; Writing–review and editing: T.T.K., N.T.T.M.; Visualization: T.T.K., N.T.T.M.; Supervision: N.K.P., N.T.B.

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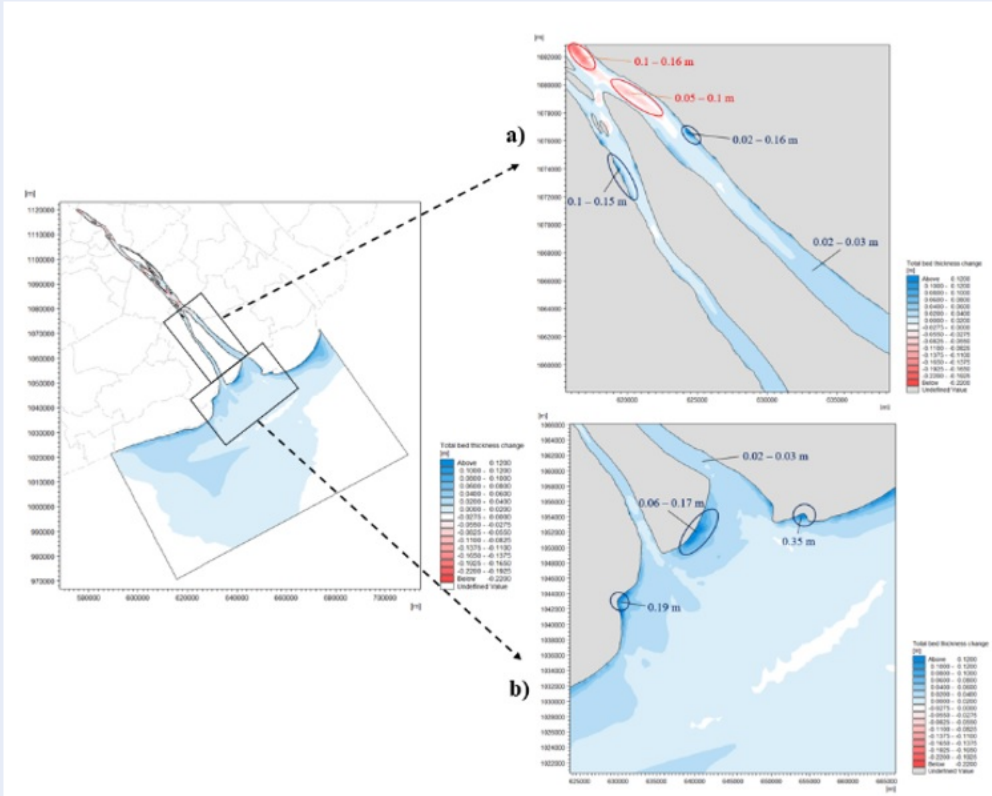

Figure 7: Bed level change in Hau Estuary after 4 months of flood season – SC2.

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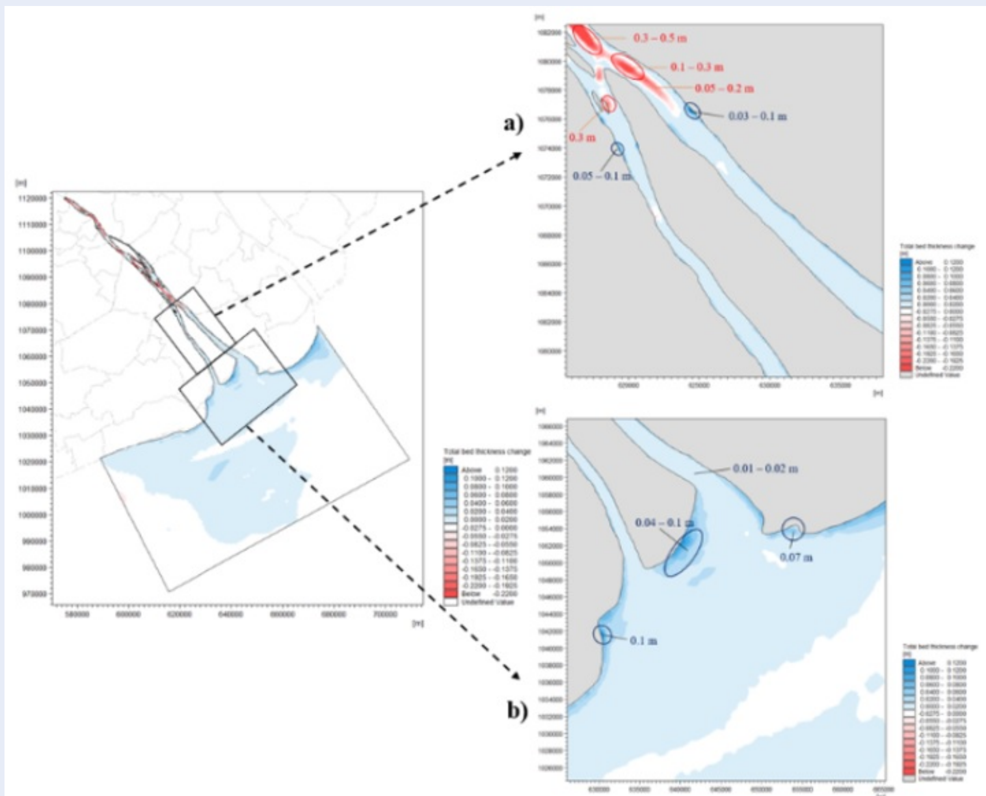

Figure 8: Bed level change in Hau Estuary after 4 months of flood season – SC3.

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Bài nghiên cứu

Mô phỏng diễn biến đáy khu vực cửa sông Hậu dưới tác động của sự thiếu hụt bùn cát và biến đổi khí hậu

Trần Thị Kim[1,2], Trà Nguyễn Quỳnh Nga[3,4], Nguyễn Thị Thanh Minh[1], Nguyễn Kỳ Phùng[5], Nguyễn Thị Bảy[3,4,*]

TÓM TẮT

Quá trình xói lở và bồi tụ xảy ra ở Đồng bằng sông Cửu Long dưới tác động của việc giảm phù sa và biến đổi khí hậu đã và đang là thách thức mà chúng ta phải đối mặt. Mục tiêu của nghiên cứu này là mô phỏng diễn biến đáy dưới tác động của dòng chảy và thủy triều tại cửa sông Hậu trong mùa lũ, theo 3 kịch bản: Kịch bản hiện trạng năm 2017; kịch bản nước biển dâng 73cm; và kịch bản thiếu hụt bùn cát 30% trên thượng nguồn sông Mekong bằng mô hình MIKE 21 FM. Kết quả hiệu chỉnh và kiểm định module thủy lực (yếu tố mực nước và vận tốc dòng chảy), và module vận chuyển bùn cát (nồng độ bùn cát lơ lửng) được đánh giá là khả quan với dữ liệu từ các trạm thủy văn Đại Ngãi và Trần Đề. Do đó, việc sử dụng mô hình MIKE là hợp lý để mô phỏng, đánh giá xu hướng xói lở và bồi tụ cho cả ba kịch bản. Kết quả cho thấy các quá trình xói lở và bồi tụ khá phù hợp với sự phân bố vận tốc dòng chảy; xu hướng bồi chiếm ưu thế so với xu hướng xói ở khu vực cửa sông Hậu. Vận tốc đạt giá trị lớn nhất phân bố ở giữa lòng sông tại đầu bờ cù lao với mức độ xói lớn nhất là 0,3m. Trong khi đó, sự bồi tụ xuất hiện chủ yếu dọc bờ cù lao và hai bên cửa sông, với mức độ lớn nhất tại ven bờ cửa sông Định An là 0,24m. Đối với kịch bản nước biển dâng và thiếu hụt bùn cát, xu hướng bồi xói không thay đổi nhiều so với kịch bản hiện trạng năm 2017. Với kịch bản nước biển dâng, mức độ xói lở giảm xuống và mức độ bồi tăng lên ở các cửa sông. Ngược lại, ở kịch bản giảm phù sa thì bờ cù lao phía thượng nguồn sẽ bị xói lở nhiều hơn so với kịch bản năm 2017; và sự bồi tụ sẽ giảm ở cửa sông.

Từ khoá: Diễn biến đáy, vận chuyển bùn cát, MIKE 21, xói lở và bồi tụ, nước biển dâng

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Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 75%
Phí xuất bản: Miễn phí
Thời gian phản biện: 30-45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit

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Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 65%
Phí xuất bản: Miễn phí
Thời gian phản biện: 45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit

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Phí xuất bản: Miễn thu phí đối với tác giả là CBVC của ĐHKHXHNV, ĐHQG-HCM; Tác giả khác: 500.000 VNĐ/bài
Thời gian phản biện: 75 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit

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Ngôn ngữ bài báo: Tiếng Việt và tiếng Anh
Tỉ lệ chấp nhận đăng 2021: 87%
Phí xuất bản: liên hệ tòa soạn
Thời gian phản biện: 45 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit

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Hình thức truy cập: Truy cập mở
Ngôn ngữ bài báo: Tiếng Việt
Tỉ lệ chấp nhận đăng 2021: 70%
Phí xuất bản: Miễn phí
Thời gian phản biện: 30 ngày
Lập chỉ mục (Indexed): Google Scholar, Scilit

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