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Effects of hydrodynamical regime on morphological evolution at Cua Dai estuary and coastlines of Quang Nam province

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ABSTRACT

In recent years, accretion-erosion processes are frequently recorded in the estuary of Cua Dai, Quang Nam province. Most recently, however, sand bars are formed in the estuary not far from the place where the Inland Waterways Authority of Vietnam had previously dredged. The estuary continues to be accreted by sand. These have been drawing special attention of national and international scientists. While there is accretion at the estuary, eroded processes are strongly recorded along the coastlines of Quang Nam province. Therefore, it is necessary to carry out a study in the effects of the hydrodynamic regime on morphological changes in the Cua Dai estuary and coastlines of Quang Nam province. The goal of this paper is to fully interpret the causes, regimes of accretion and erosion processes over the study area. In this study, satellite images and hydrodynamic models of Delft3D and MIKE 11 are applied. The results show a strong accretion process in the estuary of Cua Dai. Sandbar formation across the Cua Dai estuary comes from the interaction of flood, wave, and current conditions during the northeast monsoon. This mainly affects the changes in morphology in the estuary of Cua Dai, Quang Nam.

Keywords: Cua Dai; Quang Nam; MIKE, DELFT3D; accretion; erosion; estuary; bar formation.

1. Introduction

Machine learning, which is a part of the morphological evolution generally depends on many factors (e.g., wave action, grain size, and made-man activities). Birkemeier et al. (1987) showed most onshore volumetric loss of sediment immediately after storms for the sites on the U.S. Gulf and east coasts. Previously, Midun (1988) stated an interaction between natural processes and interference of nature by humans caused the natural phenomenon of coastal erosion. Massimo et al. (2008) used Delft3D system (Deltares, 2011a) to study the fluvial erosion and investigate how temporal evolutions of hydrodynamic processes. To date, this system is widely applied in researches in hydrodynamic, sediment transport and wave modeling (Van 1993, 2007a, b, c; Van et al., 2007). Interaction of waves and tides are considered in Katama Bay using the combined models of Delft3D-FLOW and SWAN. These studies indicated the good reproduction of waves and currents. It is, however,

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noteworthy that these studies mostly emphasize the regions where are dominated by physical processes at a large scale. MIKE system (DHI, 2005) is introduced and widely applied in several studies (i.e., Graham and Butts, 2005; Kamel, 2008; Thompson et al., 2004; Warren and Bach, 1992). The uncertainty, however, strongly depends on a large range of data requirements and parameter values (Merritt et al., 2003). In other words, there is a need to further investigate the performance of the MIKE system for the estuary and coastal areas in the tropics like Vietnam where the coastal dynamic regime is very unstable. Coastal zones of Vietnam, most recently, human activities and natural environment changes lead to an imbalance in the coastal processes, changes in dynamic actions (e.g., currents, waves, and winds) and sediment transport. For this, so far, only a small number of studies are considered (Nguyen et al., 2014; Yoshihiro, 2002).

Recently, national and international projects dealing with the hydrodynamic processes for the coastal zone of Vietnam are implemented (e.g., KHCN.06.08 (1996-2000), KC.09.05 (2001–2005) or Hong, 1997). Located in the central region of Vietnam, provinces from Quang Nam to Da Nang are frequently affected by natural disasters (e.g., floods, tropical cyclones or thunderstorms). In the context of climate change, especially, they are more and more complicated and unpredictable. As shown in Digregorio (2015), typhoons are shifting south and the number arriving at the coast of Vietnam is increasing. Plus, The northeast monsoon is arriving 10–15 days later than it did in the 1980s. This could lead to more erosion, resulting in more extreme wave conditions (Digregorio, 2015). Besides that, due to the complexity of geological structure divided by estuaries and lagoons along the coastline of Vietnam, hydrodynamic processes are becoming more complex and closely related to natural dynamical processes (e.g., waves, nearshore currents and sediment transport) and human activities. All these have negative consequences for the different sectors of agriculture or tourism and the safety of the people in the provinces of Quang Nam and Da Nang. The morphologic changes in the estuary of Cua Dai are observed from several publications (e.g., Cham et al., 2019; Cham et al., 2020; Dang & Nguyen, 2020; Asplund, 2018). It is illustrated that the erosion process expects to strongly occur in the Duy Hai commune belonged to the Cua Dai ward with a length of over 1000 m. In collaboration with partners from Indian, the project of "Research and Prediction the accretion and erosion processes for Vietnam coastal zone" is implemented under the leader of the project by Le (2003) with the emphasis of Hoi An coastal zone, Quang Nam province. The study produced a series of topographic maps and coastline collection at the mouth of Thu Bon river. Recently, Duy et al. (2016) introduced a new method to determine the diffusion coefficient expressing time scale shoreline change based on the propagation of the erosion waves for the Cua Dai estuary. Plus, Duy et al. (2017) analyzed the erosion situation of Cua Dai Beach in the current years for central Vietnam using Google Earth images. Generally, these studies showed the primary stage of morphological evolutions in the estuary of Cua Dai, Quang Nam but missing the geo-hydrodynamical effects with an application of the numerical model and its advantages like continuously hydrodynamic simulations. Hence, it is urgent importance to further study the effects of the hydrodynamic regime on morphologic evolutions in the estuary of Cua Dai, Quang Nam province.

2. Materials and Methodology

2.1. Materials

A study area, Cua Dai beach, is presented as shown in Fig. 1. It is located in Hoi An City, Quang Nam province (108°2′–108°25′E and 15°51′–15°54′N). The estuary is the boundary of the Thu Bon River system with the Eastern Sea of Vietnam to the east. The Cua Dai estuary has a total basin area of about 10,350 km^2, which is flat along the coast and elevated to the west. Before the water flows into the Cua Dai estuary, the water collecting from other main rivers (i.e., Vu Gia and Truong Giang) is added into the Thu Bon River. The Thu Bon has a total length of about 189 km, and the total annual discharge of approximately 21.1 billion m^3. The river catchment has two distinct seasons of rainy season (from September to December) and dry season (from January to August) with a total annual rainfall ranging from 2000 to 2500 mm. In this study, the sources of data come from (i) Topographic map under the projection of UTM surveyed and edited by the authors in the national project code of KC.09.03/16-20 in 2017 on a 1:10.000 scale map for Cua Dai and its surround. (ii) Topographic map for the offshore is on a 1:50000 scale map. (iii) Re-analysis wave data are available from the Climate Prediction Center (CPC)/National Oceanic and Atmospheric Administration (NOAA) of United States of America from 1979 to present (https://www.noaa.gov/). (iv) the wind and pressure fields are collected from the NCEP/NCAR reanalysis dataset from 1979-present (http://esrl.noaa.gov). Specially, the river discharge and water turbidity are extracted from the output of MIKE 11. They are considered to be the input data for Delft3D model. Sediment grain sizes are analysed from the field-works in 2017 with average size of 0.32 mm. The equipment of AWAC installed at the point of 108°24'E, 15°53'E (Fig. 2) is to measure the wave characteristics and water level. These data are used to calibrated and validated the model simulation.

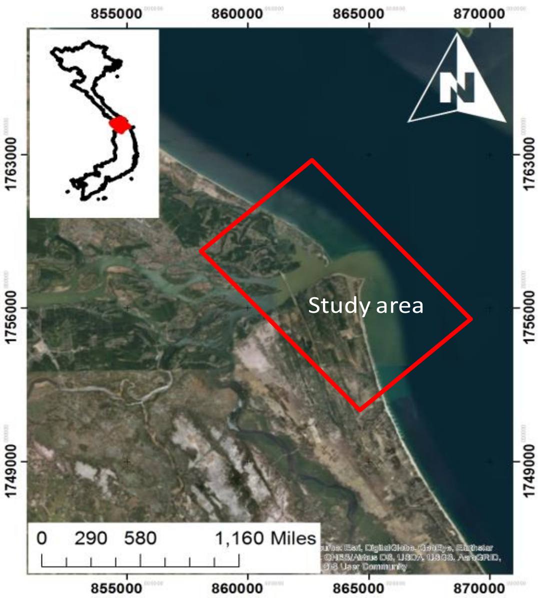

Figure 1. Study area

2.2. Methodology

2.2.1. MIKE hydraulic modeling system

The MIKE is an implicit finite difference model for one dimensional unsteady flow computation and can be applied to simulate the surface runoff, flow, sediment transport, estuaries, water quality or floodplains (DHI, 2015). For this study, MIKE 11HD package is applied. A detailed description of this model with the parameters can be found in DHI (DHI, 2015). The upstream boundary condition is discharge computed at the8 tributaries using rainfall-runoff model (*i.e.*, Nedbor-Astromnings-Model (NAM))coupled with MIKE 11. The NAM model indicates as a module of MIKE 11 under the name of MIKE-NAM. The output of NAM (*i.e.*, discharge) is used to compute the hydraulic boundaries. This model was originally developed by the Department of Hydrodynamics and Water Resources at the Technical University of

Denmark. This is a conceptual model, describing the physical characteristics of the basin, on the basis of which it calculates rainfall flows. The NAM is the conceptual hydrological model with concentration parameter. Its parameters and variables present the mean values for the entire basin. At present, the upstream area of Thu Bon river system has main 8 hydro-dams causing the reduction of sediment to the river mouth of Cua Dai. From the simulations of MIKE 11, for this area, the sediment from the river could be reach up to over 700000 m^3 (in 2009) and over 500000 m^3 (in 2017). On the basic of the different methods, meanwhile, Fila et al. (2016) estimate the different sediment for catchment area (600000 m^3/year), bed slope (440000 m^3/year) and sediment concentration (390000 m^3/year). This very like come from different approaches applied.

2.2.2. Delft3D system

A process-based numerical model system, Delft3D (Deltares, 2011a) primarily designed with a focus on applications of water flow and quality, is applied in this study. The ocean forcings (*i.e*., tidal, wave actions and sediment transport) is simulated using Delft3D model. To be more specific, a couple of Delft3D-FLOW and Delft3D-WAVE using SWAN (Delft, 2011; Deltares, 2011a, b) is applied to take into account the influences of tides, wave forcing and river discharge. The FLOW model is the hydrodynamic component of Delft3D with a three dimensional hydrodynamic and transport simulation program. It is applied to solve the depth-averaged non linear shallow water equations for non-steady flows. Simulations of hydrodynamic, sediment transport changes are computed. The WAVE model is also a component of Delft3D with two available modules of HISWA (Holthuijsen, 1989) and SWAN (Delft, 2011) as the second and third generation wave model, respectively. In this study, SWAN model is applied for wave propagation and transformation in near-shore.

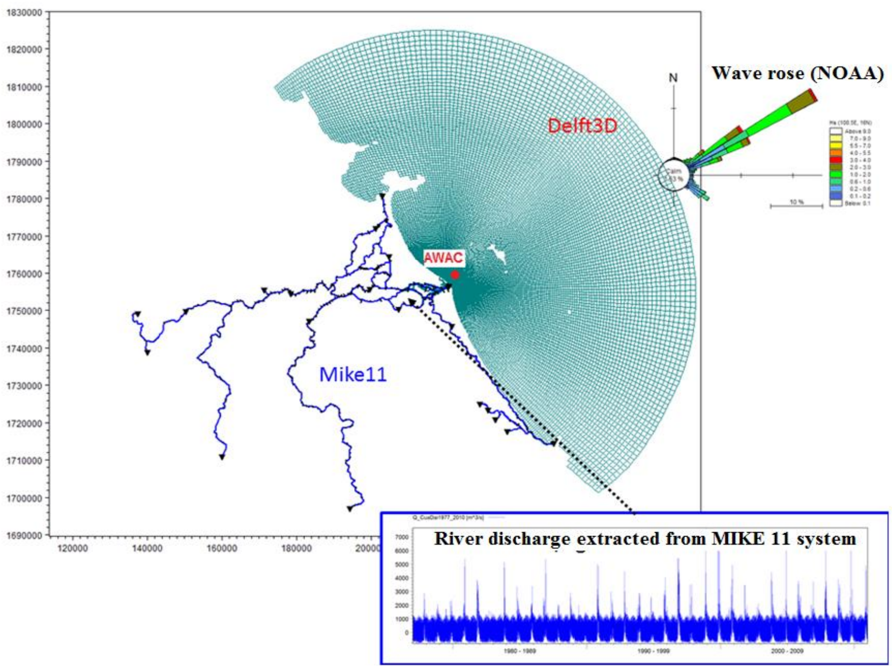

Figure 2. Model domain and computational grid

Modules of RGFGRID and QUICKIN combined within the Delft3D system are used to create smooth, orthogonal curvilinear grids and interpolate the topographic data. Fig. 2 shows the model domain, computational grid, bathymetry at the estuary. The seaward open boundary forcings are assumed to be astronomical tides. Based on the global ocean tide model TPXO 8.0 (Egbert, 1994), ten tidal constituents of Q1,O1, P1, K1, M2, S2, K2, N2, MF, MM are found to be dominant in the area and are used as the open boundary conditions of the model. Importantly, the boundary conditions of wave model are deep-water wave parameters (i.e., significant wave height, peak wave period, mean wave direction) from WAVEWATCH III model (Tolman, 2002). For simulations of sediment transport, the parameters automatically adopted from Van Rijn are used (Van, 1984, 1989; Van, 1993; 2007a).

3. Results

3.1. Calibration and validation of model simulation

The model simulations are calibrated and validated in 2017. It is observed that during the year 2017, the beach of Cua Dai is strongly opened. In the field surveys during 2017-2018 and updated in May 2019, more importantly, the topography maps used to compare with the model simulations are produced. Plus, the satellite images snapshotted the formation of sandbars is used to verify the performance of model simulations. Thus, the period is selected to calibrate and test the performance of models. It is notable that only the outputs of Delft3D (wave height, wave period, wave direction, current speed, and direction measurements) are calibrated and validated. An assumption of the output ofMIKE system used as the inputs for Delft3D is significantly acceptable. The results from the model are also against the satellite images. As the first step, model calibration and validation are performed for variables of wave height, wave period, wave direction, and current speed and direction measurements. As shown in Fig. 3, the results of the comparison between the measurements and calculations show quite good results. The calculated data fit well the observation and field surveys. The nash index reach from 0.9 to 0.92 for all cases.

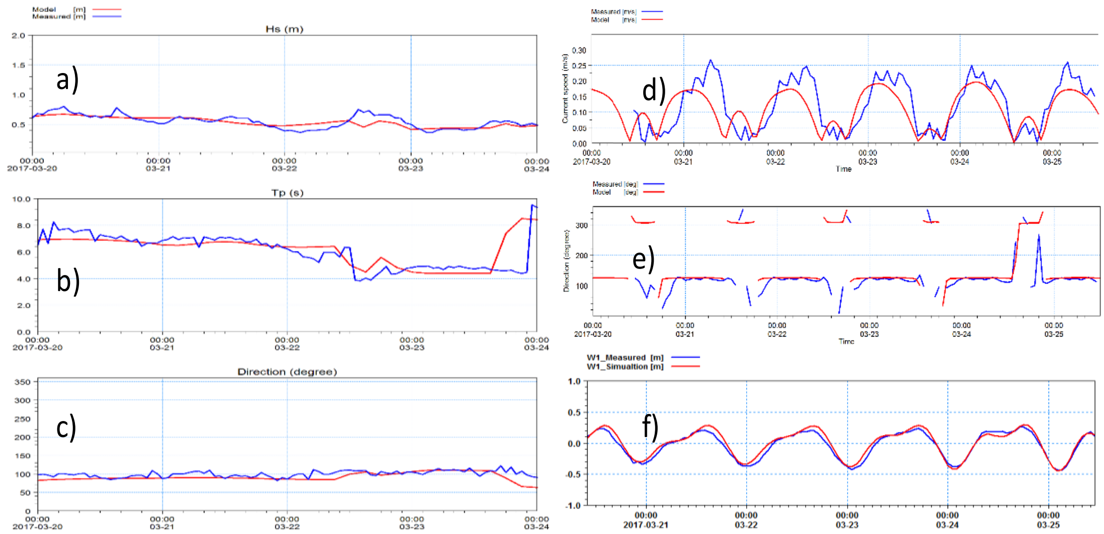

Figure 3. Comparison of model simulation from Delft3D (blue) and measured data (red) at AWAC station for parameters of wave height (m) (a), wave period (s) (b), wavedirection (degree) (c), current speed (m/s) (d), current direction (degree) (e) and water level (m) (f)

3.2. Model

Model simulations strongly illustrate an unstable hydrodynamic regime over the estuary of Cua Dai, mostly observed from September to March of the following year. During this time, a coincident with flood season occurred over the Thu Bon river is seen for the wave height higher than 1 meter in the months of October and November. The current speed of higher than 1 meter per second is recorded in the inside of the mouth of Cua Dai estuary during the flood season. On the outside of the mouth of Cua Dai estuary is affected by high waves causing the small currents. The interaction of each other factors creates an arc domain with a small velocity. This is an important condition for producing a sandbar rightly in the front of the Cua Dai mouth (Fig. 4).

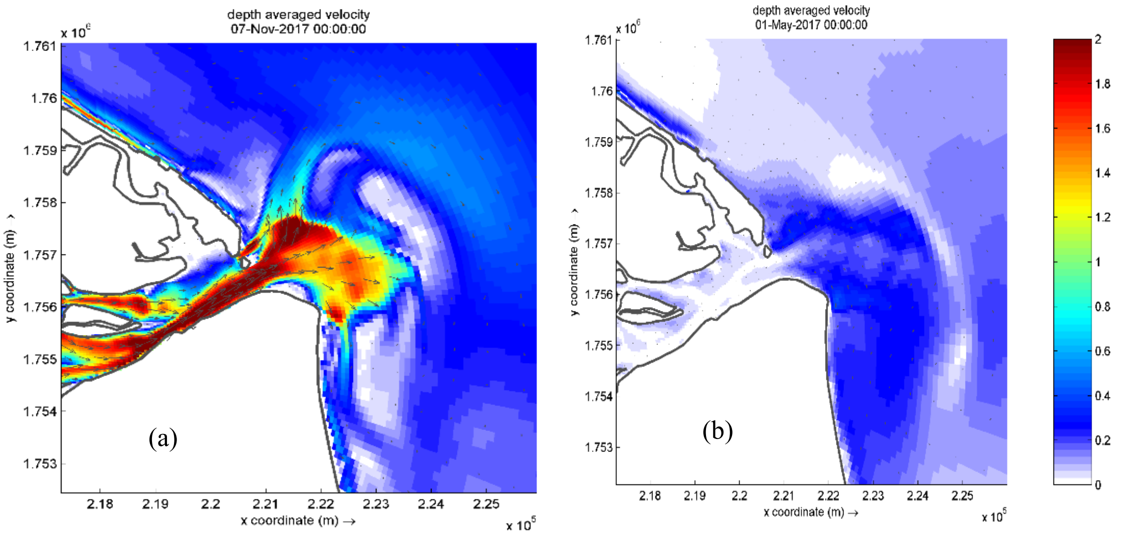

Figure 4. Current field in the estuary of Cua Dai with floods (a) and without floods (b) (m/s)

During the summertime from April to August, flows in the river are negligible. Currents in the front of the Cua Dai mouth are mainly tidal currents and inshore currents resulting from the activity of southeast waves (Fig. 4b and Fig. 5). An ensembled current in the outward of the sea with the direction of the northwest to southeast is prevailing in the southeast direction compared to the north direction (Fig. 6a). Over the study area, waves are highly affected by the northeast waves (approximately more than 70 percentages) compared to the southeast. In the north places of Cua Dai, especially, due to a deep seabed topography, the influence of waves in the northeast is dominated (Fig. 6b).

Using the Sentinel-2A satellite image at 8:00 on November 14, 2017, to create a turbidity distribution map in the Cua Dai estuary. The purpose of this is to verify the performance of model simulations. It is indicated a similarity between the turbidity simulation resulting from the model Delft3D with satellite data at the same time (Fig. 7). This is also the period of large floods recorded on the Vu Gia - Thu Bon river in 2017. The simulations of MIKE 11 showed large sediment from the river of over 500000 m^3 in 2017. Hence, floods are considered to be the main source of sediment that contributes to the accretion rate. Consequently, at the end of the winter of 2017, a sand bar is formed across the river mouth (Fig. 8). Due to the influence of the currents towards the south more to the north, however, sandbars tend to shift to the south. In the north of the estuary of Cua Dai, alluvials are formed.

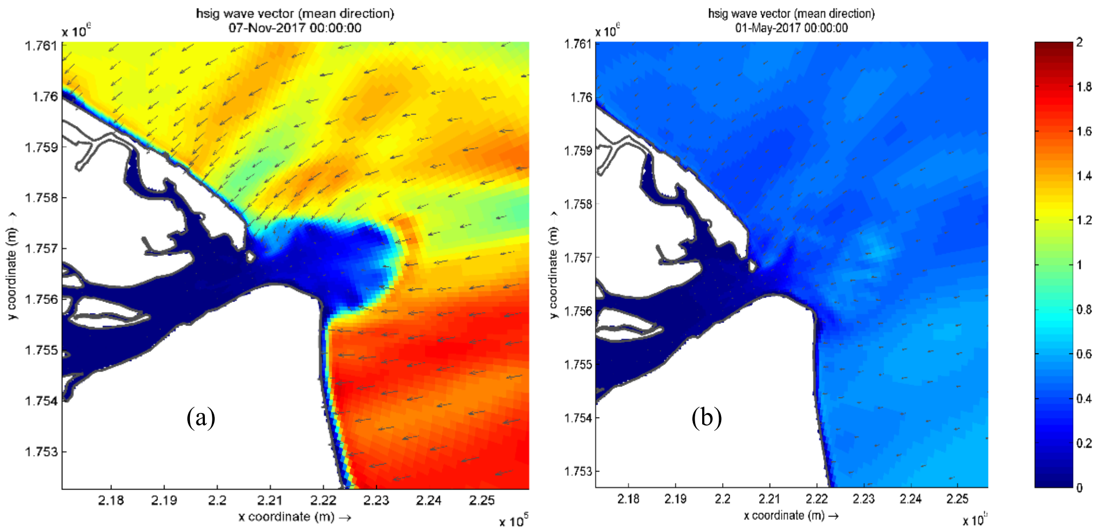

Figure 5. Wave field in the estuary of Cua Dai with floods (a) and without floods (b) (m/s)

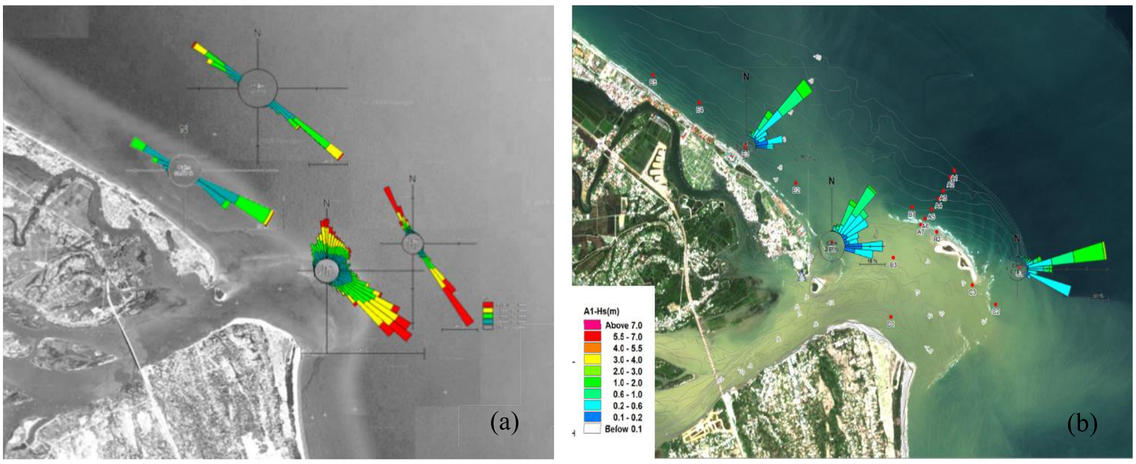

Figure 6. Current (a) and wave (b) roses

More recently, it is especially noteworthy that Huynh et al. (2018) used the Tomawac model to simulate the wavefield for the Cua Dai-Hoi An seashore and then give conclusions dealing with wave regime and its impacts on the beach erosion for this area. The results confirmed that the waves in the Cua Dai are divided into two distinct seasons (northeasterly wind season and southwesterly wind season). The results also indicated that the northern coastline of the Cua Dai seriously eroded is due to the waves dominately in the northeast and east-northeast direction. Besides that, the authors stated that during the southwesterly wind season, the mud and sand from the Cua Dai estuary to be moved by the currents along the shore to reinforce the northern coastline without a balance in accretion. This leads to increased erosion of the beach north of the Cua Dai estuary. These results are moderately valuable as references for different studies in the Cua Dai estuary. Existing problems needed to be considered are that the study of Huynh et al. (2018) did not clarify (i) the wind data of NOAA with a resolution of 30 second and points of P1 and P5 (ii) the direction and period of wave simulations in comparison with the NOAA data. In other words, the uncertainty in geo-hydrodynamical simulations for the Cua Dai estuary needs to be considered from the study of Huynh et al. (2018). On the contrary to this, in this study, the authors could be stated that the obtained results are highly reliable. For this, the obtained results (i.e., wave height, wave period, wave direction, and current speed and direction) are compared with the NOAA and measured data.

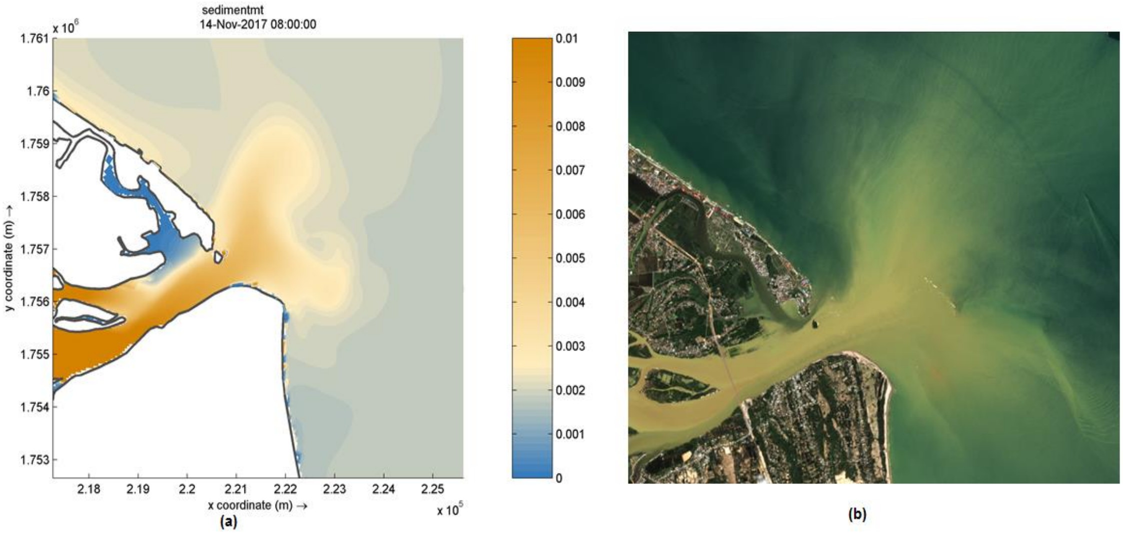

Figure 7. Water turbidity distribution simulated from the model of Delft3D (a) and Sentinel image (b) at 8:00 November 14, 2017 in the estuary of Cua Dai

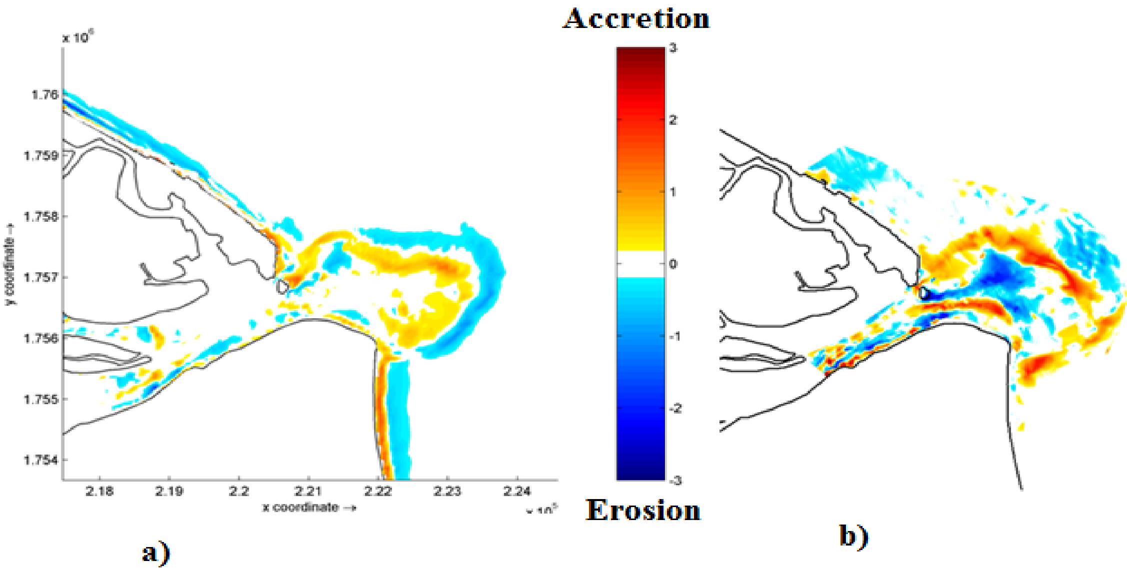

Figure 8. Seabed topography between model of Delft3D (a) and measured data (b) produced from the field surveys during 2017–2019 for the Cua Dai estuary

4. Discussions

On the basis of combined multiple models and measurement data, the effect of hydrodynamic processes on morphological evolutions at Cua Dai estuary and coastlines of Quang Nam province is fully explored. Notably, sandbar formation recently appeared near Cua Dai beach is documented. For this, the interaction of river (i.e., floods) and sea (i.e., waves and currents) conditions during the northeast monsoon mainly causes and clearly illustrated in this study. Based on different approaches (e.g., remote sensing, modeling), many studies also found that external factors of tropical cyclones, seasonal alongshore current and wave, and tidal dynamics are recognized as to be important factors for the changes in morphology at Cua Dai estuary (Mau, 2006; Tung, 2008; Tanaka et al., 2016; Tanaka et al., 2017; Do et al., 2019). In comparison with the previous studies, the new findings in this study mainly are (1) continuously updated data collection via the surveys from 2017 to the present. The data collected as the most important thing is used to clearly depict the performance of the model. Besides that, the input data with a long-term of 1979-present for the models like reanalysis data is collected and used. All things illustrate the high reliability of the obtained results. (2) parameters of models (e.g., wave height, wave direction, discharge) are compatibly adjusted to catch up with the measurement data. Meanwhile, they are considered to be constants in the previous studies. So, comprehensive simulations in real-time have not implemented yet for this area from the previous studies. In other words, sandbar information has been not fully interpreted yet. (3) hydrodynamic processes are completely documented and verified using a combination of satellite images and seabed topography surveyed and edited in the field trips. In near-future, from that, a vision of continuous target is to (1) simulate, evaluate and predict the changes in sandbars at the Cua Dai estuary and coastlines of Quang Nam where plays a significant role in local maritime transport, fisheries, and tourism activities for central Vietnam and (2) to give the effective solutions for protecting and exploiting the Cua Dai beach.

5. Conclusions

The study fully interprets the evolution of estuary morphology under the effects of geo-hydrodynamical processes for the Cua Dai Beach based on combined satellite images and numerical simulations. It is emphasized that the hydrodynamical regime and sediment transport are significantly stimulated by the performance of Delft3D system for the estuary of Cua Dai. By using the Delft3D system, the data simulations fit well-themesured data. The simulation results clearly indicate the main cause of sandbar formation across the Cua Dai estuary. It comes from the interaction of floods and waves currents during the northeast monsoon. Also, it is very likely expected to form the bow-shaped sandbanks under the water in the direction of gradually descending to the south, while alluvials are formed in the north covered the Cua Dai estuary.

To get a deep understanding of geo-hydrodynamical regime over this area, the authors suggest that it is necessary to be more collaboration in multiple levels ranging from local to the international scale. From that, the field surveys will be further implemented to develop a database system. This will be a valuable source of data for calibrating and validating the model within a long-time period.

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References

Asplund E., Malmström H., 2018. Coastal erosion in the region of Thu Bon River mouth, Vietnam. Master's thesis, Lund University, Sweden, ISSN: 1101-9824, 117p.

Birkemeier W.A., Kraus N.C., Scheffner N.W., Knowles S.C., 1987. Feasibility Study of Quantitative Erosion Models for Use by the Federal Emergency Management Agency in the Prediction of Coastal Flooding (No. CERC-TR-87-8). Coastal Engineering Research Center Vicksburg Ms.

Cham D.D., Minh N.Q., Lam N.T., Son N.T., Thanh N.T., 2020. Identification of Erosion-Accretion Causes and Regimes Along the Quang Nam Coast, Vietnam. In: Trung Viet N., Xiping D., Thanh Tung T. (eds) APAC 2019. Springer, Singapore, 809–814.

Cham Dao Dinh, Nguyen Thai Son, Nguyen Quang Minh, Nguyen Tien Thanh, Tran Tuan Dung, 2020. An Analysis of Shoreline Changes Using Combined Multitemporal Remote Sensing and Digital Evaluation Model. Civil Engineering Journal, 6(1), 1–10.

Dang A.H., Nguyen T.D., 2020. Coastal Erosion in Cua Dai Beach: Future Influence of Climate Change and Sea Level Rise on Coastal Protection. In: Trung Viet N., Xiping D., Thanh Tung T. (eds) APAC 2019. Springer, Singapore, 521–528.

Deltares, 2011a. Delft3D-FLOW: Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments. User Manual, Version 3.15, Delft.

DHI, 2005. Users Manual: MIKE 11. Danish Hydraulic Institute.

Duy D.V., H. Tanaka, Y. Mitobe, V.C. Hoang, N.T. Viet, 2016. Study on river mouth delta formation and recent beach erosion on Cua Dai Beach, Vietnam. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 72(2), 1657–1662.

Duy Dinh Van, Hitoshi Tanaka, Yuta Mitobe, Nguyen Trung Viet, Le Thanh Binh, 2017. Analysis of erosion and accretion waves on Cua Dai Beach in Central Vietnam. Tohoku Journal of Natural Disaster Science, 53, 53–58.

Fila J., M. Kampen, K. Knulst, R. Marijnissen, R.V. Noort, 2016. Coastal erosion Hoi An. Multidisciplinary Project Report. Delft University of Technology, 168p.

Graham, Douglas N., Michael B. Butts, 2005. Flexible, integrated watershed modelling with MIKE SHE. Watershed models, 849336090, 245–272.

Huynh Cong Hoai, Lieou Kien Chinh, Le Duc Vinh, 2018. The coastal wave regime and its effects on erosion in the coastline of Cua Dai. ISSN 1859-1531, 11(132-1), 31–35 (in Vietnamese).

Kamel A.H., 2008. Application of a hydrodynamic MIKE 11 model for the Euphrates River in Iraq. Slovak Journal of Civil Engineering, 2(1), 1–7.

Le P.T., 2003. Research and Prediction the accretion and erosion processes for Vietnam coastal zone" Vietnam - Indian Project (in Vietnamese).

Le Xuan Hong, 1997. Coastal erosion in Vietnam are caused by human activitives. Collections of Marine Geological and Geophysical Studies, HNIO, C-14C.91, 291–295 (in Vietnamese).

Massimo Rinaldi, Beatrice Mengoni, Laura Luppi, Stephen E Darby, and Erik Mosselman, 2008. Numerical simulation of hydrodynamics and bank erosion in a river bend. Water Resources Research, W09428, 44(9), 1–17.

Merritt Wendy S., Rebecca A. Letcher, Anthony J. Jakeman, 2003. A review of erosion and sediment transport models. Environmental Modelling & Software, 18(8–9), 761–799.

Midun Z., 1988. Coastal Erosion: Problems and Solutions. PersatuanSainsLautan Malaysia.

Nguyen Danh Thao, Hiroshi Takagi, Miguel Esteban, 2014. Coastal Disasters and Climate Change in Vietnam: Engineering and Planning.

Thompson J.R., H. RefstrupSørenson, H. Gavin, A. Refsgaard, 2004. Application of the coupled MIKE SHE/MIKE 11 modelling system to a lowland wet grassland in southeast England. Journal of Hydrology, 293(1–4), 151–179.

Van Rijn, Leo C., 1993. Principles of sediment transport in rivers, estuaries and coastal seas. Amsterdam:

Aqua publications. ISBN 90-800356-2-9 bound, NUGI 816/831, 1006, 11–13.

Van Rijn, Leo C., 2007a. Unified view of sediment transport by currents and waves. I: Initiation of motion, bed roughness, and bed-load transport. Journal of Hydraulic Engineering, 133(6), 649–667.

Van Rijn, Leo C., 2007b. Unified view of sediment transport by currents and waves. II: Suspended transport. Journal of Hydraulic Engineering, 133(6), 668–689.

Van Rijn, Leo C., 2007c. Unified view of sediment transport by currents and waves. III: Graded beds. Journal of Hydraulic Engineering, 133(7), 761–775.

Warren I.R., H.K. Bach, 1992. MIKE 21: a modelling system for estuaries, coastal waters and seas. Environmental Software, 7(4), 229–240.