■Ngày nhận bài: 21/11/2022 ■Ngày sửa bài: 09/12/2022 ■Ngày chấp nhận đăng: 14/12/2022

Analyzing effects of land reclamation on coastal geomorphology: Case study in Rach Gia Bay, Vietnam

Phân tích tác động của việc lấn biển đến địa mạo khu vực ven biển: Trường hợp nghiên cứu ở Vịnh Rạch Giá, Việt Nam

> **VAN-THONG PHAM[1,2], HOANG-MON TO[3*], THE-HUNG VO[2,4], THI-CAM-BINH NGUYEN[2], TRUNG-TIN HUYNH[5], TRONG-VINH BUI[2], THANH - PHONG LE[2], LE-PHU VO[6], TSUNG-YI LIN[7], NGOC-LOI DANG[8]**

[1)] Thanh Khoi consultant and construction investment company limited
[2)] Faculty of Geology and Petroleum Engineering, Ho Chi Minh City University of Technology -Vietnam National University Ho Chi Minh,
[3)] Department of Natural Resources and Environment, An Giang Province
[4)] Technology Center for Water and Environment Research, Ho Chi Minh City
[5)] Department of Advanced Science and Technology Convergence, Kyungpook National University, Korea
[6)] Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology Technology-Vietnam National University Ho Chi Minh,
[7)] Department of Geography, National Taiwan Normal University,
[8)] Urban Infrastructure Faculty Mien Tay Construction University
Corresponding author: thmon@angiang.gov.vn

ABSTRACT:

The rapid global population growth leads to considerable rising consumption of natural resources such as air, water, and land. The demand for land has increased in the last two decades, both inland and seaside. Land reclamation along with the coastline has been preferred as a solution for modern urban development, such as three land reclamation projects in Rach-Gia Bay, the Vietnamese Mekong Delta. The synthetic urban facilities could cause changes in coastal geomorphology, which rare studies have been conducted. This study aims to evaluate the effects of land reclamation on changes in coastal geomorphology in Rach-Gia Bay, Vietnam. Firstly, we construct an overall finite element (FE) model of Thailand gulf to search for optimal parameters by comparing numerical data with the experimental ones. Secondly, a FE model of Rach-Gia Bay is conducted for two stages with and without artificial structure to simulate tide, wave influence, and sediment transportation. Lastly, analyzing flow characteristics suggested changes in coastal geomorphology surrounding the projects. The result reveals that the accretion appeared around the construction sites, and the sedimentation has changed significantly at some locations around the concrete structures.

Keywords: Land reclamation; urban development facilities; geomorphological change; coastal water quality.

TÓM TẮT:

Sự gia tăng dân số toàn cầu dẫn đến mức tiêu thụ tài nguyên thiên nhiên tăng đáng kể bao gồm, không khí, nước và đất đai. Nhu cầu về đất đai ngày càng tăng trong hai thập kỷ gần đây cả trong đất liền và ven biển. Việc cải tạo đất dọc theo bờ biển được ưa chuộng như một giải pháp cho nhu cầu phát triển đô thị hiện đại, chẳng hạn như ba dự án cải tạo đất ở Vịnh Rạch Giá, Đồng bằng sông Cửu Long Việt Nam. Các công trình đô thị nhân tạo có thể gây ra những thay đổi về địa mạo ven biển, điều mà rất ít nghiên cứu đề cập đến. Nghiên cứu này nhằm đánh giá ảnh hưởng của việc cải tạo đất đến sự thay đổi địa mạo ven biển vịnh Rạch Giá, Việt Nam. Đầu tiên, chúng tôi xây dựng mô hình phần tử hữu hạn (FE) tổng thể của vịnh Thái Lan để xác định các tham số tối ưu bằng cách so sánh dữ liệu từ mô hình số với dữ liệu thực nghiệm. Thứ hai, một mô hình của vịnh Rạch Giá được xây dựng với hai giai đoạn có và không có công trình nhân tạo để mô phỏng thủy triều, ảnh hưởng của sóng và vận chuyển bùn cát. Cuối cùng, các phân tích về đặc điểm dòng chảy cho thấy những thay đổi về địa mạo ven biển xung quanh các dự án. Kết quả cho thấy bồi tụ xuất hiện xung quanh các vị trí xây dựng và sự lắng đọng đã bị thay đổi đáng kể tại một số vị trí xung quanh các kết cấu bê tông.

Từ khóa: Cải tạo đất; phát triển công trình đô thị; thay đổi địa mạo vùng biển; chất lượng nước ven biển.

1. INTRODUCTION

Coastal areas offer advantageous conditions, such as residential areas, sea tourists, or natural eco-parks [1]. Previous research has stressed the crucial role of the coastal area on economic prosperity, social prosperity, and human communities [1, 2]. Moreover, it is estimated that approximately 40% of the global population lives in coastal areas [3]. It leads to coastal reclamation using the embanking-filling of wetlands and building barriers, seawalls, and dikes along with the seashore. Various coastal countries such as the USA, Japan, China, Mexico, Singapore, and Vietnam have conducted seashore reclamation not only for urban development but also for agriculture, industrial use, or recreation [4-6].

The rapid development of the coastal economy and accelerated coastal population growth could yield a sharp increase in land reclamation. It causes negative environmental effects [7] (e.g., marine resources or coastal water quality), increasing losses of coastal wetlands, and a greater risk of impending natural catastrophes related to extreme events (e.g., the 2011 Great East Japan Earthquake). However, the negative impact of coastal development is not seriously considered. A framework of the master management plan is not consistently provided [8].

In the Southern part of Vietnam, Rach-Gia city is considered as the administrative, economic, and cultural center and an important traffic hub of Kien-Giang province. With the rapid development of urban areas, urban expansion is considered an inevitable trend. The land encroachment projects are expected not only to satisfy a need of the local population but also to enable the promotion of tourism development. The 1st phase of the encroachment project was the Phu-Cuong reclamation project (30 ha) initiated in the 2000s. The project has been proving the socio-economical values. After that, the 2nd phase (approximately 128.6ha) of land reclamation (Phu-Gia, Hoang-Gia, Phu Qui projects) has replenished to offer complex residential areas, including tourism, department store, and standardized residential areas. The projects could have effects on the natural marine environment, especially on the coastal morphology not only in the construction area but also in the surrounding areas. However, the effects of land reclamation, especially on coastal geomorphology, have not been seriously studied so far [6, 9].

In this paper, we used the combined method to evaluate the effects of land reclamation on changes in coastal geomorphology in Rach-Gia Bay, Vietnam. To achieve the objective, the following approach is implemented. Firstly, an overall finite element model of Thailand gulf (meshing grip of 1x1 km) is constructed to search for optimal parameters by comparing numerical data with the experimental ones. Secondly, a numerical model of Rach-Gia Bay (meshing grip of 0.2x0.2 km) is conducted for two stages with and without artificial structure to simulate tide, wave influence, and sediment transportation. Lastly, flow characteristics are analyzed to demonstrate changes in coastal geomorphology surrounding the projects.

2. NUMERICAL MODEL FOR ANALYZING CHANGES IN COASTAL GEOMORPHOLOGY DUE TO LAND RECLAMATION

2.1. Field measurement of water elevation and current speed for numerical model calibration

Due to the lack of measured data on waves, both hourly and long-term periods measurement in the Rach-Gia Bay area (see Fig. 1), the authors built a model of the Gulf of Thailand (approximately meshing grid 1x1 km). The purpose is to obtain a standard set of model parameters that can be applied to the project area and other simulation scenarios. The advantages of the general model can be listed as diverse boundary conditions, offshore water level data extracted from the global tidal model provided by DHI (Danish Hydraulic Institute), and offshore wave data from Wave-watch III data published by NOAA. In addition, hydrographic monitoring at Phu-Quoc and Tho Chu stations can provide a reliable data source for model calibration and verification in the general model. After the model is calibrated with a suitable error (through the NASH coefficient), the model parameters (e.g., roughness coefficient, manning, turbulence conditions) are used for models of Rach-Gia Bay.

The observation of water elevation and the current was carried out at the project area by the Nortek Acoustic Doppler Current Profiler® (ADCP) using the Doppler effect of sound waves scattered back from particles within the water column [10-12]. An in-situ wave measurement was carried out using the Acoustic Wave and Current Profiler® (AWAC) by Nortek, Norway. A total of 171 water samples were taken at 57 points using the 5-L horizontal sampler (Wildco®, USA). As shown in Fig. 2, a water level was measured in 2010 for 14 days on May 06- May 20, as seen in Fig. 2a and another for 5 days on Nov 1- Nov 6, as seen in Fig. 2b). The water level changes daily among the measured days.

Moreover, water samples were obtained to further laboratory analysis of the particle size distribution and total suspended solid. Table 1 shows the collected data used for a numerical model of Thailand gulf.

MIKE 21 software, a numerical model by DHI, was applied in order to assess the potential impacts of the artificial structure on the natural condition of current and sediment transportation. The integrated models, including Hydrodynamic (HD) module (MIKE 21 HD), Non-Cohesive Sediment Transport Module (MIKE 21ST), and Spectral Waves model (MIKE 21 SW), were built for the simulation. After simulation, the model can give the output as follows: a) water level and flow in MIKE 21 HD package, b) sediment load, bottom topographic change in MIKE 21 ST, and c) wave characteristics (e.g., period or wave height) in MIKE 21SW.

.

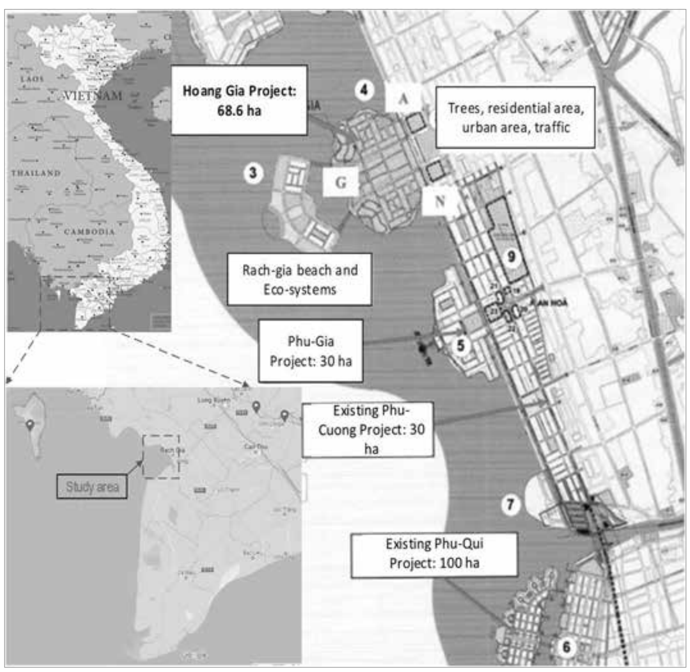


Fig. 1 Coastal reclamation projects in Rach-Gia Bay with four land reclamation projects examined in the research, including Hoang-Gia, Phu-Gia, Phu-Cuong, and Phu-Qui projects.

Table 1 Collected data for the numerical model of Thailand gulf

Parameter	Description	Source
Bathymetry	Bed-level data to define the model	US army, Vietnam Navy, project data
Water level	Measurement of water level data	Phu-Quoc and Tho-Chu stations
Wave	Wave characteristics in Phu-Quoc	Phu-Quoc station
Sediment	D_{50} of the coastal bed materials	Site survey

The simulation model was set up for the overall Thailand gulf area (namely Model TLG), as shown in Fig. 3a. This flexible meshed model with 1x1 km, and it was used to obtain a tital elevation and spectral wave transition within the typical monsoon wind conditions. The simulated data was calibrated to verify the national monitoring data at Phu-Quoc station for hourly-water level and wave and at Tho-Chu station for the water level in May for the monsoon season and in November for the dry season. It commonly used Residual Mean Square Error (RMSE) and the Nash Sutcliffe efficiency (N) coefficient [13] as calibration criteria, as follows:

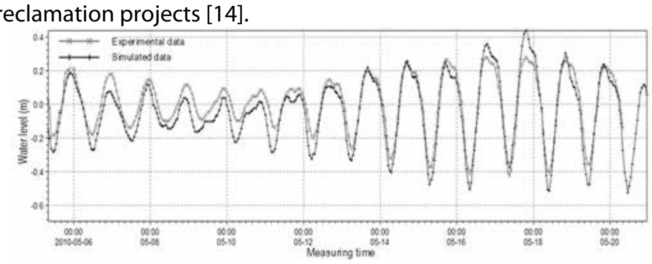
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - c)^2} \quad (1)$$

$$N = 1 - \frac{\sum(c_i - c)^2}{\sum\left(c_i - \frac{1}{n}(\sum c_i)\right)^2} \quad (2)$$

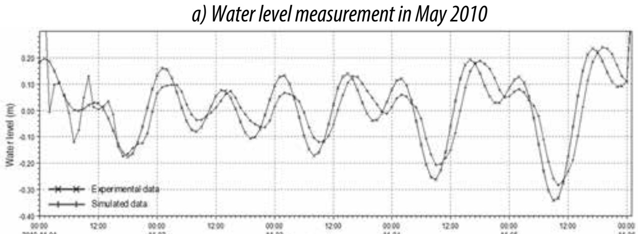
where: c_i is the simulated value, and t_i and c is the calibrated value.

As observed in Fig. 2a-b, the simulated water level is relatively matched to the measured one in Fig. 2a-b. After conducting the numerical model-updating of Thailand gulf, it is observed that simulated data was well-matched to tested data shown in Fig. 2a. The calibrated NASH efficiency in the rain and dry seasons were 0.96 (Fig. 2a) and 0.87 (Fig. 2b).

The optimal model parameters shall be kept for further detailed simulation with a finer meshing grip of Rach-Gia Bay to simulate coastal geomorphology with and without artificial structure. It is noted that the model for Estimating Equilibrium PArabolictype ShOreLines (MeePaSoL), a Mathlab-based model, which is available at "https://github.com/BSMC-20180404/MeePaSoL" was applied to simulate the shoreline changes under human interventions with reclamation projects [14].



a) Water level measurement in May 2010



b) Water level meausurement in November, 2010

Fig. 2 Comparison of water level between numerical and experimental data

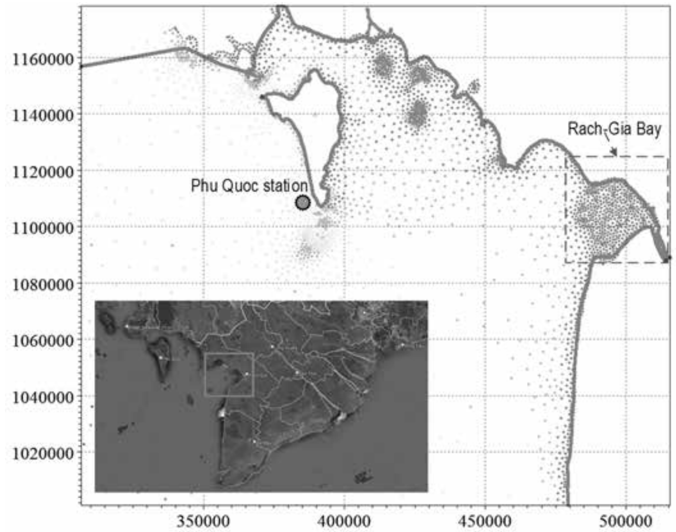


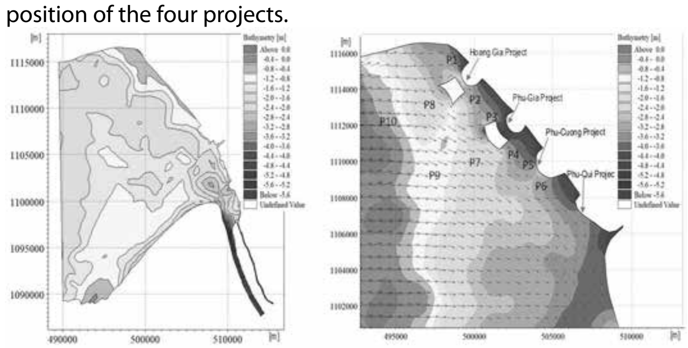
Fig. 3 Flexible triangle-mesh model of Thailand gulf for calibration of numerical model of Rach-Gia Bay (Model TLG)

2.2. Simulation model of Rach-Gia Bay for analyzing effects of land reclamation projects on coastal geomorphology

a) Description of scenario

Fig. 4 shows the bathymetry mesh of Rach-Gia Bay, which was zoomed in from the model of Thailand gulf, so-called Model TLG, (see Fig. 3) for analyzing the effects of land reclamation projects. Fig. 4a shows a detailed model simulating current conditions (without artificial structure), namely model HT. The model HT was built with a grid area of about 200 x 200 m. Boundaries for the model (e.g., water level and wave boundaries) were extracted from model TLG, which was verified.

As shown in Fig. 4b, a detailed model simulates the presence of coastal structure, including four projects (Hoang-Gia, Phu-Gia, Phu-Cuong, and Phu-Qui projects), namely model MP. The model MP was utilized to evaluate the influence of structures on the coastal and offshore hydrodynamic regimes. Also, the model was built based on the previous model in Fig. 3. It is noted that the meshing grid at the projects was adjusted to better represent the actual shape and position of the four projects.



a) Before projects (namely Model HT)b) After projects (namely Model MP)

Fig. 4 Scenario model of Rach-Gia Ba for analyzing effects of land reclamation projects on coastal geomorphology

b. Simulation cases

For the model HT, the simulation was conducted for 02 typical wind seasons, including the Southwest monsoon season (from May to October) and the Northeast monsoon season (from November to April next year). For each season, model parameters were analyzed using experimentally measured data within a month. Due to availability of natural environmental conditions and monitoring data, May (data measured in May 2010) was selected to analyze the

Southwest season, and November (data measured in Nov 2010) was selected to analyze the Northeast season. Moreover, the time-step simulation was set to 5 seconds.

For the model MP, the simulation was also conducted for 02 typical wind seasons, including the Southwest monsoon season (from May to October) and the Northeast monsoon season (from November to April next year). The data were also analyzed for one month in May (SW season) and November (NE season).

Table 2 Selected location for evaluation

ID	X	Y	Location
P1	498008.486	1115516.131	Lac-Hong
P2	501019.245	1113523.094	Hoang-Gia
P3	503563.548	1111233.221	Phu-Gia
P4	505726.206	1108688.918	Phu-Cuong 1
P5	507422.408	1106399.045	Phu-Cuong 2
P6	508355.320	1102073.729	Phu-Quy
P7	500722.410	1110851.575	Lac-Hong seafront
P8	497838.866	1113523.094	Hoang-Gia seafront
P9	493598.361	1109664.234	Mining 1
P10	498474.942	1102200.944	Mining 2

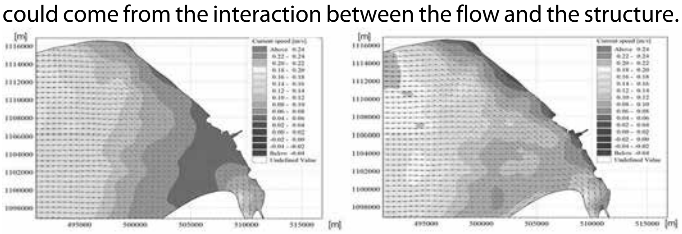
Table 2 shows ten locations, namely P1-P10, selected to evaluate the changes in tidal-induced current, wave impacts, and sediment transportation due to the effects of artificial structures. The locations were marked in Fig. 4b. It is noted that the location P9-P10, which was far from the coastline, was material mines that were dredged into projects. Meanwhile, P1-P6 was along the coastline close to four artificially simulated projects (i.e., Hoang-Gia, Phu-Gia, Phu-Cuong, and Phu-Quy).

3. ANALYZING EFFECTS OF LAND RECLAMATION ON CHANGES IN COASTAL GEOMORPHOLOGY

3.1. Tidal-induced current

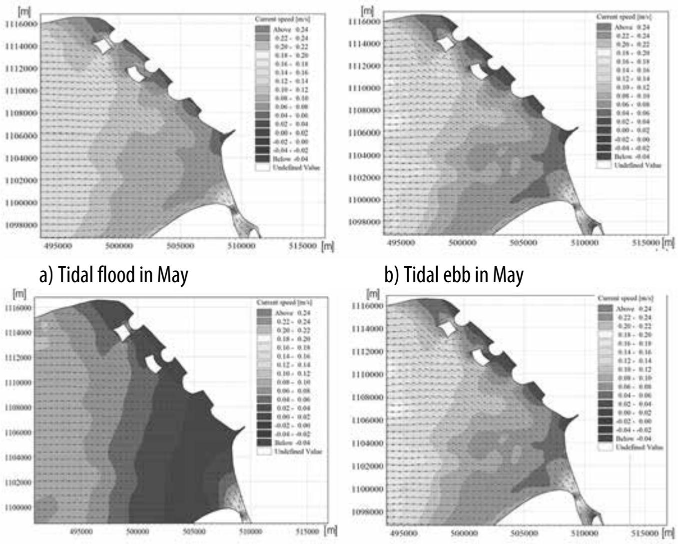
Fig. 5 shows the simulation results for the flow field at a high tide and a low tide for the model without the presence of artificial structures (Model HT). When there was no construction, the tide (from Thailand gulf) tended to approach the coast of Rach-Gia Bay in the Northeast direction. When ebb tide, the current also tends to approach the coastline in the opposite direction

Fig. 6 presents the tidal-induced current changes in various tidal regime conditions when artificial structures were assumed to be all constructed along the coastline. The average velocity of the tidal-induced current in the summer and the winter seasons was 0.44m/s and 0.48m/s, respectively. In the summer (in May), with the influence of the Southwest monsoon, the tidal current tends to close to the shoreline (see Fig. 6a) during the tidal flood, but the current flow is far away from the coastline on the tidal ebb (Fig. 6b). Similarly, the current is far away from the beach in the tidal ebbs (see Fig. 6d), and it is close to the shoreline during the flooding season (November), as seen in Fig. 6c. The simulated hydrodynamic regime indicated the minor change in various structure scenarios. The water level was kept almost un-change, but the changes in the current direction could come from the interaction between the flow and the structure.



a) Tidal flood b) Tidal ebb

Fig. 5 Current distribution of the natural environment for model HT



a) Tidal flood in May b) Tidal ebb in May

c) Tidal flood in November d) Tidal ebb in November

Fig. 6 Influences on tidal-induced currents

3.2. Wave impacts

Fig. 7 shows the wave-field result acting on the shoreline for the current condition (with artificial structures). During the Northeast monsoon season, the wave direction affects the shoreline in the Southwest direction with a maximum height of about 0.5m.

Fig. 8a-d presented the changes in wave height and wave direction for two cases: before and the artificial structure constructed for four different examined locations (i.e., mining location., Lac-Hong seafront, Phu-Quy land reclamation, and Lac-Hong). It was seen that the wave height was decreased due to the effects of artificial structure at the shoreline (P1-P5, see Table 2). Meanwhile, the offshore location did not significantly change. It witnessed a highly increasing in wave height on the P6 after the beach encroachment, with a weight percentage of 10% and 6% in the summer and winter seasons, respectively. Due to the artificial projects, the wave direction was reflected, and wave height increased significantly, as detailed in Fig. 8 and Fig. 9.

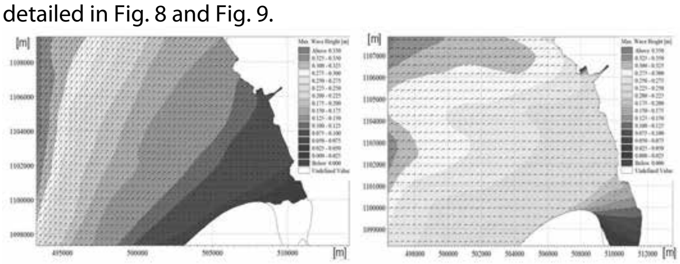
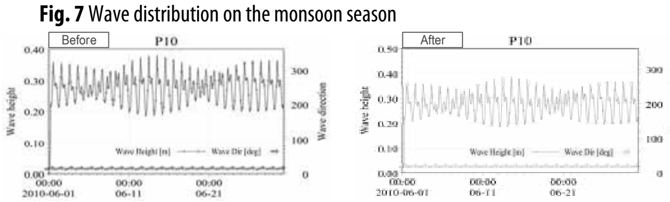
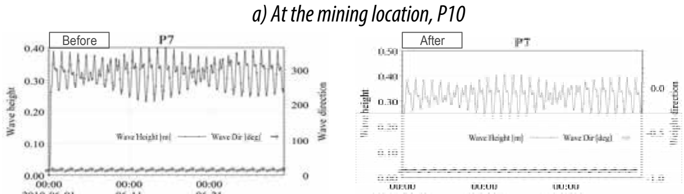


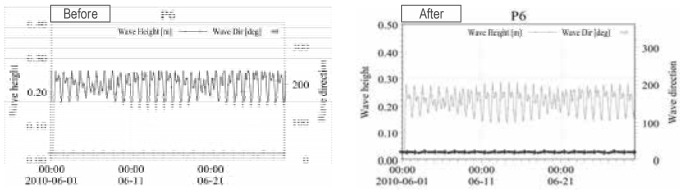
Fig. 7 Wave distribution on the monsoon season



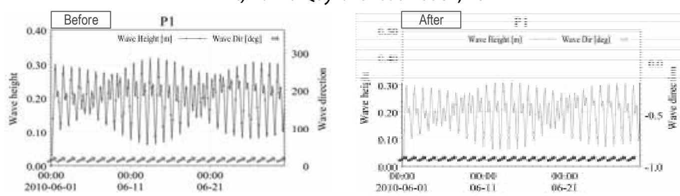
a) At the mining location, P10



b) At Lac-Hong seafront, P7



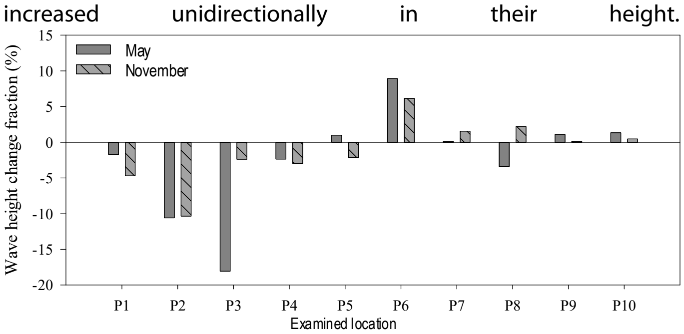
c) At Phu-Quy land reclamation, P6



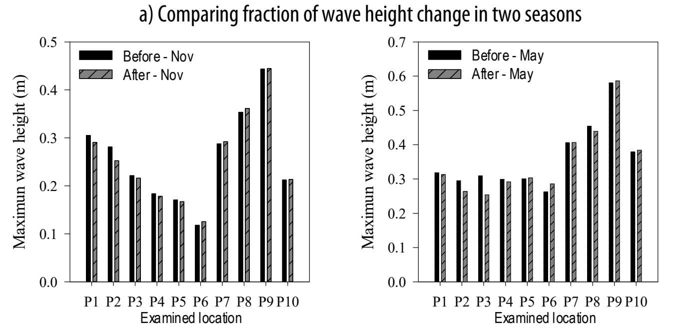
d) At Lac-Hong, P1

Fig. 8 Comparing the influence of encroachment project on wave distribution for examined locations

In the summer, the southwest wave was predominant, attacking the shoreline from the Southwest direction. Maximum wave height during the SW season was approximately 0.4m on the nearshore and 0.6m on the offshore. Otherwise, in the winter (November), the wave height on the nearshore was modeled at 0.25 - 0.3m, whereas 0.45m on the offshore. Fig. 9 compares the changes in wave height due to the artificial structures. It witnessed a decrease in the wave height on the shoreline, but the offshore location did not significantly change. There was a high increase in wave height on the edge of the beach encroachment, with 10% in the SW season and 6% in the NE season. Due to the artificial projects, the wave direction was reflected and increased unidirectionally in their height.



a) Comparing fraction of wave height change in two seasons



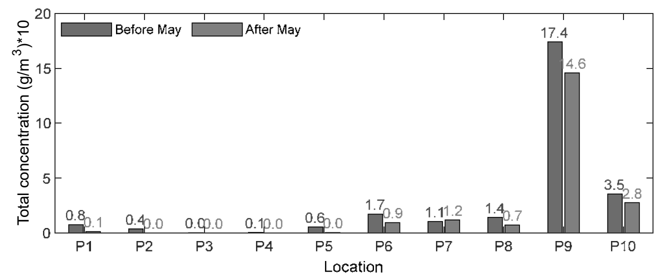
b) Maximum wave height in the same season

Fig. 9 Comparison of wave height changes due to artificial projects at different locations

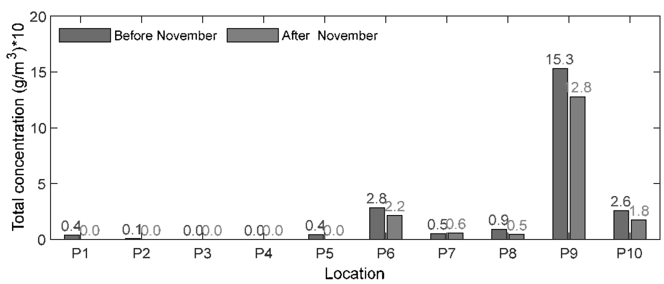
3.3. Sediment transport due to land reclamation

Fig. 10 indicates changes in the suspended sediment concentration (SSC) before and after replenishing. Generally, after the construction, the concentration of sediment was mostly decreased in various seasons, and the less SSC was on the multiple scenarios for both simulated seasons. The first-highest and second-highest sediment concentration was found at P9 (the mining location to obtain materials for leveling) and P10 (the other mining location). This numerical result is relatively consistent with real activities on-construction site. It suggests the connection between real activities and sediment concentration trends.

Moreover, the sediment trap was found on the edge of artificial beaches, which is on the dominant sediment flow, as shown in Fig. 11b. The presentence of the structures interrupted the sediment flow and changed the flow directions, which tends to move forward to the offshore. This resulted in the lack of sediment on the beaches behind the structure. Meanwhile, Fig. 11b shows the topography of Rach-Gia Bay without changing before the encroachment structure.

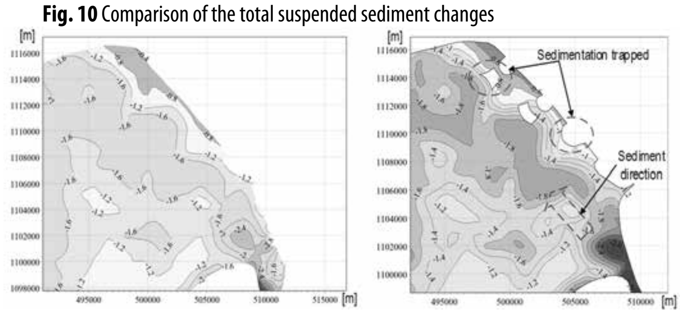


a) Monsoon season



b) Winter season

Fig. 10 Comparison of the total suspended sediment changes



a) Before land reclamation b) After land reclamation

Fig. 11 Topography change due to encroachment structure

4. DISCUSSIONS ON COASTAL GEOMORPHOLOGY CHANGE

The study area is influenced by the regular diurnal tidal regimes of Thailand gulf. Due to the topography characteristic, tidal-induced currents have complicated interaction, especially in high tidal. As shown in the previous study, the combined effect of tidal-induced currents and wave height on the tidal flood could threaten shoreline stability [15]. Simulation results indicated the potential impacts of the reclamation structure on the hydrodynamic regime, which is assessed to be not significant. However, the interaction of longshore current and artificial structure can result in the rip current on the structure edge. In addition, a zigzag current would occur when the longshore current interacts with the complex artificial headlands [1, 16]. This would be easier to form a semi-enclosed area of very low flow and poor conditions of water exchange [17].

Fig. 12 Shoreline changes impacted by the artificial headlands

The presentence of the artificial headland interrupts the longshore sediment flow, as observed in Fig. 12. The figure indicates the simulation result of the shoreline changes due to encroachment projects [14, 18]. The red line indicates the natural equilibrium shoreline. After the construction, the shoreline morphology changes, influencing the sedimentation flow and leading the changes in the beach process. The predicted shoreline (yellow dotted) indicated shoreline changes after the construction. Simulation results suggest that the sediment was trapped in the Southeast of the Hoang-Gia and Phu-Gia projects. The artificial headlands break down the equilibrium shoreline structure, leading to the re-shaping of the coastline to get a new equilibrium state of the shoreline [14, 19]. In addition, the changes in hydrodynamic and sedimentation flow would also affect the deposition and erosion process in the area.

5. CONCLUDING REMARKS

This paper identified the potential impacts of the encroachment projects on the hydrodynamic regimes (longshore current, wave distribution), sediment transportation, and morphological changes. The numerical model of Thailand gulf was first built for searching the optimal parameters by comparing numerical data with the experimental ones. Then, two scenario models of Rach-Gia Bay were conducted to simulate the effects of artificial structures on coastal geomorphology. From the analysis, the following remarks can be drawn. First, the hydrodynamic impact was not significant, but sediment traps were numerically shown in the Southeast of the Phu-Gia and Hoang-Gia projects. Second, due to the complicated artificial headland coastline, the zigzag current would occur locally. Last, the lack of sediment occurred behind land reclamation projects.

A negative impact should be studied under global sea level rise or intense typhoon events for future studies. The impact of coastal land reclamation on seawater interface and groundwater level for long-term periods of the projects is also recommended.

REFERENCES

1. Cengiz, C., Cengiz, B., and Smardon, R.C. (2022), "A Bridge between Coastal Resilience and Tourism-Recreation: Multifunctional Benefit of Boardwalk Design for Sustainable Development in the Western Black Sea Region, Turkey," *Water*, Vol. **14 (9)**, pp. 1434.

2. Wilson, M.A., Costanza, R., Boumans, R., and Liu, S. (2005) Integrated assessment and valuation of ecosystem goods and services provided by coastal systems, In *The intertidal ecosystem: the value of Ireland's shores*. Royal Irish Academy.

3. Seas, U.R.P., Action 2011. Percentage of Total Population Living in Coastal Areas. In: (ed.)^(eds.) ed.: Socioeconomic Data and Applications Center Columbia, SC, USA.

4. Tian, B., Wu, W., Yang, Z., and Zhou, Y. (2016), "Drivers, trends, and potential impacts of long-term coastal reclamation in China from 1985 to 2010," *Estuarine, Coastal and Shelf Science*, Vol. **170**, pp. 83-90.

5. Ma, T., Li, X., Bai, J., and Cui, B. (2019), "Impacts of coastal reclamation on natural wetlands in large river deltas in China," *Chinese Geographical Science*, Vol. **29 (4)**, pp. 640-651.

6. Sengupta, D., Chen, R., and Meadows, M.E. (2018), "Building beyond land: An overview of coastal land reclamation in 16 global megacities," *Applied geography*, Vol. **90**, pp. 229-238.

7. Krishnamoorthy, R., Kim, K., Kim, C., and Sa, T. (2014), "Changes of arbuscular mycorrhizal traits and community structure with respect to soil salinity in a coastal reclamation land," *Soil Biology & Biochemistry*, Vol. **72**, pp. 1-10.

8. Tùng, N.S. (2021), "Kiểm soát chặt chẽ những vấn đề môi trường của các dự án lấn biển," *Tạp chí nghiên cứu Địa lý nhân văn*, Vol. **2 (33)**, pp. 11-19.

9. Feng, Y., Wang, J., Bai, Z., and Reading, L. (2019), "Effects of surface coal mining and land reclamation on soil properties: A review," *Earth-Science Reviews*, Vol. **191**, pp. 12-25.

10. Dinehart, R., and Burau, J. (2005), "Repeated surveys by acoustic Doppler current profiler for flow and sediment dynamics in a tidal river," *Journal of Hydrology*, Vol. **314 (1-4)**, pp. 1-21.

11. Kostaschuk, R., Best, J., Villard, P., Peakall, J., and Franklin, M. (2005), "Measuring flow velocity and sediment transport with an acoustic Doppler current profiler," *Geomorphology*, Vol. **68 (1-2)**, pp. 25-37.

12. Polzin, K., Kunze, E., Hummon, J., and Firing, E. (2002), "The finescale response of lowered ADCP velocity profiles," *Journal of Atmospheric Oceanic Technology*, Vol. **19 (2)**, pp. 205-224.

13. Doummar, J., Kassem, A.H., and Gurdak, J.J.J.J.O.H. (2018), "Impact of historic and future climate on spring recharge and discharge based on an integrated numerical modelling approach: Application on a snow-governed semi-arid karst catchment area," Vol. **565**, pp. 636-649.

14. Lim, C., Hsu, J.R., and Lee, J.L. (2022), "MeePaSoL: A MATLAB-based GUI software tool for shoreline management," *Computers Geosciences*, Vol. **161**, pp. 105059.

15. Karlsrud, K., Vangelsten, B., Frauenfelder, R.J.G.J.O.T.S., and Agssea (2017), "Subsidence and shoreline retreat in the Ca Mau Province–Vietnam. Causes, consequences and mitigation options," Vol. **48**.

16. Dean, R.G. (1983) Principles of beach nourishment, In *CRC Handbook of Coastal Processes and Erosion*. CRC Press.

17. Zhao, G., Chen, Z., He, Z., Wei, J., and Gao, X. (2017), "Effect of artificial island layout on hydrodynamics and water exchange in the coastal waters," *Journal of Hydroelectric Engineering*, Vol. **36**, pp. 18-28.

18. Deng, J., Harff, J., Zhang, W., Schneider, R., Dudzińska-Nowak, J., Giza, A., *et al.* (2017) The dynamic equilibrium shore model for the reconstruction and future projection of coastal morphodynamics, In *Coastline Changes of the Baltic Sea from South to East*. Springer.

19. Lim, C., Lee, S., Park, S.-M., and Lee, J.L. (2020), "Impact Assessment of Beach Erosion from Construction of Artificial Coastal Structures Using Parabolic Bay Shape Equation," *Journal of Ocean Engineering Technology*, Vol. **34 (6)**, pp. 436-441.