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**Duong Cong Dien**

**TREND OF BEACH CHANGES IN THE CUA DAI REGION – HOI AN UNDER  
THE IMPACT OF HYDRODYNAMIC FACTORS AND CLIMATE CHANGE**

**SUMMARY OF DISSERTATION ON SCIENCES OF MATTER**

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## INTRODUCTION

### 1. Rationale

Cua Dai Beach (Hoi An, Quang Nam) plays a strategic role in tourism economic development and acts as a defensive shield for the Hoi An World Cultural Heritage site. However, since 2009, this area has suffered severe erosion, particularly along the northern shoreline, causing significant damage to infrastructure and the landscape. Although various engineering solutions such as hard embankments, soft revetments, and beach nourishment have been implemented, their efficacy remains limited; erosion continues to spread, and structures are frequently destroyed during storms. Consequently, researching sediment transport mechanisms and morphological evolution under the interaction of hydrodynamics, river mouth migration, and climate change to propose sustainable stabilization solutions is an urgent scientific and practical requirement.

### 2. Research Objectives

The thesis focuses on two primary objectives:

- First: To investigate the current status and trends of the Cua Dai estuary and beach using remote sensing and survey data analysis to identify characteristics governing sediment distribution from the river to the sea.

- Second: To apply a calibrated numerical model (DELFT3D) to simulate morphological evolution and evaluate the correlation between estuarine sand terrace migration and beach erosion, thereby proposing sustainable engineering solutions for river mouth stabilization and coastal protection.

### 3. Scope of Study

The study focuses on hydrodynamic factors, water levels, and seabed morphological changes in the Cua Dai – Hoi An area.

The spatial scope encompasses the Cua Dai estuary and the adjacent coastal zones extending 10 km on either side.

#### **4. Research Methods**

The thesis employs the following primary methods:

- Literature review;
- Synthesis and statistical analysis;
- Numerical modeling;
- Applied research methods.

#### **5. Thesis Structure**

Apart from the introduction and conclusion, the thesis comprises four chapters:

- Chapter 1: Literature Review.
- Chapter 2: Study of morphological evolution of Cua Dai Beach and Estuary using remote sensing.
- Chapter 3: Study of morphological evolution of Cua Dai Beach and Estuary using numerical modeling.
- Chapter 4: Proposed engineering solutions for the stabilization of the Cua Dai river mouth and beach.

### **CHAPTER 1: LITERATURE REVIEW**

1.1. Overview of Research Globally, research has shifted from 2D to 3D modeling, emphasizing wave-current interactions and climate change (CC) scenarios. In Vietnam, studies on Cua Dai have identified erosion causes such as upstream sediment deficit due to hydropower dams, the impact of storms and Northeast monsoons, and local sediment imbalance. However, existing research contains gaps: a lack of full quantification of multidimensional interactions during extreme events, limitations in

simulating 3D flow structures in deep estuaries, and a lack of long-term forecasts integrating dynamic sea-level rise scenarios.

1.2. Scientific Basis for Climate Change Scenarios The thesis utilizes the 2020 Climate Change and Sea Level Rise scenarios by the Ministry of Natural Resources and Environment, focusing on RCP 4.5 and RCP 8.5 to assess long-term risks up to 2100. The approach goes beyond static sea-level addition by examining dynamic interactions (storm surge + high tide + flood).

1.3. Detailed Research Objectives Based on the literature review, the thesis aims to clarify the role of river mouth migration and the submerged sand terrace in causing erosion on the northern bank, thereby orienting flow-redirection solutions for sediment redistribution

## **CHAPTER 2: STUDY OF MORPHOLOGICAL EVOLUTION OF CUA DAI BEACH AND ESTUARY USING REMOTE SENSING**

### **2.1. Research Data**

Satellite Imagery: Data collected from US and European archives (Landsat and Sentinel-2) from 1973 to the present.

Bathymetric Data: Seabed topography measured during surveys under the Vietnam-France collaborative project "Study on erosion processes and coastal protection measures for Cua Dai, Hoi An".

Water Level Data: Data from Son Tra (1994–2023) and Cua Dai stations used to calibrate shoreline detection from satellite imagery

### **2.2. Shoreline Change Analysis from Satellite Imagery**

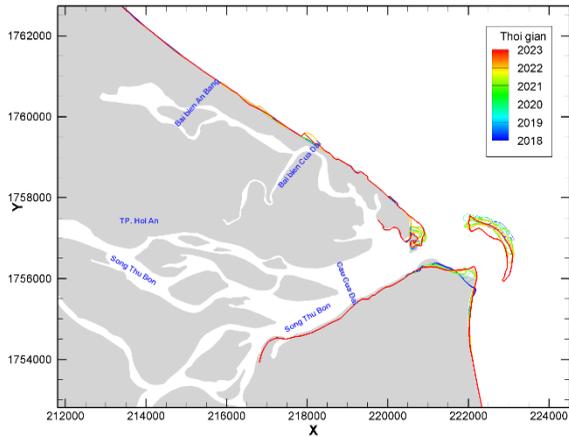
Methodology: The study applies the Normalized Difference Water Index (NDWI) method by Hanqiu Xu, using the ratio between the green band and the Near-Infrared (NIR) band. The formula is

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)} \quad (1)$$

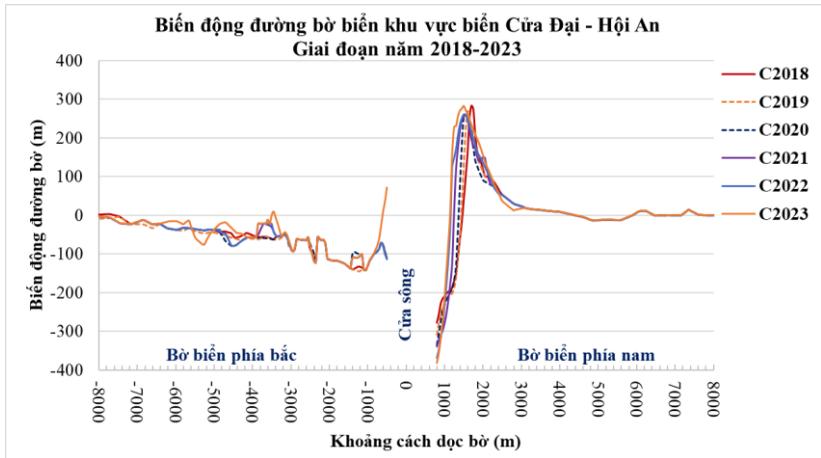
The ratio is <1 for water surfaces and >1 for land in coastal areas

Results of Analysis (2018–2023):

- Northern Coast: Exhibits strong fluctuations with a dominant erosion trend. The shoreline has retreated 300 m to 500 m compared to the period of maximum accretion. Erosion remains complex in recent years



*Fig 1. Changes in the coastline of the Thu Bon River estuary and coastal area during the period 2018-2023*



*Fig 2. Coastal change distance during the period 2018-2023*

- River Mouth Area: Highly complex evolution characterized by the emergence of sand islands (1988 and 2018). The development of these islands and shoreward sediment distribution occasionally caused accretion.

- Southern Bank of Thu Bon River: Shows distinct migration. The southward displacement averages 300 m to 500 m at the river mouth.

- Southern Coast: Relatively stable throughout the study period. Accretion/erosion volumes are small, with a dominant trend of accretion

### 2.3. Bathymetry Derivation from Satellite Imagery

Methodology:

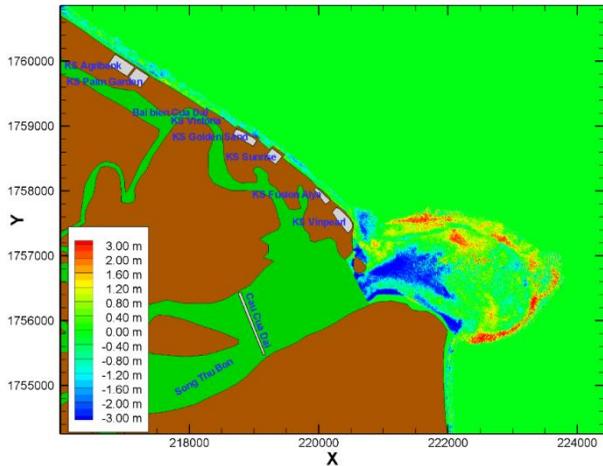
The depth determination equation, excluding surface effects, is defined as:

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0 \quad (2)$$

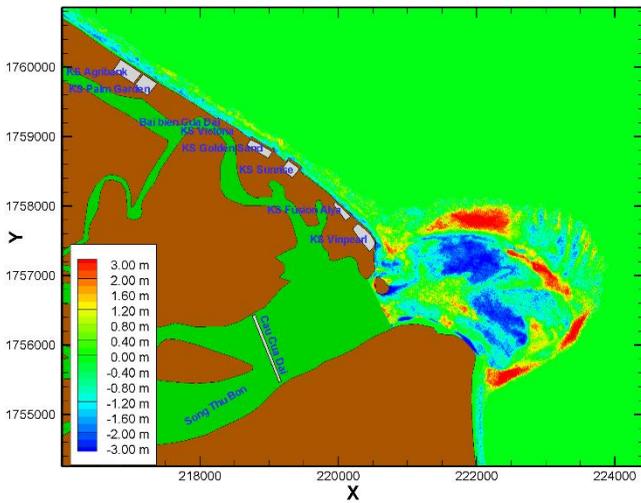
Where  $\lambda_i$  and  $\lambda_j$  are blue and green wavelengths, respectively.  $m_1$  is the empirical coefficient,  $n$  is a fixed constant ensuring that the value of  $\ln$  will be positive under any circumstances (in this study  $n=1000$ ), and  $m_0$  is the corresponding coefficient at a water depth of 0.

#### Results:

Comparison of derived bathymetry before and after the Northeast monsoon (Oct 2016 to Mar 2017) shows significant erosion in the surf zone of Cua Dai beach and adjacent areas, increasing the beach slope. This method proved effective for assessing seabed changes where hard structures prevent shoreline analysis. Additionally, analysis before and after the historic flood of November 2017 revealed the volume and location of sediment discharged during an actual flood event



*Fig 3. Map showing changes in the Thu Bon River estuary beach from March 2016 to March 2017.*



*Fig 4. Morphology change before and after flood 11/2017*

## **Conclusion of Chapter 2:**

In this chapter, the author introduces two methods for analyzing shoreline and beach changes based on satellite imagery data to clarify the evolution of the beach in the study area over many years. The shoreline interpretation method allows for the assessment of beach changes horizontally with respect to the above-water portion of the beach, while the seabed depth interpretation method allows for the quantification of changes in the submerged portion of the beach. The two methods introduced allow for a comprehensive assessment of beach area changes from different perspectives and complement each other in evaluating and analyzing the mechanisms of beach changes.

Using the NDWI index calculation method, the shoreline data were synthesized to assess changes in three areas: In the northern coastal area, erosion and sedimentation fluctuated up to over 400 m. The southern beach area remained relatively stable throughout the interpretation period. In the river and estuary area, the river shifted southward, with the furthest shift occurring at the estuary at a distance of 500 m.

The results of shoreline changes provide a basis for evaluating some patterns; however, they depend heavily on the results of seabed topographic changes across the entire beach cross-section. To assess the changes in seabed topography, the author developed a program to interpret seabed topography from satellite imagery and measurement data using the method of attenuating green and blue light reflection signals with respect to depth. The results obtained show the seabed topography field of the coastal estuary area at different interpretation times. Comparisons of the interpreted topography before and after the northeast monsoon season in October 2016 and March 2017 show that the topography in the wave-breaking zone in front

of Cua Dai beach and the surrounding area has experienced significant erosion, resulting in an increase in the beach slope. This method is particularly effective in assessing seabed changes at locations where existing hard structures have been built to protect the shoreline, making shoreline interpretation methods inapplicable. Interpretation results, before and after the historic flood from November 2017 to September 2018, show the amount of sand and the sediment area carried by the river during a real flood in the area. This is new data for estuarine sand shelf research.

Building on past methods and data series, the researcher conducted supplementary analysis extending the data series to 2023 for shoreline change interpretation and developed a program to successfully apply seabed topography interpretation methods. These are new contributions of this thesis to research in the region.

## **CHAPTER 3: NUMERICAL MODELING OF MORPHODYNAMICS**

### **3.1. Data**

Model Setup:

Digitized bathymetry (1/100,000) from Son Tra to Cua Lo. Detailed local bathymetry (1/5000 underwater, 1/2000 land) from October 2016.

Calibration Data:

Hydrodynamic surveys (waves, currents) conducted in October 2016 (SW monsoon) and March 2017 (NE monsoon).

### **3.2. Model Setup**

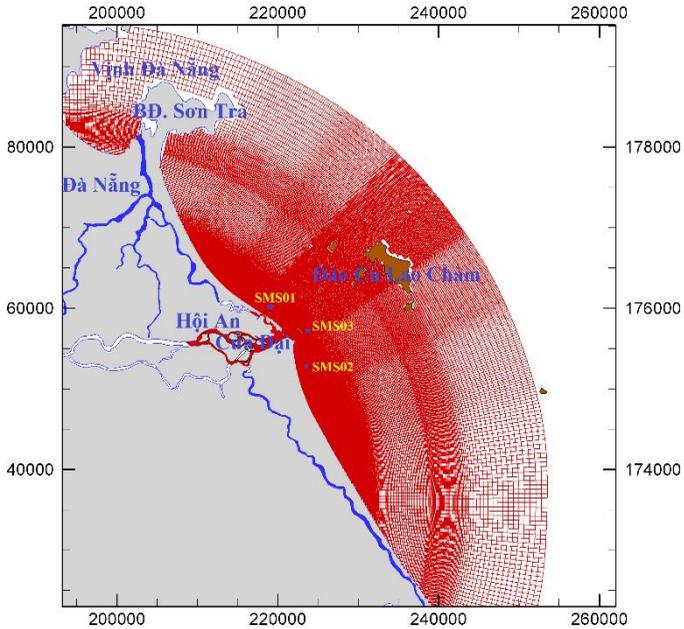


Fig 5. Grid and location of wave and current measurement stations

### Calibration, and Validation

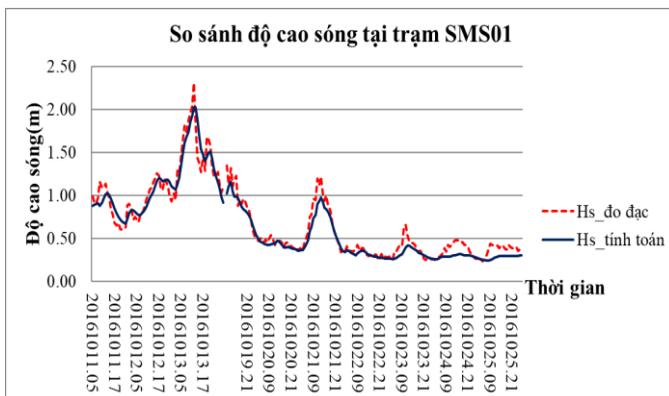
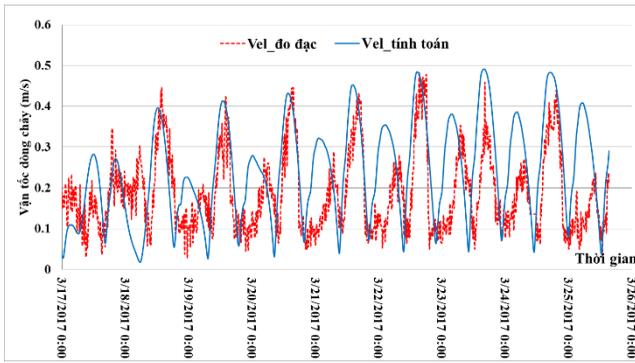


Fig 6. Comparison of calculated and measured wave heights at SMS01 station

The calculated deviations and mean square errors show that the wave height, wave period, and wave direction values throughout the calculation series from the model and actual measurements have negligible and acceptable discrepancies. Furthermore, the model's simulation results of wave height, wave period, and wave direction are quite similar to the actual measurements. The adjusted coefficients will be used to recalculate the measurement series for March 2017.



*Fig 7. Compare the flow velocities at station SMS03*

### 3.4. Long-term Morphological Simulation Methods

#### *Phân tích thủy triều hình thái học*

Morphological Tide: Based on Lesser (2009), combining M2 and a compound constituent C1 (derived from O1 and K1) to represent the total tidal signal

$$C_1 = \sqrt{2O_1K_1} \quad (3)$$

$$\phi_{C1} = \frac{\phi_{C1} - \phi_{K1}}{2} \quad (4)$$

Table 1. Synthesis of tidal morphological components for the Cua Dai area, Hoi An

Tidal wave	Freq (°/hour)	Boundary note NW		Boundary note SE	
		Amp (m)	Phase (deg)	Amp (m)	Phase (deg)
C1	14,496644	0,159	161,31	0,344	151,5
M2	28,993288	0,179	102,64	0,194	92,49

### River Discharge:

Analysis of flow data from Nong Son and Thanh My stations (1977–2023)

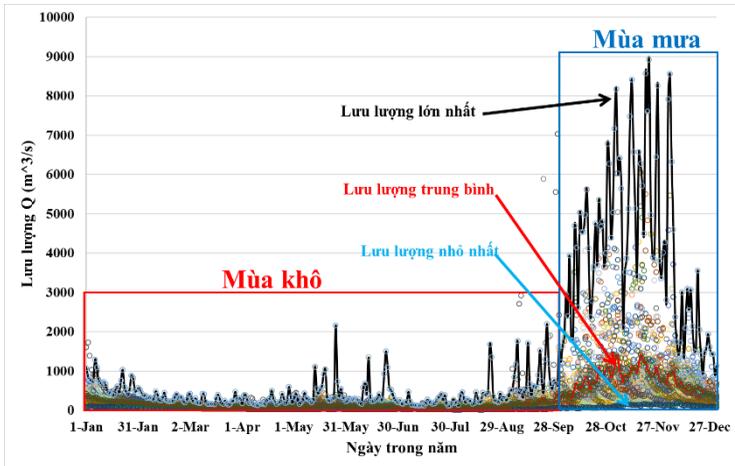


Fig 8. Diagram showing the evolution of average daily flow rate throughout the year

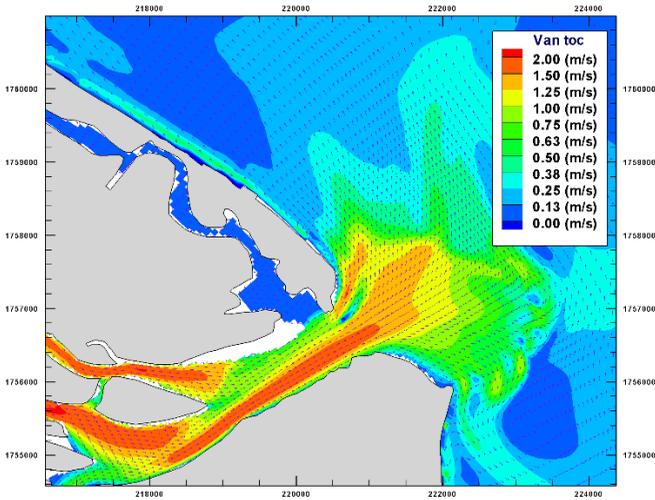
### **Wave Energy:**

Deep-water wave data reanalyzed from NCEP winds at Cu Lao Cham (1995–2023)

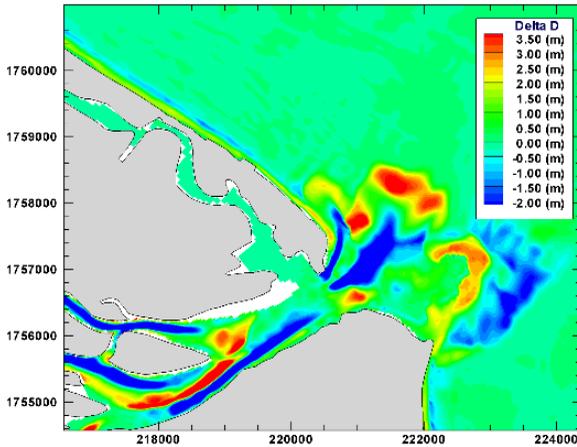
$$H_{s,mor} = \left( \frac{\sum_i [p_i H_{s,i}^{2,5}]}{\sum_i (p_i)} \right)^{1/2,5} \quad (4)$$

Where:  $i$  is the corresponding index of the wave component;  $P$  is the frequency of the wave component

### **3.5. Simulation Results**



*Fig 9. Flow field during periods of high flow*



*Fig 10. Seabed topography changes after 5 years*

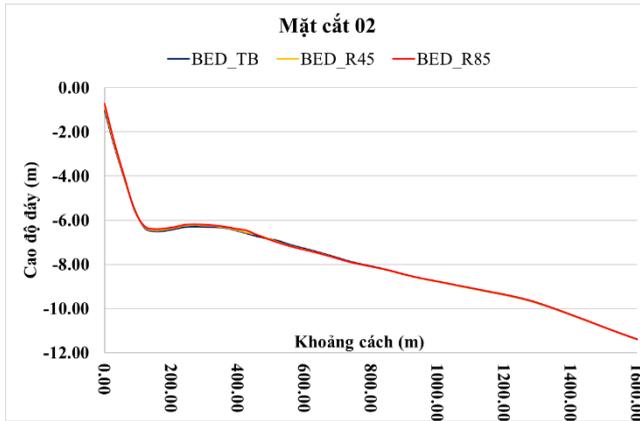
**Hydrodynamics:** In the northern beach area, wave-induced currents dominate. A longshore current divergence point exists near Fusion Alya Resort. Southward flow from this point is blocked by the river outflow. River discharge flows straight offshore in the northern section and deflects southward in the southern section.

**Morphodynamics:** The current state simulation shows erosion of the southern riverbed. Sediment is deposited on the outer edge of the sand terrace. Over 2-5 year simulations without intervention, the sand terrace continues to migrate south. The northern dunes migrate shoreward, merging with the southern spit, while the Cua Dai seabed lowers, increasing beach slope.

### **3.6. Climate Change**

Scenarios Simulations under RCP 4.5 and RCP 8.5 for the year 2100 show no significant difference in general morphological evolution compared to baseline scenarios. Minor accretion differences were observed

on high dune crests under higher water levels (RCP 8.5), while areas with hard structures showed no change



*Fig 11. Comparison of seabed topography between different water level rise scenarios at cross-section 02 (Cua Dai Beach)*

### 3.7. Conclusion of Chapter 3

To accurately simulate the current state of morphological changes in the study area, the Delft3d mathematical model was meticulously calibrated and validated with a dataset of hydrodynamic parameters, yielding fairly good accuracy. Furthermore, the model's beach change results were compared with data analyzed and interpreted from satellite imagery. This is a very difficult step when applying numerical models to simulate sediment transport and beach changes, as it is challenging to conduct large-scale beach change measurements.

The hydrodynamic calculation results show that: In the northern beach area, the current is primarily caused by waves. A north-south current exists along the shore from Fusion Alya Hotel northward, and a north-south

current exists from Fusion Alya Hotel towards the river mouth, blocked by the river outflow. Fusion Alya Hotel is the point of divergence of the longshore current. The river's flow towards the sea mainly follows two main directions: straight out to sea in the northern part and a southward deviation in the southern part.

Simulation results of the current morphological changes show that there is riverbed erosion near the southern bank. Sediment from the river is carried to the sand terrace perpendicularly in the northern half and southward in the southern half, forming alluvial deposits at the outer edge of the sand terrace.

Simulation phases with subsequent cycles of 2, 3, 4, and 5 years indicate the subsequent development of the current situation if no intervention measures are taken: the sand terrace continues to move southward. The outer sand dunes gradually shift towards the shore and merge with the southern ridge, forming a large sandbar. However, due to relatively weak dynamic factors in the southern part, the sediment does not move far but accumulates near the river mouth. At the northern tip, sand is supplied from the outer sand terrace, creating a sandbar in front with a scale of several hundred meters. The phenomenon of seabed lowering is occurring along Cua Dai beach, causing the beach slope in this area to increase.

The successful application of morphological analysis methods to input parameters and the successful simulation of the current state of sediment transport mechanisms and beach changes in the study area is a new contribution of the graduate student to research in the region.

Simulation results evaluating two climate change-induced sea level rise scenarios, RCP4.5 and RCP8.5, show no significant differences in beach changes under the impact of climate change-induced sea level rise.

## CHAPTER 4: PROPOSED ENGINEERING SOLUTIONS FOR STABILIZATION

### 4.1. Current Status The area faces severe erosion



*Fig 12. Current state of erosion in the Cua Dai - Hoi An area*

### 4.2. Objectives of Engineering Solutions

- Stabilize the river mouth and protect the southern bank from erosion.
- Mitigate erosion at Cua Dai beach without using hard structures by redirecting sediment supply to the northern beach.
- Ensure flood drainage and navigation channel stability

4.3. Basis for Proposal Erosion is attributed to sediment deficit, hydrodynamic factors (waves/storms), human structures, and climate change

#### 4.4. Proposed Solution: Groin System on Southern Bank

In this study, the author proposes a technical solution by constructing a line of 05 breakwaters on the southern bank of Cua Dai (Figure 15). The base of the breakwater is located at the current shoreline, and the top of the breakwater is located at the 1998 shoreline. This breakwater system allows the main channel of the river mouth to be aligned with the 1998 channel.



*Fig 13. The proposed plan involves constructing a welded revetment in the southern bank area of the Cua Dai River.*

#### 4.5. Evaluation of Alternatives Two scenarios were evaluated:

1. Half-Length Scenario ( $d=1/2$ ): Optimized for cost and construction.

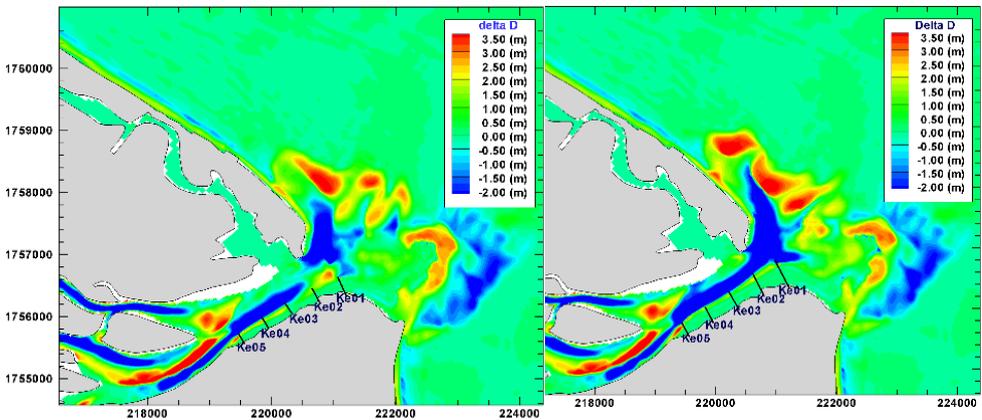
## 2. Full-Length Scenario ( $d=1.0$ ): Full design length.

### Simulation Results (5 Years):

- Scenario  $d=1/2$ : The sand terrace in front of the estuary is restored after 2-3 morphological cycles. Sediment is effectively supplied to the northern beach in subsequent phases. This option is effective in the long term and avoids abrupt morphological shocks to the northern river mouth.

- Scenario  $d=1.0$ : While providing a strong sediment supply to the north in later stages, it may cause sudden changes in the northern estuary.

In both scenarios, the redirected sediment and the remaining terrace create a large accretion zone in the south, merging with the southern spit due to the wave shadow effect of Cu Lao Cham.



Scenario  $d = 1/2$

Scenario  $d = 1,0$

*Fig 14. Simulation results of erosion and sedimentation after 5 years.*

## 4.6. Selection

Simulation results over 10 years, considering flood and hydrodynamic conditions for two embankment options, show that the half-height embankment option has more advantages than the full-height embankment and creates a sand dune area similar to the past (1965). Therefore, the half-height embankment option is optimal in terms of investment and achieves the desired results. However, these are research results based on two proposed options; to achieve the optimal length of the embankment system, simulations of multiple options within the framework of the aforementioned embankment system are necessary.

## 4.7. Conclusion of Chapter 4

This chapter introduced a technical proposal to mitigate beach erosion at Cua Dai Beach, Hoi An, and stabilize the estuary area. The proposed solution is based on previous analyses of the river's southward movement. This movement causes the sandbar created by the river to move further into the wave-shading area created by Cu Lao Cham Island, thus reducing the supply of sand from the outside. Therefore, the proposed system of breakwaters on the south side of Cua Dai River aims to bring the river-created sandbar back northward, away from the wave-shading area ahead. Sediment will be supplied to the beach after the sandbar is formed. The proposed structure consists of a system of five breakwaters of varying lengths, with the breakwater extending to the riverbank in 1988.

To ensure practical application, the author evaluated the results using two length options: one with the full length of the breakwater and one with half the full length. This allowed for the determination of the optimal length

to minimize investment costs and achieve the highest erosion control effectiveness.

The evaluation results for the half-length breakwater showed that the sand terrace in front of the river mouth was quickly restored after 2 to 3 morphological cycles. In subsequent cycles, sediment was supplied to the northern part of the beach quite well. In conclusion, this option may not be effective in the short term, but it is highly effective in the long term and does not cause significant changes to the area, especially the northern sand promontory.

Evaluation results for the full-length breakwater option: With the established annual sediment load, the new sand terrace will take 2-3 morphological cycles to create. In the next phase, sediment is supplied to the shore more vigorously and on a larger scale further north. However, this option may cause many sudden changes in some areas such as the northern estuary.

In both proposed construction options: the remaining sediment of the pre-construction sand terrace plus the new sediment brought to the southern area create a fairly large depositional area that tends to merge with the southern tip, forming a large sandbar. This result is due to the area being in the sheltered zone of Cua Lao Cham island and the new construction system weakening the wave dynamics and currents there, causing deposition right at the estuary. This sediment is unlikely to be transported far south due to insufficient dynamic field strength.

The evaluation results show that the proposed solution has proven quite effective in mitigating beach erosion and stabilizing the estuary without directly interfering with the beach itself. In the practical implementation of

this technical solution, further adjustments to the length of the embankment system and optimization calculations based on other expected results are needed to select the best parameters.

In this study, the graduate student introduced and proposed a technical solution for stabilizing estuary and beach areas, a novel contribution serving as a reference for long-term planning for protection and sustainable development of the region.

## **CONCLUSION**

Through the overall study and current situation, it is evident that the Cua Dai - Hoi An coastal area is experiencing significant changes, particularly erosion in the bathing areas and the appearance of sand islands in the middle of the river mouth in late 2017 and early 2018.

The results of the analysis of shoreline changes from 1973 to 2023 show that the northern beach area has undergone significant changes through different periods. From 2004 to the present, serious erosion has occurred at a rate of over 50 m/year. The southern shore is relatively stable and shows a tendency towards sedimentation. The inland part of the river has changed significantly with a southward shift, with the furthest point reaching 500 m.

The researcher successfully applied a method of interpreting seabed topography from Sentinel-2 satellite imagery combined with survey data to clarify beach changes and overcome the limitations of shoreline determination methods from satellite imagery due to the construction of rigid structures. The results showed that the beach in front of Cua Dai area experienced erosion right below the structures in the area with water depths of 3 to 5 meters, making the beach steeper.

From evaluating the causes of erosion combined with the characteristic geomorphology of the study area, the author deduced a correlation between the supply of sediment from the river and the distribution of sand in front of the river to propose engineering solutions to mitigate erosion at the riverbank and stabilize the southern bank of Cua Dai River. With its role as an outer shield and creating a wave convergence zone behind it, Cu Lao Cham Island contributes to creating a wave convergence point. The proposed river engineering solutions aim to shift the river mouth's position north of the wave intersection point, thereby improving the efficient distribution of sand to the northern bank.

The effectiveness of the proposed solutions was evaluated using numerical simulations and compared with the current situation. Simulation results showed that all solutions were effective in preventing erosion on the northern bank by redistributing sand from the river. Stabilization of the southern bank was achieved using a system of five breakwaters. The biggest advantage of this proposal is the protection of the coastline from afar, avoiding the construction of permanent structures in areas with high tourist traffic, such as Cua Dai in Hoi An.

In practice, the construction of permanent structures to regulate beach and river mouth areas requires evaluation of many different factors. This study only presents a technical proposal. Therefore, when implementing it in practice, an assessment of the optimal investment cost is needed to determine the best length of the structure. In addition, a thorough and scientific assessment of other environmental impacts of the project is also necessary.

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