MINISTRY OF EDUCATION AND TRAINING
MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT

VIETNAM ACADEMY FOR WATER RESOURCES
SOUTHERN INSTITUTE OF WATER RESOURCES RESEARCH

----------◊◊◊----------

PHAM TRUNG

STUDY ON COASTAL MORPHOLOGY OF THE SOUTH CENTRAL COAST IN THE CONTEXT OF SEA LEVEL RISE DUE TO CLIMATE CHANGE

Field of engineering: Hydraulic Construction Engineering
Ref. CODE: 9 58 02 02

SUMMARY OF ENGINEERING DOCTORAL THESIS

HO CHI MINH CITY - 2021

This thesis was completed at the **Southern Institute of Water Resources Research**

Supervisor 1: Assoc. Prof. Dr. Trinh Cong Van
Supervisor 2: Dr. Tran Thu Tam

Reviewer 1: Prof. Dr. Nguyen Tat Dac
Reviewer 2: Assoc. Prof. Dr. Nguyen Thanh Hung
Reviewer 3: Assoc. Prof. Dr. Nguyen Kien Quyet

This thesis will be defended in front of the preliminary evaluation committee at: Southern Institute of Water Resources Research, No. 658 Vo Van Kiet, Ward 1, District 5, Ho Chi Minh City.
At .... on ....

The thesis is available for reference at:
- National Library of Vietnam
- Library of Vietnam Academy of Water Resources
- Library of Southern Institute of Water Resources Research

INTRODUCTION

1. Necessity of the doctoral thesis study

As a key region for socio-economic development of Vietnam's Central region with a coastline stretching over 1,100 km, the South Central Coast's terrestrial area accounts for 13.45% of Vietnam and, by 2020, there were 10.8% of Vietnam population allocated in the region. This region rich in marine resources and home to many economic center and security defense facilities. In recent time, due to global climate change and human activities, erosion have been found in rivers, streams and the coastline throughout Vietnam. Especially in the South Central, the phenomenon of coastal erosion, and accretion in estuaries, canals and docks... is intensifying in both frequency and magnitude, directly affecting people's livelihoods, economy and infrastructures in those areas. The problems mentioned above are largely the result of coastal morphology in the region, which is mainly affected by fluctuations of factors from the sea and the imbalance of sediment source due to human development activities on rivers and coastal estuaries. Therefore, understanding the trend of morphological changes in the South Central Coast through the change of wave fields in the context of sea level rise (SLR) due to climate change (CC), assessing their influences so that recommendations can be made for solutions to stabilize, control and minimize adverse impacts on the environment would be a highly necessary and urgent task because it will contribute a part to the management of coastal erosion in the South Central region. Considering the above rationale, the author has chosen the "*Study on Coastal Morphology of the South Central Coast in the context of Sea Level Rise due to Climate Change*" as the subject for his doctoral thesis.

2. Objectives of the study

Although the change in coastal morphology is the result of many influencing factors, the purpose of this study is limited to determining the trend of changes in the coastline and beaches in the South Central Coast under direct impacts of wave energy flux in the context of SLR due to CC, then on that basis, propose solutions to stabilize the coastal morphology of the South Central Coast as appropriate for the region's natural conditions and requirements of socio-economic development in the study area.

3. Objects and scope of the study

- *Objects of the study:* The object of the study in this thesis is limited to the energy wave fields – the primary impact that directly causes morphological changes in the South Central Coast and consideration of future trends corresponding to various CC - SLR scenarios.

- *Scope of the study:* Coastal areas and shorelines near estuaries in the South Central Coast.

4. Approaches and Methodologies of the study

4.1. Approaches: The thesis goes with the following approaches: (i) Systemize from overall to details; (ii) Inherit and develop research methods to solve the problems posed in the distribution of wave energy along the coast and its change in the context of SLR process as the basis for the assessment trends in morphological changes of the South Central Coast as well as proposed solutions to minimize impacts.

4.2. Methodologies: (1) Legacy data study; (2) Field investigation and surveys; (3) Statistical study; (4) Numerical simulation.

5. Scientific and practical significance of the thesis

- *Scientific significance:* The thesis has built a map of the distribution of components of wave energy flux with direction along the shoreline (Pt) and perpendicular to the shoreline (Pn) averaged by each climate season at the "baseline" position and the changing trends of these quantities during the SLR process to explain the morphological trends of the South Central Coast. This is the basis to identify areas being at risk of erosions and accretion. The results of the thesis have high scientific significance in studying morphological changes of the South Central Coast.

- *Practical significance:* Outcomes of the study that be used in practice include: (1) Baseline position of the South Central Coast; (2) Maps showing spatial and chronological distributions of longshore wave energy flux Pt and onshore wave energy flux Pn (along the baseline); (3) Evaluation of SLR impacts on wave energy flux components along the baseline; (4) Orientations for structural and non-structural solutions based on the distribution map of tangent and normal wave energy flux with the baseline, and assessment of their trends in spatial and chronological changes have high practical significance. The direction of the coastal flux expressed through the direction of $\overrightarrow{P}$ will be very helpful in aligning construction of systems of coastal protection structures out into the sea (such as breakwaters and groynes etc.). When determining and analyzing the gradient of longshore Pt along the baseline, it can be referred to the erosion-accretion movements in coastal areas.

6. New contributions of the thesis.

1- The thesis has developed a method to determine Pt and Pn wave energy flux based on a coordinate system, defined by the author, in association with actual shorelines. Those are the components of energy flux (or wave power) acting in the two directions tangent (t) and normal (n) to a particular stretch of shoreline, while considering changing trends of the above-mentioned wave energy flux at the baseline during SLR in accordance with CC scenarios developed by Ministry of Natural Resources and Environment.

2- On the basis of identification and analysis of wave energy flux components in the South Central Coast, the author has proposed structural solutions and spatial arrangement of coastal protection works in some furthermost areas in the South Central Coast and adopt them in practice to the LaGi coastal breakwater project (Binh Thuan province), the structure was constructed 1 year ago, and functioning well since then.

CHAPTER 1. OVERVIEW OF THE STUDY

1.1. Overview of the study areas

1.1.1. Geographical location

The South Central Coast (SCC) is a narrow region extending toward the North-South directions, including provinces from Da Nang in the North to Binh Thuan in the south, with all of its provinces being adjacent to the sea. With this natural characteristics, South Central provinces have advantages in socio-economic development, particularly in the marine economy, but they also face many difficulties, among which the problems of coastal erosions and accretions at estuaries have become urgent and concerns to authorities and local people.

1.1.2. Situation of erosion-accretion in the SCC

The South Central Coast currently has two opposing problems: While the coastal strip faces severe erosions, estuaries, lagoons and docks in the region are prone to accretions which reduce drainage capacity and cause inland floods, hindering waterway navigation in the area.

1.1.3. Primary causes of erosion-accretion in the SCC

While acknowledging the factors influencing coastal erosions/ accretions (Figure 1.2), the scope of study in this thesis will be limited to analyzing impacts of waves through wave energy flux and trends of such impacts during SLR due to CC.

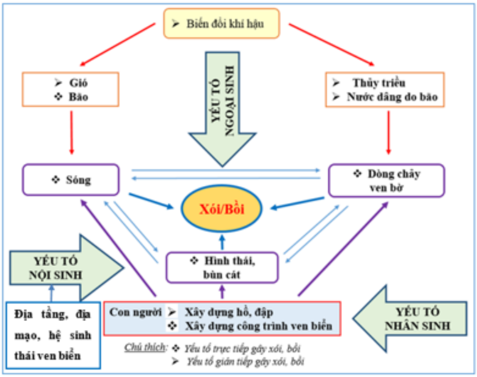


Figure 1.2: Primary causes of coastal erosions and estuary accretions

1.2. Existing studies in the world about impacts of Sea Level Rise on coastal morphology

Existing studies in the world about impacts of SLR on coastal erosion and accretion have so far gone with two primary approaches as shown in the diagram in Figure 1.13.

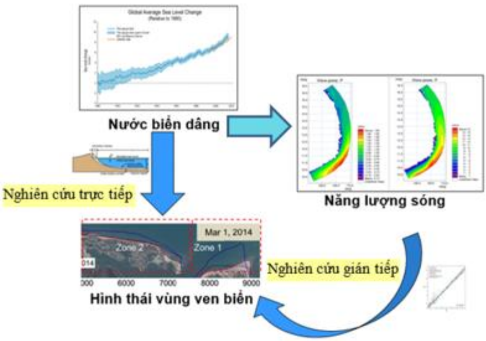


Figure 1.13: Approaches in studies about impacts of SLR on coastal morphology

The first approach would build models, mathematic expressions, etc. to determine the relationship between SLR factors and displacement of the coastline, collectively known as "*The Bruun Rule*" i.e. defining morphology according to the level of rise and fall of average sea level in a long period. The second approach is to model short-term morphology through hydro-dynamics and wave energy models,…considering influences of key factors (wave power, wave flux, transport of sediment etc.) on coastal morphology.

1.2.1. Model for determining long-term morphology

According to *Bruun*, the horizontal displacement of the coastline, R, is related to sea level rise, S, by the following formula:

$$R = \frac{L}{B+h} S \tag{1.1}$$

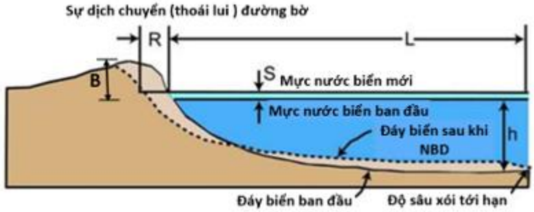


Figure 1.6: Illustration of Bruun model

The Bruun Rule has been adopted almost globally, from North America, the Caribbean, South America, Europe, New Zealand, Australia, Southeast Asia to the Middle East. Even so, this rule ignores various important local oceanographic and geological principles, so it does not and cannot predict coastline retreat due to sea level rise accurately. Therefore, coastal management strategies such as setback zones, coastal engineering models, and beach nourishment designs based on Bruun's rule and the *profile of equilibrium* concept is still being considered.

1.2.2. Model for determining short-term morphology

Studies about impacts of SLR on coastal morphology focuses on hydro-dynamic processes including waves, tides, sea currents, sediment transport... on basis of field observation data, study on physical models and math models.

Ocean waves are among the key impacts on coastal morphology, so they interest many groups of scientists and researchers. Although the huge energy potential of wave power has been recorded for a long time, however, studies about influence of wave energy flux on coastline morphology are quite limited. Figure 1.10 presents results of a study from 1984 to 2002 on the relationship between wave power and average coastal erosion rate in Bangkhuntien province (North of the Gulf of Thailand).

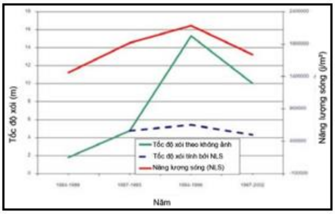


Figure 1.10: Relationship between wave power and coastal erosion rate

A study by Boston University (USA) in 2015 conducted at 8 sites in the US, Australia and Italy formulated the relationship between wave power and dimensionless coastal erosion rate as follows (Figure 1.11):

$$E^* = a^* P^*,\ a^* = 0,67 \qquad (1.4)$$

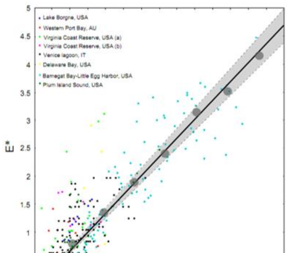


Figure 1.11: Relationship between wave power and erosion rate

1.3. Studies and solutions already adopted in Vietnam and the South Central Coast

In Vietnam, studies on wave energy through simulation models of hydrodynamic regimes only started in the 2000s. Studies about ocean wave energy mainly focus on identifying areas with large wave energy to assess the potential to harness this energy source for socio-economic development. Their scope of study is usually offshore wave energy. There is much fewer studies on wave energy for calculating coastal currents and sediment transport. Therefore, the study of wave energy is important and necessary, especially for coastal areas of the South Central Coast, where wave impacts are direct and wave-induced coastal erosions are frequent and complicated.

CHAPTER 2. SCIENTIFIC BASIS AND METHODOLOGY OF THE STUDY ON COASTAL MORPHOLOGY OF THE SOUTH CENTRAL COAST

2.1. Theoretical basis of coastal morphology

Because sediment is the intermediate element in the process of causing erosions or accretions on the coast, a study of morphological changes in coastal areas should consider scientific basis of sand transport processes (vertical and horizontal to the coast) through the following models.

2.1.1. General concept of sediment transport model

A sediment transport model usually includes: The hydraulic part describing waves, distribution of average flow velocity, turbulent viscosity coefficient γ_t and bed friction τ_b; The sediment part describing distribution of sediment concentration and/or sediment discharge as results of hydraulic conditions; Results from the sediment part (concentration, sediment discharge) are then input to a dynamic model (bed or bank) to calculate erosion rate of bed or bank.

2.1.2. Equilibrium cross-shore profile

To date, the most commonly used math expression describing shape of shore was developed by *Bruun and Dean* (also known as the *Bruun/Dean* cross-section) [45] [52], on the basis of equalizing wave energy losses in the breaking wave zone. It leads to the theory of equilibrium cross-shore profile, h = A. $x^{2/3}$ (h is the water depth at a horizontal distance of x from the shore; A is the experience dimensional factor of the cross-section profile; dimension $L^{1/3}$).

2.1.3. Longshore sediment transport model

Computational models of longshore sediment transport in the breaking wave zone in which the CERC formula is the empirical relationship $Q_{ls} = f(P_{ls})$ between the total longshore sediment discharge Q_{ls} and the quantity P_{ls} of wave power. Q_{ls} and P_{ls} are defined as follows:

$$Q_{ls} = \int_{xo}^{xl} \overline{q_{sy}} dx \qquad (2.11)$$

q_{sy} is the sediment discharge volume in longshore direction y, per one width unit in cross-shore direction x, xo is the point in the sea where bed is unaffected by erosion-accretion and xl is the furthermost point of waves coming onto shore. P_{ls} is the longshore energy flux factor, defined by:

$$P_{ls} = P_v \cos\alpha_v \sin\alpha_v \qquad (2.12)$$

There have been many attempts to define the significance of the quantity P_{ls} as the longshore component of wave energy per one longshore length unit, at the wave breaking point. *Longuet-Higgins* [77] analyzed the relationship between P_{ls} and shear components of the radiation stress S_{ij}. Determination of the quantity P_{ls} is also conducted by the PhD student in the following section of this thesis as a different symbol *Pt*, however, it was simplified by calculating at the breaking wave boundary ("*baseline*" position).

2.2 Theoretical basis of wave energy

2.2.1. Formation and propagation of ocean waves

2.2.2. Monochromatic wave energy

The total wave energy (averaged per area unit of water) is determined with the following formula:

$$E = E_p + E_d = \frac{\rho g H^2 L}{16} + \frac{\rho g H^2 L}{16} = \frac{\rho g H^2 L}{8} \qquad (2.24)$$

On average (spatially on a wave length L and chronologically in one cycle), we have the average wave energy per surface area unit of the sea, which is called wave energy density:

$$\overline{E} = \frac{E}{L} = \frac{\rho g H^2}{8} \quad (2.25)$$

Average wave energy flux $\overline{P}$ (or wave power) is the average amount of energy transmitted over 01 meter in the direction of wave propagation per time unit, through a fixed vertical plane perpendicular to the direction of wave propagation:

$$\overline{P} = (\frac{\rho g H^2}{8}) \frac{\sigma}{k} \left[\frac{1}{2}(1 + \frac{2kd}{sh(2kd)})\right] = \overline{E}nC = \overline{E}C_g \quad (2.26)$$

2.2.3. Wave energy spectrum

What commonly used today is the *wave energy spectrum*. Because $E=\rho.g.H^2/8=\rho.g.a^2/2$ (a is wave amplitude), the wave energy spectrum actually represents $a^2/2$ in accordance with wave frequency σ. There are many components with frequencies σ close together in a pooled frequency range, thus it is common to express the average energy in a frequency band $E_n/\Delta\sigma$ in accordance with σ_n. This curve is continuous and is called the *wave energy density spectrum* E(σ).

2.2.4. Formula of wave energy flux

2.2.4.1. Theoretical formula of model MIKE21 SW

In the two-dimensional Cartesian coordinate system XY, the following formulas is used to estimate the direction in which the total wave energy flux propagates:

$$\vec{P} = (P_X, P_Y) \quad (2.33)$$

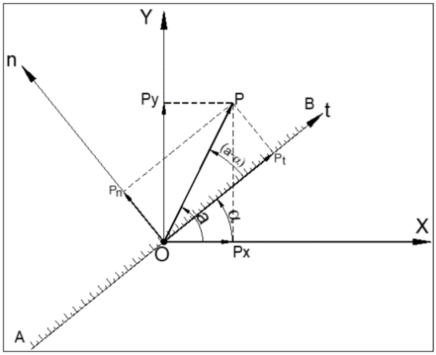
$$\vec{P} = \rho g \int_0^{2\pi} \int_0^{\infty} \overrightarrow{C_g}(f,\theta)E(f,\theta)dfd\theta \quad (2.34)$$

$$P_X = \rho g \int_0^{2\pi} \int_0^{\infty} C_g(f,\theta)\cos(\theta)E(f,\theta)dfd\theta \quad (2.35)$$

$$P_Y = \rho g \int_0^{2\pi} \int_0^{\infty} C_g(f,\theta)sin(\theta)E(f,\theta)dfd\theta \quad (2.36)$$

In the above formulas, wave energy flux in each direction is projected onto X or Y axis and then summed together. We would have X or Y flux components of the total power in all directions Px or Py.

2.2.4.2. Formula proposed by the thesis



To calculate the wave energy flux affecting a stretch of coastline (tens, hundreds of kilometers long) it is necessary to calculate integral P over the whole coastline. The method that the author adopted in the thesis is to divide the coastline to be calculated into many small segments AB (from several hundred meters to 01 km). Each segment will have a projection on the Cartesian coordinate system of ($\Delta x = X_B - X_A$), $\Delta y = Y_B - Y_A$) and the wave flux through segment AB is a vector with two components ($Px.\Delta y$ and $Py.\Delta x$). By defining a new coordinate system associated with shoreline segment AB such that the new horizontal axis is attached to the shoreline and the new vertical axis is perpendicular to the shoreline with convention of the shoreline direction t (with a positive direction along the vector AB) and the normal direction n (perpendicular and directed to shoreline segment AB). The thesis proposes a formula to calculate magnitude of the longshore wave flux component ***Pt*** in the direction *t* and the component ***Pn*** towards the shore in the direction *n* for the segment AB at a time as follows:

$$P_t(t) = P.\cos(a - \alpha) \qquad (2.37)$$

$$P_n(t) = P.sin(a - \alpha) \qquad (2.38)$$

Considering in a period from T1 to T2 (1 tidal cycle, 1 wind season...), it is possible to determine the average energy flux (or wave power) acting in accordance with the tangent direction (*Pt*) and normal direction (*Pn*) with the shoreline during that time by calculating integrals:

$$P_t = \frac{1}{(\mathrm{T2}-\mathrm{T1})}\int_{T1}^{T2} P.\cos(a-\alpha)dt \qquad (2.41)$$

$$P_n = \frac{1}{(\mathrm{T2}-\mathrm{T1})}\int_{T1}^{T2} P.\sin(a-\alpha)dt \qquad (2.42)$$

2.2.5. Baseline and calculation sequence in the Thesis

- *Determination of the baseline for calculation:*

Upon reaching the shore, wave energy would be significantly dissipated. The author has set the definition and how to identify "*baseline*" to use calculations and analysis of characteristic values of wave energy flux at the baseline (before reaching the actual shore).

Figure 2.12: Illustration of the baseline as defined in the Thesis

- *Calculation of wave energy flux components at a detailed level:*

On each segment of the baseline with average length ds=500m÷1km, we have a value $\vec{P}(\mathrm{Px}.\Delta\mathrm{y}, \mathrm{Py}.\Delta\mathrm{x})$ according to formulas (2.33) to (2.36) from the results of MIKE21 SW model. Project this vector onto the tangent and normal lines to the shoreline ds with Pt, Pn according to formulas (2.37), (2.38) and calculate integrals for a period of time according to formulas (2.41), (2.42). Plot a graph along the baseline to find the relationship with erosion situation of the segments ds. It can be called a detailed-level study for each segment ds.

- *Calculation of wave energy flux components at overview level:*

In order to make a general assessment of a longer segment AB on a larger scale (for example, a stretch of curved shoreline such as from Ke Ga cape to Phan Thiet or from Phan Thiet to Mui Ne...), i.e.

stretching over tens of kilometers, calculate integrals (plus) of Px, Py along the selected baseline. The result is the vector (ΣPx, ΣPy) of segment AB. Now project this sum vector onto the direction AB to determine $\vec{P}(P_t, P_n)$ and general evaluation for shore segment AB.

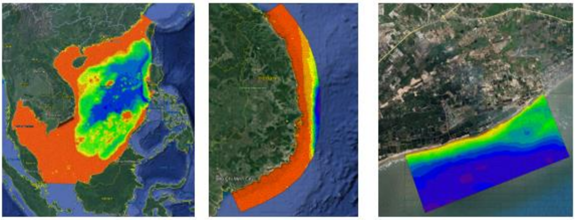
- *Identify zones at risks of erosion-accretion on gradient Pt, Pn:*

The gradient of f (symbolled as *grad* or ∇*f*) is an n-dimensional vector of which each component is a partial derivative corresponding to each variable of the function f ($\nabla f = (\frac{df}{dx_1}, \frac{df}{dx_2} \dots, \frac{df}{dx_n})$.

Taking the gradient of the longshore wave flux component Pt in accordance with the baseline (d/ds), we come to the following remark: Pt is attributable to longshore sand bearing capacity, so if Pt of the latter segment is higher than that of the previous segment (positive longshore gradient), it means that sand bearing capacity increases gradually and sand on sea bed is being taken away, causing erosions. Conversely, if longshore gradient is negative, accretion is happening. In chronological consideration, if the value of Pt at a later time is higher than the previous time (d/dt>0), it means that sand bearing capacity of that segment increases gradually. Taking away sand on the sea bed would possibility cause erosions if the two adjacent segments are not replenished with sediments (still depending on the longshore gradient Pt). If Pn at a later time is higher than that of the previous time, onshore wave energy flux and sand bearing capacity would gradually increase, raising the risk of erosion.

2.3. Computational models

The thesis has used 3 model levels, including: (i) Overview with the East Sea model to provide "input" data for the regional model; (ii) Simulated area model for the entire South Central Coast region and (iii) Local model to deal with specific projects. The thesis has inherited and used previous research results from models with the following scale and level of detail:



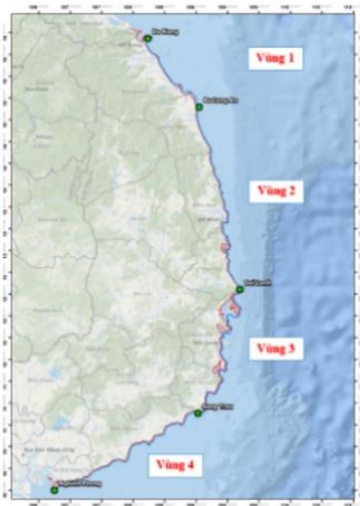
Mô hình 1 Mô hình 2 Mô hình 3

Figure 2.10: Levels of details of models used in the Thesis

The toolkit used is MIKE21/3 Couple FM model (including modules: hydrodynamics-HD, wave spectrum-SW, sand transport-ST).

CHAPTER 3. OUTCOMES OF THE STUDY ON COASTAL MORPHOLOGY OF THE SOUTH CENTRAL COAST

3.1. Calculation and development of zoning map of coastal wave energy flux of the South Central Coast



The thesis has established a baseline and divide the region into 4 zones from North to South to calculate wave energy flux for the entire South Central Coast:

- *Zone 1*: From Son Tra peninsula to Ba Lang An cape (135 segments).
- *Zone 2*: From Ba Lang An cape to Dai Lanh cape (319 segments).
- *Zone 3:* From Dai Lanh cape to Sung Trau cape (270 segments).
- *Zone 4*: From Sung Trau cape to Nghinh Phong cape (270 segments).

Calculation results show that the areas with high wave power are mainly from Dung Quat bay, Quang Ngai province, to Sung Trau cape - the contiguous point between Ninh Thuan and Binh Thuan provinces (zones 2 and 3). Average wave power in these areas is 3 to 7 times higher than that in the North Central region. Waves during Northeast monsoons have a strong influence on the entire coastline from Da Nang to Ninh Thuan (Figure 3.17) and waves during Southwest monsoons are more influencing on the coastline from Dai Lanh cape (Khanh Hoa) to Nghinh Phong cape (Ba Ria Vung Tau) (Figure 3.18).

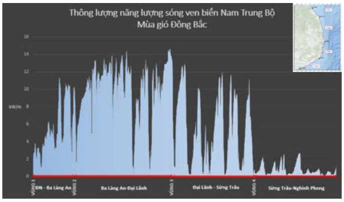


Figure 3.17: Wave power P in Northeast monsoons

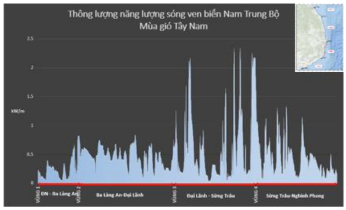


Figure 3.18: Wave power Pt in Southwest monsoons

The analysis of tangent components Pt and normal Pn of wave energy flux relative to the shoreline explains that wave regimes and sea surface currents vary according to wind seasons of the year, both in directions and intensity. This means that seasonal sand transport process is a very important factor causing coastal erosion-accretion in the South Central region. Because impact force of waves can directly cause shoreline erosions and transport material particles off the shore (normal component Pn) or along the coast to accrue elsewhere (tangent component Pt). In the Northeast circulation period (Figure 3.19), while the average coastal wave flux from Da Nang-Quang Nam (zone 1) predominantly flow toward the Northeast (Pt>0), wave flux from Binh Thuan to Vung Tau (zone 4) mostly flow in the Southwest direction (Pt<0). During the Southwest circulation period (Figure 3.20), apart from zone 4 being heavily influenced by monsoon field, where the average wave flux mainly go in the Northeast direction, the rest of the South Central region has a relatively low onshore wave energy flux, particularly the regional flow from Da Nang to Quang Nam (zone 1) remains in the Northeast direction.

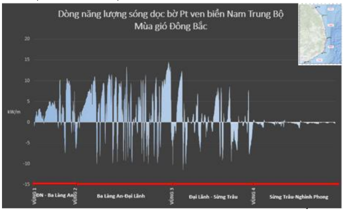


Figure 3.19: Wave power P in Northeast circulation

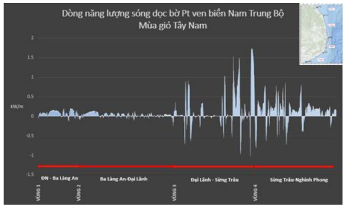


Figure 3.20: Wave power Pt in Southwest circulation

Areas with high shoreline wave energy flux (Pn>0) from Quang Ngai to Ninh Thuan coincide with locations where the coast is heavily eroded, having many bank erosion hotspots, especially during Northeast monsoons (Figure 3.21). During Southwest monsoons, when the longshore wave energy flux Pt is quite low, most onshore wave energy flux Pn in the entire South Central region have a positive value (Figure 3.22), which shows the possibility of accretion in Southwest monsoon being higher than that in the Northeast monsoon circulation period.

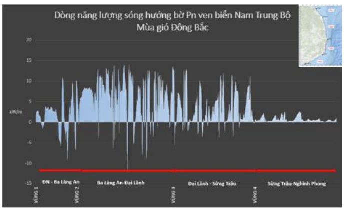


Figure 3.21: Wave power P in Northeast monsoons

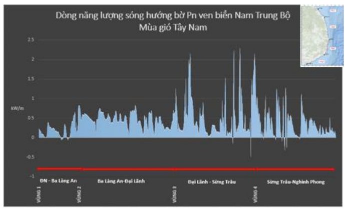


Figure 3.22: Wave power Pt in Southwest monsoons

The thesis has also developed a wave power map (kW/m) for the South Central region, including information about wave field: Significant wave height, average wave period, directions of wave energy flux as well as an Atlas of average wave energy (Figure 3.23÷Figure 3.24).

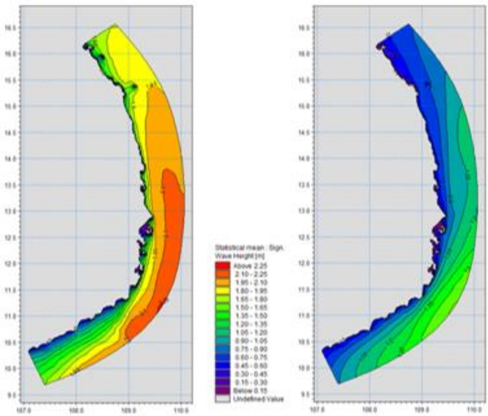


Figure 3.23: Map of average wave heights by seasons

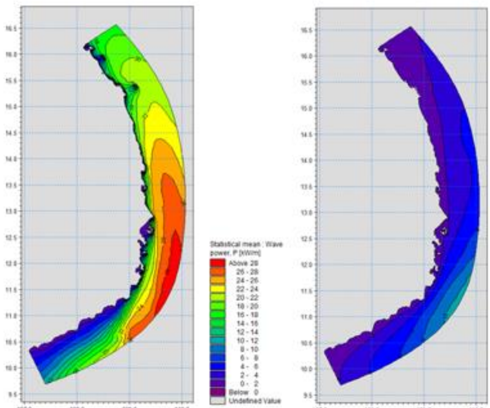


Figure 3.24: Map of average wave power by seasons

3.2. The relationship between longshore wave energy flux Pt and cross-shore wave energy flux Pn with erosion-accretion processes in the South Central region

The thesis has conducted detailed surveys on 4 coastal stretches with actual survey data to verify the relationship between wave energy flux (Pt and Pn) on the baseline with erosion-accretion conditions in these areas. The calculation of wave energy flux suggested by the author, after comparison with actual surveys, shows that:

- The shore segments affected by high Pn onshore wave power are the areas with severe coastal erosion, such as Mo Duc, Duc Pho (Quang Ngai) or Song Cau to Tuy Hoa (Quang Ngai). However, in some areas, Pn is positive (Pn>0) but small in value, so accretion can still occur (small waves carrying sediment onshore). Areas with Pn<0 (behind headlands) are considered as areas at risk of sediment shortage as sediment being washed off to the sea (for example, in northern areas of Cua Dai-Hoi An).
- In all cases, the process of erosions and accretions depend on longshore wave energy flux (or tangent flux, Pt). Using longshore wave energy flux Pt can completely explain the processes of coastal currents and sediment transport, for example, in coastal sections of Binh Thuan province such as Lien Huong - Binh Thanh, Phan Ri Cua behind La Gan cape, Ham Tien, Phu Hai behind Mui Ne, etc. This also explains the cycle of erosion-accretion changes through seasons of the year. In addition, the determination of coastal flux directions (also directions of Pt) will be very helpful in aligning construction of systems of coastal protection structures out into the sea (such as breakwaters and groynes etc.).
- When determining and analyzing gradients of Pt along the baseline in order to associate with erosion-accretion processes in coastal areas. The results are deemed to be quite consistent with field data, especially in key areas.

3.3. Case study for LaGi coastal area.

To verify the relationship between wave energy field distribution on the baseline with detailed morphological changes in coastal areas, the thesis has conducted a case study for LaGi beach, Binh Thuan province through math modeling tool which takes into account all influencing factors of waves, currents, sediment and terrain… Based on the results of simulating the current state of La Gi coastal area, the author has arrived at the following observations:

Figure 3.55: Calculation results of wave energy flux directions

- The rate of erosion-accretion in the study area varies with seasons in a hydrological year; during Northeast monsoons, it is more intense than during Southwest monsoons.
- The accretion trend is absolutely dominant in the Southern coastal areas. The accretion rate within semi-submerged strip after Northeast monsoons is about 0.3÷0.8m, up to more than 1.0m in some places. At the same time, a large mudflat is blocking the area outside the entrance to Ho Tom estuary. The seabed of the outer area is lowered, with an erosion level of 0.5m.
- The ongoing project of sea-encroachment residential areas has caused major impacts on coastal morphology in Phuoc Loc commune, La Gi town. Detailed analysis of wave energy flux: With Pt<0, the flux goes downward from the North, when facing the embankment system of the sea-encroachment residential area, which protrudes outward, the sediment transport moving Southward is blocked, causing erosion from the waveless shore (behind the embankment) to Ho Tom estuary. Analysis of onshore wave energy flux Pn and analysis of wave energy gradient also show results consistent with the fact that the trend is

“accretion in the South, erosion in the Northern segments”.

- Results of simulating hydrodynamic regime, sand transport and morphological changes in La Gi beach - Binh Thuan province is the Model level 3 presented in Section 2.3, which can be applied to specific projects in South Central Coast. On the basis of those results, it is possible to propose solutions for feasible spatial arrangement, structural designs, materials... as satisfactory to required objectives and goals. The research results have also been applied by the author to the design and construction of coastal stabilization works in La Gi town area. The project was effectively after one year of putting it into operation.

3.4. Impacts of CC-SLR on coastal morphology of the South Central Coast (SSC)

3.4.1. SLR scenario calculated for the SSC

Calculations in the scope of this thesis only consider the average SLR due to CC published by MONRE (sea level rise by 12cm in 2030-KB1, 25cm in 2050-KB2 and 50cm in 2100-KB3), and not considering influences of other factors: storm surges, monsoon surges, tectonic uplift and subduction processes.

3.4.2 Calculation results of wave characteristics and coastal morphology of the South Central region under impacts of SLR due to CC

The thesis has examined how the average SLR affects nearshore areas through detailed modeling of coastal areas in La Gi-Binh Thuan through the math modeling tool MIKE 21/3 FM, which yields some key results as follows.

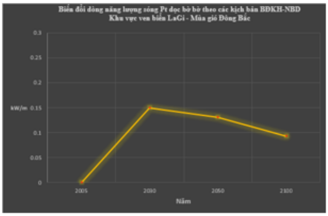


Figure 3.63: Changes of wave power Pt in Northeast monsoons

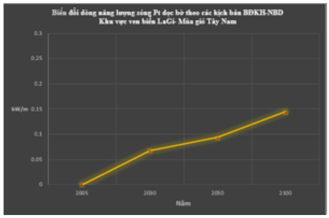


Figure 3.64: Changes of wave power Pt in Southwest monsoons

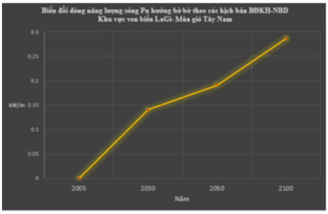


Figure 3.65: Changes of wave power Pn in Northeast monsoons

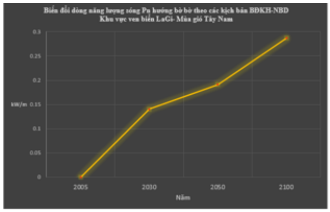


Figure 3.66: Changes of wave power Pn in Southwest monsoons

- Longshore wave energy flux Pt (kW/m) corresponding to the 3 SLR scenarios mentioned above: In the Southwest monsoon season, increase rates are 8% (scenario 1), 12% (scenario 2), and 18% (scenario 3). During Northeast wind circulation period, the value of Pt will change drastically at decrease rates of 22% (scenario 1), 19% (scenario 2) and 14% (scenario 3). For onshore wave energy flux Pn, under the same 3 SLR scenarios, increase rates are 8% (scenario 1), 11% (scenario 2) and 17% (scenario 3) in the Southwest monsoons; and increase rates are respectively 9% (scenario 1), 12% (scenario 2) and 17% (scenario 3) in the Northeast monsoons.
- The level of erosions in Northern zones will become more and more severe compared to Southern zones, although this trend will gradually decrease over time from the beginning of the century (year 2030) toward the end of the century (year 2100).

3.5. Orientating measures for improving and stabilizing coastal morphology in the SCC in context of SLR due to CC

3.5.1 Structural measures:

- *For areas with high onshore wave power Pn:*

- It is necessary to make rational land use planning in coastal areas, so as to avoid building structures or houses near the coast.

- In case the coastal area is an urban area that needs protection, it is necessary to study and find a measure to reduce wave power from a distance by using offshore breakwaters (floating or submergent).

Since the end of 2019, the project "*Embankment to protect residential area in Phuoc Loc ward, La Gi town, Binh Thuan province*" has begun construction of a system of sand-blocking/ wave-breaking works with a combination of T-shaped groins and submergent breakwaters. This is the study result of the author and his colleagues based on an analysis of impacts of wave power and sediment transport in this coastal area. The proposed measure consists of 05 segments of submergent breakwaters built with parallelly-placed large rocks at 150m off the shore; each segment is 160m long, distanced by 80m from each other; combined with 01 T-shaped groin. So far, construction of the T-shaped groin and 02 breakwater segments to the North have been completed (Figure 3.74).

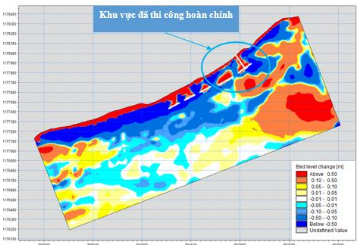


Figure 3.73: Calculated topographic changes 01 year after works completion

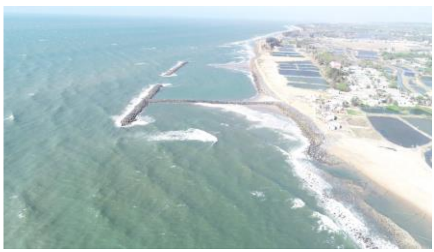


Figure 3.74: Actual construction of the T-shaped groin and 02 breakwater segments to the North

For areas where onshore wave power Pn is not high:

- "Soft" works with geotechnical-Stabiplage structures;
- Environment-friendly measures: Beach nourishment, afforestation;
- "Hard" works with reinforced concrete structures: Dikes, breakwaters,…

Figure 3.80: Coastal protection through sand replenishment (artificial beach nourishment)

For areas where longshore wave energy flux is high:

Construct (soft or hard) groyne structures to regulate sediment transport flows and maintain equilibrium for the shore.

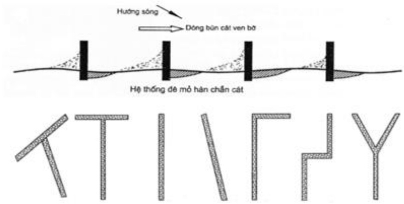


Figure 3.80: Arrangement (above) and some types of groin (below)

3.5.2 Non-structural measures:

- Promote communication campaigns to raise awareness of local people about natural disasters and causes of coastal erosion.
- Monitor coastal erosions in regard to scale, intensity and direction of displacement periodically and non-periodically base on reality.
- Build a database for bank erosion control by district and province, including status map, forecast map and erosion risk warning map.

CONCLUSIONS

1. The thesis has adopted appropriate research and study methodologies, in which the numerical modeling method was used as

a advance tool which has been calibrated and verified with field data and shown reliable results.

2. Key contributions of the Thesis include:

- Develop a method to determine "*Longshore wave energy flux*" (Pt) and "*Onshore wave energy flux*" (Pn) which are attributable to the sea's impacts on shoreline, beach and develop a distribution chart of quantities Pt and Pn on the baseline along the South Central Coast. On the basis of this distribution chart, analyze spatial and chronological gradients of wave energy flux, and identify areas at risk of coastal morphological changes. This was a scientific and practical contributions to coastal erosion in the study region;
- In the context of sea level rise, "*Longshore wave energy flux*" and "*Onshore wave energy flux*" increase insignificantly in deep waters but will increase significantly in shallow waters due to displacement of wave breaking zone closer to shore, especially after 2030.
- The results of case study show that the South Central Coast tends to have more accretions in the South and worse erosions in the North under impacts of SLR, especially in areas near estuaries. This explains that in the interaction between the sea and the rivers, influence of the sea tends to overwhelm effect from the rivers. In addition, the "appearance" of river gates and their associated systems of protection works and vessel channels have affected distributions of wave energy flux and sand transport regimes along the coast.
- The key orientation for coastal management of the South Central Coast, most importantly, is to promote development of an integrated coastal management plan for sustainable development of this region while avoiding unnecessary investments in coastal protection works. Structural solutions, especially spatial arrangement for those coastal line adjustment, could utilize information provided by wave energy flux maps which was found in this thesis.

LIST OF PUBLISHED ARTICLES AND STUDIES

1. **Pham Trung**, Tran Thu Tam, (2012), "Evaluating the influence of wind and wave directions on coastal morphology of Binh Thuan province", *A collection of Science and Technology outputs 2011, Pg. 180, Vol. 14.*
2. **Pham Trung**, Nguyen Duc Vuong, (2016), "Calculations of wind fields and storm pressures in the East Sea to establish research scenarios for Binh Thuan province", *A collection of Science and Technology outputs 2015, ISSN: 0866-7292, Pg. 189, Vol. 18.*
3. **Pham Trung**, (2019), "Coastal morphology at estuaries along the South Central Coast under impacts of sea level rise", *Water Resources Science and Technology, ISSN: 0866-7292, Pg. 100, Vol. 52.*
4. **Pham Trung**, (2019), "Onshore and longshore wave energy flux on the South Central Coast", *Water Resources Science and Technology, ISSN: 0866-7292, Tr40, No. 52.*