BÀI BÁO KHOA HỌC

USING A COASTLINE EVOLUTION MODEL TO ASSESS THE EFFECTS OF COASTAL STABILISATION MEASURES ON NHA TRANG BEACH

Vu Duy Toan[1], **Nguyen Quang Chien**[2*], **Tran Thanh Tung**[2]

Abstract: *Nha Trang city has a great advantage in sea tourism with a beautiful beach and a group of bays and nearshore islands. However, Nha Trang coastal erosion has appeared more frequently due to waves, wind, tidal currents, and extreme weather events in recent years. Protecting and nourishing the beach is essential to maintain the tourism advantage of the city. This paper presents the assessment results on the effectiveness of some shore protection alternatives for the Nha Trang beach using a combination of the SWAN wave model for a larger area and the GENESIS coastline evolution model. The simulation results show the performance, credibility, and applicability of SWAN and GENESIS models to analyzing and selecting an appropriate coastal protection plan for the Nha Trang coast, and more generally, the South-Central coast of Vietnam.*

Keywords: Nha Trang - Vietnam, coastline evolution, coastal stabilization, GENESIS model, SWAN model

1. INTRODUCTION

Figure 1. Map and Google Earth image of the study area (Google Earth, 2021)

The Nha Trang coastal resort in Central Vietnam attracts many tourists in summer, yet the beach has been shifted and locally eroded. There have been studies in the coastal processes, data acquisition (Thuan et al. 2019), hydrodynamics, and shoreline dynamics of Nha Trang (Almar et al. 2017, Nguyen et al. 2014). Tran et al. (2018) performed an EOF analysis of the shoreline and estimated the longshore sediment transport rate

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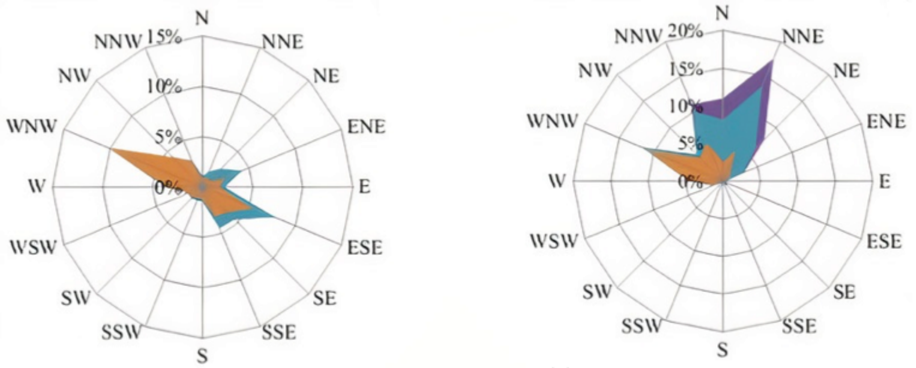
along the local coast. However, the long-term evolution of the Nha Trang coastline under the impact of nearshore structures has still not been covered yet. This research aims to fill in that gap: to predict the coastline evolution based on various factors (wave, tide, wind, and coastal morphological conditions) for coastal zone management toward sustainable development.

The current study focuses on the Nha Trang beach section, which is 300 m long, in the vicinity of the Cai River. The one-line model GENESIS is used to estimate the local coastline evolution, and alternative solutions are proposed to protect the coast. The SWAN model has been used to simulate wave propagation from offshore to the shallow water. The GENESIS model was applied to predict shoreline changes for the background scenario after one year, five years, and ten years. Base on that, preliminary solutions are proposed to protect the Nha Trang coast and use the model to predict shoreline changes accordingly.

2. PHYSICAL SETTINGS AND SHORELINE CHANGE

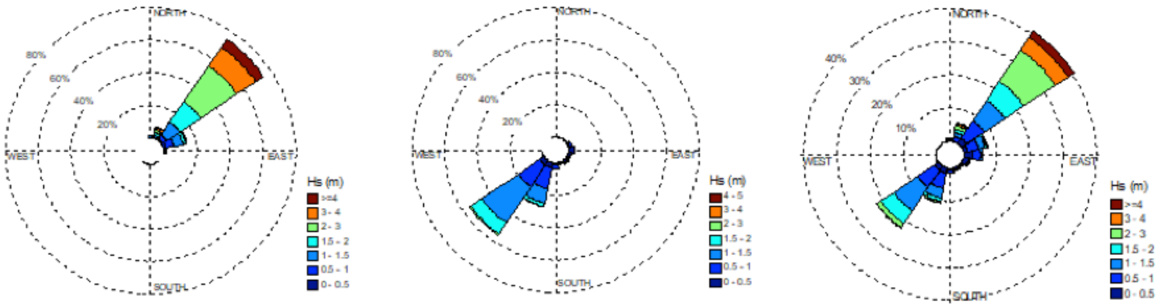
2.1. Meteorology and hydrology

Nha Trang is influenced by two monsoons that come from the northeast (NE) and southwest (SW). The NE monsoon is stronger, especially in November and January. The SW monsoon is prevalent from June to September. From 1988 to 2007, the maximum recorded NE wind speed was 28 m/s (Nov. 1988) and SE wind, 16 m/s (Sept. 1992) (Mau, 2014). Representative wind roses for the SW and NE monsoons are shown in Figure 2*a*, *b*. Precipitation and wind speed are measured at Nha Trang meteorology station (12˚13’N, 109˚12’E).



(a) Wind, September [SW monsoon]

(b) Wind, November [NE monsoon]



(c) Wave, January

(d) Wave, June

(e) Wave, annual

Figure 2. (a,b) Wind roses (data 2002-2011 (Boos and Dahlstrom 2015)) and (c,d,e) wave roses offshore Nha Trang (data 1997 – 2010)

The NE monsoon from October to March comes along with large precipitation (Lefebvre et al., 2014). Remarkably, the river discharge in Nov-2013 is 170 m^3/s, while the monthly mean rainfall of November is the highest (380 mm). This also leads to a larger river discharge in the Cai River, which associates with a larger sediment transport (Mau, 2014).

2.2. Tide and wave characteristics

Nha Trang experiences a mix of the diurnal and semi-diurnal tides. The tidal amplitude varies from ~0.4 m during neap tides to ~2.5 in spring tides. The tidal water level data in the South of Nha Trang Bay can be obtained from a local gauge.

The regional monsoon pattern influences the wave climate of Nha Trang Bay. High waves from the northeast occur during the NE monsoon, whereas lower waves are from the southeast during the SW monsoon (Figure 2*e*). The northern coastal strip is influenced mainly by the wave direction E, and the south shoreline by both NE and E wave directions, of which NE waves are particularly prevalent.

The WaveWatch III reanalysis wave data (NOAA) during 1997-2010 was collected to show the offshore wave climate pattern of the Nha Trang sea. From October to next April, the NE waves are dominant. Wave heights range from 2 m to > 4 m (Figure 2*c*). From April to September, wave directions are mainly SW, with wave height from 0.3 m to 3 m (Figure 2*d*). As the offshore wave direction is SW, waves do not propagate directly into the bay. Overall, during the northeast monsoon, East and NE waves dominate. NE monsoon strongly influences Nha Trang from October to next February; its effects can last until April. The swell waves which cause a strong impact on the bank of Nha Trang Bay are from the East. Swells due to storms also should also be considered, though distant storms do not come directly to Khanh Hoa, especially during Cai River floods and high tides.

2.3. Shoreline change

Satellite images of Nha Trang beach are available from Google Earth, and the images corresponding to the following dates had been collected: 13-8-2003, 13-8-2007, 13-8-2010, 13-8-2012, 13-8-2014 and 22-9-2016. These shorelines are manually digitized and then plotted (Figure 3), from which the shoreline evolution trends can be seen. Uncertainty in the shoreline representation can be due to digitization (image resolution ~15 m) and tidal level variation. The latter is ~12 m (assuming a typical tidal range of 2 m and a beach face slope of 15%). Thus, the total uncertainty is likely from 25 m to 30 m.

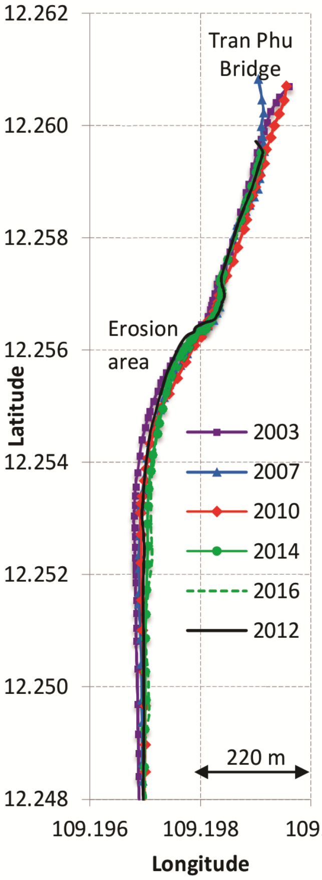


Figure 3. Nha Trang shoreline change from 2003 to 2016

The local shoreline tends to be accreted or eroded, adapting to new conditions, either physical and anthropogenic. Depending on the strength and angle of the incident waves, which vary in seasons, the shoreline position may fluctuate. For waves coming from the north, the shoreline might retreat in the south part and accrete in the north part. If waves come from the south, the reverse will occur; this makes the shoreline shift. The Nha Trang shore is eroded by coastal structures that affect the longshore sediment transport. Before 2003, when the coast evolved naturally, the vicinity of the Cai River was accreted. However, since a hard structure was built (2006), the northern part of the Cai River mouth (at Tran Phu bridge) started to erode. An embankment on the north of the river mouth was built to counter this erosion, disrupting the natural coastal balance. In addition, the hardening embankment (Hotel 387) on the south coast has cut the sediment exchange between the stream and river banks.

2.4. Sediment origin and transport

Two rivers enter Nha Trang Bay, of which the River Cai transports 80.4×10^6 tons of sediment into the bay annually, most of which during winter months (Nguyen et al., 2013). Of the sediment that River Cai flushes to its outlet, the sand fraction is ~63%; thus, the sediment in Nha Trang bay has a terrigenous origin. Most of this sand is light-colored with irregular grain shapes (Inman and Harris, 1966), though a minor part is a darker and slightly reddish sand. Only 2% of the material on the beach at Nha Trang comprises biogenous materials such as shells and corals.

The littoral drift is dependent mainly on the wave and current patterns inside the bay. The wave climate and current regime are affected by the local winds, the monsoons, and the bay's bathymetry (Mau, 2014). The southern part of this beach is steeper due to the waves and circulation in the bay. Erosion and deposition in the Cai estuary Nha Trang directly relate to the operation of the NE monsoon, which acts to redistribute sediment in the estuary.

3. MODELLING OFFSHORE WAVE TRANSFORMATION

3.1. The modeling approach

To model the shoreline change, the detailed wave characteristics reaching Nha Trang beach needs to be known. However, this information is generally not available for long terms (time scales of seasons). On the other hand, reanalyzed wave data are readily available for several locations outside the continental shelf. Therefore, a spectral wave model (SWAN) was used to transform those wave characteristics to the nearshore area. Next, a one-line model was used to simulate the evolution of the local coastline.

In a one-line model, the beach profile is assumed to move either seaward or landward without reshaping. Although this is a simplistic assumption, the model is quite valid for specific long-term coastal processes. Some widely used one-line models include LITLINE (DHI), UNIBEST (Deltares) and GENESIS (Hanson and Kraus, 1989). The authors use GENESIS due to its availability and simple interface. GENESIS calculates coastline evolution due to the change of longshore sediment transport over time and space. This model also considers the presence of a beach replenishment or coastal structures. The use of GENESIS is presented in Section 4.

3.2. SWAN wave model

The SWAN model (The SWAN Team, 2006) is a third-generation numerical wave model to compute random, short-crested, wind-generated waves in shallow coastal regions with ambient current flows. Physical processes in SWAN include wave shoaling, refraction, nonlinear interactions, depth-induced breaking, wave-current interaction, bottom friction, and white-capping dissipation. However, the model does not account for diffraction or reflections due to bottom scattering.

SWAN is used to calculate the wave condition for a large domain encompassing the study area. This domain is 1°×1° (109°E to 110°E, 11.75°N to 12.75°N), see Figure 5. The computational grid contains 360×360 cells sized $\Delta X = 302.5$ m and $\Delta Y = 307.3$ m. There are three boundary segments. The East offshore boundary is specified with deep-water wave characteristics from WW3 reanalysis data from two data points (110°E, 12°N) and (110°E, 12.5°N) during the period 2013–2014. The wave parameters are wave height H_s (m), wave period T_{sp} (s), and wave direction θ (°). The wave spectrum is of JONSWAP type. The remaining two boundaries along the North and South sides are of lateral type.

Various physical processes are considered: wind input (Komen et al. 1984), white-capping (Komen 1984), quadruplets, depth-induced wave breaking (Battjes and Janssen 1978), bottom friction and triad wave interactions, all with default parameters. The model is run in the stationary mode without any flow current effect. A uniform wind condition is setup. The accuracy thresholds for computing are Drel = 2%, dHabs = 0.02 m, dTabs = 0.02 s, Npnts = 98%, and Nmax = 15 iterations.

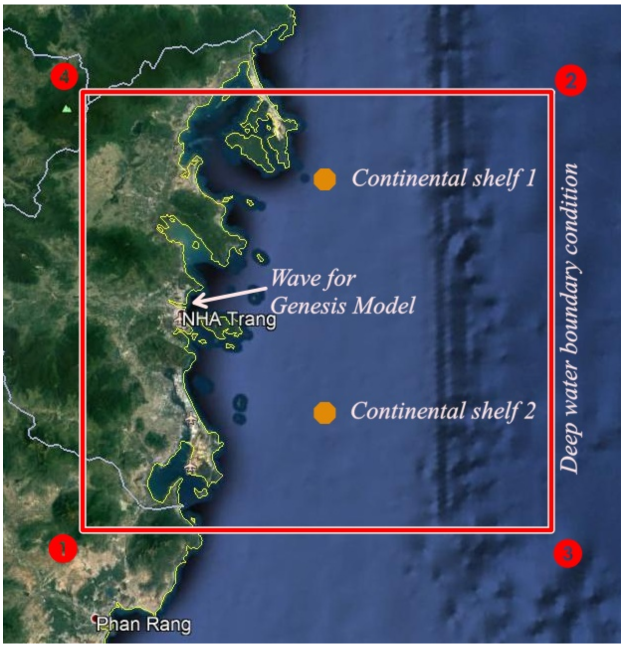
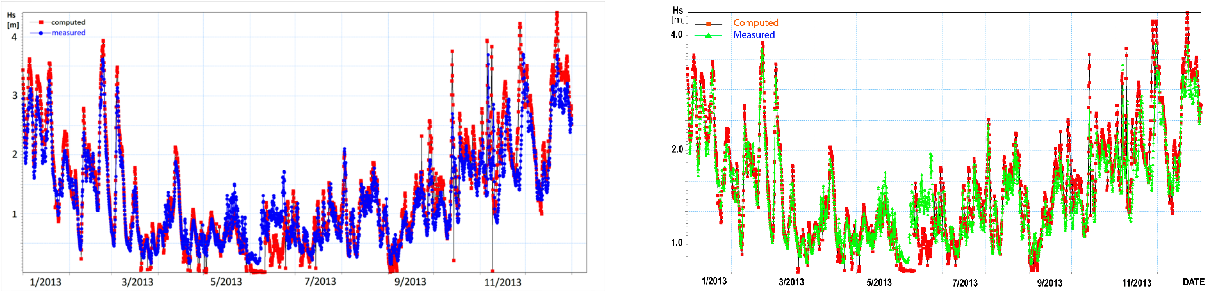


Figure 4. Comp4utational domain of SWAN; also shown are two locations (Cs1, Cs2) for model calibration (Google Earth, 2021)

Two locations on the continental shelf were chosen for calibration (Figure 4). The time chosen for calibration is the year 2013. The wave data for model calibration is extracted from WW3. Parameters for calibration with their corresponding values are the representative sand diameter D_{50} = 3 mm, Komen's coefficient for determining the rate of white-capping dissipation C_{DS2} = 2.36E-5, wave steepness for a Pierson-Moskowitz spectrum STPM = 3.02E-3, power of steepness normalized with the wave steepness of a Pierson-Moskowitz spectrum Powst = 2, coefficient which determines the dependency of the white-capping on wave number Delta = 1, and power of wave number normalized with the mean wave number Powk = 1.

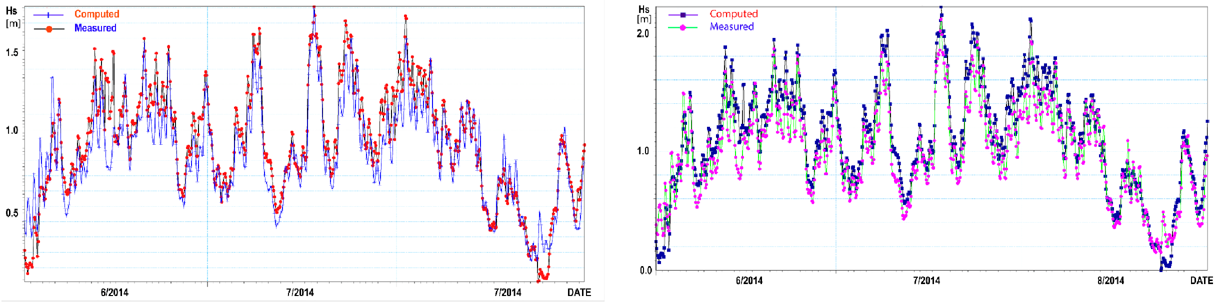
The goodness-of-fit is quantified following Nash and Sutcliffe (1970), the variable being H_s in this case. The NSE coefficient for two calibration points, Cs1 and Cs2, are 0.82 and 0.80, respectively (Figure 5*a*, *b*). Model validation is performed for the period June-Aug. 2014, and NSE for two locations, Cs1 and Cs2, are 0.87 and 0.85, respectively (Figure 5*c*, *d*). The validation results of the wave model showed that the measured and computed wave heights are almost similar in magnitude and trend. The wave period is, however, slightly underestimated. Through successful validation, the wave model which had been set up for the study area is suitable and can be used to calculate the hydrodynamic regime of the study area.

One more explanation for the underestimated results from the simulation is that the model does not include the effects of local wind. The wind blowing over the sea surface affects the propagating waves as they transfer their energy to the waves, and hence the results will not coincide with reality. Other factors contributing to the error sources of the validation are the used input wave data and grid size. The grid size with a cell size of 360×360 m^2 might be too coarse, and the simulation result can be too roughly estimated.



(a) Calibration at Cs1

(b) Calibration at Cs2



c) Validation at Cs1

(d) Validation at Cs2

Figure 5. Comparison in H_s between computed and measured data

4. MODELLING SHORELINE CHANGE

4.1. GENESIS model

The numerical model GENESIS has often been used for calculating shoreline change as caused primarily by wave action (Hanson and Kraus, 1989). The model is based on the one-line theory, with an underlying assumption that the cross-shore profile remains unchanged, hence the beach evolution can be described uniquely in terms of the shoreline position. Unlike previous models based on the same concept, GENESIS is generalized such that a simple user interface allows the system to be applied to various situations involving almost arbitrary numbers, locations, and combinations of groins and jetties, detached breakwaters, seawalls, and beach fills. Coastal processes such as wave shoaling, refraction, and diffraction, sand passing through and around groins, and sources and sinks of sand are also considered.

The GENESIS model, applied for Nha Trang beach, covers a coastal stretch from the Hotel 387 Nha Trang to the Catholic Building. The shoreline segment is 1000 m long and divided into 100 grid cells, each having $\Delta x = 10$ m. This model has two boundaries: a fixed boundary in the north for a concrete structure and a moving boundary (South) where the gradient of LST is zero. Other parameters, D_B and D_C, are derived from morphological features of the local coast; specifically $D_B = 2.0$ m and $D_C = 2.74$ m (Dahlstrom and Boos, 2015).

The offshore wave data for GENESIS was extracted from SWAN at point (12.266°N, 109.275°E) for the two years 2013 and 2014. The sampling interval is time step is $\Delta t = 3$ h. The NE waves are dominant because of the strong NE monsoon. SE waves also possibly arrive through the narrow passage between the shoreline and the Hon Tre island.

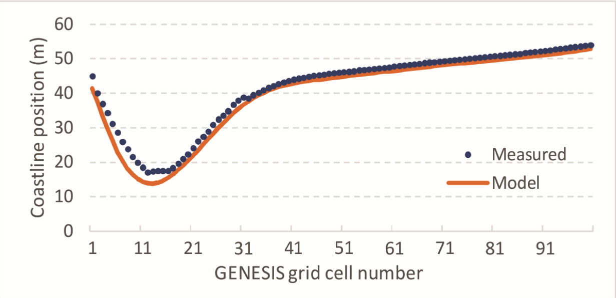


Figure 6. Comparison of shoreline in model and measured data for 27-06-2014

Calibration of GENESIS involves tuning the model parameter to predict the shoreline position closest to the actual one. The two transport parameters, K_1 and K_2, usually have the greatest effect on the predicted shoreline positions and LST.

K_1 controls the time scale of the simulated shoreline change and the magnitude of LST, while K_2 controls the distribution of sediment in the cell. For sandy beaches, experience shows that typically $0.1 < K_1 < 1.0$ and $0.5\ K_1 < K_2 < 1.5\ K_1$. Furthermore, K_2 typically varies between $0.5K_1$ and $1.0K_1$ (Hanson and Kraus, 1989). After some trials $K_1 = 0.5$ and $K_2 = 0.25$ are chosen.

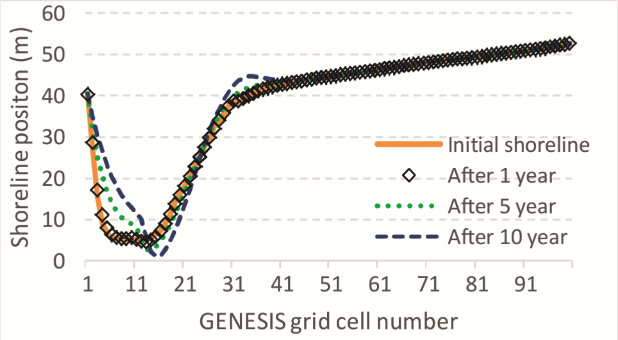
Variables such as D_C and D_B also affect the result. The time-period of 2013-2014 is chosen for model calibration. The predicted shoreline positions are compared to those measured in 2013. Comparing the predicted and measured shorelines (not shown) is done subjectively by graphical means.

Next, $K_1 = 0.5$ and $K_2 = 0.25$ were used for validation, which was performed for the time period from 27-06-2013 to 27-06-2014. The predicted and measured shoreline on 27-06-2014 can be seen in Figure 6. The computed shoreline within grid cells 1-31 is lower than the measured one. Within cells 31-100, the computed shoreline is almost the same as measured shoreline data. The tendency of predicted shoreline erosion and accretion well beyond the 2014 measured shoreline position occurs regardless of the transport parameters used. The variation of the transport parameters affects the degree to which the predicted erosion and accretion occurring.

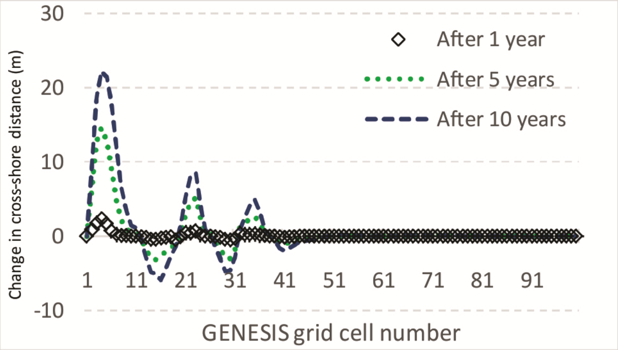
In the above analysis, the calibration and validation are based on digitized shorelines. These processes can be made more credible by using remotely sensed images with a high resolution (~5 m) and applying tidal correction to find the exact shoreline location.

4.2. Predicting the shoreline evolution

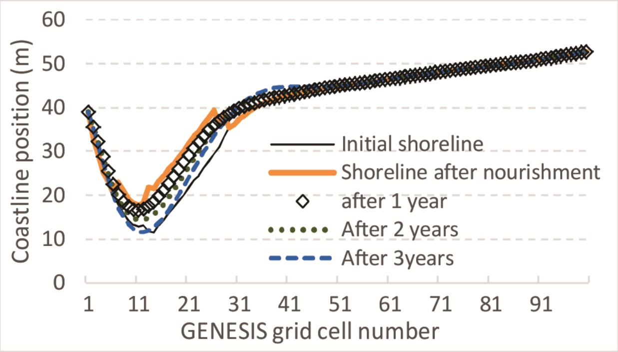
The future scenarios include: (a) no protective structure, (b) with breakwater, and (c) with beach nourishment. The coastline position is determined for each scenario after one year, five years, and ten years. Each scenario uses the same wave data collected but extrapolated to the above period.



a) without protective structures



b) with breakwaters



c) with nourishment

Figure 7. Simulated coastline evolution by GENESIS for 3 scenarios

For (b), each breakwater is 60 m long, the distance from breakwater tips to the shore is 70 m. The first breakwater is set at cells 3-10, the second one 16-23, the third one 29-35. For (c), the shoreline is shifted by 5 m between cells 8-13 and by 10 m in cells 14-27. This area was chosen because the beach showed signs of retreat.

Figure 7*a* indicates that the shoreline in grid cells

11-26 tends to be eroded. After a ten-year simulation, the beach retreats up to ~7 m in the north and accretes up to ~5 m in the south. Figure 7*b* shows that the shoreline will start to retreat past the initial shoreline in the most northern part of the beach already at the first year after building three breakwaters. After three breakwaters are built, the shoreline tends to accrete at cells 1-10, cells 16-23, and cells 31-35. The shoreline between two breakwaters tends to be eroded. Figure 7*c* shows that the coastline will regain its initial shape after three years with beach nourishment scenarios. To maintain the initial shoreline, we need to add the same amount of sand. After ten years, the shoreline has retreated to the seawall (initial position). Thus, to benefit from beach nourishment, it would be necessary to renourishment every third year.

5. CONCLUSION

This paper starts with an overview of the Nha Trang coastal process relevant to the recent evolution of the Nha Trang resort coastline. The SWAN model is used for offshore wave propagation and the GENESIS model to simulate shoreline evolution. Each model was set up, calibrated and verified with acceptable accuracy.

The Nha Trang coastline evolution has been predicted and accessed in the future (1-year, 5-year and 10-year periods) for three scenarios: (i) no protective structure, (ii) with breakwater, and (iii) with beach nourishment. However, several factors have been omitted in the modeling task. As the shoreline evolution in Nha Trang is affected by river sediment sources. More measurements of the shoreline position and beach profiles would be preferred to understand the Nha Trang coastline evolution better.

At present, the shoreline of the north beach in Nha Trang is eroded due to human activities and natural conditions. GENESIS predicted a rapid retreat of the shoreline for ten years. The result contains uncertainty as the simulation was done under simplification and assumptions. A hard-structure solution is suggested to improve the condition of the beach. By setting up a breakwater, the shoreline behind this structure tends to be accreted, while between two breakwaters, the shoreline tends to erode. Another solution is to protect the Nha Trang shoreline with nourishment. This solution needs to be performed every three years to maintain a continuous shoreline. Base on the two scenarios, the solution that combines hard structures with a soft solution need to be considered to achieve high efficiency and a low cost.

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Tóm tắt:

SỬ DỤNG MÔ HÌNH BIẾN ĐỘNG ĐƯỜNG BỜ ĐÁNH GIÁ TÁC ĐỘNG CỦA CÁC GIẢI PHÁP BẢO VỆ BỜ BIỂN ĐỐI VỚI BÃI BIỂN NHA TRANG

Thành phố Nha Trang có lợi thế lớn về du lịch biển với bãi biển đẹp và quần thể các vịnh và đảo ven bờ. Tuy nhiên trong các năm gần đây, hiện tượng xói lở bờ biển Nhà Trang do tác động của sóng, gió, dòng chảy và các hiện tượng thời tiết cực đoan đang xuất hiện ngày càng nhiều. Bảo vệ và tôn tạo bãi biển là nhiệm vụ quan trọng để duy trì lợi thế du lịch của thành phố. Bài báo sẽ trình bày kết quả đánh giá hiệu quả của các giải pháp bảo vệ bờ biển, đề xuất cho bãi biển thành phố Nha Trang thông qua việc sử dụng kết hợp mô hình sóng miền lớn SWAN kết hợp với mô hình diễn biến đường bờ GENESIS. Kết quả mô phỏng cho thấy tính hiệu quả, độ tin cậy và khả năng áp dụng kết hợp mô hình SWAN và GENESIS để phân tích lựa chọn giải pháp bảo vệ bờ hợp lý cho bờ biển Nha Trang nói riêng và các bờ biển Nam Trung Bộ nói chung.

Từ khóa: Nha Trang - Việt Nam, biến động bờ biển, giải pháp ổn định bờ biển, mô hình GENESIS, mô hình SWAN.

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