

Shoreline change model after artificial reefs deployment in Tlangoh, Bangkalan, Madura

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Abstract. Fifteen hexagonal artificial reefs were placed on Tlangoh Beach, Bangkalan, Madura Island, in 2022. The reefs have been planned to reduce shoreline erosion that has been occurring in this location since 2020. Pertamina Hulu Energy – West Madura Offshore (PHE – WMO) will deploy more artificial reefs in their CSR (company social responsibility) program. The effect of the artificial reefs on reducing shoreline erosion was usually observed by the change of morphology and shoreline in the study area. The study of shoreline change has gained significant attention due to its substantial impact on coastal environments. Understanding the dynamics of shoreline alteration is crucial for managing and planning coastal development and preserving coastal ecosystems such as artificial reef deployment. Scientists and researchers have developed a generalized shoreline change model called GENESIS to aid in this understanding. This software provides a valuable tool for predicting and analysing coastal erosion and accretion patterns. This paper discusses the shoreline change model in Tlangoh Beach, Bangkalan Madura, after deploying artificial reefs using GENESIS software. The model shows that the length of the artificial reef layout influences the developed shoreline. The longer the reef placement, the more sediment accumulates in the study area

1. Introduction

1.1. Background

The Tlangoh Village in Tanjung Bumi District, Bangkalan Regency has a pretty good white sandy beach. Since receiving assistance from PT Pertamina Hulu Energy West Madura Offshore (PHE - WMO) through Corporate Social Responsibility (CSR) activities in 2019, the beach has been increasingly visited by tourists. This visit will increase the economic activities of residents who open various businesses along the tourist beach. Quite a lot of Tlangoh villagers depend on this tourist spot for their livelihood. Some people become lifeguards, janitors, parking guards, entrance guards, ticket sellers, toilet guards, shopkeepers to shop owners. The increasing number of tourist visits despite the pandemic is certainly very helpful for the community to improve economic conditions that had slumped due to the COVID-19 pandemic.

Unfortunately, before 2022, this quite beautiful beach experienced erosion up to 30 meters as shown in. This is very worrying for the people around Tlangoh Beach who depend on this beach for their economic life. It is feared that increasingly severe abrasion will reduce tourist visits, which could lead to reduced income for the people of Tlangoh Beach.



Fig. 1. Shoreline abrasion in Tlangoh Beach (Kabar Madura / Helmi Yahya)

With the abrasion conditions as seen in **Fig. 1** above, the people of Tlangoh Village, especially those living around the beach, feel anxious, because the damage to the beach will reduce tourist visits, as well as disrupt fishing activities around the beach. Meanwhile, The Tlangoh Tourism Aware Group (Kelompok Sadar Wisata Tlangoh) and PHE WMO were expected by the community to provide solutions of the abrasion that occur. However, it seems that the efforts made are limited to reporting abrasion conditions to the authorities such as the Bangkalan Regency Maritime and Fisheries Service. Real efforts to place abrasion-resistant stones have not yet brought real results, only reducing local erosion. The community hopes that there will be assistance in building coastal protection structures from the government. Of course, this hope requires time to be realized, while the abrasion that occurs is getting worse.

In 2022, community service activities were carried out by the authors through a Community Service grant entitled Empowerment of Tourism Awareness Groups in Mitigating Abrasion at Tlangoh Beach, Tanjungbumi, Bangkalan with a Community Partnership Program Scheme. The activity is funded by the Directorate General of Higher Education, Research and Technology - Ministry of Education, Culture, Research and Technology (Directorate General of Research, Technology and Higher Education – Kemendikburistek). Apart from these activities, in the same year, PHE WMO through a CSR program carried out by DKPU ITS succeeded in placing 15 artificial reef units on the coast of Tlangoh village. The hexagonal-shaped Artificial Reef design is the result of research by the head of the proposer since 2019, funded by the Directorate General of Research, Technology and Higher Education - Ministry of Education and Technology through the Multi-Year National Competitive Research Grant Applied Research scheme with the research title: Design of a Hexagonal Artificial Reef for Conservation and Rehabilitation of Coastal Ecosystems.

This paper discusses the influence of artificial reef deployment in Tlangoh Beach, on the shoreline change using a numerical model. This effort is taken to estimate how effective the artificial reefs are in changing the shoreline and reducing the current shoreline abrasion. A generalized shoreline change model called GENESIS (Hanson & Kraus, 1989) was chosen to aid in understanding the shoreline change, after deploying artificial reefs.

1.2. Shoreline Model

The study of shoreline change has gained significant attention in recent years due to the substantial impact it has on coastal environments. Understanding the dynamics of shoreline alteration is crucial for

managing and planning coastal development, as well as for preserving coastal ecosystems. To aid in this understanding, scientists and researchers have developed a shoreline change model, which provides a valuable tool for predicting and analyzing coastal erosion and accretion patterns. This paper aims to discuss the shoreline change model after artificial reef deployment, its importance, and the key elements involved in its implementation. Shoreline change models play a pivotal role in identifying areas prone to erosion or accretion and predicting future changes along the shoreline. By accurately assessing the rate and direction of shoreline change, coastal managers can make well-informed decisions regarding land use, infrastructure development, and environmental protection. Additionally, shoreline change models assist in quantifying the impact of natural and anthropogenic factors on coastal evolution, providing a basis for appropriate mitigation strategies.

The following are key components of the shoreline change model:

- 1. Data Collection:** The accuracy of any shoreline change model relies heavily on the quality and availability of data. Comprehensive data on tides, wave dynamics, sediment transport, coastal morphology, and historical shoreline positions must be collected and integrated into the model. Remote sensing techniques, such as satellite imagery and aerial photography, can be employed to obtain the necessary information at various temporal and spatial scales.
- 2. Morphological Analysis:** One fundamental aspect of shoreline change modeling is the morphological analysis, which involves understanding the evolution of coastal landforms. This analysis elucidates the factors contributing to erosion and accretion, such as wave energy, sediment budget, and geological characteristics. By examining how these elements interact, scientists can develop a more accurate representation of coastal dynamics within the model.
- 3. Numerical Modeling:** Numerical modeling is a vital component of the shoreline change model, as it simulates the dynamic nature of coastal processes. These models employ mathematical equations, such as the wave propagation equation and sediment transport equations, to mimic the behavior of waves, currents, and sediment movement. This simulation enables researchers to predict future shoreline changes and evaluate the effectiveness of various coastal management options.

1.3. GENESIS

GENESIS (**GENERAL**ized model for **SIM**ulating Shoreline change). is software developed to model shoreline changes and sediment transport parallel to the shoreline caused by breaking wave mechanisms. GENESIS is part of a structured modeling system SMS (Shoreline Modeling System) developed by Mark B. Gravens, Nicholas C. Kraus from CERC (Coastal Engineering Research Center), and Hans Hanson from the University of Lund, Sweden (Hanson and Kraus 1989) . GENESIS is used to show sediment transport that occurs at Tlangoh Beach. **Fig. 2** below shows an illustration of longshore sediment transport. Q_{in} shows the input transport sediments while Q_{out} shows the sediment flow out from the study area. When the volume of Q_{in} is higher than Q_{out} , the shoreline is experiencing sediment deposition. On the contrary, when the volume of Q_{in} is less than Q_{out} , the shoreline is experiencing abrasion, which occurs in Tlangoh Beach, Bangkalan Madura.

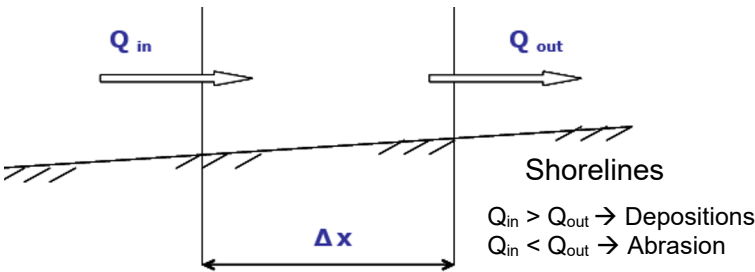


Fig. 2 Longshore Sediment Transport

There are several basic assumptions in the GENESIS model (Hanson and Kraus 1989), namely:

- a. The beach profile shape is constant.
- b. The shoreward and seaward limits of the profile are constant.
- c. Sand is transported alongshore by the action of breaking waves.
- d. The detailed structure of the nearshore circulation is ignored.
- e. There is a long-term trend in shoreline evolution.

The empirical predictive formula for the longshore sand transport rate used in GENESIS is:

$$Q = (H^2 C_g)_b \left[a_1 \sin 2\theta_{bs} - a_2 \cos 2\theta_{bs} \frac{\partial H}{\partial x} \right]_b \dots\dots\dots 1$$

where

- H = wave height
- Cg = wave group speed given by linear wave theory.
- b = subscript denoting wave breaking condition
- θ_{bs} = angle of breaking waves to the local shoreline

The nondimensional parameters a_1 , and a_2 are given by

$$a_1 = \frac{K_1}{16(\rho_s/\rho - 1)(1 - p)(1.416)^{5/2}} \dots\dots\dots 2$$

and

$$a_2 = \frac{K_2}{8(\rho_s/\rho - 1)(1 - p)(1.416)^{7/2}} \dots\dots\dots 3$$

where:

- K_1, K_2 = empirical coefficient, treated as a calibration parameter
- ρ_s = density of sand (taken to be $2.65 \times 10^3 \text{ kg/m}^3$ for quartz sand)
- ρ = density of water ($1.03 \times 10^3 \text{ kg/m}^3$ for seawater)
- p = porosity of sand on the bed (taken to be 0.4)
- $\tan \beta$ = average bottom slope from the shoreline to the depth of active longshore sand transport

The factors involving 1.416 are used to convert from significant wave height, the statistical wave height required by GENESIS, to root-mean-square (rms) wave height.

2. Methodology

Fig. 3 shows the overall calculation processes in GENESIS. The minimal information required is (i) shoreline position, (ii) Waves, structure configurations and other engineering activities, (iii) beach profiles, and (iv) boundary conditions.

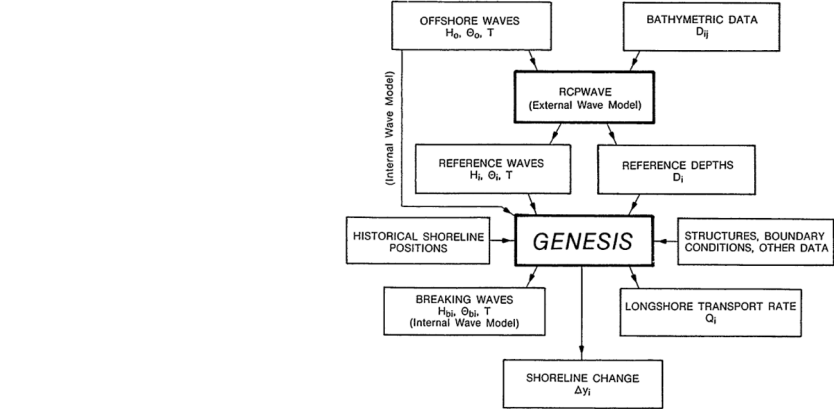


Fig. 3 GENESIS overall calculation flow. (Hanson and Kraus 1989)

2.1. Input Data

The following are input key components of the shoreline change model using GENESIS:

2.1.1. Bathymetric Maps. Bathymetric map of the area study location is prepared in the form of a discretization of the stretch of shoreline to determine a numerical grid. The position of the shoreline is expressed as the distance offshore on each numerical grid measured from the base line. The base line is determined in the direction that is closest to the coast and as far as possible does not cut the shoreline. The location of the offshore boundary condition as the starting point for wave transformation was chosen in deep water where wave dynamics do not cause sediment transport. A longshore (x) axis can be drawn parallel to the shoreline changing trend, while a shore-normal (y) axis is then drawn pointing offshore to create a right-hand system, as shown in **Fig. 4**. Based on the availability and quality of data, extent of the modeled area, detail desired, and the level of effort, the grid spacing is specified.

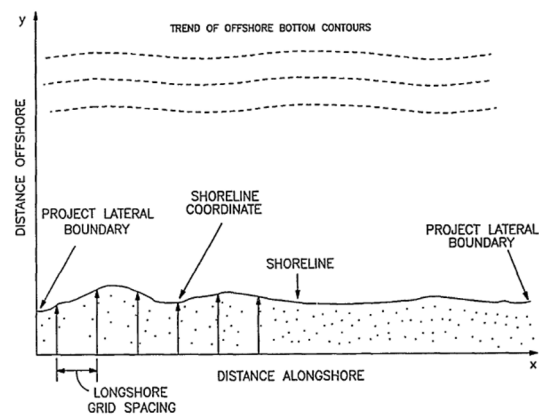


Fig. 4. GENESIS Model Coordinate system (Hanson and Kraus 1989)

2.1.2. Wave climate data resulting from hindcasting or ECMWF. The time series of wave data used is hindcasting data or deep-sea waves which include the period, height, and direction of wave propagation towards the normal shoreline for a period of 25 years (2002-2022). The data in this study were obtained from ECMWF. The beach is assumed to have a bathymetric contour parallel to the coast, wave transformations (refraction and diffraction) are calculated internally in the GENESIS Program. The data display that has been adjusted to the local orientation of GENESIS is presented in Fig. 5 below.

	A	B	C	D	E
1	Date	Time	Height	Period	Direction
2	20020101	100	0.310	3.890	298.310
3	20020101	200	0.290	3.920	298.710
4	20020101	300	0.280	3.940	299.530
5	20020101	400	0.270	3.980	300.730
6	20020101	500	0.260	3.920	302.710
7	20020101	600	0.260	3.780	307.760
8	20020101	700	0.250	3.710	311.690
9	20020101	800	0.250	3.650	314.500
10	20020101	900	0.240	3.610	315.040
177471	20220331	1400	0.130	2.180	86.460
177472	20220331	1500	0.120	2.190	84.390
177473	20220331	1600	0.120	2.210	82.520
177474	20220331	1700	0.110	2.210	80.890
177475	20220331	1800	0.120	2.150	105.530
177476	20220331	1900	0.130	2.120	85.880
177477	20220331	2000	0.100	2.120	90.380
177478	20220331	2100	0.100	2.090	91.340

Fig. 5. Typical wave Input in GENESIS

2.1.3. Existing activities. The position of existing or planned coastal structures such as seawalls, groynes, breakwaters. Also, beach fill or dredging projects.

2.1.4. Sediment grain size data (D_{50}) The representative grain size expressed in D_{50} obtained from soil laboratory test. Beaches with a gentler slope generally have smaller sand sizes. This condition causes waves to break more quickly at locations farther from the shoreline. Simulation with the GENESIS program requires a single grain size in millimeters. The grain size is considered to adequately represent the varying grain conditions in the field. The D_{50} in this study was 0,15mm.

2.1.5. Depth of closure. This depth of closure parameter states a depth at which no change in bathymetry. Based on references from the book (State of the Art Practice in Coastal Engineering, W.G. Mc Dougal), the value of depth of closure can be approximated by the formula:

$$dc = 1.57He$$

D_c = depth of closure

H_e = wave height

In this model, a significant wave of 2.27 m was taken. From the calculations, the depth of closure value for Tlangoh beach is 3,925 m.

2.1.6. Shoreline Discretization.

In determining shoreline discretization, several considerations are required. One of the most important things is the direction of the dominant wave. The wave angle area that will be calculated by GENESIS is only in the range -90° to 90° , where the line perpendicular to the base line is the 00° angle which can be seen in **Fig. 6**.

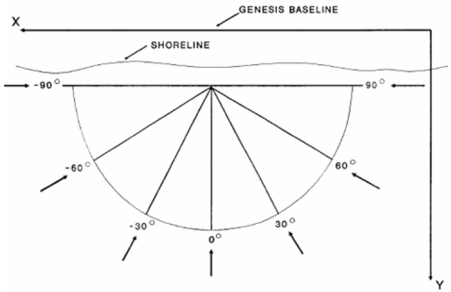


Fig. 6. Incoming wave direction in GENESIS

Therefore, the direction of the shoreline must be matched with the actual angle of the incident wave. The wave data resulting from hindcasting that will be considered in modeling is wave data with the appropriate angle of incidence in the local GENESIS coordinates. The discretization of the shoreline and its relation to the direction of wave arrival at GENESIS local coordinates in this modeling is carried out using a relatively very long baseline size (3.6 km, distance between grids 5m) as shown **Fig. 7.**, for Tlangoh Beach it is located on the shoreline slope 200 – 600 or 1000-3000m from the model domain boundary.

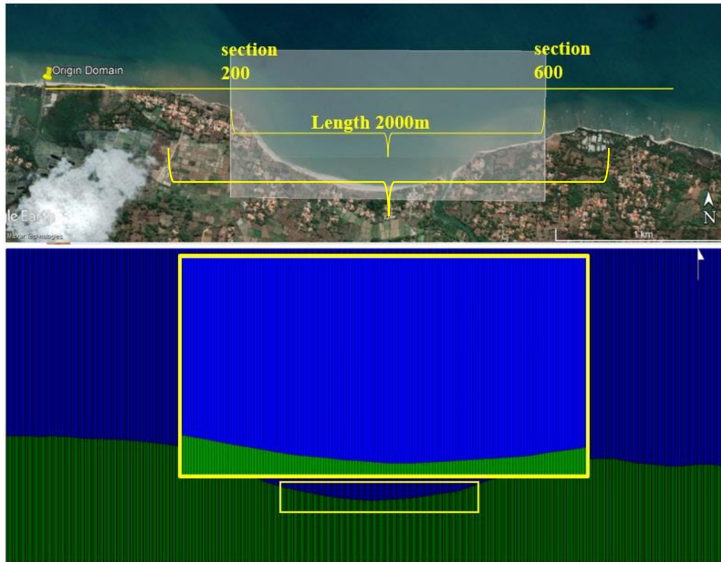


Fig. 7. Tlangoh Beach discretization.

The discretization of the shoreline of Tlangoh Beach, performed at the right and left side areas of the study location with the following criteria:

- The distance between grids (Δx) is 10 meters.
- The number of grids is 200, the overall baseline length reaches 3.6 km.
- The baseline forms a 90° angle to the north.

The simulation grid covers the shoreline and waters where the waves will propagate. Sediment transport, structure position, and shoreline boundaries are located on the cell walls, while the shoreline position is in the middle of the cell. The grid along the shoreline model is the same, namely $\Delta x = 5\text{m}$. All shorelines are moved into this grid coordinate system by not allowing two shorelines on one grid. Existing structures along the shoreline in this case are not considered because the dimensional factors are not very significant compared to the size of the shoreline being modeled.

2.2. Boundary Condition

The initial shoreline position data is in the form of coordinates (x, y). Fixed boundaries of the shoreline to be reviewed are positions where changes in the shoreline can be considered insignificant to the simulation results. This boundary is called a pinned-beach boundary which is generally placed at a point far from the simulation location, in this case, it is placed at both ends of the baseline. This type of boundary condition is used in this modeling.

3. Results and Discussion

3.1.1. Existing condition

Overall, depending on the simulation duration, the result of the GENESIS explains the following:

- Initial shoreline position and shoreline position after a certain time in the future.
- The magnitude of the shoreline changes that occur after a certain time.
- Sediment transport discharge (m^3/year) occurs after a certain time, including sediment transport discharge to the right, sediment transport discharge to the left, net sediment transport discharge (net), or gross sediment transport discharge.
- Shoreline position at the end of the simulation

In this model, the results that will be analyzed are only longshore transport which shows the volume of sediment transport and its direction in the modeled area. A positive value (+) indicates the direction of sediment movement towards the positive x-axis (baseline), while a negative value (-) indicates the opposite direction of sediment transport, which is the negative x-axis.

The shoreline position resulting from the model for the year 2022 – 2047 is shown in Fig. 8, where the biggest changes are seen in the area on the left side of the bay. In detail, the shoreline changes after several years from 2022 are shown in Fig. 9. It is seen that; the shoreline has advanced (accretion) by 1-7.5m and will be experienced abrasion in 25 years (2047) by 1.0-12.5m.

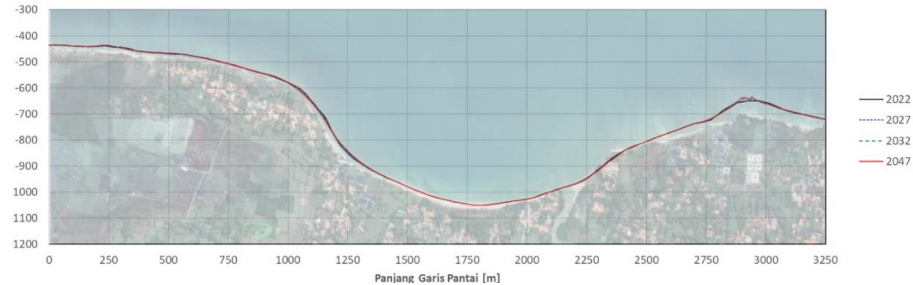


Fig. 8. Shoreline prediction without additional structures 2022 - 2047

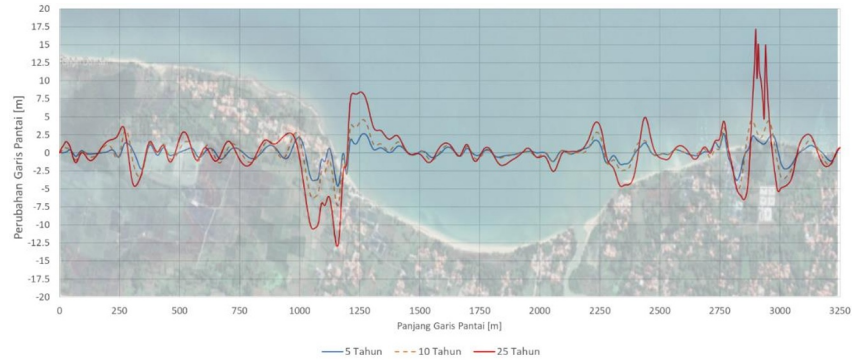


Fig. 9. Shoreline change 2022 – 2047

Fig. 10 is the modeling result displayed in the graph showing the net sediment transports in Tlangoh Beach. The value (+) indicates volume of sediment accretion with maximum value of 6,254.97 m³/year, and the maximum sediment volume of abrasion (-) is 19,828.8m³/year.

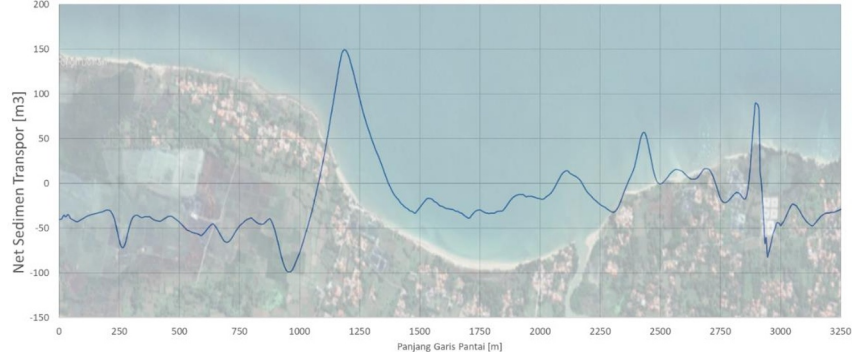


Fig. 10. Net Sediment Transport 2022 - 2047

3.1.2. Scenario 1 Single Rows Artificial Reefs

Based on Fig. 8 and Fig. 9 above, the shoreline changes occurred mostly at Tlangoh Beach on the left side of the beach. To reduce changes in the abrasion, a series of hexagonal artificial reef will be placed in a 15-meter single rows as seen in Fig. 11. In the initial scenario, the breakwater is 15 meters or 3 segments, where the width of this model is 5 meters. The transmission coefficient of the breakwater is set 0.8 to represent the submerged breakwater.

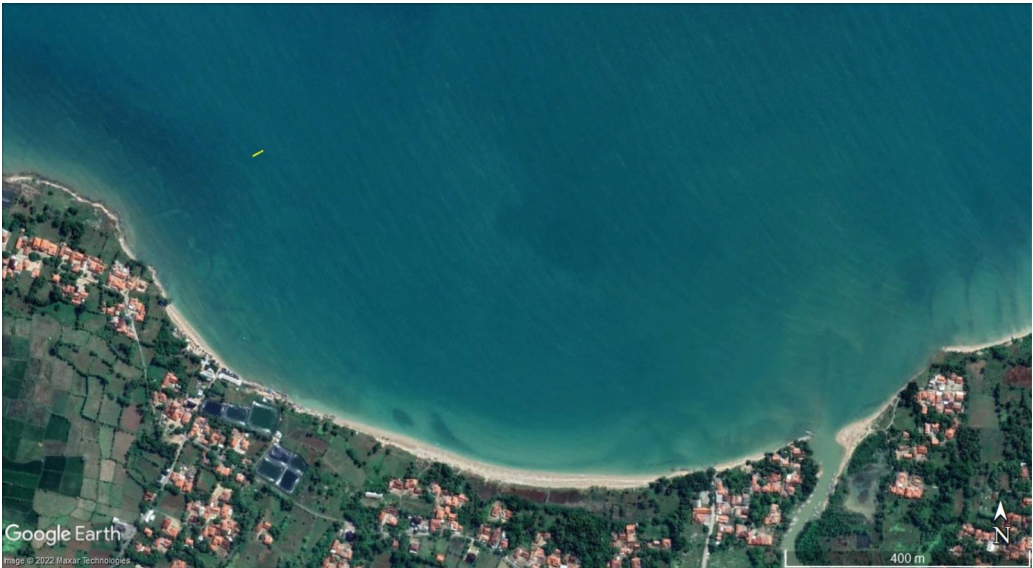


Fig. 11. Single row artificial reef placement.

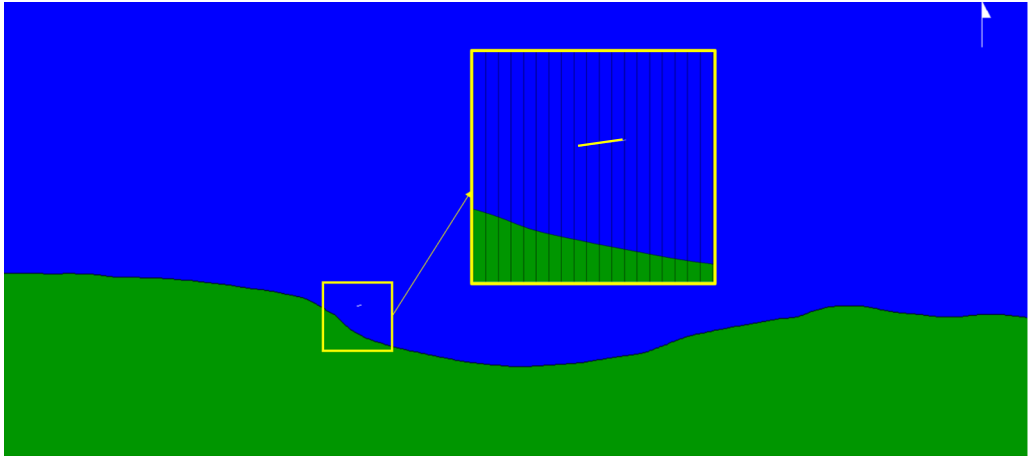


Fig. 12. Grid Domain Artificial Reefs as Detached Breakwater Scenario 1 - 15m single row artificial reefs

Fig. 13. and Fig. 14. shows the result of shoreline changes after installing a submerged breakwater at a depth of 2.5 meters or 200 m from the shoreline. The yellow box shows the location where the shoreline has changed.

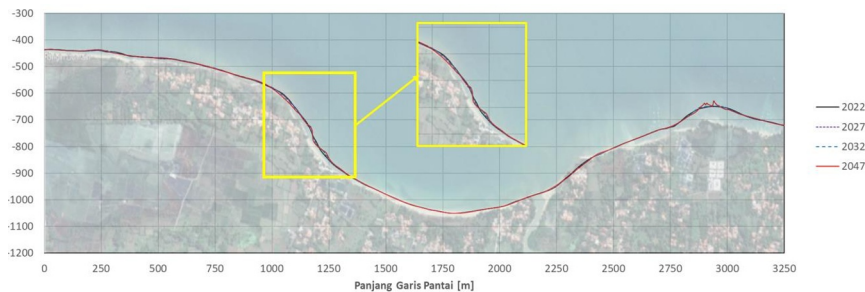


Fig. 13. Shoreline comparison before and after artificial reef deployment

Fig. 14. is the result of modeling simulations for the period 2022-2047, the abrasion and accretion phenomenon at Tlangoh Beach shows the location of the breakwater placement in the area marked with a yellow box. At the location of the breakwater, there is an area that shows the growth of sand (salient) up to 30 meters over 25 years, but also causes abrasion or a retreating shoreline on the left side of the breakwater building. The transport volume of accreted sediment is 5,444 m³/year while the transport volume of abrasion sediment is 19,439 m³/year from the previous one (without breakwater) of 19,828.8 m³/year.

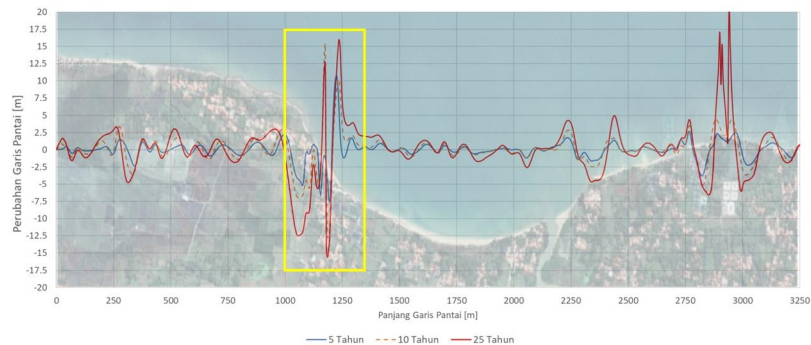


Fig. 14. Shoreline comparison after artificial reefs deployment

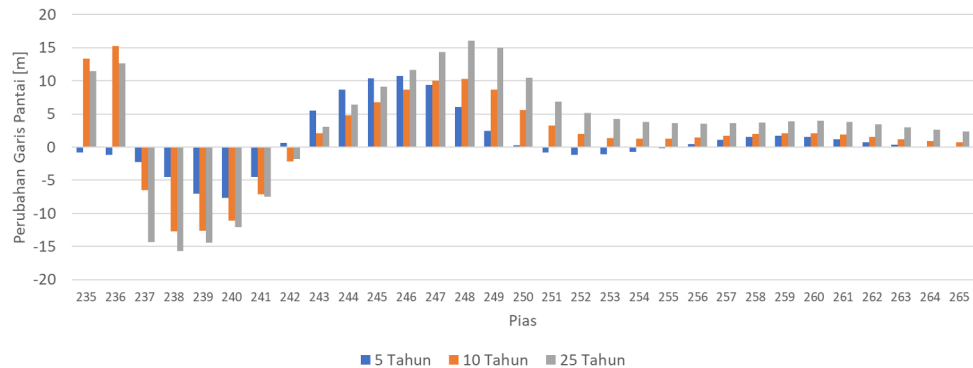


Fig. 15. Shoreline change in the vicinity of artificial reefs (Scenario 1)

3.1.3. Scenario 2. Two series of artificial reefs with 10m gap

In scenario 2, two series of artificial reefs are installed as detached breakwater with a segment gap of 10 meters as shown in Fig. 16. Domain grid model as shown in Fig. 17, where the breakwater installation is on segment grid 248 to 252.

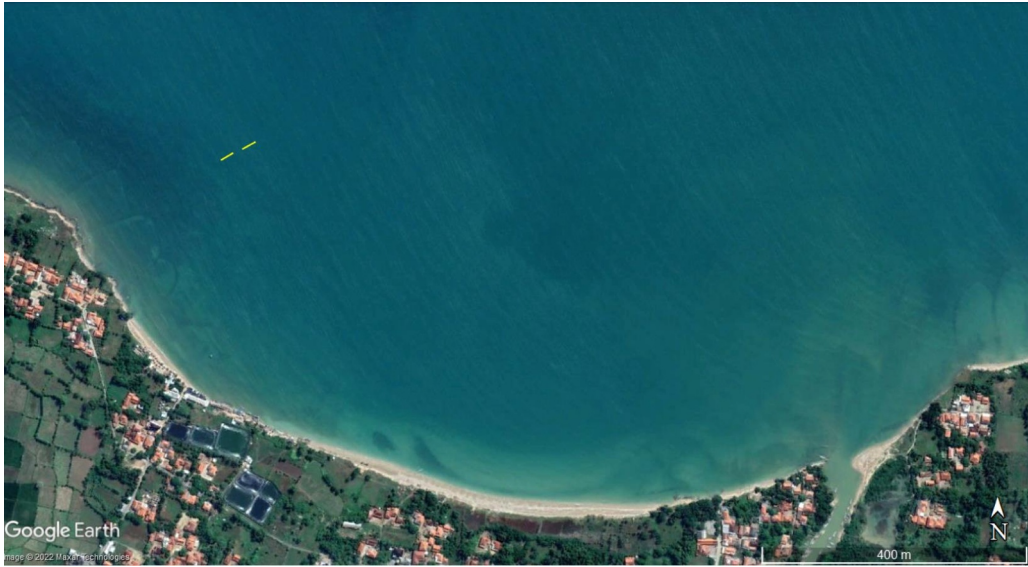


Fig. 16. Artificial Reefs Deployment Layout as Detached Breakwaters

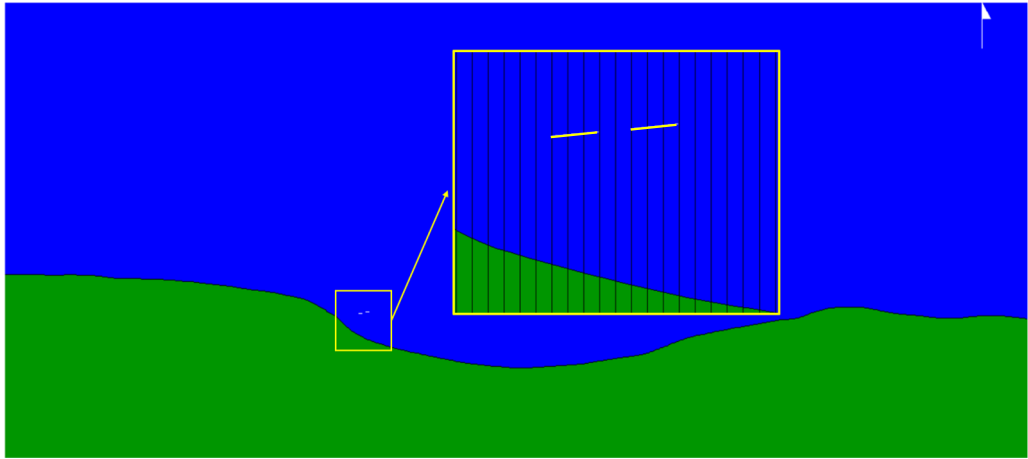


Fig. 17. Domain Grid Domain Artificial Reefs as Detached Breakwater Scenario 2

Fig. 17 is the result of modeling simulations for the period 2022-2047, the abrasion and accretion phenomena at Tlangoh Beach show the location of the breakwater placement in the area marked with a yellow box. At the location of the breakwater, there is an area that shows the growth of sand (salient) up to 17 meters over 25 years, but also causes abrasion or a retreating shoreline on the left side of the breakwater building. The transport volume of accreted sediment is 5,779 m³/year while the transport volume of abrasion sediment is 20,332 m³/year from the previous one (without breakwater) of 19,828.8 m³/year.

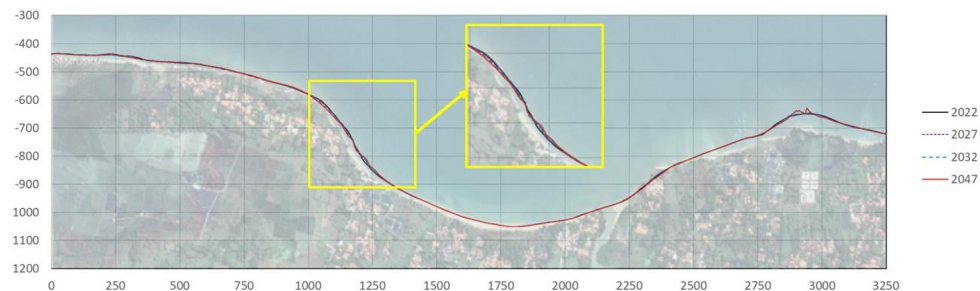


Fig. 18. Shoreline change estimation after Artificial Reefs deployment.

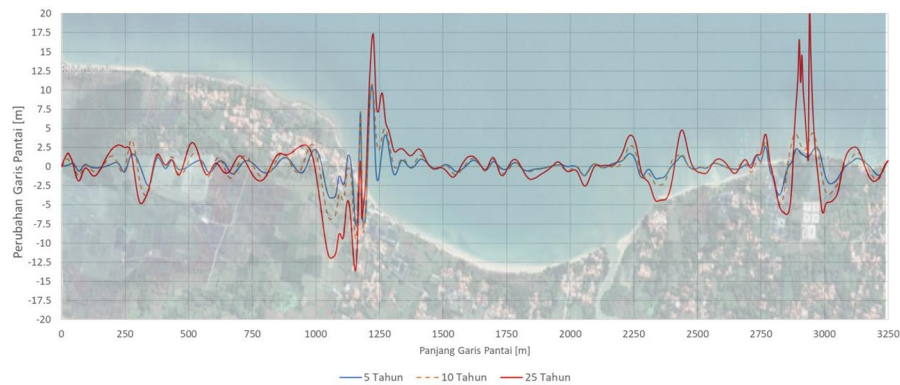


Fig. 19. Shoreline comparison after artificial reefs deployment

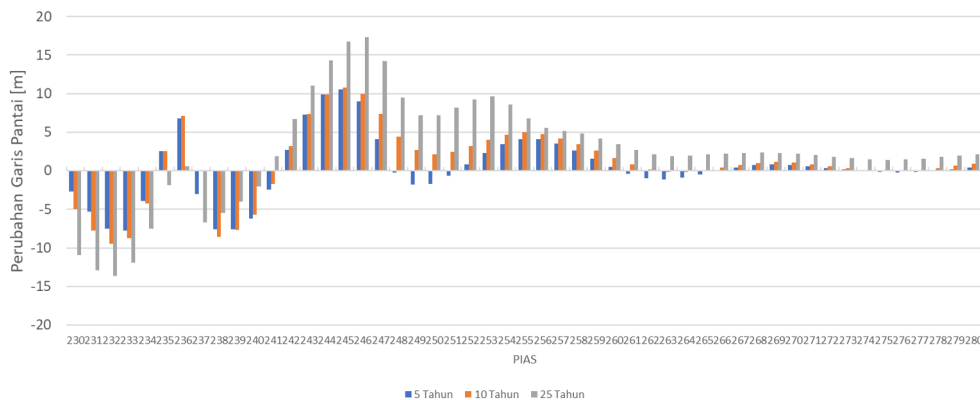


Fig. 20.. Shoreline change in the vicinity of artificial reefs (Scenario 2)

3.1.4. Scenario 2. Two series of artificial reefs with 30m gap

To reduce changes in the shoreline, in this discussion we will simulate changes in the shoreline by creating a 30-meter-long breakwater in 2 segments as seen in Fig. 21. In scenario 3, wave breakers are installed in parallel with a distance between breakers (gap) of 20 meters. Domain grid model as shown in Fig. 22, where the breakwater installation is on segment 252 to 264.

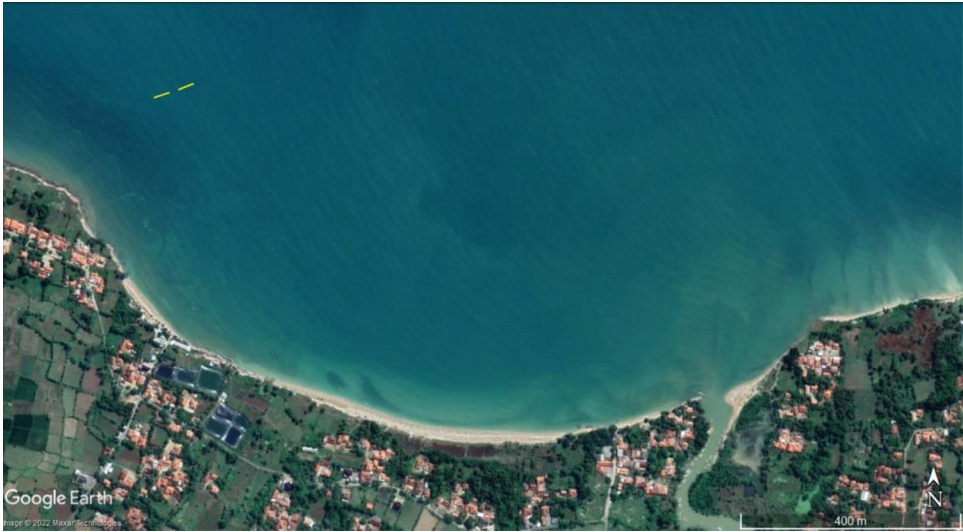


Fig. 21. Skenario 3 Pemasangan Pemecah Gelombang Parallel

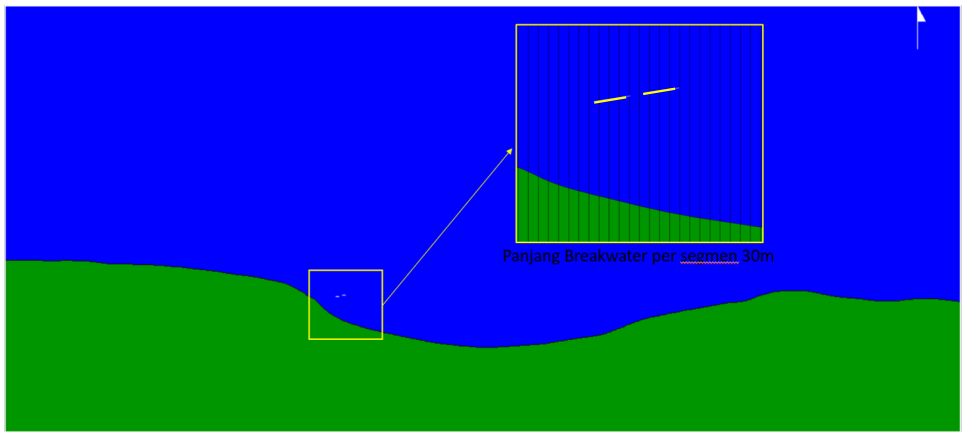


Fig. 22. Domain Grid Domain Artificial Reefs as Detached Breakwater Scenario 3

Fig. 23 is the result of modeling simulations for the period 2022-2047. the abrasion and accretion phenomenon at Tlangoh Beach were shown the location of the breakwater placement in the area marked with a yellow box. At the location of the breakwater, there is an area that shows sand growth (salient) of up to 10 meters over 25 years, but it also causes abrasion or a retreating shoreline on the left side of the breakwater building. is a detail of changes in the shoreline around the location where the breakwater is installed. Changes in the shoreline over the past 25 years have experienced accretion of up to 9 meters, but on the left side of the breakwater there has also been erosion of the shoreline of up to 8.5 meters. The accretion sediment transport volume is 5,486.32 m³/year while the abrasion sediment transport volume is 20,417.37 m³/year from the previous one (without breakwater) of 19,828.8 m³/year.

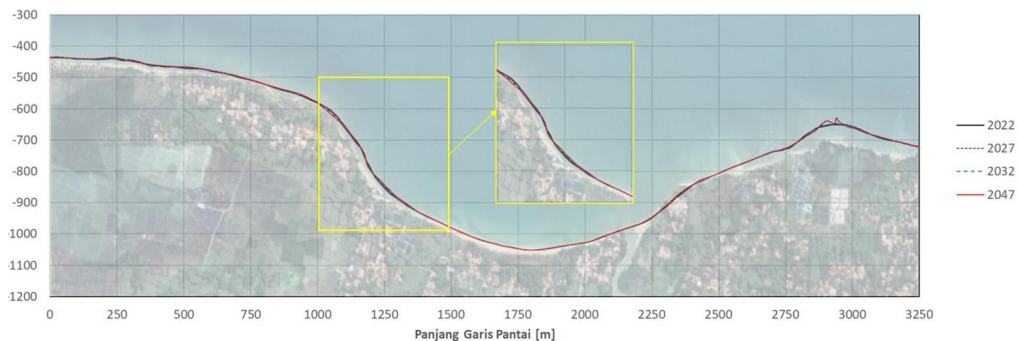


Fig. 23. Prediction of Shoreline Changes After Breakwater Installation

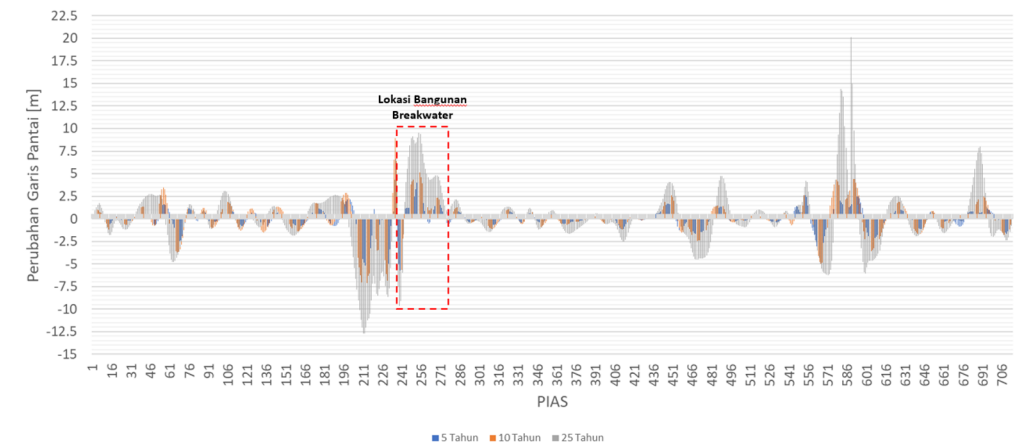


Fig. 24. Comparison of Shoreline Changes After Installation of Breakwater (Scenario 3)

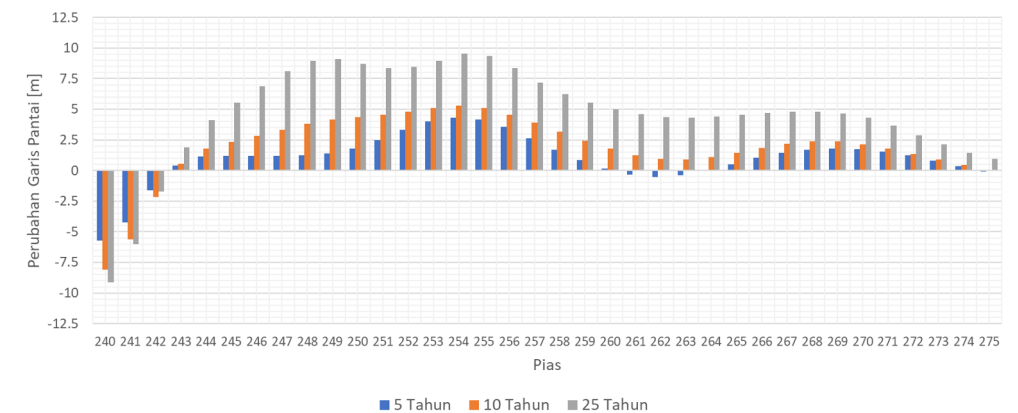


Fig. 25. Shoreline change in the vicinity of artificial reefs Scenario 3. (Segments 252 – 264)

4. Conclusion

In conclusion, the shoreline change model is a critical tool for understanding and predicting coastal erosion and accretion patterns after artificial reef deployment. Through the integration of various data

sources and the application of numerical modeling techniques, the decision-makers can evaluate the vulnerability of Tlangoh Beach and make informed decisions regarding coastal management practices. Efforts to continually refine and enhance the accuracy of shoreline change models will contribute to the preservation of coastal ecosystems and shorelines, minimize risks associated with coastal development, and maintain the ecological integrity of our shorelines.

To reduce abrasion that occurs on Tlangoh Beach, and restore the condition of the beach, 3 scenarios of artificial reef deployment are proposed to reduce the impact of abrasion on Tlangoh beach.

- Scenario 1: Fifteen artificial reefs placed in single rows show the volume of accretion sediment transport (+) of 5,444 m³ / year.
- Scenario 2: Two series of artificial reefs with a 10m gap show the volume of accretion sediment transport (+) of 5, 779 m³ / year.
- Scenario 3: Two series of artificial reefs with a 30m gap show the volume of accretion sediment transport (+) of 5,486.32 m³ / year.

It is necessary to prevent efforts to take sand/sediment or coastal exploitation activities around Tlangoh Beach and the mouth of the river that flows into the sea.

References

- Hanson, H., & Kraus, N. C. (1989). GENESIS: a generalized model for simulating shoreline change. Report 1: technical reference. *Technical Report - US Army Coastal Engineering Research Center*, 89–19.