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Oceanographic conditions and sediment dynamic of the Barrang Caddi Island (Spermonde Archipelago, Indonesia)

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Abstract. Small islands are vulnerable to long-term natural disasters like coastal erosion due to their size and topography. Barrang Caddi is one the small island in the Spermonde Archipelago (South Sulawesi) that encountered serious coastal erosion. Several attempts have been done by the relevant parties like by building a wave breaker to prevent erosion. But in fact some parts of the island are still eroded. A comprehensive oceanographic study of the wave climate and coastal processes at work to delineate the factors responsible for shoreline change and to identify the location that need protection is needed. In this study, physical oceanographic data including waves, currents, tide, bathymetry, sediment characteristics and sediment transport were collected in the Barrang Caddi Island to analyze the factors responsible for shoreline change (erosion) in the island. Results of the study showed that tide in the study site is mixed tide, predominantly semidiurnal with tidal range of 118 cm. Current measurements using an electromagnetic current meter revealed that current velocities at the study site were relatively low and vary spatially and temporally with magnitude of 0.02 – 0.58 m/s. Under normal conditions (no storms) the significant wave height ($H_{1/3}$) varied from 0.04 to 0.20 m. The wave height decreases from the fore reef to the reef flat due to the presence of coral reefs that reduce wave energy (wave height). Sediments were dominated by biogenic sand with grain diameter of 0.38 – 1.04 mm. Island erosion analysis showed that wave action was a main factor that responsible for shoreline change (erosion) at the island. Current velocity alone with average of 0.19 m/s was not strong enough to move (erode) sediments at the island.

1. Introduction

Small island areas are vulnerable to long-term natural disasters like coastal erosion due to their size and topography. The erosion of the small island coast is a topic that is of concern throughout the world because it can cause huge losses of coastal land (residential), habitat, and the island. Coastal erosion is also threatening activities which can provide economic benefits such as aquaculture activities, tourism, mining, and transportation.

A wide variety of process and features can contribute to erosion in the small island coastal zone [1]. The obvious ones are storms and their associated waves, strong current, wind and gravity [2]. Commonly these factors act in combination. Important but small in scale is bioerosion, where organisms directly cause erosion. Some other factors in erosion are raising sea level. The rise of sea level makes it possible for processes such as waves and currents to continue attack sediments and rocks along the advancing shoreline. The presence of human modifications, such as structure, along



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the coast is also may contribute to erosion in the small island. Structures of rock, steel, and concrete that are built along the coast can be a major factor in erosion, both directly and indirectly.

Barrang Caddi is one the small island in the Spermonde Archipelago (South Sulawesi, Indonesia) that encountered serious coastal erosion. Several attempts have been done by the relevant parties like by building a wave breaker to prevent erosion. But in fact some parts of the coast of the island are still eroded. A comprehensive oceanographic study of the wave climate and coastal processes at work to delineate the factors responsible for shoreline change and to identify the location that need protection is needed. In this study, physical oceanographic data including waves, currents, tide, bathymetry, and bed sediment were collected in the Barrang Caddi Island to analyze the factors responsible for shoreline change (erosion) in the island.

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2. Material and Methods

2.1. Study Site

This study was conducted from July to October 2017 at Barrang Caddi Island. Measurements of coastal oceanographic parameters including waves, currents, tides, and bathymetry, and sediment characteristics were conducted to determine the main parameters or factors causing coastal morphological changes (erosion/accretion) at the study site.

2.2. Data Collection

Water level was measured every hour for seven days (25 July to 1 August 2017) using a tide staff at a pier of the east side of the Barrang Caddi Island to determine type of the tide and tidal range of the island. Water depth contour (bathymetry) of the island was produced from Indonesian Coastal Environment Map. Sediment characteristics of the island were determined by collecting bed sediment samples at the west, east, north, and south of the island using a sediment corer (PVC pipe with diameter of 10 cm and length of 30 cm). Sediment corers were pushed into the sediments to extract sediments that are approximately 15-20 cm in length. Only the top 3 cm of the sediments were used for grain size analysis in the laboratory. Sediment samples were dry sieved using standard laboratory test sieves of mesh sizes 0.063 mm, 0.125 mm, 0.250 mm, 0.500 mm, 1.0 mm, and 2.0 mm.

Current velocity measurements at three different depths, i.e. water surface, water column (middle), and near the bed were carried out for 3 days at the west, east, south and north side of the Island using an Electromagnetic Current Meter (Kenek LP 1100). At the east side, measurements were made for 13 hours at one hour intervals to cover one tidal cycle. While at the other three sides, measurements were made for 4 hours, i.e. two hours during shift period of flood tide to ebb tides, and two hours during shift period of ebb tides to flood tides.

Wave height and wave period measurements were conducted at four transects along west side of the island. At each transect, wave heights were measured at 3 points, i.e. fore reef, reef crest, and reef flat by observing wave crest and wave trough of the 51 incoming successive waves using a 2m length scaled pole. Wave period was measured using a stopwatch by counting the number of times the wave reaches its peak in a certain period of time for 51 incoming successive waves.

2.3. Coastal Erosion Analysis

Hjulstrom's Curve was used to analyze sediment movement (erosion) due to currents. The graph takes sediment particle size and water velocity into account (Figure 1). The upper curve shows the critical erosion velocity in cm/s as a function of particle size in mm, while the lower curve shows the deposition velocity as a function of particle size. To analyze sediment movement (erosion) to waves, a formula of [3] was used to predict whether the island sediment is eroded or accretion based on wave height, wave period and sediment particle size at the study site:

$$\text{Erosion if : } \frac{H}{W_s T} \geq 3.2$$

$$\text{Accretion if: } \frac{H}{W_s T} < 3.2$$

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Where, H is significant wave heights, W_s is sediment settling velocity, and T is wave period

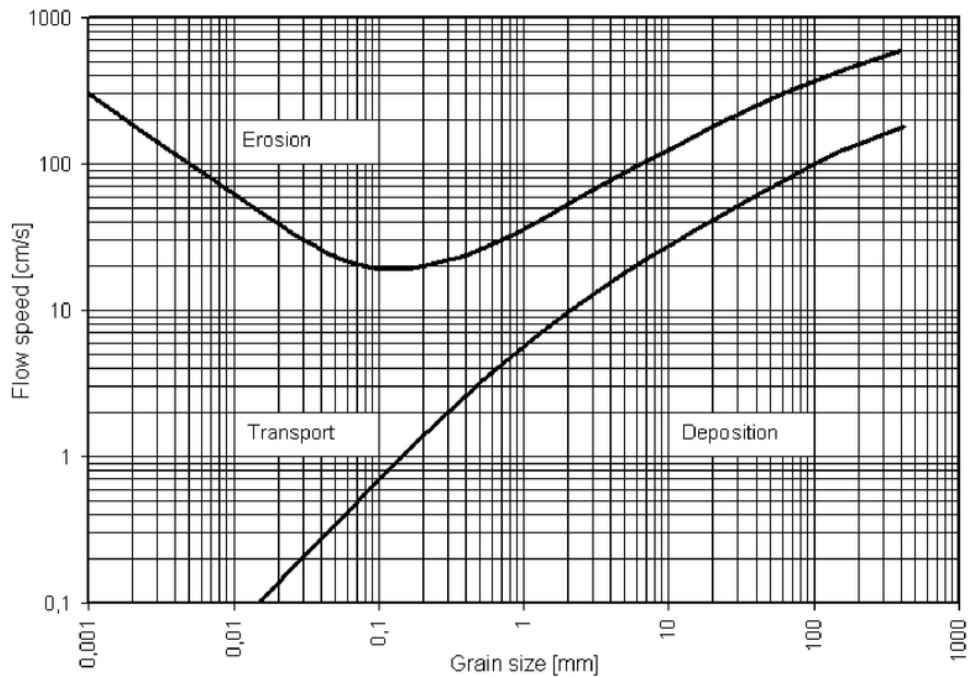


Figure 1. The Hjulström curve (https://en.wikipedia.org/wiki/Hjulström_curve)

3. Results and Discussion

3.1. Tide

Water level measurements indicated that tide at study site is Mixed Tide Prevailing Semidiurnal, i.e. two high tides and two low tides occur during a 24-hour period but exhibit two highs and two lows of significantly unequal height. Tidal range at the study site was also determined. Tidal range is the difference in water level between high tide and low tide. Tidal range at the study site was 118 cm and can be classified as microtidal coasts [4].

3.2. Bathymetry

The depth of Barrang Caddi Island water varied from less than 1 m to 34 m. At the west and south sides of the island, the coastal morphology was gentler with depth of the reef flats from less than 1m. While at the east and north sides of the island, the coastal morphology was steeper where the depth of the reef flats varied from 2 m to 6 m.

3.3. Sediment Characteristics

Sediments at the study site were dominated by biogenic sediment consisting of sand mixed with coral rubble, shells, fish bones and other marine organisms. Input of terrigenous sediment from erosion of

rocks on land is relatively small due to the location of the study far from the mainland river mouth. Sand in the study sites is non-cohesive with very small mud content (<1%). The grain size of sediments at the study sites is presented in table 1. As shown in table 1, sediment particle size at north side of the island was slightly finer than those at the west, south, and east side of the island.

Table 1. The Grain size distribution of bed sediment in Barrang Caddi Island.

Location	Grain size (mm)	Type of sediment
East side	0.72	Coarse sand
North side	0.38	Medium sand
West side	1.04	Very coarse sand
South side	0.77	Coarse sand

3.4. Current Velocity

The result of current measurement using Drifter showed that the current velocity was relatively weak at the study site (0.04 - 0.21 m/s). Current measurements using an electromagnetic current meter (better accuracy) on four sides of the island at three different depths (surface, water column, near bed) indicated that current velocity varied spatially and temporally with a range and mean velocity of 0.02 - 0.58 m/s and 0.19 m/s, respectively.

Figure 2 shows the relationship between tide and tidal currents measured for 13 hours at east side of the island. Theoretically, magnitude of tidal current velocity will follow the tidal cycle, i.e. minimum or effective zero current velocity occurs during high or low water (slack waters) while maximum velocity occurs during phase between high water (flood tide) and low water (ebb tide) [5].

As shown in figure 2, the current velocity variation did not fully follow the rising and falling pattern of the water level (tide) indicating that variation of current velocity at study site was not only caused by the tide. Other factors such as winds and waves may influence current velocity at the study site. Wind that blows over the water surface can generate surface currents that have a speed of about 3% of the wind speed at 10 m height for winds between 5 and 30 m/s [6]. This surface current velocity will decrease as the depth increases. In addition to wind, measured current velocity can also be influenced by the presence of longshore current generated by breaking waves after arriving at the beach [7].

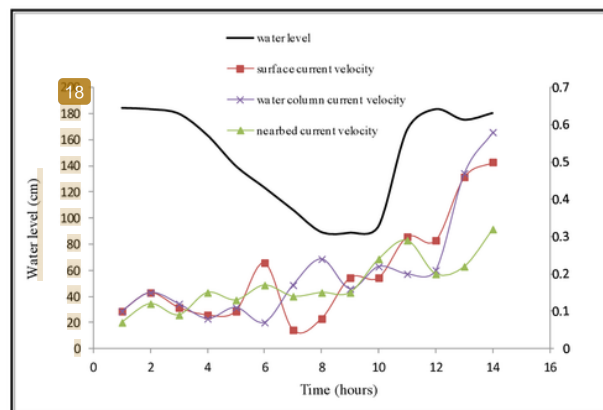


Figure 2. The relationship between the tide (water level) with the tidal current. The secondary Y-axis represents the current velocity in units of m/s.

Hjulstrom's Diagram can be used to analyze sediment movement (erosion) due to current. The size of sediment particles in the study sites was 0.38 - 1.04 mm. Based on Hjulstrom's Diagram, it takes a current strength of 0.25 to 0.37 m/s to erode the sediments of 0.38 to 1.04mm. The mean velocity of current at the study site was only 0.19 m/s which means that the current velocity alone was not strong enough to erode sediment at the study site.

3.5. Wave

Results of direct wave height measurements conducted at four transects along west side of the island is presented in Figure 3. Under normal conditions (11 storms) the significant wave height ($H_{1/3}$) varied from 4 cm to 20 cm. The wave height decreased from the fore reef to the reef flat due to the presence of coral reefs that reduce wave energy (wave height).

Meta-analyses conducted by [8] revealed that coral reefs provide substantial protection against natural hazard by reducing wave energy by an average of 97%. Similarly, [9] reported that live corals together with seagrasses, and mangroves supply more protection services than any individual habitat or any combination of two habitats. Specifically, they found that mangroves are the most effective at protecting the coast under non-storm and storm conditions, live corals and seagrasses also moderate the impact of waves and storms, thereby further reducing the vulnerability of coastal regions.

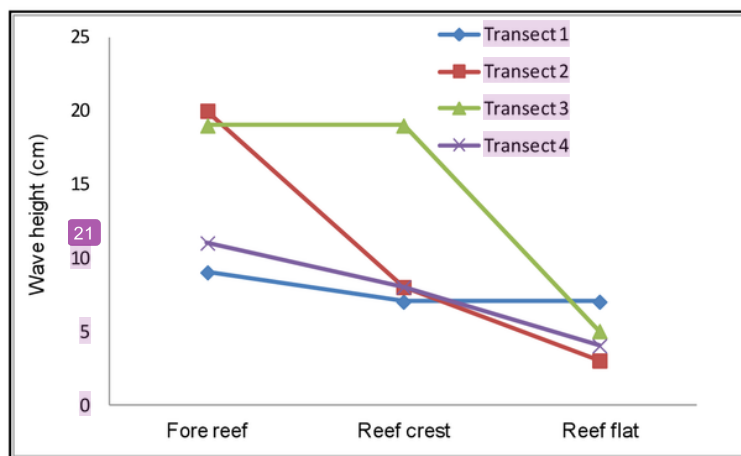


Figure 3. Wave heights at the fore reef, reef crest, and reef flats on four wave measurement transects

Wave conditions in a coastal waters determine the occurrence of erosion or accretion. The most important wave parameters in this case are the significant wave heights ($H_{1/3}$) and the wave period (T). Large waves with small wave periods that usually occur in extreme conditions or storms will cause coastal erosion. Conversely, small waves with larger periods that occur in normal conditions (calm) will cause the coast to experience accretion.

In addition to wave parameters, settling velocity of sediment particles also determines whether the coast is eroded or accreted. Settling velocity depends on the size of the sediment particles where the larger the particle the greater the settling velocity. In this study, [3] formula was used to predict whether the island sediment is eroded or accretion based on wave height, wave period and sediment particle size data. Large wave energy that has the potential to cause coastal erosion occurs when the wind blows from the west at the study site because the fetch length is greater and the wind frequency from the west is greater than the other direction. The result of erosion/accretion analysis showed that waves coming from west with wave height > 1.0 m can cause erosion in north side of the island (table 2).

Table 2. Result of erosion/accretion determination for wave coming from west direction.

Location	$H_{1/3}$ (m)	T (seconds)	W_s (m/s)	$H_{1/3} / (W_s \times T)$	Remarks
East side	0.4	4	0.125	0.8	Accretion
North side	1.0	4	0.05	5.0	Erosion
West side	1.2	4	0.17	1.8	Accretion
South side	1.1	4	0.13	2.1	Accretion

4. Conclusion

Tide in the study site is mixed tide, predominantly semidiurnal with tidal range of 118 cm. Sediments were dominated by biogenic sand with grain diameter of 0.38 – 1.04 mm. Current velocities at the study site were relatively low and vary spatially and temporally with magnitude of 0.02 – 0.58 m/s. Current velocity alone with average of 0.19 m/s was not strong enough to move (erode) sediments at the study site. Under normal conditions (no storms) the significant wave height ($H_{1/3}$) varied from 0.04 to 0.20 m. The wave height decreases from the fore reef to the reef flat due to the presence of coral reefs that reduce wave energy (wave height). Island erosion analysis showed that wave action was a main factor that responsible for shoreline change (erosion) at the island. Waves coming from west with wave height > 1.0 m can cause erosion in north side of the island

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