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Assessing the Impacts of Large Currents and Sedimentation on Coastal Ecosystems

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Abstract

Beach erosion is the erosion of beach sand which results in the beach getting closer to land. Ulakan Tapakis Beach is a beach located in Padang Pariaman district which is a destination that is visited by many people. Apart from the many beach attractions, this beach has clear water. Of the many beaches that are tourist destinations, there are beaches that are religious areas. Currently, this beach is experiencing heavy erosion, and several historical buildings have almost disappeared. This research aims to look at coastal areas that are prone to abrasion, and determine the amount of sediment eroded by waves. In this study, wind data from 2013 to 2022 was used, and using the Airy Wave theory, the planned wave height was 1.10 m with a wave period of 4.6 seconds. The wave height when it broke was 1.02 m and occurred at a depth of 1.30 m. The dominant current speed occurs towards the coast which is located in the southwest direction at 53.33%, with a current speed of 0.033 m/second which results in sediment transport (the amount of beach eroded) of 277.2 m3/hour. Buildings need to be built to reduce coastal erosion for beaches located in the southwest direction.

INTRODUCTION

The beach is the boundary between land and sea, it is a dynamic area (Asyiawati & Akliyah, 2014; Prayogo, 2021). This is because the boundary between land and sea in the form of a water line always changes over time due to tidal and receding waves, winds that change direction and the influence of seasonal winds (CERC, 1984). Change rapidly in response to natural processes and human activities.

West Sumatra is a province surrounded by beaches. One of them is Padang Pariaman Regency which has a coastline with a coastline length of 60.50 km (Kurniawan & Triyatno, 2024; Yulia & Utama, 2024). The development of beach tourism is one source of income for the community's economy, with beach tourism such as Kata beach, Kasiak beach, Gandoriah beach, Ulakan Tapakis beach, Arta beach, Tiram beach and Cermin beach, at Ulakan Tapak beach. Since 2017, abrasion has occurred along the Pariaman coast. The largest abrasion occurred on May 27 2017.

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The abrasion conditions that hit the entire Ulakan Beach area, even though groynes had been installed, abrasion still occurred, even a number of large trees supporting the cliffs at that location fell. In 2018 dozens of residents' houses and shops were destroyed (Pariaman, in the news). The cultural heritage of Sheikh Burhanudin's grave, which has become a religious tourism destination, is slowly disappearing.

This research examines the magnitude of the current speed on the beach and the amount of sediment material transported due to the current speed. Apart from that, we will also look at the influence of the wind which causes waves which will result in areas of abrasion using the wind rose method. Research on the amount of abrasion on the Padang coast according to Aldian et al., (2022); Fitri et al., (2023). using satellite image maps. Analysis of the amount of abrasion is obtained based on changes in the coastline by overlaying the image map, so that the beach is accessed and abrasion (Ukkas, 2009). research in Bone Bay was to analyze the amount of abrasion based on the characteristics of sediment grains transported by waves.

Research by Tasya et al., (2024) regarding abrasion at Ujung Tape Beach, Pinrang Regency, using satellite image maps, found that abrasion at Ujung Tape Beach was caused by natural and human factors as well as allogenic factors in the form of waves, ocean currents and tides. This beach is experiencing abrasion and accretion. Research conducted by Sihotang et al., (2020). determined the amount of coastal abrasion on the Bandengan beach, Jepara Regency, using satellite imagery, which found the beach in a state of abrasion and accretion. The research currently being carried out is to determine the dominant wind direction using the windT rose method that occurs at Pariaman Beach, where as a result of the wind the beach experiences abrasion due to wind energy transporting coastal sediments.

The research location is along the Pariaman coast with a coastline length of 60.50 km. In coastal science planning, the waves that are taken into account are waves caused by wind and tides. Meanwhile, waves resulting from volcanic eruptions (tsunami) are considered a disaster, so the characteristics of tsunami waves cannot be used in planning (Kamurahan, 2021; Siregar et al., 2020). Waves in nature are complex (non-linear). As a result of this non-linearity, waves are difficult to describe. Some experts simplify the wave form, and the wave theory used is the Airy. The theory created by Airy is also called the small amplitude wave theory. What is meant by one wave is one valley and one peak that is formed in T seconds (Supit et al., 2024; Ulum et al., 2021).

Waves that propagate in the sea towards the coast will experience a change in shape due to the influence of changes in sea depth, which is called diffraction (Azhar et al., 2012; Karamma et al., 2020). The shallower the depth of the sea, the greater the wavelength will be due to the increase in wave height. As a result, in shallow seas the waves will break, due to the increase in wave height. As a result of breaking waves, sediment transport and wave turbulence processes occur which result in wave currents (Triatmadja, 1999; Triatmodjo, 2020). the theory of waves states that to determine the amount of abrasion by determining the length and speed of the wave. The research is expected to be able to determine the abrasion area using the wind rose concept. This is done so that the government can immediately identify and overcome the dangers of abrasion in coastal areas.

METHODS

The method used is quantitative descriptive method and literature study. Wind data from 2013 to 2022 was used, obtained from the Minangkabau

Meteorology, Climatology and Geophysics Agency (BMKG), which was obtained in the form of recording daily wind speeds at Ulakan Tapakis Beach. From the wind data from 2013 to 2022, the direction and height of the waves that occurred, namely the most dominant wind, was determined using the Wind Rose theory, by grouping the wind data that frequently occurs (Bantara et al., 2024; Gamellia et al., 2019; Simamora & Nurdiansyah, 2020). Next, calculate the planned wave height. To determine the amount of abrasion, the height of the breaking wave and the position where the breaking wave occurred are needed. From the height and depth of the breaking wave, the speed of the wave current and the amount of sediment transported (abrasion) is calculated.

Waves that arrive at the beach carry energy, which is formed from potential energy (m.g.H) that occurs when the wave breaks. That energy cannot be removed, so after arriving at the beach the energy turns into current. The magnitude of the current that occurs is kinetic energy (motion) that moves beach material. As a result of the movement of coastal material, an abrasion process occurs. Currents that reach the coast can be currents parallel to the coast and currents perpendicular to the coast.

Especially for Pariaman beach, the abrasion process occurs along the coast, therefore it can be classified as experiencing longshore currents. Longshore current flow is parallel to the coastline and is limited between the breaking wave area and the coastline. Most longshore currents are generated by the longshore component of waves that form an angle with the shoreline. The abrasion results and wave direction are said to be balanced if the wave height remains (constant) according to Airy wave theory (Triatmodjo, 2016).

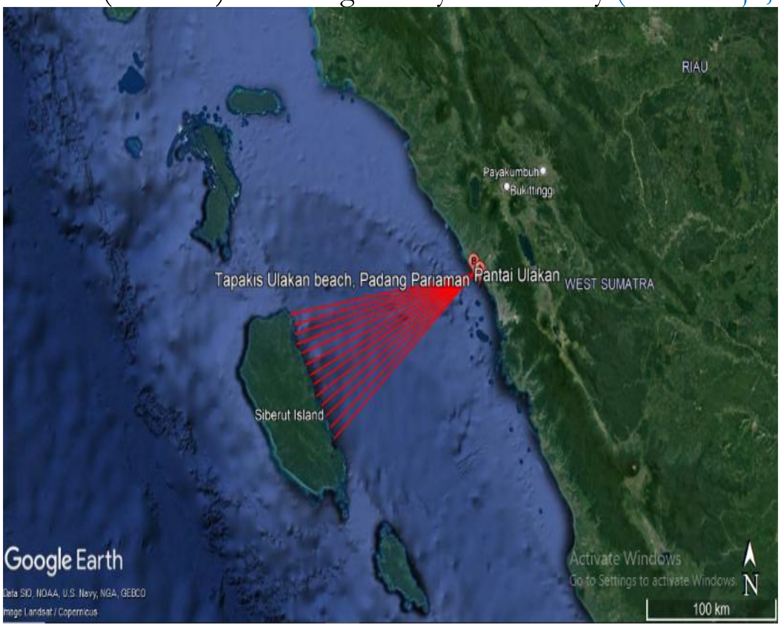

Fig 1. Wave direction on Pariaman beach (Religious tourism area, Ulakan beach)

Figure 1 is the research area analyzed based on image maps using the ARGIS quantum method. From the ARGIS results, the dominant wind direction will be determined, which means the abrasive coastal area using the wind rose method.

RESULT AND DISCUSSION

The first, determine the dominant wind direction by using a wind rose (wave rose) from winds recorded from the Minangkabau Meteorological and Geophysical Station (BMG) with latitude -00.79355 and longitude 1000.28917.

Calculation of wind direction according to Yulia & Utama, (2024). by grouping wind speeds from 2013 to 2022, they are shown in table 1 as follows:

Table 1. Wind direction and magnitude

Wind Speed (knots)	North	South	East	West wind direction	North West	Northeast	South East	South West
0-5	0	0	0	1	0	0	0	9
6-10	1	0	0	3	12	0	0	44
11-15	2	0	0	1	3	0	0	10
16-20	0	0	1	1	0	0	0	1
21-25	0	0	0	0	0	0	0	0
26-30	1	0	0	0	0	0	0	0
Amount	4	0	1	6	15	0	0	64
Total				90				

From table 1, it can be seen that the dominant wind from the Southwest is 64 events out of 90 events or 71.11%. The wind rose graph is depicted in figure 2, based on angina data from 2013 to 2022:

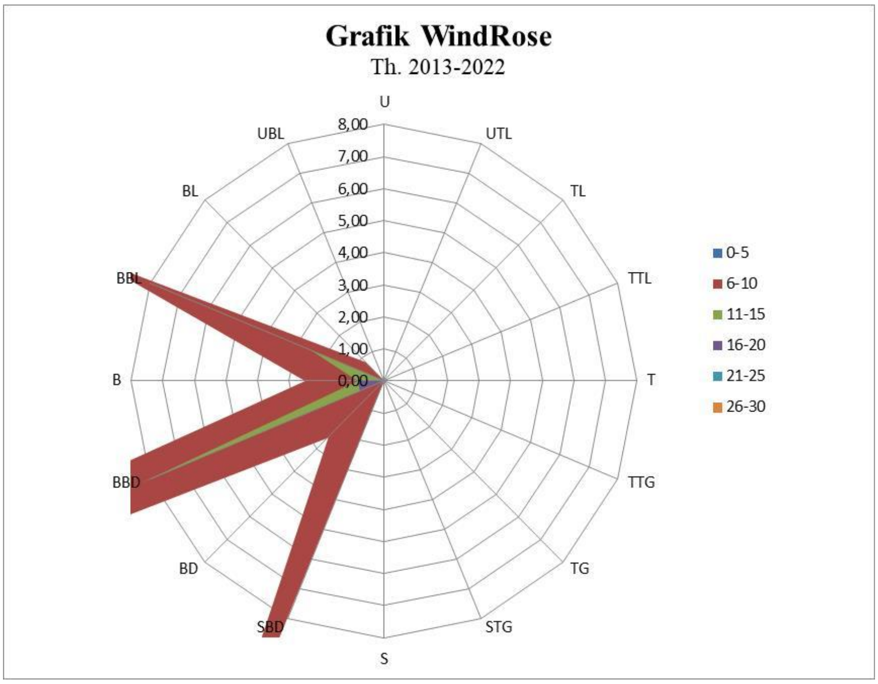

Fig 2. Windrose graphic on Ulakan Tapakis Pariaman beach

From figure 2, it can be concluded that the wave direction is from the Southwest

The second, determination of wave direction according to Fetch theory

Table 2. Wave height and period 2013 – 2022

Year	High (m)	Period (second)
2013	1,046	4,389
2014	0,587	3,564
2015	0,286	2,508
2016	0,735	3,927

Year	High (m)	Period (second)
2017	0,573	3,531
2018	0,465	3,234
2019	0,352	2,805
2020	0,392	2,904
2021	0,330	2,673
2022	0,446	3,003

The third, Calculate significant wave height (Hs) using formula:

$Hs = 0{,}0056 \times U^2$ (m)
$Ts = 0.33\ U$ (det)
obtained: Hs = 1.1 m and Ts = 4.6 seconds
Beach slope = m = 0.005
Lo = 1.56 T2 = 1.56 (4.6)2 = 33 m
The dominant wind direction is from the Southwest, so αo = 45^0
Lo = 1.56 T2 = 1.56 (4.62) = 33 m

The fourth, determine the height and depth of breaking waves
Take d = 1.3 m
d/Lo = 1.3/33 = 0.039
With d/Lo = 0.039, from table C1 we get: d/L1 = 0.08215
So L1 = 1.3/0.08215 = 15,82 m
with d/Lo = 0.039, from table C1 we get: Ks = 1.069

$$\frac{Lo}{\sin \alpha o} = \frac{L1}{\sin \alpha 1}$$

$$\frac{33}{\text{Sin } 45^0} = \frac{15{,}82}{\text{Sin } \alpha 1}$$

sin ∝ 1 = 0.313, we get ∝ 1 = 190, 81

$$Kr = \sqrt{\frac{\cos \alpha_0}{\cos \alpha_1}}$$

$$\text{Kr } 1.3 = \sqrt{\left(\frac{\cos 450}{\cos 190,\ 81}\right)} = 0.867$$

$$\frac{H1}{Ho} = Ks.\ Kr$$

H1 = Ho x Ks x Kr
H1 = 1.1 x 1.069 x 0.867= 1,02 m
d = 1.3 m

$$\frac{H1}{d} = \frac{1{,}02}{1{,}3} = 0{,}78 \quad (2.12) \text{ or } db/Hb = 1.28$$

The breaking depth occurred at a depth of 1.3 m with a breaking wave height of 1.02 m

The fifth, determine the speed of the longshore current

$$V = \frac{5\pi.\gamma b}{16\ cf}\sqrt{(g\,.\,db)}\quad x\ m\ x\ \sin\ \varphi b\ \ meter/detik \quad (2.14)$$

γb = 0.78
k = 2π/L = (2 x 3.14)/15,82 = 0.40

$$cf1 = 18 \log \frac{12\ h}{k}$$

$$cf1 = 18 \log \frac{12 \times 1.02}{0.40} = 26{,}74$$

From the calculation results, the value db = 1.3 m
known beach slope: m = 0.005
The angle of the wave when it breaks:

$$V = \frac{5\pi.0{,}78}{16\ x0{,}1337}\sqrt{(9{,}81\ .1{,}3)}\quad x\ 0{,}005\ \ x\ \sin\ 19{,}81\ \ meter/second$$

V = 0,033 m/second
Coastal current speed 0,033 m/second = 120 m/hour

The sixth, determine the amount of sediment on the beach

The direction the wave is coming	Significant wave height in the deep sea (m) = Hs	Significant wave height in the deep sea (m) = Hs	Refraction coefficient at a depth of 1.3 m = Kr br	Wave incidence angle at a depth of 1.3 m (α)
45	1.1	4,6	0.7	190 81

Significant wave height (Hs)= 1.1 m
Wave period = 4.6 seconds Refraction
Coefficient (Kr) = 0.70 at a depth of 1.3 m,
α = 190 81 at a depth of 1.3 m
Lo = 1.56 T2 = 33 m
Co = Lo/T = 33/4,6 = 7,17 m/second
Ho = Hs x Kr br
Kr br = 0.70, So, Ho = 1.1 x 0.70 = 0,77 m
From the graph I : Hb/Ho = 1.02/0.77= 1.32
So, Hb = 1,32 Ho = 1.32 x 0.77 = 1.02 m
Hb/gT2 = 1.02/9.81 x 4.62 = 0.0049
From the graph II : db/Hb = 0.91
db = 0.91 x Hb = 0.91 x 1.02 = 0.93 m
db/Lo = 0.93/33 = 0.028 , from table C1 tanh 2πd/L = 0.4071 = cd
so, cb/cd = 0.3786/0.4071 = 0.93
αbr = arc sin 0.93 (sin – 160) = -8.42
Kr br = (cosα / cos α br)1/2 = (cos-160)/cos-8.420)1/2= 0.837 ~ 0.84
So take it Kr br = 0.84 is true (Oke)
S = 0.014 Ho2 x Co x Kr br x sinα br x cosα br
S = 0.014 (0.77)2 X7.17 X0..84 X sin – 8.420 X cos – 8.420

S = 0.014 x 0.59 x 7.17 x 0.84 x - 0.146 x 0.99 = - 0.077 m3/second

Every second 0.077 m3 of grain is transported. The beach is experiencing an erosion process.

CONCLUSION

Based on the results of the analysis it can be concluded the first, From the wind speed from 2013 to 2022, the wind rose was obtained with the dominant wind direction being in the southwest direction at 71.11%. So by using wind data we can determine the area of the coast that is abrasion. The second the current speed at the beach is 0.12 km/hour with the amount of sediment transported being 0.077 m3/second or 277.2 m3/hour. From this research, it can be determined that the amount of sediment transported is determined by the height of the breaking wave.

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