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Analysis of Coastal Abrasion Rate and Sediment Fractions at Tiram Beach, West Sumatra

Analisis Tingkat Abrasi dan Fraksi Sedimen di Pantai Tiram Provinsi Sumatera Barat

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Abstract

Tiram Beach, located in Padang Pariaman Regency, West Sumatra Province, is one of the coastal areas under environmental pressure from coastal abrasion. Abrasion leads to shoreline retreat and negative impacts on local socio-economic activities. This study aims to analyze the rate of coastal abrasion and sediment fractions at Tiram Beach over 20 years (2003–2023), and to identify the dominant sediment characteristics in the area. The research methods included analysis of Landsat satellite imagery (2003, 2013, and 2023). Results show that Tiram Beach has undergone consistent shoreline retreat, with abrasion rates ranging from 2.2 to 3.1 meters per year. The sediment is predominantly composed of coarse sand and gravel, classified as poorly sorted, with skewness values indicating a dominance of coarse particles in certain zones. Contributing factors to abrasion include high-energy waves from the Indian Ocean, strong coastal currents, and human activities such as tourism and coastal infrastructure development. In conclusion, coastal abrasion at Tiram Beach is significant and poses a threat to the sustainability of the coastal zone if left unmanaged. Mitigation measures such as the construction of coastal protection structures, rehabilitation of coastal vegetation, and integrated coastal spatial planning are recommended to reduce future impacts.

Keywords: Abrasion, Sediment Fraction, Shoreline Change, Satellite Imagery

Abstrak

Pantai Tiram yang terletak di Kabupaten Padang Pariaman, Provinsi Sumatera Barat merupakan salah satu wilayah pesisir yang mengalami tekanan lingkungan akibat proses abrasi. Abrasi pantai dapat menyebabkan kemunduran garis pantai, hilangnya daratan, serta berdampak terhadap aktivitas sosial dan ekonomi masyarakat. Penelitian ini bertujuan untuk menganalisis tingkat abrasi dan fraksi sedimen di Pantai Tiram selama kurun waktu 20 tahun (2003–2023), serta untuk mengetahui karakteristik sedimen yang mendominasi wilayah pesisir tersebut. Metode yang digunakan meliputi analisis citra satelit Landsat (2003, 2013, dan 2023). Hasil penelitian menunjukkan bahwa Pantai Tiram mengalami abrasi dengan laju kemunduran garis pantai antara 2,2–3,1 meter per tahun. Karakteristik sedimen di pantai ini didominasi oleh pasir kasar (coarse sand) dan kerikil, dengan klasifikasi pemilahan yang buruk (poorly sorted) dan nilai skewness yang mengindikasikan dominasi butiran kasar di beberapa lokasi. Faktor-faktor yang memengaruhi abrasi antara lain gelombang tinggi dari Samudera Hindia, arus laut yang kuat, serta aktivitas manusia di sekitar pantai seperti pembangunan dan pariwisata. Abrasi di Pantai Tiram memiliki tiga kategori yaitu tinggi, sedang, dan rendah sehingga dapat mengancam keberlanjutan kawasan pesisir jika tidak dikelola dengan baik. Oleh karena itu, diperlukan upaya mitigasi seperti pemasangan struktur pelindung pantai, rehabilitasi vegetasi pesisir, serta pengelolaan ruang pesisir yang berkelanjutan.

Kata kunci: Abrasi, Fraksi Sedimen, Garis Pantai, Pantai Tiram, Citra Satelit

1. Introduction

Padang Pariaman Regency is a city located in West Sumatra Province, on a low, gently sloping plain on the West Coast of Sumatra. This city has potential biological resources such as fish and shrimp. Besides these resources that the local government and community can utilize, the government is also currently leveraging the tourism potential, including Tiram Beach, a tourist destination. Abrasion is defined as the event of land erosion that occurs in coastal areas. Abrasion is also defined as the continuous release of beach material (sand or clay) due to sea wave impacts or changes in the balance of sediment transport on a beach (Munandar & Kusumawati, 2017). This event causes the shoreline in an area to retreat, thereby impacting the ecosystem and settlement areas behind it. From this statement, it can be said that abrasion not only disturbs the balance of the ecosystem in the coastal ecosystem but can also disrupt various human activities in that area (Muthmainnah et al., 2022).

According to Rifardi (2012), marine sediments originate from land and the results of biological, physical, and chemical activities (processes) occurring both on land and in the sea itself. However, there is some input from volcanogenic and cosmic sources. Marine sediments consist of materials from various sources. Factors influencing the type of sediment accumulated include underwater topography and climate patterns. Sediment is material or particles found on the earth's surface (on land or ocean), which have undergone transportation processes from one place (area) to another and have undergone deposition. Sediment is an important factor in the ocean, as noted by Siswanto (2011), who observed that the accumulation of deposited material over a period will affect the area and land in coastal and beach areas.

Coastal abrasion and sediment fractions are part of coastal dynamics that are worth studying. This is what encourages the researcher to study the topic more deeply and to conduct research on beach abrasion and sediment fractions at Tiram Beach. The objectives of this research are to measure abrasion rates over the past 20 years and to determine the sediment type at Tiram Beach, West Sumatra Province.

2. Material and Method

2.1. Time and Place

This research was conducted in May 2024 in the waters of Tiram Beach, West Sumatra, and sample analysis was carried out at the Physical Oceanography Laboratory, Department of Marine Science, Faculty of Fisheries and Marine, Universitas Riau.

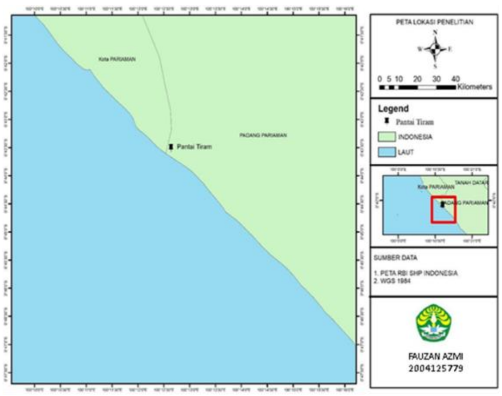

Figure 1. Location Map

2.2. Methods

The method used in this research was a survey method, namely, field observations that produce primary data. Primary data are obtained directly from field measurements, and secondary data are obtained from satellite imagery and other sources.

2.3. Procedures

2.3.1. Determination of Sampling Location

The determination of research locations and sediment sampling used a purposive sampling method, in which samples are carefully selected to be relevant to the research design, given that the three stations are deemed to represent the study area.

Tabel 1. Coordinate Points of Research Stations at Tiram Beach

Station	Latitude	Longtitude
1	0° 43. 176'S	100 ˚ 12. 164'E
2	0° 43. 198'S	100 ˚ 12. 194'E
3	0° 43. 219'S	100 ˚ 12. 220'E

2.3.2 Image Processing

Image data processing to calculate the abrasion rate was performed by overlaying raster data in year sequence in ArcGIS, using vector data in polyline format. After digitization is completed, calculations can be performed by comparing the new year (2023) with the old years (2003) and (2013). If the value is positive or there is an increase in beach area, then sedimentation occurs. Conversely, if the value is negative or there is a decrease in beach area, then abrasion occurs. Abrasion measurement is guided by station points and presented with a map layout of the beach change calculation results.

Interpretation of shoreline changes to calculate abrasion and sedimentation lengths was performed by overlaying raster data in year sequence in ArcGIS, using vector data in polyline format. After the digitization process is complete, the method to calculate shoreline movement is: if the new shoreline in 2023 is in front of the old shoreline in 2013, then sedimentation (accretion) has occurred; in other words, the shoreline change has a positive value. Conversely, if the 2023 shoreline in 2023 is behind the 2013 shoreline in 2013, then abrasion occurs; in other words, the shoreline change has a negative value.

2.3.3. Abrasion Measurement with Ground Check

Abrasion measurement by field check (ground check) was conducted to see the actual conditions at the research location. Abrasion measurement is shown in Figure 2.

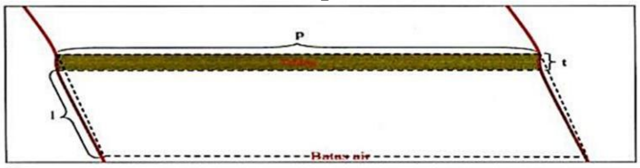

Figure 2. Abrasion Measurement Scheme (Suwarsono et al., 2011)

Based on Figure 2, the formulas for the abraded surface area and the mass of abraded substrate are: A = p.l and m = ρ.v with v = p.l.t According to Suwarsono et al. (2011), the abrasion rate can be calculated using the following equation: $v = \frac{\frac{m}{A\rho}}{t}$

Description:

V	: Abrasion Rate (m/year)	M	: Mass of Abraded Substrate (Kg)
A	: Cliff Height Due to Abrasion.	ρ	: Density of abraded substrate (1,5 x 10^3 kg/m^3).
T	: Time (Year)		

2.3.4. Wave Characteristic

According to Ghalib (2010), wave energy can be divided into two forms: kinetic energy, present in the orbital motion of water particles. Potential energy is possessed by water when displaced from its actual position. The total wave energy (E) per unit area is:

$$E=\frac{1}{8}\rho g h^2$$

Description:

E	: Total Wave Energy per unit area (m/year)	ρ	: Water Density (kg)
g	: Acceleration due to gravity	h	: Wave Height (1,5 x 10^3 kg/m^3).
$\frac{1}{8}$	: Time (Year).		

2.3.5. Beach Slope

Beach slope measurements were conducted to determine the steepness of the beach surface from the tide line to the land. The slope is calculated by dividing the vertical difference between two points on the beach by the distance between them. According to Sunu et al. (2008), beach slope can be classified into four categories based on percentage slope as follows:

Tabel 2. Slope Classification (Sunu et al., 2008)

Slope (%)	Beach Slope Category
< 5%	Very Gentle
5% - 10%	Gentle
10% - 15%	Steep
> 15%	Very Steep

2.3.5. Sediment Sampling and Water Quality

Sediment sampling was done using a shovel during low tide. The collected sediment samples were placed in plastic bags, labelled by station, and then analyzed in the laboratory. Parameters measured included: temperature, pH, Salinity, Current velocity, and Brightness. The results of these measurements were used as supporting data to describe the water conditions at Tiram Beach.

2.4. Data Analysis

The obtained data will be processed and then presented in tables and mapped using ArcGIS 10.4. Then, the beach abrasion rate will be correlated with sediment fractions, currents, and waves in the study area, and the results will be discussed descriptively.

3. Result and Discussion

3.1. General Conditions of the Research Location

A Tiram Beach is a beach located in the Ulakan Tapakis District, Padang Pariaman Regency, West Sumatra Province. This beach is located 12 km from Minangkabau International Airport (BIM). Tiram Beach is located on the west coast of Sumatra Island. It faces the Indian Ocean directly, where currents and waves approaching the shore are quite strong, potentially causing beach abrasion.

Ulakan Tapakis District is traversed by 2 river estuaries: the Ulakan River estuary and the Tapakis River estuary (Tiram River estuary). This Ulakan Tapakis District has beaches named Tiram Beach and Ulakan Beach. Tiram Beach has an area of about 10.5 ha with a long coastline. Around the beach area and the Tiram River estuary, various human activities take place, as Tiram Beach attracts many visitors who come to enjoy its beauty. However, fishing is also common in the waters around this beach. These activities can also cause problems, including environmental damage and changes in beach conditions.

Tiram Beach is classified as a gentle, white, sandy, and slightly gravelly beach. This beach has flat characteristics and tends not to be steep. This beach also has a tropical climate, with an average temperature of 26-31°C. This condition keeps the weather on the beach warm and humid year-round. This beach experiences two seasons: the rainy season, which usually lasts from November to March, and the dry season, which lasts from April to October. The rainy season brings higher rainfall, while the dry season tends to be drier and ideal for tourism activities.

3.2. Water Quality

Water quality parameters are important to measure because they can determine the state of the water at the research location. The measured parameters include chemical and physical parameters: salinity, temperature, current, and waves.

Tabel 3. Water Quality Parameters at Tiram Beach

Station	Salinity (‰)	Temperature(°C)	Current (m/s)	Wave Height (m)
1	28	29	0,3	0,42
2	26	29	0,3	0,42
3	30	30	0,5	0,51

Based on the results in Table 3, the highest salinity value is at station 3, which is 30‰, and the lowest salinity is at station 2, which is 26‰. The highest temperature is at station 3, 30°C, and the lowest is at stations 1 and 2, 29°C. The highest current velocity is at station 3, which is 0.5 m/s, and the lowest current velocity is at stations 1 and 2, which is 0.3 m/s. The highest wave height is at station 3, which is 0.51 m, and the lowest wave height is at stations 1 and 2 with a value of 0.42 m. These physical water conditions determine how much energy is available to transport and deposit sediment material along the coastline. The higher values of salinity, temperature, current, and waves at Station 3 indicate strong water energy. This condition increases sediment transport seaward, triggering abrasion along the beach. Changes in these water-quality parameters can cause an imbalance in the coastal system, ultimately accelerating abrasion.

3.3. Beach Slope

Beach slope measurement at Tiram Beach was conducted directly in the research area. Wave data is divided into wave height and wave energy. Based on the calculated beach slopes at the three stations, the values range from 5.51% to 5.88%, which are categorized as gentle. Based on the classification by Sunu et al. (2008), this range falls into the gentle category. This gentle beach slope spreads wave energy farther toward the land, making it more susceptible to abrasion.

Tabel 4. Beach Slope at Tiram Beach

Station	Slope Magnitude (%)	Category
1	5,88	Gentle
2	5,63	Gentle
3	5,51	Gentle

3.4. Abrasion Rate

Abrasion measurements using Landsat 5 and 8 satellite imagery at Tiram Beach are shown in Figure 3 through shoreline changes.

Figure 3. Shoreline Change Map at Tiram Beach

Figure 3 above shows long lines in green, purple, and yellow depicting shoreline changes at Tiram Beach from 2003-2023; for clarity.

Tabel 5. Abrasion Rate at Tiram Beach with Satellite Imagery (m)

Station	Year 2003-2013 (m)	Year 2013-2023 (m)	Year 2003-2023 (m)	Rate of Change 2003-2023 (m/year)	Category
1	18	35	53	2,65	Medium
2	29	15	44	2,2	Low
3	47	15	62	3,1	High

The beach abrasion rate in Table 5 indicates that abrasion has occurred at Tiram Beach. The results of the shoreline change calculation found that station 3 experienced the highest abrasion with a shoreline change of 3.1 m/year, and station 2 experienced the lowest abrasion with a shoreline change of 2.2 m/year.

Tabel 6. Direct Beach Abrasion Measurement

Station	Abrasion Rate (m/year)
1	2,42
2	2,18
3	2,61

The abrasion rate at Tiram Beach, based on Table 6, shows that station 3 has the highest abrasion rate of 2.61 m/year, and station 2 has the lowest abrasion rate of 2.18 m/year. The abrasion level is one of the main indicators in assessing the stability of coastal areas. Tiram Beach, located on the western coast of Sumatra and facing the Indian Ocean, is an area vulnerable to abrasion due to high sea waves, strong currents, and significant environmental changes. Over 20 years (2003-2023), this beach has shown a fairly high tendency for abrasion. Based on satellite imagery analysis, the abrasion rate ranges from 2.2 to 3.1 m/year, with low, medium, and high categories.

This abrasion phenomenon is influenced not only by natural factors such as waves and sea currents but is also reinforced by the water and sediment characteristics in the area. Water quality measurements indicate that station 3 has the strongest physical parameters: salinity of 30‰, current velocity of 0.5 m/s, and wave height of 0.51 m. This condition indicates that the area is exposed to high hydrodynamic energy, making it more vulnerable to beach erosion processes. Additionally, the beach slope, which falls into the gentle category (5.51-5.88%), makes the beach more receptive to wave energy and spreads it towards the land. Thus, beaches with gentle slopes tend to experience more intense abrasion than those with steep slopes (Sunu et al., 2008).

Another influencing factor is the characteristics of sediment fractions and parameters. The sediment type at Tiram Beach is sandy gravel. This sediment is classified as poorly sorted, indicating poor sorting due to the strength of currents and waves during deposition. This condition indicates instability in the sediment system in that area. According to Blott & Pye (2001), poorly sorted sediments are usually formed in environments with rapid transportation or disturbed by various physical factors, such as strong currents or large waves. Nichols (2009) adds that poor sorting reduces the sediment's ability to form stable beach structures, thereby influencing the abrasion process.

The highest abrasion level at Tiram Beach occurs at Station 3. Based on direct measurement results (ground check), the average rate of shoreline change at this station reaches 2.61 m/year. Meanwhile, satellite imagery shows an average shoreline change rate of 3.1 m/year. This high abrasion is influenced by the strong sea currents and waves around that station, which are significantly higher compared to other stations. Where a current velocity of 0.5 m/s, salinity of 30‰, wave height reaching 0.51 m, and wave energy of 326.27 Nm/m² were found. It is this wave energy that will hit the beach, eroding it or releasing materials from around the beach towards deeper waters, which can cause beach abrasion or accretion. This opinion is supported by Fajri et al. (2013), who state that large wave heights generate high-speed longshore currents, which erode or carry much material to deeper beaches, where it is lost in coastal currents.

The characteristics of sediment fractions at station 3 show a dominance of coarse fractions: gravel 65.19%, sand 29.18%, and mud 5.64%, with a sandy gravel sediment type, indicating that this sediment requires high energy to be transported and deposited. This indicates that the waters around station 3 are in a high-energy state, continuously eroding the land. The presence of this coarse sediment also indicates that the deposition process is not optimal, so abrasion is more dominant (Dey et al., 2009). The mean sediment diameter (mean size) at station 3 is 0.88 mm, the highest among all stations. According to the Wentworth classification, this size falls into the coarse sand category. If sediment is dominated by coarse sediment grains, it indicates that the flow strength transporting the sediment is quite large. In addition to oceanographic factors, the high tourism activity at this location also contributes to abrasion at that station. This opinion is supported by Handoyo (2015), who states that factors causing shoreline changes fall into two categories: natural and human factors. Natural factors include waves, currents, wind, sedimentation, and tides. Human factors include excavation, landfilling, and beach reclamation.

The medium abrasion level at Tiram Beach occurs at Station 1. Based on direct measurement results (ground check), the average rate of shoreline change at this station reaches 2.42 m/year. Meanwhile, satellite imagery shows an average shoreline change rate of 2.65 m/year. This abrasion level is influenced by sea currents and waves around that station, but the intensity of those currents and waves at this location is not as great as at station 3. Where the current velocity at this station 1 is 0.3 m/s, and the salinity is 28‰, with a wave height ranging around 0.42 m and wave energy of 221.28 Nm/m². The difference in abrasion rate values is estimated to be due to wave impact on this beach. Fajri et al. (2013) state that abrasion strength is determined by wave size. Large wave energy can have a strong impact on the beach, leading to destructive beach waves with high height and rapid propagation. Opa (2011) adds that when waves approach the beach, they begin to friction with the seabed and cause wave breaking at the beach edge.

The sediment fractions at station 1 are dominated by gravelly sand, with sand at 49.74%, gravel at 42.31%, and mud at 7.95%. This condition indicates that the sediment is poorly sorted, leading to unstable deposition. According to Hasan et al. (2021), poor sorting is an important indicator of unstable water dynamics and higher abrasion potential. Besides the influence of oceanographic factors, the presence of coastal vegetation, such as Pine trees around station 1, can also potentially reduce abrasion rates because the roots of that vegetation can help hold sediment grains and strengthen the coastal soil structure. Sujarwo & Darma (2011) add that tropical forests on lowlands play an important role as a source of community needs and provide quite diverse environmental services, can dampen tsunami wave impacts, prevent beach abrasion, and protect terrestrial ecosystems from wind and storm exposure.

The lowest abrasion level at Tiram Beach occurs at Station 2. Based on direct measurement results (ground check), the average rate of shoreline change at this station is only 2.18 m/year. Meanwhile, satellite imagery shows an average shoreline change rate of 2.2 m/year. This low abrasion rate is comparable to the oceanographic conditions around the station, where sea currents and waves around that station are not as strong and large as at other stations, being significantly lower compared to other stations. Where a current velocity of 0.3 m/s, salinity of 26‰, wave height reaching 0.42 m, and wave energy of 221.28 Nm/m² were found. The sediment fractions at station 2 are dominated by gravel (73.83%), sand (20.96%), and mud (5.21%). The high gravel percentage indicates that this location has a heavier substrate. Currents do not easily carry coarse sediment like this away unless they have a lot of energy.

Besides oceanographic factors, the presence of coastal protection structures like breakwaters (breakwater) at this station can also dampen the strength of currents and waves heading towards the shoreline, so that the abrasion process can be minimized effectively. Husain et al. (2021) support this: Breakwaters are marine structures used to protect water areas from wave disturbances. Breakwaters are also commonly used to protect beaches from wave surges, thereby reducing beach abrasion. Wirawan et al. (2024) also add that breakwaters (APO) are one type of artificial defence structure aimed at dampening waves during tides and reducing the impact of beach abrasion.

3.5. Validation of Shoreline Change

The accuracy of shoreline change data from satellite imagery interpretation was validated using direct field measurement data. This validation was done by comparing the shoreline change rate from satellite imagery with direct measurement results (ground check) at three station points. The comparison results are shown in Table 7.

Table 7. Comparison of Abrasion Values from Satellite Imagery and Ground Check

Station	Satellite Imagery (m/year)	*Ground Check* (m/year)
1	2,65	2,42
2	2,20	2,18
3	3,10	2,61

The difference between image data and field measurement data was analyzed using the Root Mean Square Error (RMSE) method.

Table 8. Data Validation using the Root Mean Square Error (RMSE) Method)

Station	Satellite Imagery (x)	*Ground check* (x')	(x-x')	$(x-x')^2$
1	2,65	2,42	0,23	0,0529
2	2,2	2,18	0,02	0,004
3	3,1	2,61	0,49	0,2401
				$\sqrt{0,0978}$
RMSE				0,31273

An RMSE value of 0.31 m indicates that the data from satellite imagery interpretation has a small error level and is acceptable. According to Congalton & Green (2009), RMSE is a statistical measure used to assess how accurately interpretation results match reference data. An RMSE of 0.5 m is considered high accuracy and suitable for shoreline monitoring. This shows that long-term satellite imagery is highly accurate in depicting shoreline changes at Tiram Beach.

3.6. Sediment at Tiram Beach

Sediment fractions at Tiram Beach can be determined through the percentage of existing sediment grains. This is supported by Dey et al. (2009), who state that to understand sediment characteristics, it is necessary to know the percentage of sediment grains. The percentages of sediment fractions and their types at each station are shown in Table 9.

Table 9. Percentage of Sediment Fractions at Tiram Beach

Station	Fraksi Sedimen			Type
	%Gravel	%Sand	%Mud	
1	42,31	49,74	7,95	Gravelly Sand
2	73,83	20,96	5,21	Sandy Gravel
3	65,19	29,18	5,64	Sandy Gravel

Determining the mean diameter (Mz) is important for identifying the sediment type in an area and estimating its source. The mean grain diameter of the sediment on this beach is classified as coarse sand.

Tabel 10. Mean Sediment Diameter

Station	Mean size (mm)
1	0,3
2	0,7
3	0,8

The mean grain diameter of the sediment at Tiram Beach ranges between 0.3 and 0.8mm, with the highest value at station 3 and the lowest at station 1. The surface sediments of the waters at Tiram Beach can be grouped into three sediment types: gravel, sand, and mud. The sand fraction dominates at station 1 (49.74%), the gravel fraction dominates at station 2 (73.83%), and at station 3 (65.19%). Water conditions strongly influence this sediment fraction. The location of Tiram Beach, facing directly onto the Indian Ocean, makes it prone to year-round high waves (0.42-0.51 m) and currents (0.3-0.5 m/s). Salinity values range from 26 to 30‰; high salinity indicates the dominance of seawater and a low influence of freshwater, leading to minimal supply of fine sediment from land and thus strengthening the dominance of coarse sediment at Tiram Beach. Additionally, the temperature in these waters, ranging from 29 to 30°C, also influences the weathering of organic material. According to Hasan et al. (2021), high salinity on open beaches correlates with low input of fine sediment and dominance of coarse grains due to little sediment load from rivers or estuaries.

The sediment distribution on this beach does not differ much between one station and another. This is due to the abundance of sand and also gravel dominating the beach. This distribution of sediment fractions greatly influences shoreline changes at Tiram Beach. Dominance of sand and gravel indicates that this region has fairly strong wave and current energy. This condition influences shoreline dynamics. The high wave energy hitting the beach, combined with the dominance of coarse fractions such as sand and gravel, makes it more vulnerable to abrasion. Coarse sediment generally has low cohesion, so when marine energy increases, it is easily transported into the sea. This causes loss of sediment mass and impacts shoreline retreat. According to Arief (2018), beaches dominated by coarse sediment, such as sand and gravel, tend to be more vulnerable to land loss in high-energy environments and when lacking vegetative protection or beach structures. This happens because coarse sediment is non-cohesive, easily lifted and moved when hit by large waves. The sediment fractions at each station vary; this is suspected to be caused by currents and waves, which are the main force factors determining the direction and distribution of sediment and the sedimentation process. This is supported by Siswanto's (2011) opinion, which states that currents and waves influence the distribution of sediment fractions, the main factors determining the direction and distribution of sediment, and the sedimentation process.

4. Conclusions

Based on research, Pantai Tiram over the past 20 years (2003–2023) has experienced significant coastal abrasion, with the rate of shoreline retreat ranging from 2.2 to 3.1 m/year and an RMSE of 0.31 m, indicating a relatively small and acceptable error rate. This shows that satellite imagery, in the long term, is quite accurate in depicting shoreline changes. The sediment type in the Pantai Tiram area is sandy gravel, with a mean particle size of 0.3–0.8 mm. The sediment at this beach can be transported by medium- to high-energy waves and currents. This condition is consistent with Pantai Tiram's characteristics as an open beach facing the Indian Ocean, which naturally receives strong wave impacts throughout the year

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