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Concept of Coastal Abrasion Disaster Risk Management

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Abstract

This study aims to analyze the hydro-oceanographic characteristics, identify the natural and anthropogenic factors causing coastal abrasion, assess the level of abrasion impact, and formulate an appropriate coastal abrasion management concept in the Batauga coastal area, South Buton Regency. A descriptive field-survey approach supported by hydro-oceanographic analysis and qualitative assessment was employed. Primary data were collected through bathymetric measurement, tidal observation, current measurement, field observation, documentation, and semi-structured interviews with relevant stakeholders. Bathymetric data were obtained using a GPS-integrated echosounder, tidal data were analyzed using the least squares method, and current velocity was calculated based on buoy displacement and validated with a digital current meter. The results show that the Batauga coast has a gentle bathymetric profile, allowing wave energy from the Flores Sea to reach the shoreline with limited attenuation. The mixed prevailing semidiurnal tidal pattern expands the active intertidal zone, while longshore currents contribute to sediment transport and sediment imbalance. In addition, illegal sand mining significantly accelerates abrasion by reducing sediment volume and altering seabed morphology. The level of abrasion impact is categorized as high, as indicated by shoreline retreat, seabed degradation, scouring around coastal structures, infrastructure vulnerability, and ecosystem damage. Therefore, a hybrid coastal protection system combining structural measures, non-structural strategies, vegetation rehabilitation, sediment stabilization, and strict control of sand mining activities is recommended for sustainable abrasion management in Batauga.

Introduction

Indonesia's geographical location as an archipelagic nation boasts extensive coastal resources, necessitating sustainable management to ensure sustainable benefits (Susdarwono & Wiranta, 2023; Supriatna & Lenz, 2025; Suherman et al., 2025).

Indonesia's archipelagic nature means that the islands are surrounded by coasts and seas. Ocean waves are influenced by wind, temperature, salinity, and sea depth. The differences between land and sea conditions mean that waves occur day and night. Ocean waves surrounding Indonesia are influenced by currents, wind, and waves, which contribute to abrasion. Abrasion can cause turbidity and landslides on coastal cliffs, which in turn impacts coastal communities (Sugandi, 2016; Andriani et al., 2026).

Indonesia has over 108,000 km of coastline, making it the second longest in the world. Therefore, Indonesia requires special regulations to protect its coastal areas. Coastal areas are the interface between land and sea. These areas are highly dynamic and interconnected, with

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terrestrial and marine ecosystems interacting intensively. These areas are heavily utilized for human activities such as government centers, settlements, industry, ports, fisheries, agriculture, and tourism. In fact, beaches have a dynamic equilibrium, tending to adjust their profile to dissipate the energy of incoming waves. Normal waves are easily destroyed by coastal mechanisms, while large waves or storms with high energy, even if they occur for a short period, will cause erosion. This can occur in two ways: the beach returns to its original state by the normal waves, or material is transported elsewhere and never returns, causing erosion in one location and sedimentation in another (Hakim et al., 2012; Li et al., 2025; Ockelford et al., 2025).

Abrasion is a problem that threatens coastal conditions (Bagindo et al., 2023; Jamilah et al., 2025; Setiadi et al., 2023). It can threaten the shoreline, causing it to retreat, damaging fishponds and rice paddies along the coastline, and also threatening structures directly adjacent to the sea, both those used for tourism and residential purposes. Coastal abrasion is defined as the retreat of the shoreline from its original position (Triatmodjo, 2016). Coastal abrasion can also be caused naturally by the destructive power of ocean waves and ocean currents (Tampubolon, 2022; Kurniadi et al., 2023; Panda et al., 2026). Besides natural factors, abrasion can also be caused by human activities, including sand mining, the construction of artificial structures such as jetties and groins, reclamation parallel to the shoreline, harbor breakwaters, the construction of dams upstream and along river ditches, as well as the extraction of coral reefs and the logging of mangrove forests (Azkiah & Syafani, 2022). Determining the level of coastal change that can be categorized as coastal damage is challenging. Assessing coastal change requires a benchmark to allow for a more objective assessment of the extent of damage. Coastal change should not be viewed momentarily, but rather over a period of time (Jenkins et al., 2026; MM et al., 2026; Bosserelle et al., 2022). Temporary shoreline changes do not necessarily mean the coast is unstable, as the analysis of shoreline change recognizes the dynamic equilibrium of coastal areas. Dynamic equilibrium means that, when viewed over a specific period (for example, one year), the coast does not experience permanent progress or decline.

However, at certain times, the coast may advance or retreat depending on the prevailing season (Munandar & Kusumawati, 2017). The wave phenomena that dominate nearshore water movement are those caused by local winds (wind waves) and long waves or low-frequency waves (low-frequency waves). Waves generated by local winds blowing along the coast transfer their energy to the waves, with the dominant direction of the waves being in accordance with the prevailing wind direction. Waves generated by these local winds are random waves with varying heights and periods. Previous research by Mulyadi (2017) found that determining the level of coastal change that can be categorized as coastal damage is challenging. Assessing coastal change requires a benchmark to allow for more objective assessments of the extent of damage (Setyandito and Triyanto, 2007; Cruz-Ramírez et al., 2024; Agbaje et al., 2024).

South Buton Regency is a regency in Southeast Sulawesi located in a coastal area. South Buton Regency has seven administrative sub-districts, all of which are coastal areas and directly face the Flores Sea, with a total population of 95,261 (BPS, 2021). The danger of extreme waves and abrasion in South Buton Regency is one of the disasters considered a high risk in this area, with a potential area of 7,646 hectares, classified as high. The potential population exposure to wave and abrasion hazards is based on the high number of activities in areas vulnerable to extreme waves and abrasion. The potential population exposure in South Buton Regency reaches 22,273 people and is classified as moderate (National Disaster Risk Assessment of Southeast Sulawesi Province, 2021).

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Batauga District is the regency capital and one of the sub-districts in South Buton Regency, located on the coast. Batauga District, consisting of seven sub-districts and five villages, is prone to extreme weather, forest and land fires, flooding, extreme waves, abrasion, and landslides (Suntoro et al., 2025; Asfian et al., 2025). The South Buton Regency Government considers this a disaster threat, as outlined in the South Buton Regent's Decree No. 129, dated February 23, 2022, concerning the determination of an emergency response status for extreme weather disasters in South Buton Regency. Extreme weather, including waves and abrasion, recurred in December 2022, prompting the South Buton Regency Government to issue Decree No. 605, dated December 23, 2022, for the Batauga coastal area. Several factors contributing to coastal abrasion in Batauga District include erosion caused by rainfall and river currents flowing towards the coast, as well as high sea waves. Furthermore, human activities such as sand mining, port construction, and settlements along the coast can also accelerate coastal abrasion.

Methods

Research Design

This study employed a descriptive field-survey design supported by hydro-oceanographic analysis and qualitative assessment. The approach was used to examine the physical characteristics of the Batauga coastal area, identify the natural and anthropogenic factors contributing to coastal abrasion, assess the level of abrasion impacts, and formulate an appropriate coastal abrasion management concept. The study combined primary data obtained through direct field measurements, field observations, and stakeholder interviews with secondary data from maps, policy documents, previous studies, and relevant coastal disaster reports. This design was considered appropriate because coastal abrasion in Batauga is influenced not only by physical oceanographic processes, such as waves, tides, currents, and bathymetry, but also by human activities, particularly sand mining and coastal infrastructure development.

Research Location

The research was conducted in the coastal area of Batauga, South Buton Regency, Southeast Sulawesi Province. This location was selected purposively because it directly faces the Flores Sea and has experienced recurring abrasion, shoreline retreat, and coastal infrastructure vulnerability. The study area includes coastal zones around Batauga Port and adjacent settlements where abrasion impacts and indications of sand dredging activities were observed. The location also represents an open coastal system with limited natural protection, making it relevant for analyzing hydro-oceanographic dynamics and coastal disaster risk management.

Data Types and Sources

The data used in this study consisted of primary and secondary data. Primary data included bathymetric measurements, tidal observations, ocean current measurements, field documentation of shoreline and coastal morphology, observations of infrastructure and ecosystem damage, and semi-structured interviews with relevant stakeholders. Bathymetric data were collected to describe seabed depth and slope, tidal data were used to determine sea level characteristics, and current data were used to analyze sediment transport mechanisms. Qualitative data were collected to identify anthropogenic pressures, especially illegal sand mining and coastal land-use activities.

Secondary data included regional maps, historical shoreline information, coastal disaster documents, government regulations, previous research, and supporting literature related to

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coastal abrasion, hydro-oceanography, and coastal protection strategies. These data were used to strengthen the interpretation of field findings and compare Batauga's coastal condition with other coastal areas in Southeast Sulawesi.

Data Collection Techniques

Data collection was carried out through several techniques. First, a hydro-oceanographic field survey was conducted to measure bathymetry, tides, and ocean currents. Bathymetric measurements were performed using a GPS-integrated echosounder along survey tracks arranged perpendicular to the shoreline. This method was used to obtain a representative cross-sectional profile from offshore areas toward the coast. The depth data were corrected using tidal observations so that all measurements referred to the same vertical datum, particularly the Lowest Low Water Level.

Second, tidal observations were conducted using a tide staff or peilschaal during the observation period. The tidal data were used to calculate the main tidal parameters, including Mean Sea Level, Highest High Water Level, and Lowest Low Water Level. These parameters were required to understand sea level fluctuation, the width of the intertidal zone, and the potential interaction between waves and coastal land.

Third, current measurements were carried out using buoy tracking and a digital current meter. Buoy measurements were conducted at selected points during flood and ebb conditions by recording the initial and final coordinates and the travel time of the buoy. Current meter measurements were used as validation data to confirm current velocity at different depths. These data were then used to determine current direction, current velocity, and the potential role of longshore currents in sediment transport.

Fourth, field observations were conducted to document physical indicators of abrasion, such as shoreline retreat, sediment loss, scouring around coastal structures, seabed morphological changes, and damage to infrastructure or coastal ecosystems. Observations were also used to identify the presence of anthropogenic activities, particularly sand dredging or illegal sand mining, that may contribute to sediment imbalance.

Fifth, semi-structured interviews were conducted with selected stakeholders, including local government representatives, coastal community members, fishermen, and technical or environmental informants who had knowledge of coastal conditions in Batauga. The interviews focused on the history of abrasion, observed shoreline changes, sand mining activities, infrastructure damage, community impacts, and existing or proposed mitigation efforts.

Data Analysis

The data were analyzed using descriptive hydro-oceanographic analysis and qualitative interpretation. Bathymetric data were corrected to the tidal datum and processed to produce seabed profiles and depth contours. The corrected data were interpolated using mapping and engineering software to identify seabed slope, shallow-water zones, local depressions, and morphological patterns that influence wave propagation and current movement.

Tidal data were analyzed using the least squares method to determine tidal harmonic constants and the main tidal parameters, namely Mean Sea Level, Highest High Water Level, and Lowest Low Water Level. The tidal type and tidal range were then interpreted to assess their contribution to abrasion intensity, especially through repeated wetting and drying cycles in the intertidal zone.

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Ocean current data were analyzed by calculating buoy displacement and dividing the displacement distance by observation time to obtain instantaneous current velocity. The results were compared with current meter measurements to validate current speed and direction. The analysis focused on identifying flood and ebb current patterns, longshore current characteristics, and their role in sediment transport and seabed scouring.

Wave characteristics were analyzed descriptively based on field conditions, coastal exposure to the Flores Sea, fetch direction, bathymetric slope, and the interaction between waves and currents. The analysis emphasized how wave energy reaches the shoreline, how breaking waves interact with the coast, and how wave direction contributes to the formation of longshore currents.

The level of abrasion impact was assessed by integrating physical indicators observed in the field, including shoreline retreat, reduction of sediment volume, seabed morphological degradation, scouring near port structures, infrastructure vulnerability, ecosystem degradation, and the influence of sand dredging activities. The impact level was categorized descriptively based on the intensity and extent of these indicators.

Qualitative interview data and field documentation were analyzed through thematic interpretation. The themes included natural abrasion drivers, anthropogenic pressures, sand mining activities, infrastructure and ecosystem vulnerability, community impacts, and mitigation needs. The findings from interviews were compared with hydro-oceanographic data to ensure consistency between physical evidence and stakeholder information.

The coastal abrasion management concept was formulated by synthesizing the results of bathymetric, tidal, current, wave, impact, and anthropogenic analyses. The proposed mitigation approach considered both structural measures, such as breakwaters, revetments, and seawalls, and non-structural measures, such as sediment stabilization, mangrove rehabilitation, sand mining control, and community-based coastal management.

Results and Discussion

Hydro-Oceanographic Condition Analysis

The hydro-oceanographic data used in this study are data obtained from field surveys in the Batauga area, including bathymetry, currents, and tides, which were used to analyze coastal abrasion dynamics. Bathymetry is one of the main parameters in hydro-oceanographic studies, describing the depth and shape of the seabed. Based on the hydro-oceanographic survey in Batauga, bathymetric measurements were conducted using a sounding method with the aid of an echosounder integrated with a GPS system to obtain depth data simultaneously and accurately. This method allows for detailed information on the morphology of the waterbed, which is crucial for analyzing coastal dynamics. Bathymetric measurements in the Batauga area indicate that the water depth in the study area ranges from +1.0 meters to -5.5 meters relative to the LLWL (Lowest Low Water Level) datum. This depth range indicates that the surrounding waters are classified as shallow to moderate, which has significant implications for wave-shore interaction processes. This relatively shallow depth distribution indicates that ocean waves from open waters do not experience significant energy attenuation before reaching the shoreline. This is due to the absence of drastic changes in depth that could gradually disperse wave energy. Thus, wave energy tends to remain strong upon reaching the shore. Furthermore, the results of interpolated bathymetric data processed using software such as Surfer and AutoCAD Civil 3D indicate that the seafloor contour has a relatively gentle slope. This gentle slope of the seafloor plays an important role in determining the wave-breaking zone, which tends to occur close to the shoreline. This gentle bathymetry also contributes to

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the concentration of wave energy in coastal areas. When waves break near the shore, the released energy directly interacts with coastal sediments, increasing the potential for abrasion. Based on the coordinates of bathymetric measurement points in the field, significant depth variations are observed over relatively short distances. This variation indicates that, despite the general gentle slope, some parts of the seafloor experience local elevation changes, which can affect current patterns and sediment distribution.

Furthermore, it was discovered that these local depth variations were not only caused by natural sediment transport processes but also by anthropogenic activities such as illegal sand mining in the coastal area of Bandar Batauga. This uncontrolled dredging activity created artificial depressions on the seafloor, significantly altering the original bathymetric contours of the waters. These excavation pits resulted in irregular depth patterns, potentially altering the direction of wave propagation and creating local current turbulence that accelerated seafloor scouring in the surrounding area. The bathymetric measurements were conducted using sounding trajectories designed perpendicular to the coastline. This aimed to obtain a more representative cross-sectional profile of the seafloor. This method allowed for systematic analysis of depth changes from seaward toward the coast. Furthermore, the bathymetric data obtained were corrected for sea level fluctuations measured using a peilschaal during the observation period. This correction was essential to ensure that the depth data used were based on the same datum, namely LLWL, so that they could be compared consistently. In the context of coastal dynamics, the bathymetric conditions in Batauga significantly influence the formation of longshore currents. The gentle slope of the seabed allows waves to arrive at a specific angle, resulting in a longshore current component that plays a role in sediment transport. Sediment transport resulting from the interaction between waves and currents can cause an imbalance in the distribution of coastal material. Under certain conditions, more sediment is carried away from a location than is deposited, leading to abrasion.

Furthermore, survey results indicate that the land contour around the coastal area has an average elevation above +2.0 meters above sea level. This difference in elevation between the land and the seabed is relatively small, thus increasing the area's vulnerability to abrasion and inundation. From a geomorphological perspective, these bathymetric conditions indicate that the Batauga area is classified as a gentle slope coast. This type of coastline is generally characterized by high wave energy in the nearshore zone and a relatively rapid rate of shoreline change. Overall, the bathymetric conditions in Batauga indicate that the area is quite susceptible to abrasion. This is due to the combination of shallow water depths, a gentle seabed slope, and the absence of natural structures that can dampen wave energy. Thus, it can be concluded that bathymetry in the Batauga region plays a very important role in controlling hydrooceanographic dynamics, especially in the process of wave propagation, current formation, and sediment transport which ultimately contribute to coastal abrasion.

Tidal Analysis

During the research process, tidal analysis was conducted using the main parameters, namely Mean Sea Level (MSL), Highest High Water Level (HHWL), and Lowest Low Water Level (LLWL). These parameters are used to identify sea level dynamics and determine critical boundaries for interactions between the sea and land. Conceptually, HHWL is the maximum sea level elevation, while LLWL is the minimum elevation occurring during the observation period. MSL is used as a reference datum for mean sea level, which serves as a reference in hydro-oceanographic analysis (Mutaqin & Ningsih, 2023; Saraswati et al., 2021).

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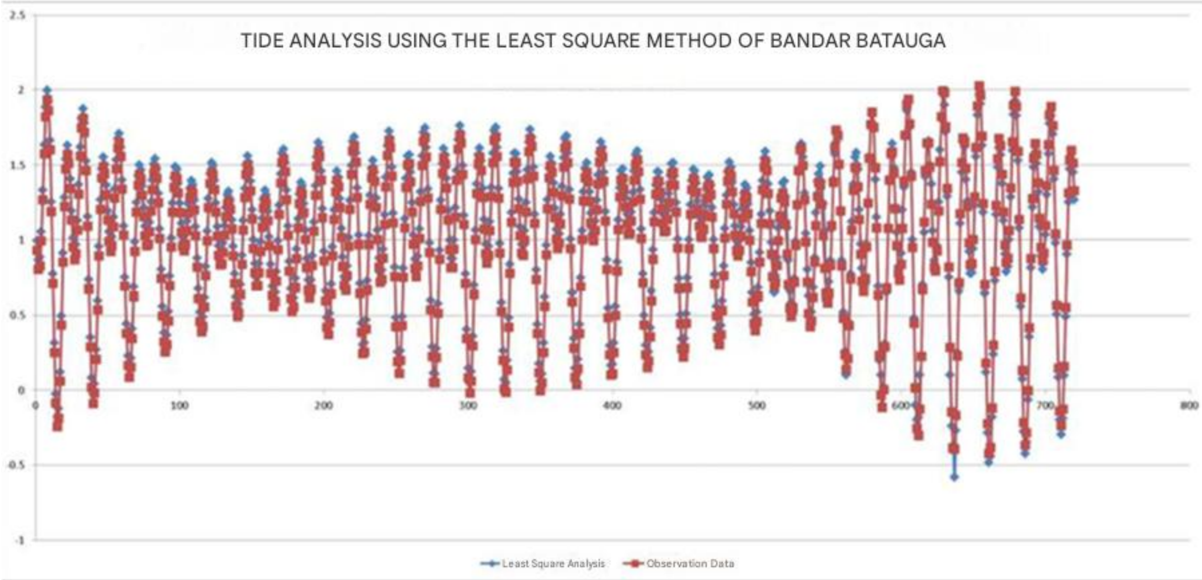

Figure 1. Tidal Analysis Graph Using the Least Squares Method

From tidal forecasting using the Least Squares method, the tidal harmonic constants can be determined, including the following.

Table 1. Tidal Harmonic Constants

	So	M2	S2	N2	K2	K1	O1	P1	M4	MS4
AMPLITUDO (m)	1.0397	0.5105	0.1596	0.1224	0.0416	0.3325	0.2196	0.1572	0.0022	0.0032
Fasa		8.34	-38.7	77.9	-89.51	29.78	-64.25	-87.81	52.53	-71.08

The graph shows the agreement between the observational data and the analysis results, indicating that the least squares method is quite representative in describing the tidal characteristics in the study area. Based on the analysis, the tidal range in the Batauga area is quite large. This indicates that sea level fluctuations have significant amplitude, resulting in a large intertidal zone. This zone is an active area that periodically experiences submersion and drying, making it the most vulnerable to abrasion. At maximum tide (HHWL), the sea level reaches its highest elevation and has the potential to overtopping, especially in low-elevation areas. This condition causes coastal material to become water-saturated, which reduces the cohesive strength of the sediment and accelerates erosion. This phenomenon was also found in a study in Southeast Sulawesi, where maximum tide conditions caused inundation in low-elevation coastal areas, accelerating erosion and coastal abrasion (Trihatmanto et al., 2025). Furthermore, the mixed-prevailing semidiurnal tidal type in Batauga indicates that there are two high tides and two low tides per day. This frequency causes the coastline to experience repeated wetting and drying cycles, which mechanically accelerates the weathering of coastal materials.

Compared to other areas in Southeast Sulawesi, such as Kendari Bay, tidal patterns are relatively similar, but with a smaller range. This results in a narrower intertidal zone in Kendari, limiting wave interaction with the land (Fanela, N. et al. (2013). Conversely, in Batauga, the greater tidal range results in a larger coastal area exposed to wave energy. In the Wakatobi and South Konawe regions, despite having similar tidal characteristics, abrasion rates are lower due

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to natural protection in the form of coral reefs and mangrove vegetation. These natural structures are able to dampen wave energy and reduce the impact of maximum tides on the land. In contrast, the Batauga region lacks adequate natural protection, so seawater energy during high tides directly interacts with the shoreline. This increases the intensity of abrasion, especially in areas with elevations close to or below the high tide. Therefore, based on a descriptive analysis approach to field data, it can be concluded that tides in the Batauga region are a major factor controlling abrasion dynamics. This is due to a combination of a large tidal range, high tide frequency, and the dredging of coastal material in gently sloping coastal geomorphology. and open.

Ocean Current Analysis

Ocean currents are a key parameter in hydro-oceanographic studies, playing a crucial role in controlling coastal dynamics, particularly in sediment transport and shoreline changes. In the context of this research, ocean current analysis was conducted based on field research results, including current speed and direction at several observation points around the Batauga Port area. Based on field measurements, ocean currents in the Batauga area exhibit patterns influenced by a combination of tides and waves. Under certain conditions, currents move parallel to the shoreline (longshore currents), formed by the angle of wave incidence relative to the shoreline. This phenomenon is a common mechanism in open coastal areas, where wave energy is transformed into lateral water mass movement along the coast. The presence of longshore currents in Batauga has direct implications for sediment transport. Sediment dislodged by wave energy is carried by these currents to other locations, causing an imbalance in the distribution of coastal material. This condition is a major cause of abrasion in certain areas, particularly in zones experiencing a sediment supply deficit.

Table 2. Data on current measurements in Batauga waters using buoys

Name	X (m)	Y (m)	Time (s)
Point 02 Ebb Start	689054.459	9074571.435	600
Point 02 Ebb End	689061.962	9074473.407	—
Point 01 Ebb Start	689174.028	9074307.124	600
Point 01 Ebb End	689183.585	9074301.220	—
Point 02 Flood Start	688977.099	9074487.271	900
Point 02 Flood End	688941.022	9074423.279	—
Point 01 Flood Start	689070.311	9074266.321	900
Point 01 Flood End	689073.073	9074192.426	—

Source: Field Survey

As validation material, current measurements were also taken using a digital current meter while observing the current using the buoy. The measurement results are shown in the following table:

Table 3. Data on Batauga water current measurements using a Current Meter

Condition	Coordinates (X - Y)	Max Velocity Recorded (m/s)	Depth (m)
Flood (Point 1)	689073.0727 - 9074192.426	0.1	0.5
Flood (Point 1)	689073.0727 - 9074192.427	0.1	1.0
Ebb (Point 2)	689061.9623 - 9074473.407	0.2	0.5
Ebb (Point 2)	689061.9623 - 9074473.408	0.1	1.0

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Source: Field Survey

By calculating the buoy displacement using the following equation:

$Perpindahan = 2\sqrt{(X2 - X1)2 + (Y2 - Y1)2}$

And calculating the velocity using the following formula: $Kecepatan\ arus = Perpindahan$ $waktu$

Then the instantaneous current velocity at the highest tide and The lowest tide can be seen in the following table:

Table 4. Observations of Instantaneous Currents in Batauga Waters

Name	X (m)	Y (m)	Time (s)	Distance (m)	Velocity (m/s)
Point 02 Ebb Start	689054.459	9074571.435	600	98.31471	0.164
Point 02 Ebb End	689061.962	9074473.407	—	—	—
Point 01 Ebb Start	689174.028	9074307.124	600	11.23359	0.019
Point 01 Ebb End	689183.585	9074301.220	—	—	—
Point 02 Flood Start	688977.099	9074487.271	900	73.46105	0.082
Point 02 Flood End	688941.022	9074423.279	—	—	—
Point 01 Flood Start	689070.311	9074266.321	900	73.94659	0.082
Point 01 Flood End	689073.073	9074192.426	—	—	—

Table 5. Summary of Current Velocity Characteristics in Batauga Waters

Description	Value (m/s)
Average Flood Current Velocity	0.082
Average Ebb Current Velocity	0.091
Maximum Flood Current Velocity	0.082
Maximum Ebb Current Velocity	0.164
Highest Current Velocity Recorded	0.164

The analysis shows that current speeds in the Batauga coastal area are significant, especially during peak and low tide conditions. During high tide, currents tend to move inland, while during low tide, they move back toward the open sea. This cycle causes repeated sediment mobilization, which, in the long term, accelerates changes in coastal morphology.

Furthermore, the interaction between currents and the gentle bathymetry in the Batauga area results in a more even distribution of current energy along the waters. The slight slope of the seabed allows currents to move without significant resistance, increasing their capacity to transport sediment. This condition reinforces the role of currents as a primary agent in the abrasion process. In relation to waves, ocean currents in Batauga do not exist in isolation but are the result of the transformation of wave energy coming from the open ocean. Waves arriving at a certain angle will produce a force component parallel to the shoreline, which then forms a longshore current. This aligns with research stating that longshore currents are formed by the interaction between waves arriving at a certain angle to the shoreline and the morphology of the seabed, which in turn plays a role in sediment transport and accelerates abrasion

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(Darmiati, 2013). Furthermore, research in the Wakatobi region shows that longshore currents play a dominant role in sediment redistribution, particularly on beaches lacking natural protection (Rasma et al., 2025). This situation is similar to the Batauga region, where limited protective vegetation causes ocean currents to act directly on coastal material. Ocean currents also play a role in the process of seafloor scouring. Based on field observations, indications of scouring are visible in local depth changes around the construction area. This indicates that currents have the ability to intensively transport bottom sediment. This condition is exacerbated by the presence of holes from illegal sand mining found in the field. These holes create abrupt changes in the seafloor profile, triggering local turbulent currents. Furthermore, the uneven current pattern along the coastline results in the formation of erosion and deposition zones. In certain areas, currents carry sediment away from the coast, resulting in abrasion, while in other areas, sediment buildup (accretion) occurs. This pattern reflects unbalanced coastal dynamics. On a temporal scale, current variations are also influenced by the wind season. During the easterly wind season, current speeds tend to increase due to increased wave energy from the open ocean. This condition increases the current's capacity to transport sediment and increases the potential for abrasion in the Batauga coastal area. Compared to other areas in Southeast Sulawesi, such as Kendari Bay, ocean currents tend to be weaker due to the more enclosed waters. This causes sediment transport to occur more slowly than in Batauga, which is a coastal area. Open waters. In the South Konawe region, the presence of mangrove vegetation has been shown to reduce current speed in the coastal zone, thereby reducing the intensity of abrasion (H Halim, 2016). This contrasts with the situation in Batauga, which lacks adequate natural protection, allowing ocean currents to function optimally in transporting sediment.

Other research in Wakatobi also shows that the interaction between currents and coral reef ecosystems can dampen current energy before it reaches the coast (Imran, 2024). This situation is not found in Batauga, allowing current energy to remain high until it reaches the shoreline. Furthermore, a study by Supiyati et al. (2024) showed that the combination of longshore currents and waves is a major factor in shoreline change in coastal areas of Indonesia. This confirms that ocean currents in Batauga play a significant role in the abrasion process. In the context of this research, ocean currents serve not only as supporting parameters but also as a key factor in explaining the abrasion mechanism. Currents act as a medium for sediment transport, linking wave energy to physical changes in the shoreline. The interaction between currents, waves, and tides forms an interconnected dynamic system. When these three factors work together, the intensity of abrasion increases significantly, especially in areas with vulnerable geomorphological conditions. Therefore, based on the results of this study, supported by comparative studies, it can be concluded that ocean currents in the Batauga region contribute significantly to the abrasion process, primarily through sediment transport and seafloor erosion.

Wave Characteristics

Wave characteristics are key parameters in hydrooceanographic studies, playing a role in controlling coastal dynamics, particularly the abrasion process. The parameters used include wave height and wave period, which determine the amount of wave energy reaching the coast. Based on research in the Batauga region, waves developing in these waters are influenced by open ocean conditions (the Flores Sea) with a relatively long fetch. These conditions cause waves to have considerable energy when they reach the shoreline, thus having a high potential to trigger abrasion. Regionally, this condition aligns with coastal characteristics in several areas of Southeast Sulawesi that face the open ocean. Research in Wakatobi waters indicates that

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ocean waves originating from open waters have relatively high energy and play a role in coastal sediment dynamics, especially in areas unprotected by natural ecosystems (Kasim, 2020).

Furthermore, research in the Kendari region and its surroundings shows that the interaction between waves and ocean currents produces quite strong turbulence, which contributes to sediment transport and changes in seafloor morphology (Jansit et al., 2024). This confirms that wave energy acts not only directly on the coast but also through longshore currents. The direction of wave arrival in the Batauga region is not perpendicular to the shoreline, resulting in an uneven distribution of wave energy. This condition triggers the formation of longshore currents, which play a role in moving sediment along the shoreline. This phenomenon is also found in other coastal areas of Southeast Sulawesi, where waves with specific angles of arrival produce significant lateral sediment transport (Pribawastuti et al., 2024). The relatively gentle bathymetry in the Batauga area prevents waves from experiencing significant energy attenuation before reaching the coast. As a result, breaking waves occur very close to the shoreline, concentrating wave energy directly on the coastal zone. This condition is similar to the characteristics of open beaches in Southeast Sulawesi, which tend to have high wave energy levels and are susceptible to abrasion (Kurnia & Hakim, 2021).

Furthermore, waves also play a role in stirring up bottom sediments, which are then carried by ocean currents, causing an imbalance in the sediment balance. Over the long term, this condition leads to a sediment deficit in some coastal areas, a key indicator of abrasion. The interaction between waves and tides also amplifies the intensity of abrasion, particularly during high tides (HHWL), when waves can reach higher land areas. This condition causes abrasion not only to the coastline but also to deeper inland areas. Unlike areas like Wakatobi, which have natural protection in the form of coral reefs and other coastal ecosystems, the Batauga area has limited natural protective structures. This causes waves to directly impact the coast without experiencing significant energy reduction, thus increasing the intensity of abrasion. Therefore, based on the analysis of this research, supported by comparative studies in Southeast Sulawesi, it can be concluded that wave characteristics in Batauga play a dominant role in the abrasion process. This is influenced by the high wave energy from the open ocean, the direction of wave arrival, the gentle bathymetry, and the lack of natural protection in the coastal area.

Identification of Factors Causing Abrasion in Batauga

Coastal abrasion in the Batauga region is the result of a complex interaction between hydro-oceanographic parameters, including waves, ocean currents, tides, and indications of sea level rise. Based on hydro-oceanographic research, these four parameters operate simultaneously in a dynamic system that controls shoreline changes both spatially and temporally. This interaction pattern aligns with the characteristics of abrasion in coastal areas of Southeast Sulawesi, which is generally controlled by a combination of primary oceanographic factors such as waves, currents, and tides (Harisma et al., 2023). Wave energy plays a primary role in the abrasion process. The area's location directly facing the Flores Sea results in the formation of waves with relatively high energy due to the long fetch. The bathymetry, which tends to be gentle to steep near the coastline, prevents waves from experiencing significant energy dissipation before breaking. Consequently, wave energy is released directly in the coastal zone, triggering the release of sediment particles from the beach body. This condition is similar to research findings in the Wakatobi region, which showed that exposed beaches exposed to high waves experience more intense abrasion (Rasma et al., 2025).

The released sediment is then transported by ocean currents, particularly longshore currents. These currents are formed by the angle of wave incidence relative to the shoreline and serve as a mechanism for sediment distribution along the coast. An imbalance between transported and

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deposited sediment causes sediment deficits in certain locations, which then develop into abrasion. The interaction between waves and currents indicates a coupled process, where waves act as an energy source, while currents serve as a medium for sediment transport. This mechanism was also found to be a dominant factor in shoreline change in the Konawe coastal area (Harisma et al., 2023). Tides contribute to expanding the extent and intensity of abrasion. The mixed tidal type with a semidiurnal tendency results in a significant sea level range, resulting in a wide and active intertidal zone. At maximum tides, waves are able to reach higher land areas, increasing the intensity of erosion in previously relatively stable zones. Conversely, during low tide, backwash carries the weakened sediment back to the sea, creating a recurring dual erosion mechanism. This pattern is consistent with research showing that tidal fluctuations play a role in accelerating shoreline degradation (Purwanti & Koestoer, 2024).

Furthermore, tidal dynamics also influence ocean current speed. Increased current speed during the maximum high and low tide phases increases sediment transport capacity, accelerating the redistribution of coastal material. This reinforces the role of currents as a primary agent in reducing sediment volume in the coastal zone, as observed in studies of coastal stability in the coastal areas of Southeast Sulawesi (Awaluddin et al., 2024). Indications of sea level rise also amplify the intensity of abrasion by increasing the water surface elevation relative to the land. This allows waves with greater energy to reach the shoreline without breaking prematurely. Furthermore, sea level rise contributes to the gradual shift of the shoreline inland, especially in areas with gentle coastal topography. This impact demonstrates that small changes in sea level can significantly expand the area affected by abrasion, as explained in a study of shoreline dynamics in coastal areas of Indonesia (Setyawan et al., 2019).

Overall, abrasion in the Batauga region is the result of a systemic interaction between wave energy, sediment transport mechanisms by currents, sea level fluctuations due to tides, and the influence of sea level rise. Waves act as triggers for sediment release, currents transport material, tides control the intensity and extent of the process, and sea level rise acts as a long-term reinforcing factor. The interaction of these four parameters causes an imbalance in the coastal system, which has implications for shoreline instability and accelerated abrasion.

Anthropogenic (Human) Factors

In addition to the variables formulated in the study, field observations indicate an additional factor, sand dredging, that contributes to abrasion dynamics. Based on the results of this study, the primary anthropogenic factor causing physical damage to the beach is illegal sea sand mining in the Batauga area. Field observations indicate that the exploitation of this beach material is carried out using heavy equipment, such as excavators, to dredge large volumes of sand. This activity directly destroys the natural profile of the beach and disrupts the sediment balance in the area. Based on information from local authorities and media reports, this dredging practice has caused significant morphological degradation, with the land losing its natural protection against wave impacts. The specific impacts of illegal mining activities on abrasion in Batauga include:

Loss of Natural Protection

Dredging of coastal sand results in the loss of sandbars that act as natural wave breakers. As a result, waves from the Flores Sea can reach the shoreline with full force, accelerating land erosion and shoreline retreat.

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Changes in Seabed Structure

The use of excavators creates irregular depressions or pits on the seabed. This alters local bathymetry, triggering turbulent currents. These turbulent currents have greater scouring power than normal currents, accelerating the transport of coastal material to the open sea.

Sediment Transport Imbalance

Mechanical sand mining removes material that should be part of the natural sediment transport cycle. With the loss of large amounts of sediment, coastal areas lose their ability to recover (natural recovery), resulting in permanent and ongoing erosion.

This condition is exacerbated by the lack of protective vegetation around mining areas. Without vegetation roots to bind the soil, coastal material disturbed by heavy equipment becomes highly unstable and easily eroded, even by medium-sized wave energy.

In this context, anthropogenic factors, such as illegal mining, play a key role in accelerating the rate of coastal damage in Batauga. The interaction between dynamic ocean energy and the forced removal of coastal material by humans causes the abrasion process in this area to become very massive and threatens the existence of infrastructure and the living space of coastal communities in the future.

Analysis of the Impact Level of Abrasion Disasters

Coastal abrasion in the Batauga region is the result of complex interactions between hydro-oceanographic parameters, including waves, ocean currents, tides, and indications of sea level rise. Based on field survey results, these four parameters operate simultaneously in a dynamic system that controls shoreline changes both spatially and temporally. This interaction pattern indicates that coastal dynamics in the study area are unstable, especially in exposed coastal areas lacking natural protection.

Wave energy plays a primary role in the abrasion process. The geographic location directly facing the Flores Sea results in the formation of waves with relatively high energy due to their long fetch. The bathymetry, which tends to be gentle to steep near the coastline, prevents waves from dissipating significantly before breaking. As a result, wave energy is released directly into the coastal zone, triggering the release of sediment particles from the beach body. This finding aligns with the findings of Rachmat and Noviadi (2016) on the coast of Lasolo Bay, Southeast Sulawesi, which showed that waves are a dominant factor in the coastal abrasion process.

The released sedimentary material is then transported by ocean currents, particularly longshore currents. These currents are formed by the angle of wave incidence relative to the shoreline and serve as a mechanism for sediment distribution along the coast. An imbalance between transported and deposited sediment causes a sediment deficit in certain locations, which then develops into abrasion. This mechanism demonstrates a coupling process between waves and currents, as explained in research by Harisma et al. (2023) in the Konawe region, which states that wave-current interaction is a dominant factor in shoreline change.

Tides play a role in expanding the reach and intensity of abrasion. The mixed tidal type with a semidiurnal tendency produces a significant sea level range, making the intertidal zone expansive and dynamically active. At maximum tides, waves can reach higher land areas and increase the intensity of erosion in previously relatively stable zones. Conversely, at low tides, backwash carries weakened sediment back to the sea, creating a repeating erosion mechanism. This phenomenon aligns with the research findings of Yudhicara and Yossy (2016), which stated that the interaction of tides and waves accelerates the process of coastal degradation[3].

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Furthermore, tidal dynamics also influence ocean current speed. Increased current speed during the maximum high and low tide phases increases sediment transport capacity, thereby accelerating the redistribution of coastal material. This condition reinforces the role of currents as a primary agent in reducing sediment volume in coastal zones, as found in research by Surya et al. (2025) on the coast of Bombana, Southeast Sulawesi.

Indications of sea level rise also amplify the intensity of abrasion by increasing the water surface elevation relative to the land. This condition allows waves with greater energy to reach the coastline without breaking prematurely, causing a gradual shift of the shoreline inland. This impact is particularly significant in areas with gentle coastal topography, where small changes in sea level can significantly expand the area affected by abrasion, as explained by Karim and Muhammad (2018) in their study of coastal dynamics in coastal areas of Indonesia[5]. In addition to hydro-oceanographic factors, anthropogenic activities such as sand mining are suspected to have exacerbated the level of abrasion in the study area.

This activity contributes to a significant reduction in sediment volume, thus accelerating the sediment deficit in the coastal zone. Furthermore, the extraction of seabed material can cause changes in bathymetric morphology in the form of basins, which have the potential to increase current turbulence and intensify scouring processes around the coastline. This situation indicates that the interaction between natural factors and human activities is a primary driver of the ongoing increase in abrasion intensity.

Overall, the interaction between waves, ocean currents, tides, and sea level rise forms an integrated hydro-oceanographic dynamic system. Within this system, sediment release and transport occur continuously, resulting in an imbalance in the sediment balance and ultimately coastline retreat. Geomorphological indicators such as reduced sediment volume, changes in seabed morphology, and indications of scouring around coastal structures indicate that the abrasion process is ongoing and intensive.

Based on these conditions, the level of abrasion impact in the Batauga area can be categorized as high. This classification is based on the presence of significant physical changes in the coast, including shoreline retreat, seabed morphological degradation, and reduced sediment volume due to sand dredging activities in coastal areas. These activities accelerate the imbalance in the sediment balance and continuously strengthen the abrasion process. This finding is consistent with the research of Rasma et al. (2025) in Wakatobi, which showed that exposed coastal areas without natural protection tend to experience high-intensity abrasion due to the dominance of wave energy and ocean currents[6], and the research of Mappatoba et al. (2024), which confirmed that high-energy wave characteristics contribute significantly to accelerated coastal abrasion.

In addition to impacting geomorphological aspects, abrasion also has environmental and socioeconomic implications. The gradual loss of sediment causes a reduction in coastal land area, potentially disrupting community activities, particularly in the marine and fisheries sectors. This indicates that abrasion in the Batauga region is not only a physical phenomenon but also has multidimensional impacts that require integrated management.

Rate of Shoreline Change

A comparison of historical shoreline conditions with existing conditions during the 2021 survey indicates a trend of shoreline retreat in the Batauga area. Historically, the shoreline tended to advance seaward with relatively stable sediment distribution. However, in 2021, erosion was identified in the coastal zone, characterized by a reduction in sediment material and changes in coastal morphology, becoming steeper in several areas. This finding aligns with

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research by Rachmat and Noviadi (2016), which showed that changes in coastal morphology are a primary indicator of abrasion.

These changes indicate a landward shift in the shoreline due to an imbalance in the sediment balance. Compared to previous conditions, the coastal system in 2021 exhibited a stronger dominance of abrasion processes, influenced by increased sediment transport by longshore currents. This finding is also supported by research by Harisma et al. (2023), which stated that sediment imbalance is a primary factor in shoreline change in the coastal areas of Southeast Sulawesi.

Furthermore, areas facing the open sea experienced more significant shoreline retreat than relatively protected areas. This pattern is consistent with research by Rasma et al. (2025), which showed that exposed coasts experience higher rates of abrasion than protected coasts. The findings regarding shoreline retreat in Batauga align with various studies in Southeast Sulawesi, which have similar coastal characteristics.

Research by Harisma et al. (2023) on the Konawe coast showed that the rate of shoreline change was dominated by abrasion processes due to the interaction of waves and longshore currents, which resulted in uneven sediment distribution.1 This condition aligns with Batauga, where sediment transport mechanisms are the primary factor in shoreline change.

Furthermore, a study by Rachmat and Noviadi (2016) in Lasolo Bay identified that exposed coastal areas with high wave exposure experienced significant shoreline retreat over a certain time period. This is consistent with Batauga's direct exposure to the Flores Sea, which therefore receives relatively high wave energy.

Another study by Mappatoba et al. (2024) showed that high-energy wave characteristics directly contribute to increased coastal erosion rates, especially in areas without natural protection.[3] This finding strengthens the interpretation that the lack of protective vegetation in Batauga is a factor accelerating shoreline change.

Furthermore, Rasma et al. (2025) in a study in Wakatobi stated that beaches with gentle morphology tend to experience faster shoreline shifts due to a combination of sea level rise and wave dynamics.[4] This characteristic is identical to the relatively gentle coastal geomorphology of Batauga.

Furthermore, research by Ashad and Mas'ud (2024) in Kolaka showed that shoreline changes correlate with damage to coastal infrastructure due to progressive abrasion.[5] This is relevant to the potential impacts in Batauga, particularly on port facilities and coastal areas. A comparison of historical shoreline conditions with those in 2021 in Batauga shows a landward retreat of the shoreline, characterized by reduced sediment and changes in coastal morphology, indicating the dominance of abrasion processes. This finding aligns with the research by Harisma et al. (2023) in Konawe, Rasma et al. (2025) in Wakatobi, and Halim and Halili (2016) in Soropia, all of which showed that open coastal areas in Southeast Sulawesi are prone to abrasion due to the influence of waves and currents, thus confirming that the pattern of shoreline change in Batauga is consistent with regional characteristics and is included in the high vulnerability category. In addition to these natural factors, anthropogenic activities such as sand dredging in coastal areas are suspected to accelerate shoreline retreat by directly reducing sediment volume. This condition has the potential to strengthen the imbalance in the sediment balance, thereby accelerating the dominance of the abrasion process in the study area.

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Infrastructure and Ecosystem Damage Assessment

The assessment of infrastructure and ecosystem damage in the Batauga coastal area indicates that abrasion has had a significant impact on the coastal area, particularly in areas adjacent to human activities such as settlements and port facilities. Based on the results of the hydro-oceanographic survey in this study, early indications of damage are shown by a reduction in beach width and erosion in coastal zones adjacent to key infrastructure. This condition directly affects residential areas located near the coastline. Several areas show buildings moving closer to the sea due to shoreline retreat. This phenomenon indicates increasing physical pressure on building structures, especially in areas with low elevations and without natural protection. Furthermore, public facilities such as the Batauga Port also show signs of being affected by abrasion. Observations indicate signs of scouring around port structures, which has the potential to reduce the long-term stability of the structures. This condition aligns with the findings of Purwanti and Koestoer (2024), who stated that port infrastructure is highly vulnerable to shoreline changes due to wave and current dynamics.

From an ecosystem perspective, abrasion also causes coastal environmental degradation, especially in areas lacking protective vegetation such as mangroves. This loss of vegetation accelerates erosion due to the lack of natural barriers against wave energy. A similar finding was found in research by Suleman and Bur (2023), which stated that coastal ecosystem damage increases the region's vulnerability to abrasion. Furthermore, productive land around the Batauga coast is also under pressure from abrasion. Soil erosion reduces the area of land available for community use, both for fishing and other coastal businesses. This impact demonstrates that abrasion is not only physical but also impacts the community's economy. From a coastal dynamics perspective, the damage is the result of the continuous interaction between waves, currents, and tides. This combination of factors accelerates the release and transport of sediment, increasing the potential for damage to infrastructure and coastal ecosystems. Comparatively, conditions in Batauga are similar to other coastal areas in Southeast Sulawesi. Research by Awaluddin, Takwir, and Bahdad (2024) shows that the port area in Mawasangka is experiencing a decline in coastal stability due to abrasion triggered by similar hydro-oceanographic dynamics.

Furthermore, a study by Irfan, Lestari, and Imran (2024) also shows that port development and activities can exacerbate abrasion if not balanced by an adequate coastal protection system. This is relevant to the conditions in Batauga, where pressure on the port area continues to increase in line with coastal dynamics. Another study by Harisma et al. (2023) confirms that sediment imbalance due to longshore currents is a major factor in coastal damage in Southeast Sulawesi. This situation strengthens the interpretation that the damage in Batauga is not merely a local phenomenon, but part of a regional pattern.

Conclusion

This study used a descriptive field-survey approach supported by hydro-oceanographic analysis and qualitative assessment. The research was conducted in the coastal area of Batauga, South Buton Regency, Southeast Sulawesi Province, which was selected because it directly faces the Flores Sea and has experienced coastal abrasion, shoreline retreat, and infrastructure vulnerability. Primary data were collected through bathymetric measurement, tidal observation, current measurement, field observation, documentation, and semi-structured interviews with relevant stakeholders. Bathymetric data were obtained using a GPS-integrated echosounder along survey tracks perpendicular to the shoreline, while tidal data were collected using a tide staff and analyzed to determine Mean Sea Level, Highest High Water Level, and

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Lowest Low Water Level. Current data were measured using buoy tracking and validated with a digital current meter during flood and ebb conditions.

Field observations were conducted to identify physical indicators of abrasion, including shoreline retreat, sediment loss, seabed morphological changes, scouring around coastal structures, infrastructure vulnerability, ecosystem degradation, and illegal sand mining activities. Secondary data were obtained from maps, government documents, previous studies, and relevant literature on coastal abrasion and hydro-oceanographic conditions. The data were analyzed descriptively by interpreting bathymetric conditions, tidal characteristics, current velocity, wave exposure, shoreline changes, and anthropogenic pressures. The results of these analyses were integrated to assess the level of abrasion impact and to formulate an appropriate coastal abrasion management concept through a hybrid coastal protection approach combining structural and non-structural measures.

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