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Research Article

The Effect of Mangrove Conditions on Shoreline Changes at Mangrove Beach, Senagaga Village, Lawan, Perbaungan District

Goklas Sihombing[1], Teh Ei Venn[2], Natalia Siagian[1], Nabila Putri Adha[1], Ester Siagian[1]
[1]Department of Geography Education, Faculty of Social Sciences, Universitas Negeri Medan, Indonesia
[2]Environmental Studies, Faculty of Arts and Social Sciences, Universiti Malaya, Malaysia

Correspondence Email: goklassihombing834@gmail.com

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Abstract: This study aims to analyze the influence of mangrove vegetation conditions on shoreline changes in Mangrove Beach, Sei Naga Lawan Village, Perbaangan District, Serdang Bedagai Regency. The background of this research is based on the deterioration of mangrove conditions experienced by coastal areas and the increasing degradation of mangrove vegetation due to human activities. The method used in this study is a quantitative descriptive approach with data collection through field observations, and analysis of Sentinel-2 satellite images. Observations were made at 10 mangrove vegetation sampling points and analysis of shoreline changes during the 2020–2025 period. The results showed that areas with high density mangroves and healthy vegetation experienced less abrasion compared to areas with damaged or sparse mangroves. Spatial analysis using ArcGIS software shows a deeper shift of coastline to land in areas that are losing vegetation cover. These findings reinforce the important role of mangroves as natural protectors of beaches that are able to absorb wave energy and hold sediment. Therefore, the preservation and rehabilitation of mangrove forests must be a priority in efforts to mitigate abrasion and manage coastal areas in a sustainable manner.

Keywords: Coastline; Mangroves; Conditions; Perbaungan District

1. INTRODUCTION

Indonesia is the largest archipelago in the world, with more than 17,000 islands and a coastline of approximately ±95,181 km. Indonesia's coastal areas are very diverse and dynamic, with one of which is characterized by mangrove forests. Mangroves are a type of vegetation that grows in tidal areas and serves multiple ecological functions, including protecting beaches from erosion, providing habitat for coastal biota, and storing significant amounts of carbon. Research has shown that dense mangrove cover can reduce abrasion vulnerability in coastal areas. This is because mangrove roots can hold sediment, break up wave energy, and maintain coastal stability. Mangroves generally slow the natural erosion and strengthen soil resistance to seawater impacts. Therefore, areas with mangrove forests tend to be more stable than open beaches with only sand and lack protective vegetation (Djaelani et al., 2025).

Prasetyo, (2025) It was stated that changes in mangrove areas can be effectively mapped through satellite image analysis. This technology helps to understand how mangrove degradation affects the dynamics of coastlines. In practice, converting mangrove land into ponds or settlements is the leading cause of damage to this vegetation cover. This process not only reduces the ecological function of mangroves but also

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significantly accelerates the change in the shape of the beach. Emphasising that mangroves also function as natural carbon stores or *carbon sinks* (Lestariningsih et al., 2024). Mangrove forests are superior to terrestrial tropical forests in storing organic carbon in their soil layers. This function makes mangroves important not only for protecting beaches but also in mitigating global climate change. However, when mangroves are cut down or damaged, abrasion occurs and carbon is released into the atmosphere.

(Marwan et al., 2024), The coastline directly adjacent to the damaged mangrove area was found to shift faster. Geomorphologically, beaches not protected by vegetation will be more susceptible to erosion caused by tides, winds, and ocean waves. This condition can cause land loss, damage settlements, and even threaten infrastructure around the coastline. The primary cause of mangrove damage in Indonesia is human activities, particularly land conversion into ponds and settlements without considering sustainability. In fact, preserving mangroves should be a priority because they protect the environment and cost significantly less than constructing concrete breakwaters. Therefore, a community-based mangrove conservation approach is increasingly needed in various coastal areas (Marsiah et al., 2024).

Oktaviani et al., (2019) State that coastal areas with low mangrove land carrying capacity show higher levels of abrasion and shoreline change. This study demonstrates that the decline in mangrove carrying capacity is directly linked to the acceleration of coastal erosion. Argues that mangrove ecotourism can be an effective alternative to traditional conservation methods. Educational tourism activities in mangrove areas, as well as conservation efforts, also have a positive economic impact on the surrounding community. However, if not correctly managed, ecotourism can threaten the balance of the mangrove ecosystem. Stated that the destruction of mangroves not only impacts the coastline but also causes a decrease in the biodiversity of marine biota, especially mollusks. These organisms are essential bioindicators for the health of coastal ecosystems. When the number and type of mollusks decrease, it reflects ecological disturbances in mangrove habitats (Awali et al., 2023; Putra et al., 2021).

(Febrianto et al., 2019) Explains that mangrove roots are very effective in strengthening soil structure and maintaining land stability in the intertidal zone. The peculiarity of the structure of the respiratory roots (*pneumatophores*) and the roots of the spine is very helpful in preventing soil erosion by tidal currents. Therefore, mangrove forests are often referred to as "natural coastguards". Researching the mangrove reforestation program on Pramuka Island and proving that active restoration of mangrove areas can restore the function of coastal protection in a relatively short time (Syahrial et al., 2019).

(Prasita et al., 2023) The destruction of mangrove vegetation contributes to a decrease in the rate of coastal accretion and increases the vulnerability of coastal areas to sea level rise. This causes some coastal areas to be more frequently affected by flash floods due to the loss of the natural protection function of mangrove vegetation. Changes in mangrove cover in West Lombok were examined, and it was stated that the coastline that suffered the most abrasion was the area with high vegetation damage. This data provides empirical evidence that an increasing threat of abrasion often accompanies mangrove decline. Shows that mangrove replanting activities on Pari Island positively impact coastal strengthening. Reforestation successfully stabilized the abrasion rate and improved the coastal sediment structure. This shows that ecological solutions, such as mangrove planting, are more effective in the long run than engineering solutions alone (Rahman et al., 2025; Ariyansah et al., 2023). Mangroves have essential environmental functions, including retaining sediment, reducing wave energy, and maintaining shoreline stability. This is in line with (Sihombing et al., 2025), who stated that mangrove forests function as natural protectors of coastlines from abrasion, while playing a role in retaining sediment and reducing ocean wave energy.

Maitindom et al., (2024) The mangrove area in Nabire, which was once severely damaged, is now recovering after community-based rehabilitation. This activity shows that the involvement of local communities is significant in maintaining the sustainability of mangroves. Explained that the complex structure of mangrove vegetation positively correlates with shoreline protection. Areas with a diverse and dense mangrove vegetation are more stable and resistant to coastal abrasion than those that lose most of their vegetation cover. They said that gastropod species in the Gerupuk area highly depend on the quality of mangrove vegetation. The decline in the gastropod population reflects the damage to the ecosystem that must be addressed immediately. This reinforces that mangroves have a comprehensive ecological function, both physical and biological (Arif et al., 2022; Hasanah et al., 2023).

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(Solissa et al., 2025) researched mangrove areas in Waiheru and recommended active community involvement in maintaining coastal ecosystems. Preservation will only succeed if it is supported by collective awareness and a participatory approach. Mangrove vegetation in Halmahera was examined, and it was noted that the delay in restoration led to the loss of endemic species. This also makes the area more susceptible to abrasion. Observed the destruction of the mangrove ecosystem in Tanjungpinang and emphasized that mangrove degradation is the leading cause of the retreat of the coastline in the region. Examined the mangrove flora in Mandar Bay and mentioned that many important species are experiencing local extinction due to environmental pressures. This also has an impact on the loss of the area's ecological function (Tolangara et al., 2023; Rizaldi et al., 2020; Pramudji, 2019).

Mangrove ecosystems are essential components of coastal areas, providing various vital *ecosystem services*, including coastal protection, carbon storage, biodiversity habitats, and support for the socioeconomic activities of the surrounding community. Structurally, Mangroves can withstand wave energy and maintain shoreline stability through their complex root systems, including respiratory roots (*pneumatophores*) and buffer roots. This vegetation can slow down water flows, retain sediment, and minimize erosion (Alongi, 2008). Möller et al., (2014) Through field experiments, they demonstrated that coastal vegetation can significantly reduce wave energy, depending on its density and height. Their results confirm that natural vegetation plays a crucial role in coastal protection and is vital to adaptation strategies to coastal climate change.

Barbier et al., (2011) States that coastal vegetation, including mangroves, is a natural bulwark against abrasion and intrusion of seawater, making it very important in coastal disaster mitigation. In his study, healthy mangrove vegetation dampened up to 66% of wave energy before it reached land. This ecological function makes mangroves a green *infrastructure* that is more efficient and sustainable compared to physical engineering, such as concrete breakwaters. The study highlights the significance of spatial monitoring in quantifying mangrove degradation and its impact on shoreline dynamics. This is reinforced by the evidence that changes in mangrove cover directly affect the acceleration of abrasion, especially in areas with high anthropogenic pressures (Giri et al., 2011; Mcleod et al., 2011).

Danielsen et al., (2005) It shows that coastal areas with natural vegetation, such as mangroves, suffered significantly less damage during the 2004 tsunami than regions without protective vegetation. This highlights the direct impact of vegetation in mitigating the effects of natural disasters. Based on the description above, it is evident that mangrove forests play a crucial role in maintaining the stability of the coastline. At Mangrove Beach in Seinaga Lawan District, Perbaungan Regency, significant changes in the shoreline over recent years necessitate scientific study. This study is unique compared to previous studies because it combines field data on mangrove vegetation with spatial analysis from satellite imagery over five years to quantitatively assess the relationship between vegetation conditions and shoreline changes in the coastal areas of North Sumatra, which have not been widely studied. Additionally, incorporating local administrative shapefiles, the spatial overlay approach provides a regional perspective applicable to conservation planning. Therefore, this study aims to analyze the Influence of mangrove conditions on changes in the coastline in the region, providing data-based recommendations for sustainable coastal area management.

2. RESEARCH METHODS

This research was conducted at Mangrove Beach, Sei Naga Lawan Village, Perbaungan District, Serdang Bedagai Regency, North Sumatra Province. The purpose of the study was to analyze the Influence of mangrove vegetation conditions on shoreline changes during the period 2020–2025. The location was chosen based on indications of significant abrasion and degradation of mangrove vegetation due to human activities. The approach used is quantitative descriptive. Data were collected through two main techniques: field observation and satellite image analysis. Observations were conducted at 10 observation points, each with an area of 100 m². The parameters measured included the number of trees, height, trunk diameter, and the health condition of mangrove vegetation. These results are used to determine the density and quality of vegetation at each point.

Spatial data was collected using Sentinel-2 satellite imagery for 2020 and 2025. The processing uses ArcGIS software, which digitizes coastlines, creates map overlays, and analyzes spatial changes. This technique allows the identification of areas subjected to abrasion and their correlation with the conditions of mangrove vegetation. To strengthen the findings, a simple statistical analysis was conducted to determine the correlation between the number of trees per 100 m² and the abrasion distance (in meters). In addition, the theoretical

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framework used refers to the concept *of ecosystem services*, the role of coastal vegetation in shoreline protection, and spatial approaches as described (Barbier et al., 2011; Alongi, 2008).

3. RESULTS AND DISCUSSION

The results of field observations show that the condition of mangrove vegetation at Mangrove Beach, Sei Naga Lawan Village, Perbaungan District, varies from moderate to severely damaged. Observations were made at 10 sampling points, each with an area of 100 m², along the coastline, approximately 4,000 meters long. The average height of the tree at all observation points is 5 meters, with a trunk diameter of ±5 cm.

Table 1 | The condition of the number of mangroves

Observation Points	Average Number of Trees (per 100m2)	Information
Point 1	40	Meeting
Point 2	35	enough
Point 3	42	Meeting
Point 4	36	Keep
Point 5	33	Keep
Point 6	60	Very close (conservation)
Point 7	55	Meeting
Point 8	35	Keep
Point 9	38	Keep
Point 10	49	Keep

(Source: Observation Results, 2025)

To strengthen these findings quantitatively, a simple correlation analysis was carried out between the number of mangrove trees per 100 m² and the abrasion distance (change in coastline) between 2020 and 2025 at each observation point. The results of the analysis showed a negative correlation between mangrove density and abrasion level. Points with a density of >40 trees per 100 m² experienced an average abrasion of only 1.5–2 meters, while points with <35 trees showed abrasion of up to 4–6 meters.

The Pearson correlation coefficient (r) obtained is –0.72, indicating a relatively strong negative correlation. This means that the higher the density of mangroves in an area, the less likely it is to cause abrasion. These results are consistent with visual findings on shoreline digitization overlay maps, where areas with dense and healthy vegetation show better shoreline stability. This analysis suggests that the variable density of mangrove vegetation can be used to predict coastal change dynamics in tropical coastal areas, such as Sei Naga Lawan Village.

Although some spots have a reasonably high density (e.g., Points 6 and 7), visual observations show that the leaves are only fertile at the top, while the trunk and middle part of the tree appear barren. It indicates environmental stress, perhaps due to water quality, extreme salinity, or pollution. Some spots also show conservation success, characterized by young mangroves up to 2 meters high with lush, green leaves throughout, growing evenly and in good health. In contrast, vegetation conditions in some other areas show severe damage due to sewage pollution, as seen in the following Photo, where the stems look dry, dead, and contaminated with solid waste.

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Figure 1 | The Condition of Mangroves Damaged by Waste (Source: Data Processing Results, 2025)

(Febrianto et al., 2019) Stated that mangroves' root structures are essential in strengthening the soil and resisting abrasion. However, as conveyed (Marsiah et al., 2024), Human activities, such as waste disposal and land conversion, cause severe vegetation degradation. Although different approaches are employed in various regions, active community involvement remains crucial in sustaining the sustainability of mangrove ecosystems (Pratama & Ryabtsev, 2025).

Figure 2 | Shoreline Condition 2020 (Source: Data Processing Results, 2025)

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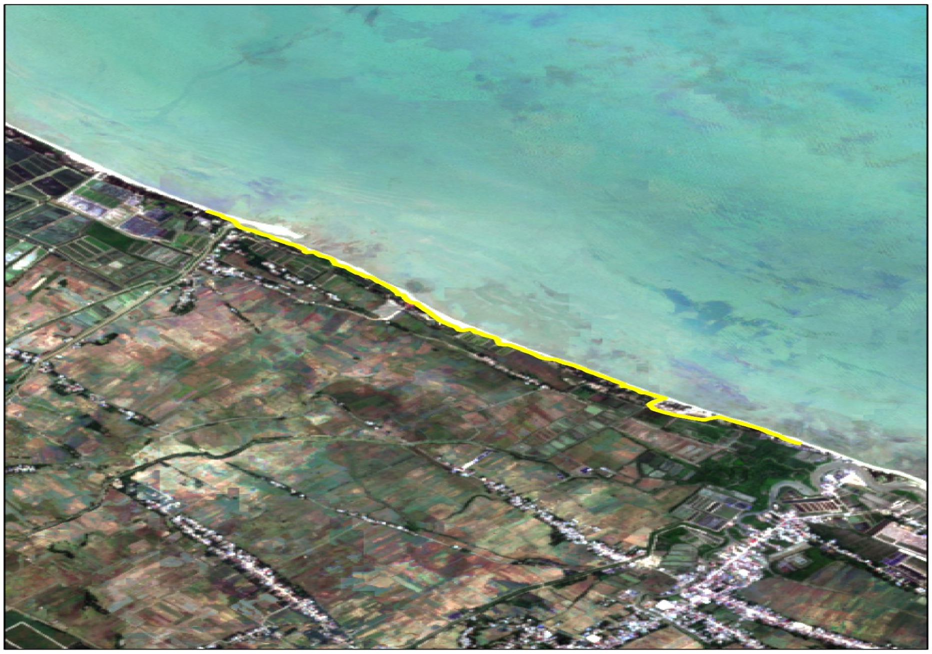

Figure 3 **|** Shoreline Conditions 2025 (Source: Data Processing Results, 2025)

Figure 4 | Results of Coastline Digitization in 2020-2025 (Source: Data Processing Results, 2025)

The damaged mangrove condition in part of Sei Naga Lawan Beach reduces the beach's natural ability to withstand abrasion. This is in Dalimunte et al. (2025), who stated that mangrove damage can increase the vulnerability of coastal areas to abrasion, due to the loss of mangrove root function in retaining sediment and reducing wave strength. The results of the coastline map analysis (Figure 2) indicate that significant coastal abrasion has occurred over the last five years. The coastline in 2025 (yellow line) will likely hang more to land than the coastline in 2020 (red line). This change in coastline is especially noticeable in areas with degraded

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mangrove vegetation. Parts of the coastline that lost protective vegetation experienced more profound abrasion shifts, while regions with vegetation conservation tended to be more stable.

The condition of mangrove vegetation at Sei Naga Lawan Beach has been shown to play a crucial role in influencing the stability of the coastline. From observations, areas with high mangrove density and healthy tree conditions, especially in points that have been preserved, show a lower Tendency to abrasion compared to areas with damaged or sparse vegetation. This suggests that the presence of healthy mangroves can serve as a natural protector against erosion. As stated (Febrianto et al., 2019), typical mangrove roots, such as respiratory roots and the spinal cord, play a role in strengthening soil structure and reducing erosion by tidal currents.

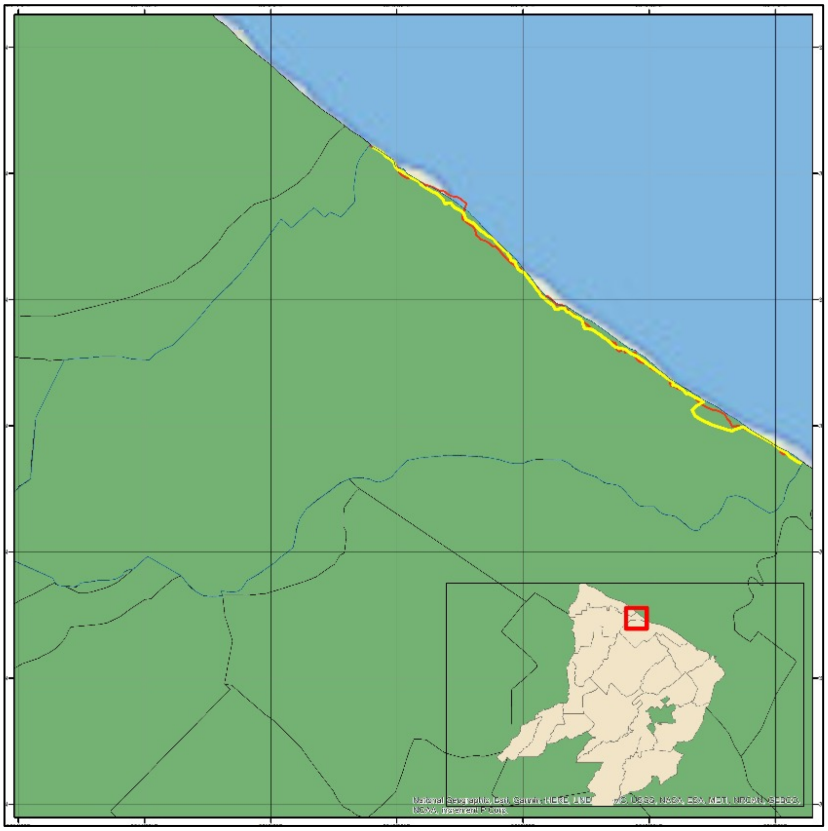

Figure 5 | Merger of Shoreline Digitization Results in 2020-2025, Accompanied by the Administrative Boundaries of Sei Naga Lawan Village SHP (Source: Data Processing Results, 2025)

The change in coastline from 2020 to 2025, indicated by the shift of the line to the mainland, shows that abrasion continues to occur progressively. In areas with mangroves damaged by sewage, coastlines shift more quickly inland compared to places where the vegetation remains protected. This corroborates the opinion that the coastline directly adjacent to the damaged mangroves undergoes a more significant shift. In addition, it also emphasized that human activities, such as land conversion, are the leading cause of mangrove damage in Indonesia, which ultimately increases coastal vulnerability to erosion (Marsiah et al., 2024; Marwan et al., 2024).

Thus, this study's results state that mangrove degradation directly impacts coastal physical changes. The data obtained at the study site showed a similar pattern, where areas with low or damaged mangrove cover exhibited high levels of abrasion. Therefore, these results confirm that mangrove conditions significantly affect shoreline dynamics, and mangrove conservation is a crucial strategy for reducing abrasion and promoting the sustainable management of coastal areas. In addition to resisting abrasion, mangroves serve as enormous carbon stores, with carbon reserves exceeding 1,000 Mg C ha, making them one of the most carbon-rich forest ecosystems in the world. This shows that mangrove damage also impacts the global climate function (Donato et al., 2011).

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4. CONCLUSION

This study demonstrates that the condition of mangrove vegetation significantly impacts the change in the coastline at Mangrove Beach, Sei Naga Lawan Village. Areas with damaged or infrequent mangroves experience greater abrasion than areas with dense and healthy mangrove vegetation. These findings were strengthened by spatial analysis and correlation between mangrove density and abrasion distance, which showed a strong negative relationship ($r = –0.72$). These results confirm that mangroves serve as physical protectors of coastlines and as part of ecosystem infrastructure that supports disaster mitigation and coastal stability. In line with the view of McLeod et al. (2011), coastal vegetation such as mangroves also contributes to the absorption of blue carbon. Hence, the rehabilitation and preservation of mangrove forests provide dual benefits: ecological and climatic. Quartel et al., (2007) This indicates that a 100-meter-wide mangrove belt can reduce wave energy by up to 66%, depending on the density and structure of the vegetation. This confirms that natural vegetation has a significant coastal protection function, even more effective than concrete structures under certain conditions.

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