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A spatial study of mangrove ecosystems toward coastline changes in the west coastal area of Pandeglang Regency, Banten

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Abstract

The west coast of Pandeglang Regency which is directly facing the Sunda Strait has a wide mangrove ecosystem potential. The mangrove ecosystem has an important role as a protector of the coastline due to abrasion and accretion. Changes in mangrove ecosystems on the west coast of Pandeglang Regency certainly result in changes in the coastline. High tides and tides, including tsunami, are also factors that influence the changes in the coastline that occur on the coast. The purpose of this study is to find out the relationship between mangrove ecosystem changes to changes in the coastline. Research methods utilize remote sensing through NDVI analysis and overlay, as well as linear regression analysis to examine the relationship between changes in mangrove area and the occurrence of abrasion and accretion. The results of this study show that within 10 years there have been changes in mangrove ecosystems in each period. Mangrove ecosystems in the research area increased from 2010 to 2015 but decreased again in 2020 due to the 2018 tsunami. This change certainly also affects the occurrence of abrasion covering an area of 30.237 ha and accretion of 50.239 ha over for a period of 10 years, and indicates a positive relationship between mangrove area changes and abrasion and accretion based on regression analysis results. Spatially the largest mangrove ecosystem changes occur in the Sumur sub-district.

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INTRODUCTION

Indonesia is the second-longest maritime country after Brazil, which is about 99,093 km (Sui et al., 2020). This condition makes most of Indonesia's coasts vulnerable and threatened due to hydro-oceanographic activity that triggers rising sea levels and changes in wind speed in certain circumstances. Natural disasters caused by hydro-oceanographic changes can be mitigated through the sustainable management of coastal and marine resources. Mangrove ecosystems represent one of the most important coastal resources, playing a crucial role in protecting shorelines from abrasion and accretion processes. Recent regulatory frameworks,

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particularly Government Regulation No. 27 of 2025 on the Protection and Management of Mangrove Ecosystems, emphasize that mangrove ecosystems possess significant ecological, social, and economic functions and must be managed in an integrated and sustainable manner to maintain coastal stability and environmental resilience. Mangrove roots are capable of trapping sediment and reducing water flow velocity, thereby promoting sediment accumulation and contributing to shoreline accretion processes (Gijsman et al., 2024). Mangrove root structure that can settle sediment indirectly can protect the beach from seawater waves so that it is useful in preventing coastal shallowing or abrasion that can erode coastal land (Jia et al., 2023). Distribution of distributed mangrove ecosystems throughout the Indonesian Archipelago about 23% of the world's mangrove ecosystems belongs to Indonesia (Aznawi, et al., 2026).

Several previous studies have demonstrated that mangrove ecosystems play a significant role in controlling coastline dynamics. Mangrove function as natural coastal protectors against erosion and extreme weather impacts (Xu et al., 2024). This role is attributed to the complex root structure of mangroves, which is capable of dissipating wave energy and enhancing coastline stability against erosion processes (Weaver & Stehno, 2024). Furthermore, the global distribution and dynamics of mangrove ecosystem changes have been extensively studied using remote sensing approaches, revealing a strong relationship between mangrove changes and environmental pressures as well as anthropogenic activities (Hamilton & Casey, 2016). The presence of mangroves has also been proven to be effective in reducing coastal erosion rates through sediment trapping and deposition mechanisms in coastal areas (Besset et al., 2019). However, coastline dynamics are not solely influenced by mangrove presence, but are also the result of complex interactions among oceanographic factors, land use changes, and coastal vegetation characteristics (Mentaschi et al., 2018).

The west coast of Pandeglang Regency is included in the 3.4 million hectares of mangrove ecosystem area in Indonesia. This means that this coast is one of the regions in Indonesia that has a wide mangrove ecosystem potential. Several types of mangroves can be found in this region, such as Sonneratia alba, Bruguiera spp., Avicena spp., Lumnitzera racemosa and Rizhopora. One of the areas with good ecosystem potential is the Ujung Kulon National Park area (Shintianata et al., 2024). The diversity of mangrove ecosystems in this region is relatively high, but along with increasing population growth resulting in a decrease in its area. The decline of mangrove ecosystems along the coast is also caused by the tsunami disaster around the Sunda Strait in 2018 caused by the eruption of mount Anak Krakatau. BNPB noted that along 302 km of coastline on the coast has been abrasion around 30 – 40 meters from the shoreline.

Although numerous studies have examined the relationship between mangroves and coastline changes, most of the primarily focus on descriptive analysis or spatial mapping without quantitatively assessing the statistical relationship between changes in mangrove area and the occurrence of abrasion and accretion. Furthermore, remote sensing-based studies that integrate spatial analysis with regression modeling remain relatively limited, particularly in coastal regions of Indonesia such as Pandeglang Regency. This study offers novelty by integrating NDVI analysis, spatial overlay techniques, and linear regression modeling to quantitatively examine the relationship between changes in mangrove area and the dynamics of abrasion and accretion.

Changes in mangrove ecosystems certainly result in changes in the coastline which will then cause harm to the surrounding community. Therefore, this research examines the changes in mangrove ecosystems covering their area and density and their relation to the changes in the coastline that occurred on the west coast of Pandeglang Regency within 10 years (2010 – 2020) spatially. Monitoring of changes in mangrove ecosystems and coastline in the form of abrasion and accretion can be mapped using Geographic Information Systems (GIS). The use of GIS can be done by the remote sensing approach method, namely by using satellite imagery.

METHOD

This research was conducted along the west coast of Pandeglang Regency, Banten Province. Pandeglang Regency is bordered by Serang Regency in the north, Lebak Regency in the east, the Indian Ocean in the south and Sunda Strait in the west. Its position overlooking the Sunda Strait is vulnerable to natural disasters. While the analysis unit in this study is three sub-districts that have mangrove ecosystems and are limited to a boundary towards the mainland 10 meters contour height of the coastline and the boundary towards the ocean as far as 12 miles from the provincial coastline, while the boundary to the side as far as at least 700 meters and a maximum of 2,100 meters from the mangrove weight point of the first period (T0). The three sub-districts have mangroves and the location is directly facing the Sunda Strait so that it has a coastline that can be studied for changes.

Variable used in this study include mangroves, abrasion, accretion, wave height, tides and land use. Data on mangrove area and density, abrasion area and accretion were obtained by extracting Landsat 7 ETM+ imagery in 2010 and Landsat 8 OLI/TRS in 2015 and 2020. Identification of mangrove ecosystem is done by composite method red green blue (RGB) with a combination of band 4 (near-infrared / NIR), band 5 (mid-infrared) and band 3 (red) on Landsat 7 ETM+ in 2010. While RGB composite with a combination of band 5 (near-infrared / NIR), band 6 (short-wave infrared / SWIR-1) and band 7 (short-wave infrared / SWIR-2) on Landsat 8 OLI/TRS in 2015 and 2020. Furthermore, Normalized Difference Vegetation Index (NDVI) method is used to calculate the density value of mangrove vegetation by comparing the ratio of a near-infrared ban (NIR) and red band. The formula used to calculate NDVI is as follows:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad (1)$$

Furthermore, the results of the calculation of index values (Table 1) of each point are classified into the mangrove ecosystem header density class based on the NDVI value issued by the Indonesian Ministry of Forestry in 2005 (Whidayanti et al., 2021). Data on shoreline changes using the Single Band Threshold band SWIR-1 method to determine land and sea boundaries, further digitizing the coastline each year of research. Single Band Threshold band 5 (1.55 mm – 1.75 mm) is a good type of infrared wave to depict the coastline with Landsat TM and ETM satellite imagery (Karaman, 2021). After digitizing the coastline each period, the overlay techniques are performed to obtain the area of abrasion and accretion. The results of mangrove data processing, abrasion and accretion are analyzed to determine the relationship between mangrove ecosystems to change in coastline along the west coast of Pandeglang Regency spatially.

Table 1. Classification of Mangrove Density based on NDVI

No	Value of NDVI	Density Classification
1	0.006 – 0.328	Low
2	0.335 – 0.427	Medium
3	0.434 – 0.750	High

(Source: Department of Forestry, 2005)

While the high data and wave direction are obtained from BMKG and the tidal of seawater is obtained from BIG. Both oceanographic data are processed with GIS techniques and analyzed descriptively. Land use data around mangrove areas obtained from the process of digitization on-screen manually based on the results of interpretation of Google Earth imagery. Furthermore, descriptive analysis is carried out to link wave data, tides and land-use changes to changes in mangrove ecosystems and changes in the coastline for ten years.

RESULTS AND DISCUSSIONS

Mangrove

Mangrove distribution and area in this research was identified using NDVI supervision and analysis methods to analyze its density. Based on the results of Landsat image classification shows that the mangrove distribution is at eight points scattered along the west coast of Pandeglang Regency facing the Sunda Strait (Figure 1). The eight points are in Sumur sub-district as many as six points, Panimbang sub-district there is one point and another point is in Carita sub-district (Figure 2).

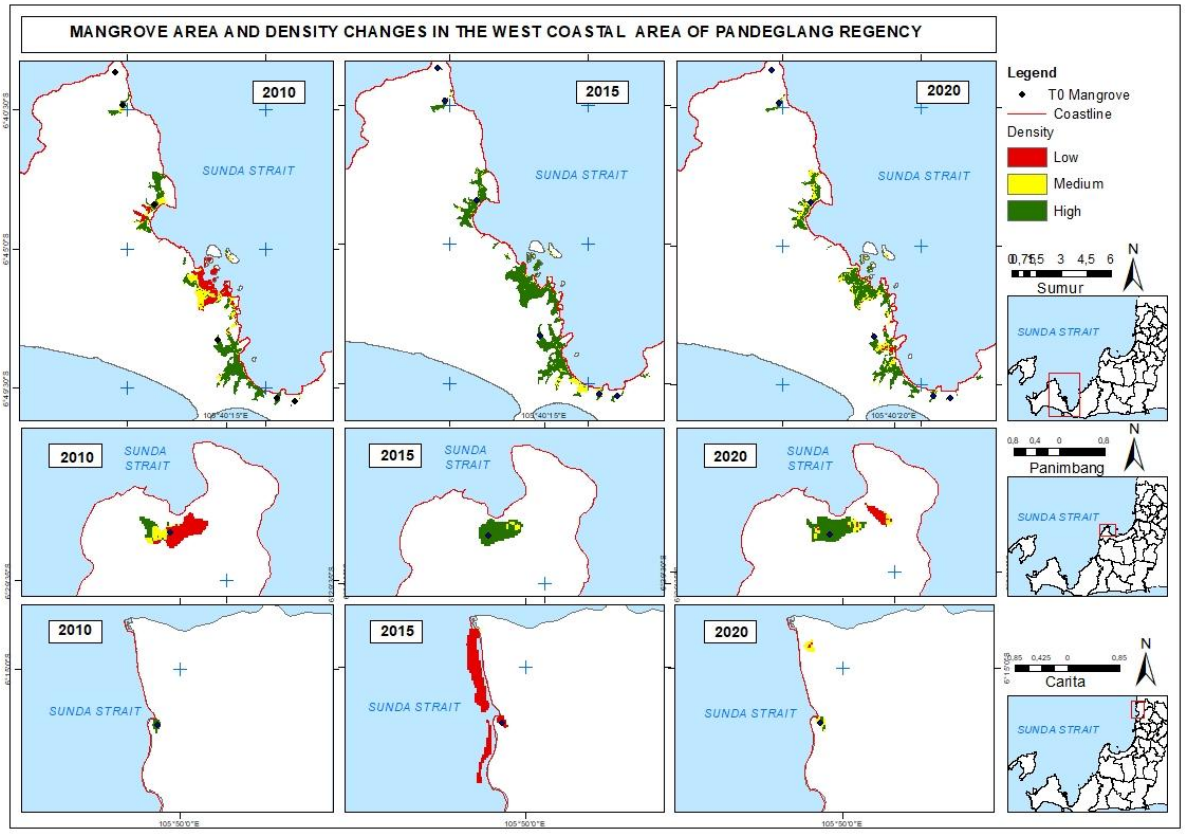


Figure 1. Map of Mangrove Area and Density in the West Coastal of Pandeglang Regency (2010 – 2020)

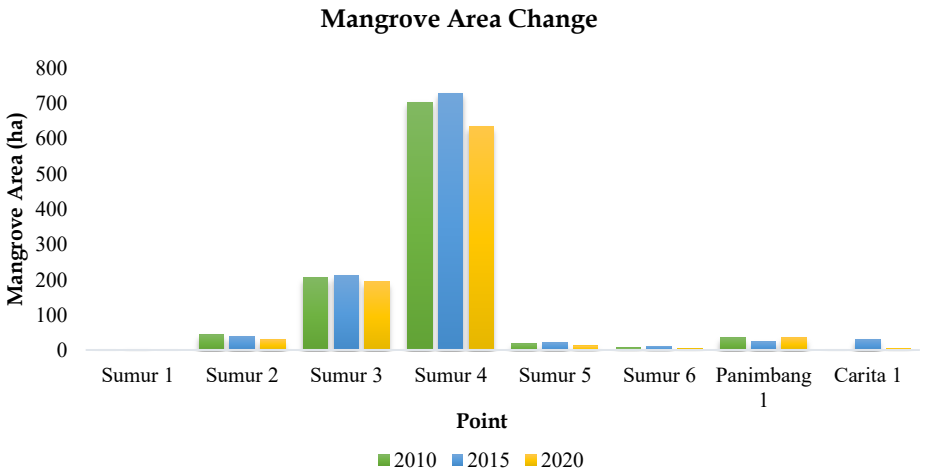


Figure 2. Graphic of Mangrove Area in the West Coastal Area of Pandeglang Regency (2010 – 2020)

Figure 1 and 2 shows that over for ten years divided into three observation periods, namely 2010 – 2015, 2015 – 2020 and 2010 – 2020 there has been a change in mangroves, both in terms of area and density and distribution. In general, in 2010 the total mangrove area in the research area of 1011.794 ha and increased by 5% in 2015 or an area of 1066.893 ha. Meanwhile, in 2020 it again decreased to 909.899 ha caused by the tsunami disaster in 2018.

In the first five-year period, namely in 2010 – 2015, Carita points experienced the largest increase. While the percentage decrease in the highest area occurred at Panimbang point or about 30.65%. meanwhile, in the next five years, namely, in 2015 – 2020 the largest decline in mangrove area due to the tsunami disaster occurred at Sumur point 6 or about 70.17% of mangrove area has been lost. However, the Panimbang point experienced an increase in mangroves area of 11.14 ha or about 46.43% due to the change of land use into a tourism area and one of them is mangrove tourism. In addition, the high waves at this point tend to be lower when compared to other points in the Sumur sub-district. This causes in this period the mangrove area at Panimbang point increases.

Coastline

Over for ten years, the west coast of Pandeglang Regency overlooking the Sunda Strait has changed in the coastline. Changes in the coastline are caused by oceanographic factors that include wave height, sea currents and tides, changes in land use and the existence of mangrove ecosystems. These shoreline changes can lead to abrasion and accretion in the region.

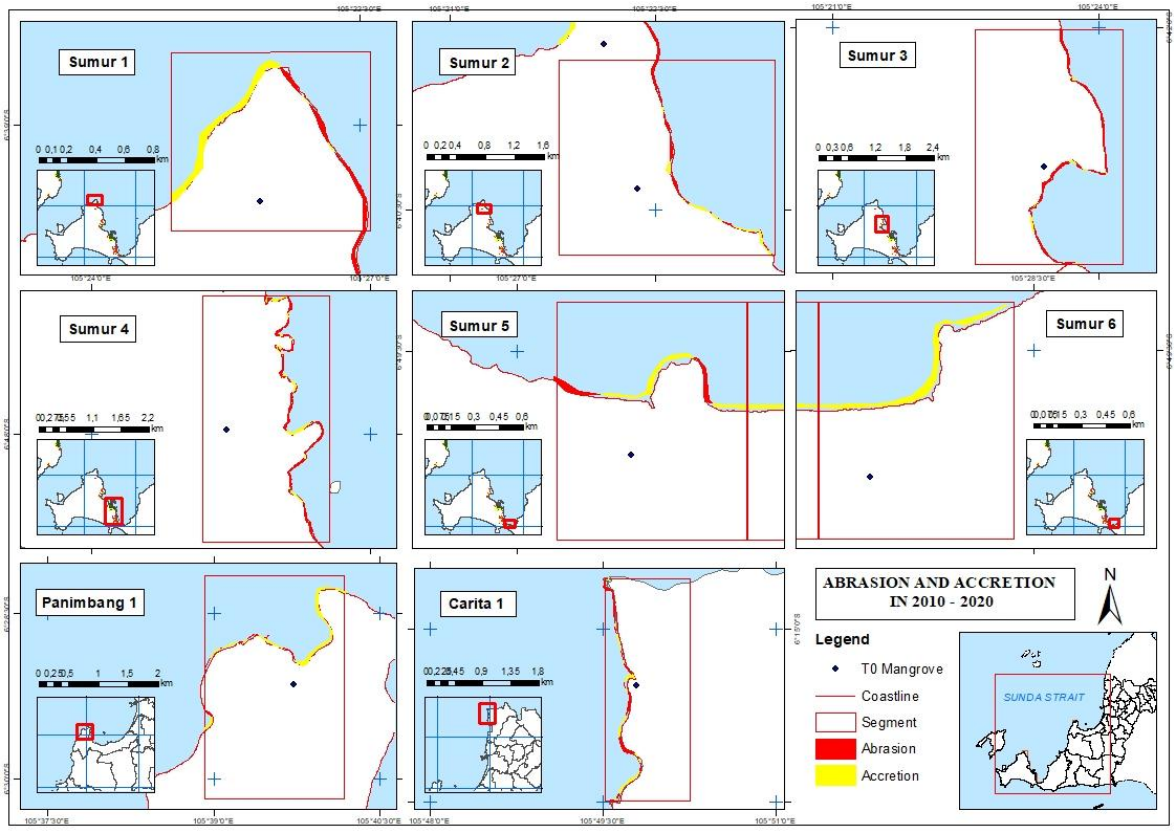


Figure 3. Map of Abrasion and Accretion Along with West Coastal Area of Pandeglang Regency in 2010 - 2020

Figure 3 shows that over for ten years, the west coast of Pandeglang Regency which is directly facing the Sunda Strait, especially those in the mangrove area has experienced abrasion of 30.23 ha and accretion of 24.57 ha. However, if calculated per period, in the first period of 2010 – 2015 abrasion occurred an area of 34.53 ha with the largest abrasion level was at the points of

well 3 which is an area of 16.64 ha. While the largest accretion occurs at the point of Carita which is an area of 23.6 ha.

While in the next five years, namely in 2015 – 2020 there has been abrasion covering an area of 32.7 ha and accretion of 17.09 ha. The tsunami disaster that occurred in 2018 caused the coast in this period to experience abrasion that tends to be greater than the previous period. The largest abrasion is at the Carita point with an area of 23.31 ha, while Sumur point 6 has the smallest abrasion of 0.061 ha. While the largest accretion occurred at the Sumur point 5 which is an area of 5.18 ha and the smallest accretion occurred at the Sumur point 1 which is an area of 0.274 ha. In addition to the high waves until the tsunami disaster, the occurrence of abrasion and accretion is also caused by changes in mangrove ecosystems that occur.

The Effect of Decreasing Mangrove Area on Abrasion

Mangrove ecosystem changes that occurred from 2010 to 2020 on the west coast of Pandeglang Regency directly facing Sunda strait are assumed to affect the occurrence of changes in the coastline, both abrasion and accretion. This means that the decrease in mangrove area will result in wider abrasion. This assumption is taken based on the role of mangroves in preventing or naturalizing the occurrence of coastal abrasion that can erode coastal land. The presence of mangroves can indirectly protect the beach from the currents and large waves of seawater, so that the coastline will not be easily eroded or eroded by seawater waves. Mangroves have an important role in protecting the coastline from abrasion, so it can be assumed that changes will affect changes in the coastline.

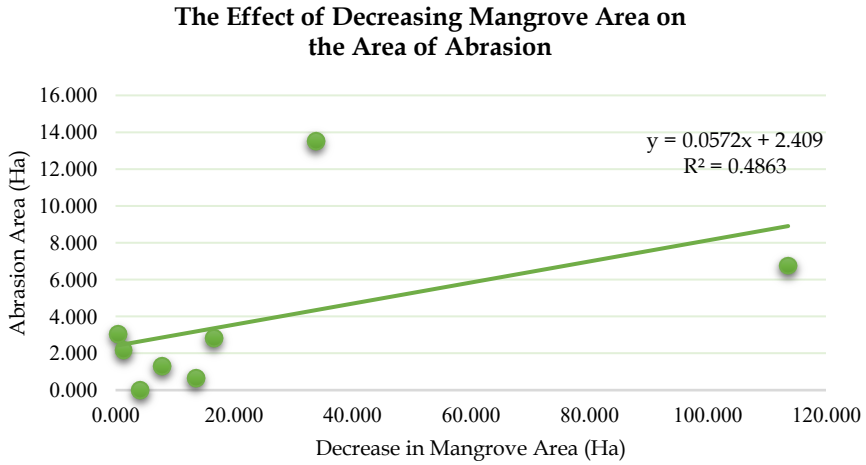


Figure 4. Scatterplot the Relationship of Mangrove Area Reduction with Abrasion Area

Based on the scatterplot the relationship between the decrease in mangrove area and the area of abrasion above shows a positive value. This means that the wider the decline in mangroves area that occurs at a point, the greater the area of abrasion that occurs at that point. The result of linear regression calculation between the decrease in mangrove area and abrasion area obtained the result of the coefficient of determination of both variables or R^2 value of 48.63%. This means that the area of abrasion can be explained by 48.63% with a decrease in mangroves area, while 51.36% is explained by other variables not described in this research. So, based on the linear regression test, the decrease in mangrove area has an influence of 48.63% on the area of abrasion that occurs, while the remaining 51.36% is influenced by other factors.

This relationship is also consistent with the spatial pattern presented in Figure 3, which indicates that areas experiencing significant mangrove loss, such as Sumur and Carita sub-districts, tend to exhibit higher levels of abrasion. This condition suggests that mangrove degradation contributes to increased coastal vulnerability to erosion processes. The relatively high coefficient of determination indicates that mangroves play a significant role in controlling abrasion along the west coast of Pandeglang Regency. However, this value also suggests that

abrasion is a complex phenomenon that is not influenced by a single factor alone. Other variables, such as oceanographic conditions, sediment dynamics, and human activities, also contribute to determining the magnitude of coastline changes.

The findings of this study support previous literature indicating that mangrove ecosystems play a significant role in reducing wave energy and enhancing shoreline stability. The complex structure of mangroves is capable of slowing current velocity and increasing sediment deposition, thereby reducing the rate of coastal erosion (Besset et al., 2019). In addition, other studies have reported that coastal areas with well-preserved mangrove cover tend to experience lower erosion rates compared to areas affected by mangrove degradation (Xu et al., 2024).

However, several studies also emphasize that the effectiveness of mangrove in reducing abrasion is highly dependent on environmental conditions, such as wave characteristics, sediment supply, and land use changes (Mentaschi et al., 2018). In the context of the study area, the 2018 tsunami accelerated mangrove degradation and increased abrasion intensity, further indicating that external factors play an important role in shaping coastline dynamics.

The Effect of Increasing Mangrove Area on Accretion

Mangrove roots can collect sediment (mud) and slow down river flow, so that it will cause sedimentation. Sedimentation occurring on the beach can expand the shoreline or be called accretion. Mangroves that thrive and strong will be a means of sedimentation due to the settlement of mud or small materials on the beach. Therefore in this research, it is assumed that the addition of mangrove area can cause sedimentation or expand the coastline (accretion), which means the wider the addition of mangroves the accretion that occurs on the west coast of Pandeglang Regency.

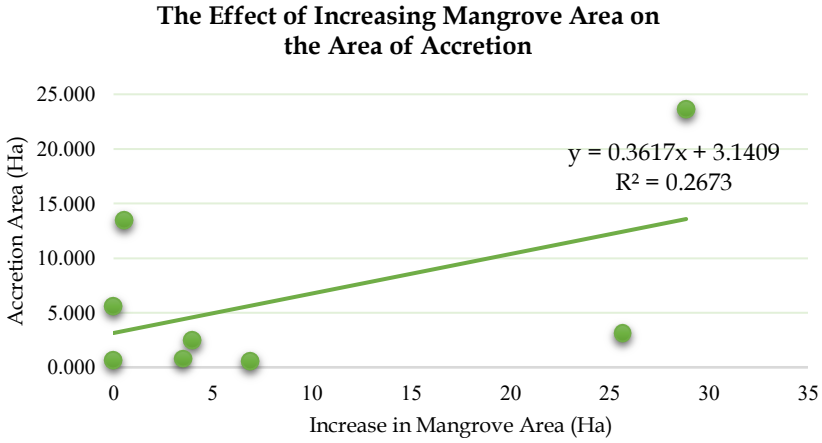


Figure 5. Scatterplot the Relationship of Mangrove Area Addition with Accretion Area

Based on the scatterplot the relationship between the addition of mangroves area and the area of accretion above shows a positive value. This means that the wider the mangrove area that occurs at a point, the greater the area of accretion that occurs at that point. The result of linear regression calculation between the addition of mangrove area with accretion area obtained the result of the coefficient of determination of both variables or R^2 value of 26.73%. This means that the accretion area can be explained by 26.73% with the addition of mangrove area, while 73.27% is explained by other variables not described in this research. So, based on the linear regression test, the addition of mangrove area has an influence of 26.73% on the area of accretion that occurs, while the remaining 73.27% is influenced by other factors. These factors may include sediment dynamics, hydrodynamic conditions, and coastal geomorphology.

This relationship is also supported by the spatial pattern presented in Figure 3, which shows that areas experiencing mangrove expansion tend to coincide with zones of accretion. This spatial correspondence indicates that mangrove growth contributes to sediment accumulation

processes along the coastline. However, the relatively low coefficient of determination suggests that accretion is influenced by more complex and interacting factors compared to abrasion. When compared to the regression results for abrasion, the influence of mangrove area on accretion is weaker, indicating that mangroves play a more dominant role in coastal protection (reducing erosion) than in land formation processes.

The findings of this study are supported by previous research indicating that mangrove ecosystems play an important role in sediment accumulation processes through mechanisms such as trapping suspended particles and reducing water flow velocity (Jayson-Quashigah et al., 2025). The complex root structure of mangroves enhances the deposition of fine sediments in coastal areas, thereby contributing to land formation processes (accretion) (Das et al., 2026). Furthermore, mangrove restoration has been shows to increase sedimentation rates and accelerate shoreline recovery processes in various tropical coastal regions (Das et al., 2026).

However, the effectiveness of mangroves in promoting accretion is strongly influenced by sediment availability and local hydrodynamic conditions. In areas with limited sediment supply or high wave energy, accretion processes tend to be constrained despite increase in mangrove extent (Rasyidi et al., 2024). This condition indicates that the relatively low coefficient of determination observed in this study reflects the more dominant role of other environmental factors in controlling accretion processes compared to changes in mangrove area alone.

CONCLUSION

Based on the results of this study, it can be concluded that mangrove ecosystems along the west coast of Pandeglang Regency, which directly faces the Sunda Strait, have experienced significant changes in both area and density. These changes influence coastline dynamics, particularly in terms of abrasion and accretion processes. A positive relationship is observed between the decrease in mangrove area and the increase in abrasion, indicating that greater mangrove loss leads to wider coastal erosion. Conversely, the increase in mangrove area is positively associated with accretion, suggesting that mangrove expansion contributes to sediment accumulation and shoreline growth.

However, this study has several limitations, including reliance on remote sensing data was limited temporal resolution and the lack of comprehensive quantitative integration of other influencing factors such as sediment supply, ocean currents, and human activities. Additionally, the regression analysis only considers mangrove area as a predictor, which may not fully capture the complexity of coastline dynamics. Therefore, future research is recommended to integrate multi-source data, including higher-resolution satellite imagery and field observations, as well as to incorporate more comprehensive oceanographic and socio-economic variables using advanced modeling approaches to better understand coastal processes.

AUTHOR CONTRIBUTIONS

The authors made substantial and independent contributions to the conception and design of the study, data acquisition, analysis and interpretation of data, as well as drafting and revising the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

REFERENCES

Aznawi, A. A., Basyuni, M., Siregar, L. A. M., Hanafiah, D. S., Arifanti, V. B., Yenny, I., … Kajita, T. (2026). Mangrove structure, composition, and distribution through restoration of

Indonesia's mangrove: A systematic review. Forest Science and Technology, 1–19. https://doi.org/10.1080/21580103.2026.2650303

Besset, M., Anthony, E. J., & Bouchette, F. (2019). Multi-decadal variations in delta shorelines and their relationship to river sediment supply: An assessment and review. Earth-Science Reviews, 193, 199-219. https://doi.org/10.1016/j.earscirev.2019.04.018

Besset, M., Gratiot, N., Anthony, E. J., Bouchette, F., Goichot, M., & Marchesiello, P. (2019). Mangroves and shoreline erosion in the Mekong River delta, Viet Nam. Estuarine, Coastal and Shelf Science, 226, 106263. https://doi.org/10.1016/j.ecss.2019.106263

Das, S., Dutta, S., Roy, J., Choudhury, M. R., Sen, P., Chanda, A., Dutta, H., Nandi, S., & Ghosh, T. (2026). Mangroves in the Anthropocene: A global synthesis of carbon storage, biodiversity, and coastal resilience under climate and anthropogenic stressors. Science of the Total Environment, 1003, 181405. https://doi.org/10.1016/j.scitotenv.2026.181405

Gijsman, R., Horstman, E. M., Swales, A., Balke, T., Willemsen, P. W. J. M., van der Wal, D., & Wijnberg, K. M. (2024). Biophysical modeling of mangrove seedling establishment and survival across an elevation gradient with forest zones. Journal of Geophysical Research: Earth Surface, 129(5), Article e2024JF007664. https://doi.org/10.1029/2024JF007664

Government of the Republic of Indonesia. (2025). *Government Regulation No. 27 of 2025 on the Protection and Management of Mangrove Ecosystems*. https://peraturan.go.id/files/pp-no-27-tahun-2025.pdf

Hamilton, S. E., & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Global Ecology and Biogeography, 25(6), 729–738. https://doi.org/10.1111/geb.12449

Jayson-Quashigah, P.-N., Staneva, J., Chen, W., Djath, B., Mahu, E., & Appeaning Addo, K. (2025). Evaluating mangroves as nature-based solutions for coastal protection under current and future sea level rise scenarios. Frontiers in Marine Science, 12, Article 1526082. https://doi.org/10.3389/fmars.2025.1526082

Jia, M., Wang, Z., Mao, D., Ren, C., Song, K., Zhao, C., Wang, C., Xiao, X., & Wang, Y. (2023). Mapping global distribution of mangrove forests at 10-m resolution. Science Bulletin, 68(12), 1306–1316. https://doi.org/10.1016/j.scib.2023.05.004

Karaman, M. (2021). Comparison of thresholding methods for shoreline extraction from Sentinel-2 and Landsat-8 imagery: Extreme Lake Salda, track of Mars on Earth. Journal of Environmental Management, 298, Article 113481. https://doi.org/10.1016/j.jenvman.2021.113481

Mentaschi, L., Vousdoukas, M. I., Pekel, J.-F., Voukouvalas, E., & Feyen, L. (2018). Global long-term observations of coastal erosion and accretion. Scientific Reports, 8, Article 12876. https://doi.org/10.1038/s41598-018-30904-w

Rasyidi, G., Silalahi, A., Rodhianto, I., & Ulasaswini, A. A. (2024). Mangrove planting as a natural protection measure coastal environment risk vulnerability. Sociality: Journal of Public Health Service, 3(2), 83–90. https://doi.org/10.24252/sociality.v3i2.50487

Shintianata, D., Lubis, A. A., Sugiharto, U., Andini, F. P., Meiliastri, S. S., & Elias, M. S. (2024). Tracing heavy metal dynamics in mangrove sediments: A study from Ujung Kulon National Park. ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 29(4), 519–529. https://doi.org/10.14710/ik.ijms.29.4.519-529

Sui, L., Wang, J., Yang, X., & Wang, Z. (2020). Spatial-temporal characteristics of coastline changes in Indonesia from 1990 to 2018. Sustainability, 12(8), Article 3242. https://doi.org/10.3390/su12083242

Weaver, R. J., & Stehno, A. L. (2024). Mangroves as coastal protection for restoring low-energy waterfront property. Journal of Marine Science and Engineering, 12(3), Article 470. https://doi.org/10.3390/jmse12030470

Whidayanti, E., Handayani, T., Supriatna, & Manessa, M. D. M. (2021). A spatial study of mangrove ecosystems for abrasion prevention using remote sensing technology in the

coastal area of Pandeglang Regency. IOP Conference Series: Earth and Environmental Science, 771(1), Article 012014. https://doi.org/10.1088/1755-1315/771/1/012014

Xu, X., Fu, D., Su, F., Lyne, V., Yu, H., Tang, J., Hong, X., & Wang, J. (2024). Global distribution and decline of mangrove coastal protection extends far beyond area loss. Nature Communications, 15, Article 10267. https://doi.org/10.1038/s41467-024-54495-9

Zhou, X., Wang, J., Zheng, F., Wang, H., & Yang, H. (2023). An overview of coastline extraction from remote sensing data. Remote Sensing, 15(19), Article 4865. https://doi.org/10.3390/rs15194865