Spatio-temporal dynamics of mangroves in Eastern Maumere Bay (Indonesia) in relation to climate change and anthropogenic pressures

[1]Angelinus Vincentius, [1]Guido R. J. Parera, [1]Erfin, [2]Yuliana Onang,
[3]Yakobus N. Randi, [4]Oktavianus D. L. Laru

[1] Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, 86111 Maumere, Indonesia; [2] Management Study Program, Faculty of Economics and Business, Nusa Nipa University, 86111 Maumere, Indonesia; [3] Student of Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, 86111 Maumere, Indonesia; [4] Student of Management Study Program, Faculty of Economics and Business, Nusa Nipa University, 86111 Maumere, Indonesia.
Corresponding author: A. Vincentius, angelinusvincentiustonda@gmail.com

Abstract. The objective of this study was to evaluate the relationships between the spatial-temporal dynamics of coastlines (erosion, accretion) as a result of climate change and other anthropogenic factors, with the spatial-temporal dynamics of mangrove ecosystems. The study was conducted from June to October 2025. The study used Landsat 5_TM and Landsat 8_OLI satellite images of East Maumere Bay (Kojadoi Island and Talibura Subdistrict) acquired for 1995, 2000, 2005, 2010, 2015, 2015, and 2025; data on anthropogenic factors; and wind and current data. Shoreline changes were analysed using the Digital Shoreline Analysis System (DSAS) method. Mangrove and anthropogenic data were analysed using the Normalized Difference Vegetation Index (NDVI), supplemented with field measurements and interviews. Erosion reached -216.04 m and accretion reached 102.73 m at Kojadoi; erosion reached -436.99 m, and accretion reached 185.49 m at Talibura. The relationship between X (erosion) and Y (change in mangrove extent) at Kojadoi was: $Y = 6E\text{-}05X^2 - 1.6321X + 23{,}364$, $R^2 = 0.6534$, $r = 0.8083$, with X explaining 65.34% of the variation in Y. The relationship between X (change in mangrove extent) and Y (accretion) in Talibura: $Y = -4E\text{-}05X^2 + 3.5665X - 51{,}734$, $R^2 = 0.4857$, $r = 0.6969$, indicating that 48.57% of the variation in variable Y is explained. Anthropogenic factors contribute to changes in mangrove forest area and coastline movement (advancement or retreat). Since 1995, there has been widespread conversion of mangrove ecosystems into open land, covered with shrubs and other vegetation, agricultural use, and built-up land. Sustainable mangrove management and human activities are needed to reduce negative impacts on mangrove ecosystems.

Key Words: mangroves, climate change, coastal change, anthropogenic factors, Maumere Bay.

Introduction. Mangrove ecosystems in archipelagic regions such as Sikka Regency, East Nusa Tenggara Province, Indonesia, are severely threatened by climate change (UNFCCC 2021; NASA 2022), as well as by anthropogenic factors (human activities) such as land conversion (Vincentius et al 2018; Bhokaleba & Erfin 2022). This is a serious problem for the stability and sustainability of coastal and marine ecosystems, as mangroves provide many ecosystem services of socio-economic value. Mangroves act as coastal protectors (Beck & Lange 2016). They contribute to the protection and stabilization of coastlines by controlling erosion in coastal areas and flooding (Koch et al 2009; Gedan et al 2011). Mangroves assist in the filtration and retention of pollutants, contribute to hydrological regulation (Barbier 2016; Arifanti et al 2022; Shumway 2023), and carbon sequestration (Adame et al 2021; Vincentius et al 2024).

Mangroves provide habitat and food for many terrestrial and aquatic species that live in these ecosystems (Hauhouot 2010), and are therefore important for maintaining biodiversity (Barbier et al 2011). Mangroves also provide wood for smoking fishery products, cooking food, and building homes for residents, are used in fishing gear, provide medicinal plants, and can support the development of ecotourism activities (Egnankou 2010; Halim & Setiawan 2023). They are a source of food and income (Walters et al 2008), fish stocks for industry (Blaber 2007), raw materials and other economic products (Hamza 2024). Despite their many functions and benefits, mangrove ecosystems are highly vulnerable to disturbances, both natural and human-induced, which can cause a decline in their condition and extent (Field 1995; Alongi 2002).

The eastern part of Maumere Bay is one of the coastal areas in Sikka Regency, naturally blessed with mangrove ecosystems. The presence of settlements in this area has led to interactions between the residents and the mangrove ecosystem, including the use of wood for building materials as well as land conversion, resulting in the degradation of the mangrove ecosystems. The degradation or loss of mangroves can cause the coastline to recede inland, accelerate sandy beach erosion, increase flooding in coastal areas, and accelerate damage to coastal infrastructure such as piers and other coastal structures (Parera et al 2024).

The importance of mangrove ecosystems, which are highly vulnerable to change, requires continuous monitoring to detect threats from human activities and natural disasters. Monitoring changes in mangrove ecosystems is essential to evaluate their growth and identify areas that need rehabilitation (Monsef & Smith 2017). Direct monitoring of mangrove forests and coastline damage is not easy due to the difficulty of mapping in the field and the lack of temporal data on mangrove and coastline areas. Therefore, remote sensing techniques are increasingly used as an alternative (Jia et al 2023).

In spite of all the services they provide, mangrove forests are not considered an important environment by many inhabitants in Maumere Bay; they are therefore subject to considerable anthropogenic pressure due to the expansion of residential areas and pressure from traditional agriculture. In addition to these disturbances, mangroves are also targeted for illegal logging. Meanwhile, global temperatures are rising, causing ice near the poles to melt at an increasing rate. This adds to global warming and causes even more ice to melt, creating a vicious cycle that leads to sea level rise and coastal erosion (Sasmito 2020). The coastline is threatened by the impacts of climate change, which affect mangrove dynamics through slow but relentless sea level rise, changes in rainfall patterns, and higher temperatures. Sea water rise is one of the greatest threats to mangrove ecosystems due to the sensitivity of many species to increased salinity, and can lead to the extirpation of these species (Ward et al 2016).

Several organizations investing in environmental issues in the Maumere Bay area, such as the Coral Reef Rehabilitation and Management Program and the NGO Wetlands International, have attempted to mitigate the declining trend in mangrove extent and condition by organizing awareness-raising sessions and training for coastal residents, mangrove reforestation activities, and conferences and workshops. The extent and pattern of coastline change need to be monitored to determine their relationship with changes in mangrove extent and cover. These changes can be monitored using remote sensing approaches (Sasmito 2020).

To harmonize management efforts, it is necessary to understand and map the spatio-temporal dynamics of climate change as measured by indicators of coastline shifts and evaluate their relationship to the dynamics of mangrove extent/cover. Therefore, this study aims to map these dynamics in East Maumere Bay over 30 years (1995-2025) and obtain mathematical equations for the relationship between climate change (as measured by coastline shifts) and anthropogenic factors, with changes in mangrove area/cover in the East Maumere Bay region, Indonesia. The results of this study can inform mangrove restoration and conservation efforts in order to maintain the ecological and economic functions of mangroves amid global climate change.

Material and Method

Time and place. This research was conducted in eastern Maumere Bay, Sikka Regency, East Nusa Tenggara Province, Indonesia. The research location included Kojadoi Island and Talibura Subdistrict (Figure 1), where mangrove ecosystems occur naturally along the coastline. The research was conducted from June to October 2025 in two stages, namely the field data collection stage and the data analysis stage. Field data were collected in June 2025.

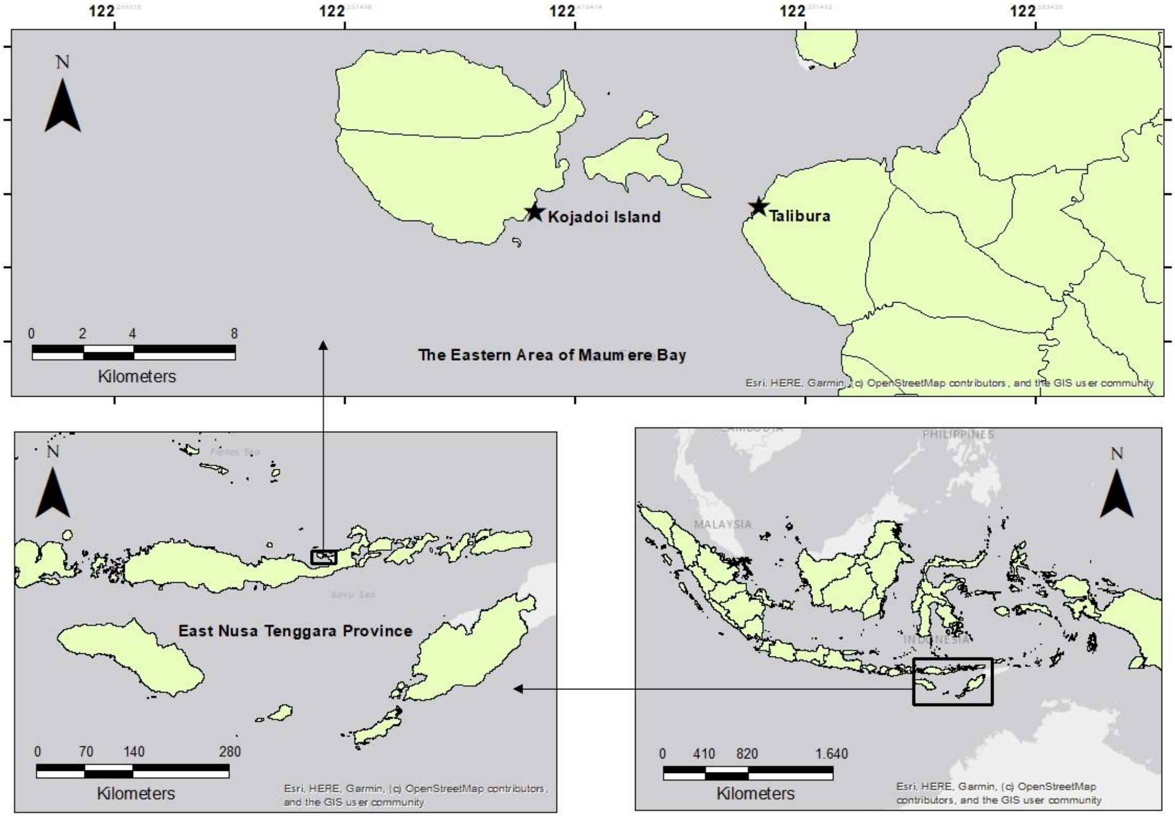

Figure 1. The study sites are in the eastern reaches of Maumere Bay, East Nusa Tenggara Province, Indonesia.

Equipment, materials, and secondary data. The equipment and materials used in this study included computers equipped with ENVI 5.1, ArcGIS 10.4, Ocean Data View 4.7.10, WRPlot View 8, Surfer 13, Microsoft Word, and Excel software. Field observations were conducted using motorboats, roll-up tape measures, nylon ropes, cameras, a GPS unit, and charts of the survey sites. Secondary datasets used in this study are shown in Table 1.

Table 1

Sources of secondary data used in the study

Data type	*Data source*	*Spatial resolution*	*Acquisition time*
Landsat 5 TM	Earthexplorer.usgs.gov	30 m	Data from 1995 (Acquired on August 15, 1995) Data from 2000 (Acquired on January 4, 2000) Data from 2005 (Acquired on August 29, 2005) Data from 2010 (Acquired on February 16, 2010)
Landsat 8 OLI	Earthexplorer.usgs.gov	30 m	Data from 2015 (Acquired on May 21, 2015) Data from 2020 (Acquired on August 22, 2020) Data from 2025 (Acquired on August 12, 2025)
Predicted data tides	http://tides.big.go.id/pasut/	± 0.08171	1995-2025
Bathymetry	http://tides.big.go.id/BATNAS/	180 m	June 2025
Surface current	https://cds.climate.copernicus.eu/	0.0830	2025
Wind	https://cds.climate.copernicus.eu/	0.0830	1995-2025

Data collection. The secondary data used consisted of Landsat 5 TM and Landsat 8 OLI satellite imagery. The Landsat 5 TM and Landsat 8 OLI satellite data acquisitions for the eastern part of Maumere Bay, from Kojadoi Island to Talibura Subdistrict, were from the following dates: August 15, 1995 (1995 data); January 4, 2000 (2000 data); August 29, 2005 (2005 data); February 16, 2010 (2010 data); May 21, 2015 (2015 data); August 22, 2020 (data from 2020); and August 12, 2025 (data from 2025). The images were acquired from the official Earthexplorer.usgs.gov platform. The images were selected for high quality and clarity, and taken during clear weather without thick clouds or overcast skies to reduce distortion caused by pollution or high humidity.

Additional secondary data included bathymetric data from the Indonesian Geospatial Agency (BIG) Bathymetric Office (BATNAS BIG) in raster (*.tif) format; current and wind data from the Copernicus Climate Data Store (https://cds.climate.copernicus.eu/); and tidal prediction data from BIG stored in *.txt format (Fitriana et al 2019).

Field data collection in 2025 included evaluating mangrove cover and composition. Data were collected in 10×10 m (100 m^2) plots at 18 representative points, each representing one pixel in the satellite image. The circumference of each mangrove tree was measured at chest height (±130 cm above the ground) to calculate tree diameter. In addition, the trees were identified to species level based on Noor et al (2012) and counted. The parameters obtained were mangrove tree trunk circumference, diameter, species, and the number of mangrove trees.

Anthropogenic data were collected in two ways. Firstly, through processing satellite images to identify landuse change, in particular the conversion of coastal areas and mangrove forests to settlements, fish ponds, agricultural land, and other uses.

Secondly, through in-depth interviews with 50 respondents selected using purposive sampling with the criterion of being over 45 years of age (it was estimated that these respondents would have a good understanding of the climate change phenomena and other changes that had occurred in the research area since 1995).

Processing satellite data to observe coastline change

Geometric and atmospheric corrections. The first step in image processing is geometric correction to ensure the position of objects in the image matches their actual positions. However, the Landsat 5 TM and Landsat 8 OLI images obtained had already been geometrically and atmospherically corrected by the data provider, so this step was not necessary.

Coastline delineation. The coastline delineation process began with the Single Band Threshold method, which uses the Infrared Band to delineate the coastline using the Infrared Band (Winarso et al 2009) on Landsat 5 TM and Landsat 8 OLI images. The Infrared Band used on each Landsat image was the SWIR-1 Band. This single-band method has weaknesses in the transition zone between land and sea. To minimize inaccuracy, an additional method was used, namely the Band Ratio method, which compares one band with another. The bands used in the Band Ratio method were the Green Band, NIR Band, and SWIR-1 Band. The Green Band was used for land observation. The NIR Band was used for vegetated coastline boundaries. The SWIR-1 band was used to detect coastlines covered by soil and rocks (Winarso et al 2001). Multiplying the Single Band and Band Ratio method outputs produced information for determining land and sea boundaries along the coastline (Alesheikh et al 2007).

Coastline correction for tidal fluctuations. The difference in water level at the time of recording each satellite image will cause a shift in the observed coastline, with the horizontal distance depending on the slope of the coast. According to Kasim (2012), it is very important to apply tidal corrections to each coastline delineation in order to be able to analyse changes over time. This study used Mean Sea Level (MSL) as a reference datum for adjusting the coastline. Each coastline feature obtained was shifted seawards by r at high tide and landwards by r at low tide (Suhana et al 2016).

MSL was obtained from tidal constants predicted by the Indonesian Hydrographic Office (PUSHIDROSAL), so that the coastline shift distance (r) was obtained through the equation (Akhrianti et al 2024):

$$r = \frac{\eta}{\tan \beta}$$

Where:
r = the shift distance
η = the difference in sea surface level
tan β = the tangent of the slope (angle between the surface and the horizontal base) of the beach

Coastal change analysis. The Digital Shoreline Analysis System (DSAS) version 5.1 method is a temporal analysis of shoreline change that can be used in Geographic Information System (ArcGIS 10.4) software. DSAS calculates statistics on the rate of change for a time series of shoreline vector data. This program requires several parameters for measuring shoreline change rates, in particular a baseline, shoreline, and transect data (Himmelstoss et al 2018).

Shoreline change is calculated based on the intersection between the shoreline and the transect. Measurements of shoreline change rate used were End Point Rate (EPR), calculated in m/year, and Net Shoreline Movement (NSM) in meters. EPR is a relatively simple method for measuring or predicting shoreline change (Himmelstoss et al 2018).

Processing of supporting data on coastline change. Supporting data in the form of bathymetric data in raster format (*.tif) was then mapped in ArcGIS 10.4 software using the Bilinear Interpolation method. Current and wind data were stored in *.nc format, processed using Ocean Data View (ODV) V5.4 software, then exported as text files (*.txt) and processed using Microsoft Excel to obtain current and wind speed and direction values. Wind direction and speed were further processed using WRPLOT software to obtain wind rose graphs for the research location. The BIG tidal prediction data used was stored in *.txt format, and processed in Microsoft Excel using the Admiralty method, a tidal calculation method that can determine two harmonic constants, namely amplitude (A) and phase difference, so that tidal type and height can be determined (Fitriana et al 2019).

Image data processing to observe changes in the mangrove area and cover

Band composites and image cropping. A composite image is a new image resulting from the merging of several satellite imagery bands with the same resolution to obtain an image using red, green, and blue colours to represent the combined information contained in the constituent channels and display the results. The bands used in Landsat 5 TM images are 1, 2, 3, and 4, while Landsat 8 OLI uses bands 2, 3, 4, and 5. Mangroves can be clearly seen in such False Colour Composite (FCC) images. The FCC combinations used were bands 4, 3, and 2 for Landsat 5 TM, and bands 5, 4, and 3 for Landsat 8 OLI, with mangrove forests appearing in dark red. The two images were then cropped to focus on the study area, namely the eastern reaches of Maumere Bay, Indonesia.

Image classification. Classification is a process to group pixel reflectance values into specific classes based on the pixel Digital Number (DN). The classification method used was Supervised Classification (Support Vector Machine, SVM). Satellite images recorded in 1995, 2000, 2005, 2010, 2015, 2020, and 2025 were digitally processed to produce maps of the area showing mangrove forest cover over a period of 30 years.

Vegetation index. According to Huete et al (2002), vegetation indices are spectral transformations of two or more bands designed to enhance the contribution of vegetation resulting from photosynthetic activity and variations in canopy structure. The Normalized Difference Vegetation Index (NDVI) is widely used to calculate forest health by combining two bands, namely Red and Near Infrared (NIR). Plants strongly absorb the Red band produced by the sensor, while the near-infrared (NIR) band reflects electromagnetic waves produced by vegetation. The equation for the NDVI vegetation index (Huete et al 2002) is as follows:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Where:
NDVI = Normalized Difference Vegetation Index
NIR = Spectral reflectance values in the near infrared band
R = Spectral reflectance values in the red band.

Healthy vegetation is characterized by high NDVI values and vice versa. NDVI values range from -1 to +1. If the value obtained is negative, the object observed by the sensor is most likely water, while values close to +1 represent vegetation (Pujiono et al 2013).

Anthropogenic factors. The measurement of anthropogenic factors through satellite image data processing used land use change analysis to detect changes such as deforestation, settlement expansion, or other land use/land cover (LULC) changes. In this study, the NDVI (Normalized Difference Vegetation Index) was used to analyse the spatial patterns of land use cover types associated with anthropogenic factors, such as population distribution or economic activity, and to identify anthropogenic (man-made) objects, such as the conversion of mangrove land into buildings, roads, or industrial facilities. The information from LULC spatial analysis was supplemented by data regarding climate change and anthropogenic impacts on mangroves obtained through interviews with respondents at the research site.

Statistical analysis. Linear regression analysis was used to obtain mathematical equations for the reciprocal relationships between paired variables representing the spatiotemporal dynamics of the coastline from 1995 to 2025 and the spatiotemporal dynamics of mangroves from 1995 to 2025. In addition, the strength of the relationship between variables was determined through correlation analysis using the Pearson method. The Y (dependent) variable estimation model used three types of regression equations, namely simple linear regression, polynomial regression, and exponential regression. The Y variable estimation model producing the highest coefficient of determination was selected for each pair of variables, as the coefficient of determination reflects the accuracy, or how well the model represents reality. The following regression analyses were performed:

a. The relationship between changes in coastline (abrasion, meters) as variable X, and changes in mangrove extent (hectares) as variable Y.

    The rationale, according to the findings of Ward et al (2016), is that coastlines continue to be threatened by the impacts of climate change, which affect mangrove dynamics through sea level rise. Sea water is one of the greatest threats to mangrove ecosystems due to their sensitivity to increased salinity, which affects species specific to this ecosystem and can lead to extirpation (extinction at the local level).

b. The relationship between changes in mangrove extent (hectares) as variable X, and changes in coastline (accretion, meters) as variable Y.

    The rationale, according to the results of research by Kumara et al (2010), is that mangrove density contributes to the rate of accretion, sediment distribution, and surface elevation; Parera et al (2024) explain that the relationship between mangroves and coastlines is interrelated; if mangrove cover is moderate to high, the coastline will experience accretion, and if the density is low, it will experience abrasion. Bengen (2001) explains that mangrove forests are one of the best defences to protect coastal areas from abrasion.

Results and Discussion

Coastal change. The coastline is an imaginary line that marks the meeting point between land and water, where the water surface (sea) is periodically dynamic, but a specific, fixed water level is selected (Poerbandono & Djunarsjah 2005). The coastline describes the meeting point between water and land in coastal areas at the highest high tide level (BSN 2010).

In general, changes in the coastline, both abrasion and accretion, have been observed along the coast of Kojadoi Island and Talibura District from 1995 to 2025. An example of coastline changes over 30 years in eastern Maumere Bay (Zone A and Zone B) can be seen in Figure 2. The changes in the coastline are shown by the distance between the coastline shown in red and the coastline shown in blue. The red line represents the coastline in 1995, while the blue line represents the coastline in 2025.

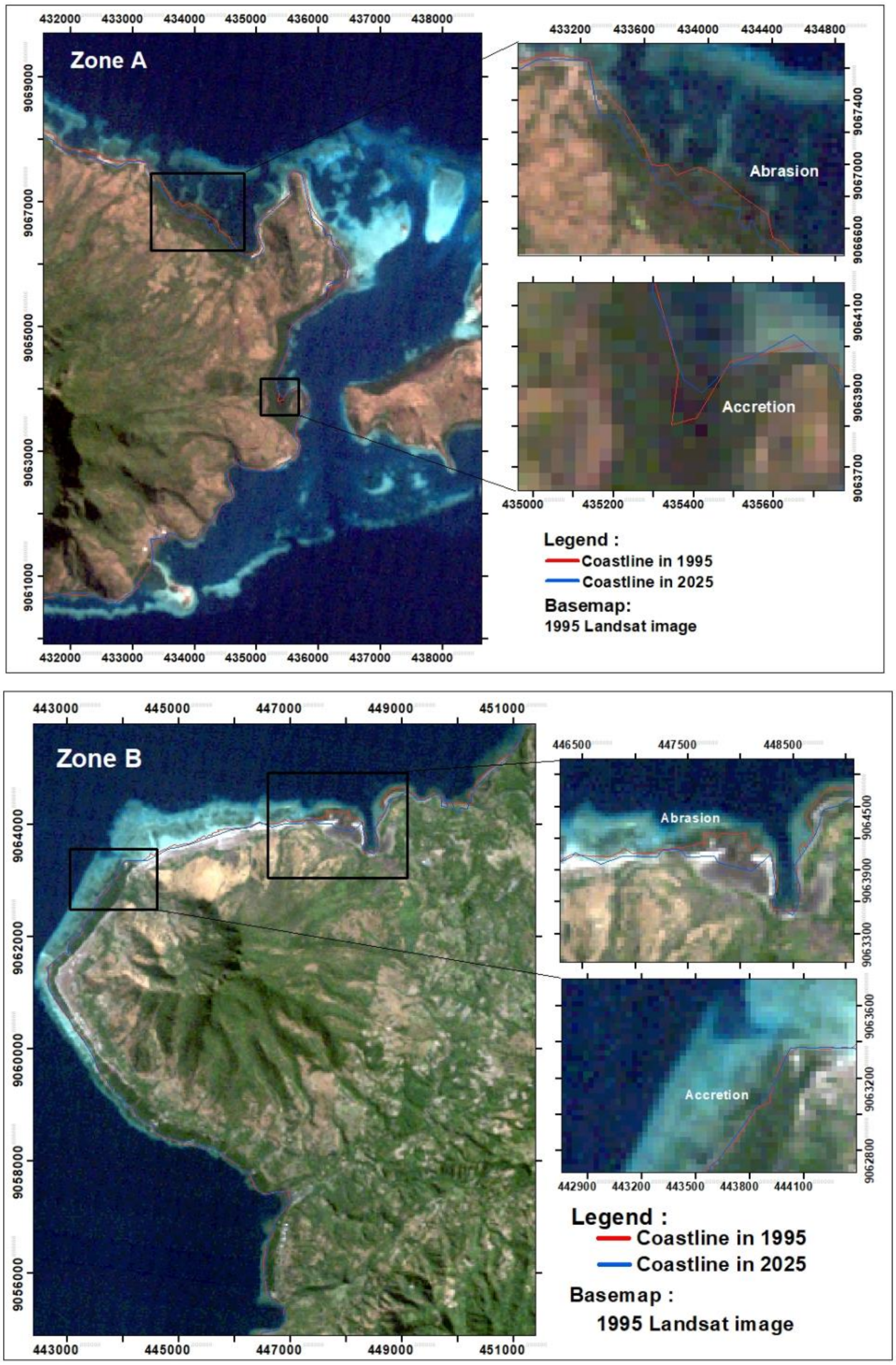

Figure 2. Changes in coastline shape in selected areas of eastern Maumere Bay from 1995 to 2025 based on Landsat imagery

The DSAS analysis covered two zones in eastern Maumere Bay: zone A (Kojadoi Island) and zone B (Talibura Subdistrict), and was able to detect the average distance of coastline shift and determine the areas with the most significant changes. The spatial resolution was 30 m, giving 30 m-wide onshore-offshore transects. The extent (width) and direction (accretion or abrasion) of coastline change in eastern Maumere Bay over the 30 year period from 1995 to 2025 can be seen in Figure 3.

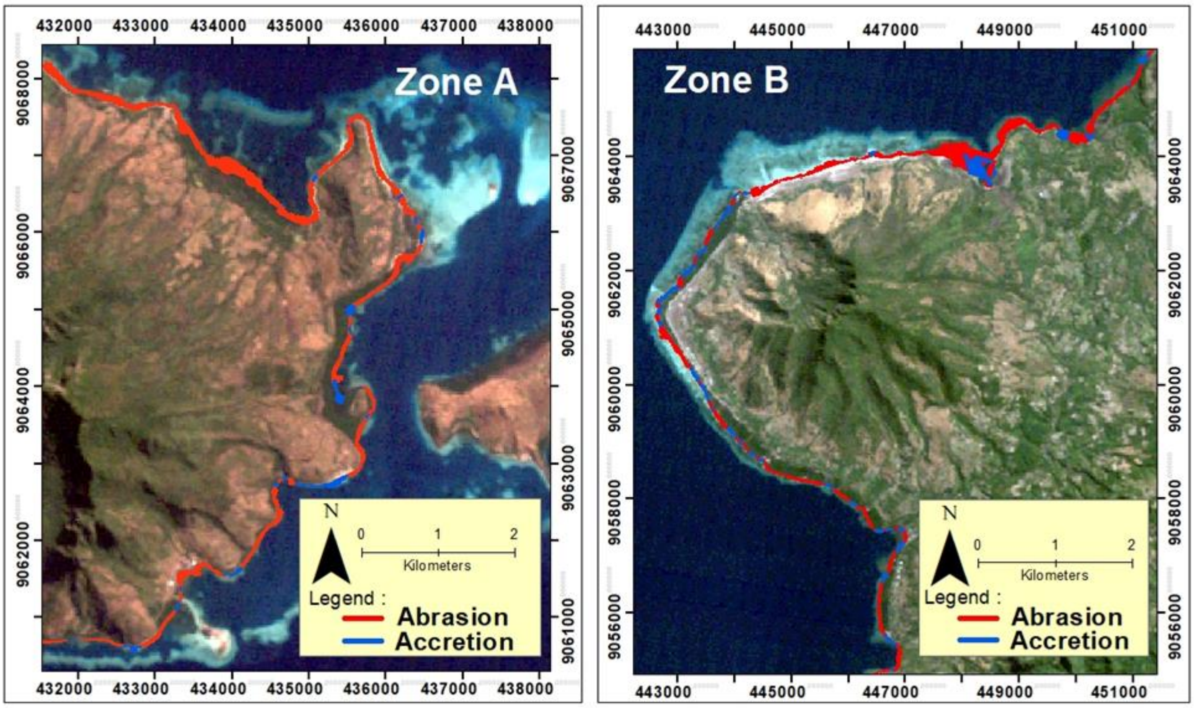

Figure 3. Coastline change between 1995 and 2025 in two observation zones within eastern Maumere Bay: (A) Kojadoi Island, (B) Talibura Subdistrict.

According to Triatmodjo (1999), abrasion is the process of coastal erosion by ocean waves and currents caused by natural and human factors, such as sea level rise due to global warming or environmentally unfriendly human activities that result in a reduction in the extent of coastal land above sea level, shifting the coastline inland. Meanwhile, accretion is the process of increasing the extent of coastal land above sea level, shifting the coastline seawards, and is mostly caused by sedimentation, which is the process of depositing materials such as sand and mud on the coast, and can be affected by human activities inland and along the coast. The spatiotemporal dynamics (spatial changes over time) on the coastline can be clearly seen through Landsat satellite imagery, as the detected changes are greater than the spatial resolution of the satellite imagery used (30 m pixels). Shifts in the coastline (Table 2 and Table 3) show that abrasion and accretion, which are natural processes, can occur simultaneously over each time period in both zones (A and B) studied in eastern Maumere Bay.

Maximum and minimum abrasion and accretion describe the highest and lowest values, respectively, based on the DSAS results, representing the points in each zone with the greatest and least shift in each direction over the full 30 years and over every five years. Coastline shift varied considerably between the six five-year periods. At both sites, there was a biennial pattern of alternating years with higher abrasion/lower accretion and vice versa. The pattern was reversed between the two sites, with high abrasion at site A coupled with low abrasion at site B, and so on. In Zone A (Kojadoi Island), abrasion was greatest during the periods 2000 to 2005, and 2020 to 2025 while accretion was greatest in 2005-2010 and 2015-2020, with an overall net abrasion of -216.04 m over 519 (86%) of the pixel transects and net accretion of 102.73 m over 102 (14%) transects. In Zone B (Talibura Subdistrict), over a period of 30 years (1995-2025), net abrasion reached -436.99 m over 540 (69.9%) of pixel transects, and accretion reached 185.49 m over 233 (30.1%) transects.

Table 2
Coastline changes (abrasion) >1 pixel (30 meters) from 1995 to 2025 in the eastern reaches of Maumere Bay

Time period	*Zone A (Kojadoi Island)*			*Zone B (Talibura Subdistrict)*		
	Number of transects	*Maximum (m)*	*Minimum (m)*	*Number of transects*	*Maximum (m)*	*Minimum (m)*
1995-2000	287	-71.23	-0.07	693	-367.30	-0.002
2000-2005	511	-141.45	-0.14	254	-203.34	-0.0001
2005-2010	193	-128.21	-0.08	623	-157.49	-0.09
2010-2015	384	-96.29	-0.003	146	-91.62	-0.004
2015-2020	204	-81.82	-0.03	572	-116.14	-0.028
2020-2025	467	-130.05	-0.07	261	-194.38	-0.32
1995-2025	519	-216.04	-0.07	540	-436.99	-0.03

Table 3
Coastline changes (accretion) >1 pixel (30 meters) from 1995 to 2025 in the eastern reaches of Maumere Bay

Time period	*Zone A (Kojadoi Island)*			*Zone B (Talibura Subdistrict)*		
	Number of transects	*Maximum (m)*	*Minimum (m)*	*Number of transects*	*Maximum (m)*	*Minimum (m)*
1995-2000	334	112.42	0.10	85	145.95	0.18
2000-2005	122	59.29	0.10	519	132.99	0.00008
2005-2010	434	75.39	0.09	148	119.47	0.29
2010-2015	240	106.11	0.19	632	148.30	0.55
2015-2020	419	966	0.27	196	188.36	0.97
2020-2025	156	86.57	0.01	493	111.03	0.46
1995-2025	102	102.73	0.12	233	185.49	0.01

Coastline changes basically involve abrasion and accretion processes that can occur naturally due to natural factors such as climate change and human activities. Accretion and abrasion occur along with the advance and retreat of the coastline. Due to the influence of sediment transport along the coast, sediment can be transported over considerable distances and cause coastline changes far from the source. Abrasion can cause damage to coastal infrastructure, such as buildings and roads, and threaten the safety of residents (Triatmojo 1999). Meanwhile, accretion can cause changes in the shape of the coast and the expansion of land area, creating new habitats for flora and fauna, silting up ports and estuaries, and can cause or worsen flooding around the estuary and in the lower reaches of rivers when river water discharge is high (Bird & Ongkosongso 1980).

The depth and bathymetric profile of coastal waters were found to be factors supporting coastline change in the study area. The isobaths tend to be parallel to the coastline, where the gentle slope and shallow waters enable sediment resuspension, which is influenced by the speed and direction of wind and water movement, including wave action and tidal currents (Darmiati et al 2020). Over the 30-year study period (1995-2025), on average, the winds in eastern Maumere Bay (Kojadoi Island and Talibura District) most often blew from the west (22.9%), with the highest wind speeds recorded during west and northwest (13.7%) winds (Figure 4). The next most frequent direction with the second-highest wind speeds was from the south (18.3%). Windspeed was generally low when the winds blew from the southeast, east, and northeast, with rare and light winds from the north and no recorded winds from the southwest.

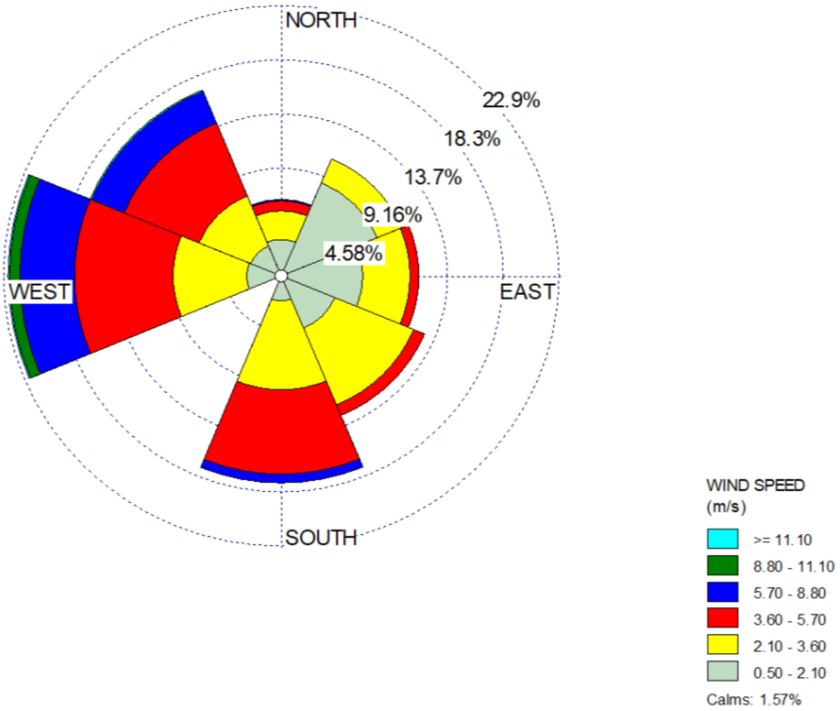

Figure 4. Wind speed and direction in eastern Maumere Bay from 1995 to 2025.

The beaches along the eastern coast of Maumere Bay (Kojadoi Island and Talibura District) are influenced by water movement driven by the monsoon winds as well as tidal factors. Surface currents in the research area irregularly change direction during the west monsoon (December-March), and longshore currents frequently occur. Longshore currents cause coastal abrasion due to sediment movement, and if the sediment is subsequently carried to a location where the influence of longshore currents is reduced, it will also result in accretion (Ukkas 2009). Analysis of the data obtained indicates that during the east monsoon (August-November), the currents typically move towards the southeast. During the west monsoon, the current velocity ranges from 0.005 to 0.775 m s^{-1}, while during the east monsoon, it ranges from 0.014 to 0.584 m s^{-1}. During the transition season, current velocity ranges from 0.01 to 0.6 m s^{-1} moving in a southeasterly direction. The tides along the coast from Kojadoi to Talibura are mixed semi-diurnal tides, which means that there are two high and low tides in a day, but one tide is stronger than the other (Pariwono 1999). Data on the tidal amplitude and pattern in the eastern waters of Maumere Bay in August 2025 are shown in Figure 5.

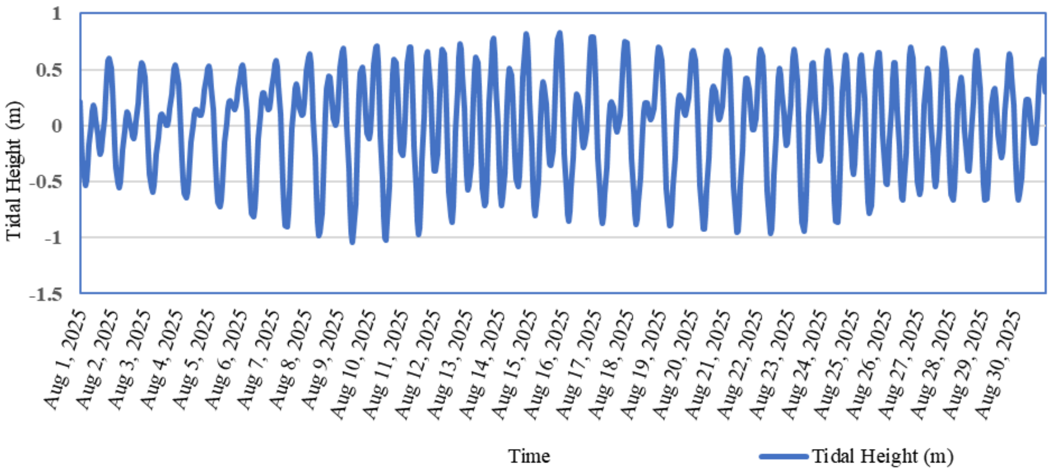

Figure 5. Tidal amplitude and patterns in Sikka Regency Waters in August 2025.

Changes in mangrove cover and area

Classification of mangrove land cover. Most mangrove ecosystems in the study area are located in coastal environments dominated by muddy and sandy substrates. Observations in the mangrove ecosystems of Kojadoi Island and Talibura Subdistrict identified six true mangrove species, namely *Avicennia alba*, *A. marina*, *Rhizophora apiculata*, *R. mucronata*, *Sonneratia alba*, and *Bruguiera gymnorrizza* (Figure 6). *Rhizophora apiculata* was the most abundant and widespread mangrove species in eastern Maumere Bay, with 182 trees in 18 plots, including 57 on Kojadoi Island, 106 at Darat Pantai, and 19 in Nangahale, both on the Talibura coast. The differences in mangrove species composition at these three locations can be attributed to differences in human population density, where more densely populated areas, such as Nangahale, exert greater pressure on mangroves, thereby reducing the number of species compared to Kojadoi Island, which has a sparse human population and a higher number of species. The higher pressure on mangroves in Nangahale compared to Kojadoi Island included the construction of settlements, port infrastructure, roads, and pollution. In comparison, mangrove ecosystems in other locations along the Talibura coast are in moderate condition (Vincentius et al 2025).

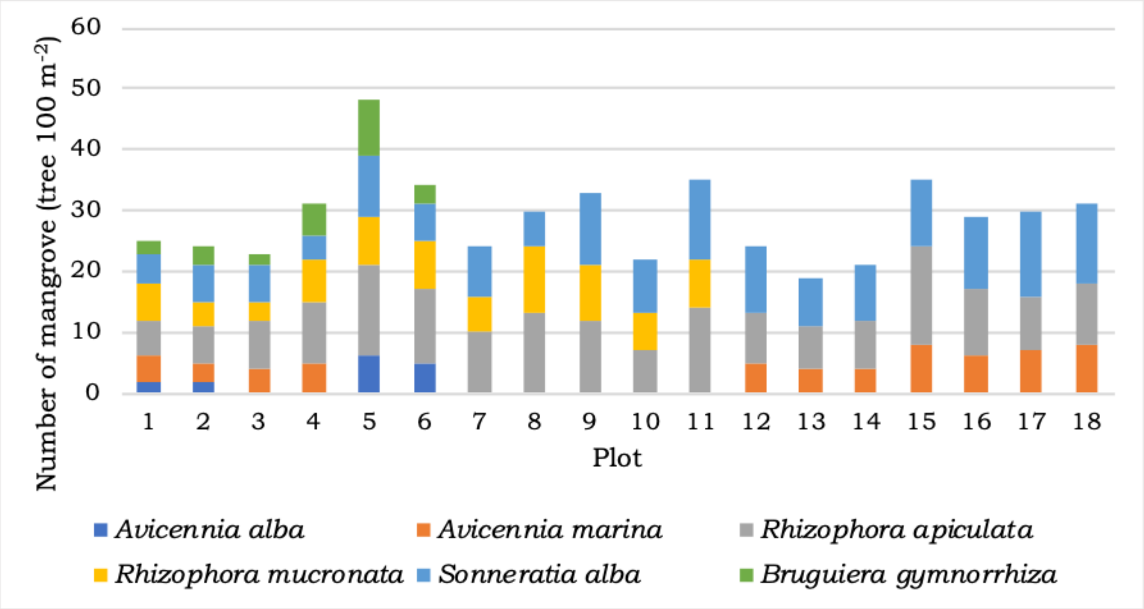

Figure 6. Mangrove community species composition (number of mangrove trees per species) in 18 (10 x 10 m) plots in Kojadoi Island and Talibura Subdistrict, eastern Maumere Bay, in 2025.

The classification of mangrove land cover over 30 years (1995-2025) reveals many changes in mangrove condition, based on mangrove canopy density classes (Table 4 and in mangrove ecosystem extent (Table 5). These changes were likely caused by a combination of natural factors and changes in land use (LULC) due to interactions with human communities around the bay (Parera et al 2024), similar to the natural and anthropogenic factors causing mangrove degradation in Riau (Jhonnerie 2014).

Table 4
Mangrove extent and density classes in eastern Maumere Bay from 1995 to 2025

Year	*Zone A (Kojadoi Island) (Ha)*				*Zone B (Talibura Subdistrict) (Ha)*			
	Area	*Mangrove density class*			*Area*	*Mangrove density class*		
		Low	*Medium*	*High*		*Low*	*Medium*	*High*
1995	132.21	25.29	41.49	65.43	181.89	9.63	98.01	74.25
2000	109.89	21.51	62.28	26.1	163.08	20.16	48.78	94.14
2005	116.28	15.84	46.71	53.73	182.88	24.21	102.78	55.89
2010	105.66	12.78	42.84	50.04	210.24	33.12	115.74	61.38
2015	121.86	23.4	45.54	52.92	205.61	14.49	48.65	142.47
2020	110.79	7.47	25.83	77.49	248.67	17.19	53.82	177.66
2025	94.50	3.78	36.72	54	238.80	36	47.55	155.25

Table 5
Changes in mangrove ecosystem extent in eastern Maumere Bay from 1995 to 2025

Time period	*Zone A (Kojadoi Island) (Ha)*		*Zone B (Talibura Subdistrict) (Ha)*	
	Decreased (Ha)	*Increased (Ha)*	*Decreased (Ha)*	*Increased (Ha)*
1995-2000	39.06	16.74	48.42	29.61
2000-2005	27	33.39	29.61	49.41
2005-2010	25.83	15.21	41.49	68.85
2010-2015	15.48	31.68	24.48	20.24
2015-2020	28.44	17.37	4.4	47.07
2020-2025	20.97	4.68	24.3	14.13
1995-2025	49.05	11.34	32.85	89.46

Changes in mangrove extent can be caused by several factors, including climate change, human activities, and natural processes such as abrasion and accretion (Kuenzer et al 2011). Abrasion can cause a reduction in mangrove extent due to soil erosion and damage to mangrove vegetation, while accretion can increase mangrove extent due to sedimentation and the accumulation of organic material (Alongi 2002). Tables 3 and 4 show changes in the area of mangroves in Zone A of Kojadoi Island during the period 1995-2025, with mangrove extent increasing by 49.05 ha and decreasing by 11.34 ha, giving a net reduction in mangrove extent of 37.71 ha, from 132.21 ha in 1995 to 94.50 ha in 2025. Changes in Zone B of Talibura Subdistrict from 1995 to 2025 occurred in the opposite direction, with an increase in mangrove extent (89.46 ha) greater than the decrease in mangrove extent (32.85 ha), resulting in a net increase in mangrove extent of 56.91 ha, from 181.89 ha in 1995 to 238.80 ha in 2025. The increase in mangrove extent in Zone B of Talibura Subdistrict may be due to several factors, including natural processes such as accretion and sedimentation, as well as effective mangrove conservation and management efforts (Giri et al 2011). Accretion can increase the area of mangroves due to the process of sedimentation and accumulation of organic material, thereby enabling the growth of new mangrove vegetation (Alongi 2002). Changes in the extent of mangrove ecosystems in eastern Maumere Bay can be seen in Figure 7.

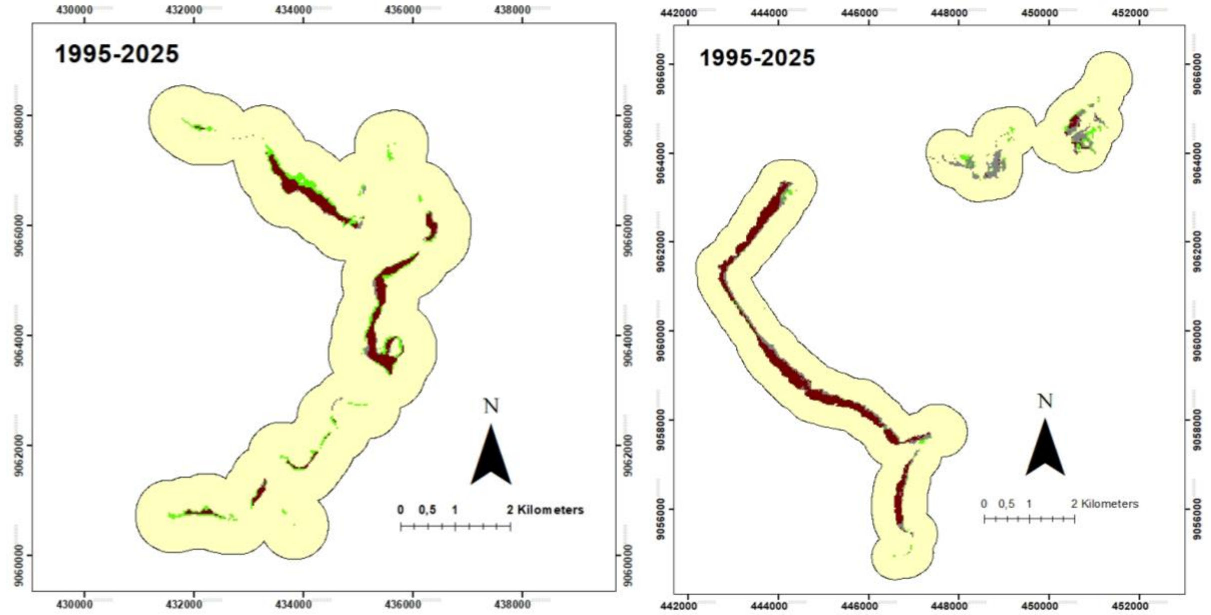

Figure 7. Changes in mangrove ecosystem extent in eastern Maumere Bay (1995-2025) based on the classification of satellite imagery.

During the field survey, mangrove trees were often found to have been cut down for various purposes, such as for use as building materials, fuel, and clearing paths for fishing boats. Serious attention from all stakeholders is urgently needed to ensure the sustainability and maintain the health and existence of mangrove ecosystems around the coasts of Kojadoi Island and Talibura District. Many studies have sounded the alarm to protect mangroves from degradation and deforestation (FAO 2007; Polidoro et al 2010; Giri et al 2011). The role of the government, especially the local government of Sikka Regency, is vital and urgently needed, as a facilitator and catalyst for proactive and productive development in mangrove management, as well as support and opportunities for local communities in community-based management (Datta et al 2012). The interviews revealed that mangrove reforestation efforts continue to be pursued by facilitating local community groups to carry out mangrove management activities, including mangrove planting and socialization. These activities are carried out by government agencies, students, and other community groups.

The relationship between changes in the coastline and mangrove extent. The relationship between coastline shifts and mangrove ecosystems can be complex, but in general, abrasion tends to cause a reduction in mangrove extent due to soil erosion and damage to mangrove vegetation, while accretion can increase mangrove extent due to sedimentation and the accumulation of organic material, and mangroves themselves can promote sediment deposition and accretion. Therefore, in the regression analysis of the relationship between abrasion and changes in mangrove extent, abrasion is the independent variable (X) and mangrove extent is the dependent variable (Y). Conversely, in the relationship between mangrove extent change and accretion, mangrove extent is the independent variable (X) and accretion is the dependent variable (Y).

Zone A (Kojadoi Island). The relationship between abrasion and change in mangrove extent was calculated after quadratic transformation of the data from 1995 to 2025. Regression analysis produced a polynomial equation (Figure 8) with a higher R^2 value than linear or exponential regression.

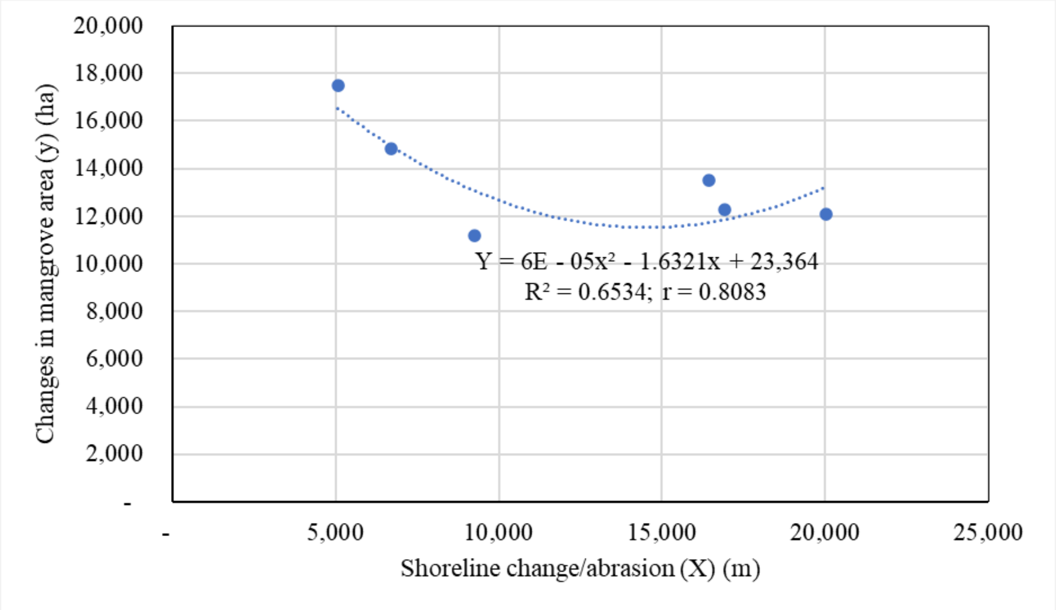

Figure 8. Polynomial regression of the relationship between coastal abrasion and the change in mangrove extent at Kojadoi Island, eastern Maumere Bay (1995-2025) (very strong correlation between X and Y).

The polynomial regression equation (Y = 6E-05X^2 - 1.6321X + 23,364, R^2 = 0.6534, r = 0.8083) indicates that variable X (abrasion) can explain 65.34% of the variation in variable Y (change in mangrove extent), while 34.66% of the variation in variable Y cannot be explained by variable X. The correlation coefficient (r) value of 0.8083 indicates a very strong correlation between variables X and Y. Compared to the equation from an analysis of coastline changes and mangrove extent in Kendal (Hazazi et al 2019) where Y=74.24X-41.856 with an R^2 value of 0.3514, this study yielded a higher coefficient of determination. This indicates that the polynomial regression model used in this study can explain the variation in the data better than the regression model used by Hazazi et al (2019).

The regression analysis of the relationship between variable X (changes in mangrove extent) and variable Y (accretion) also produced a polynomial regression equation (Figure 9) with a higher R^2 value compared to linear or exponential regression.

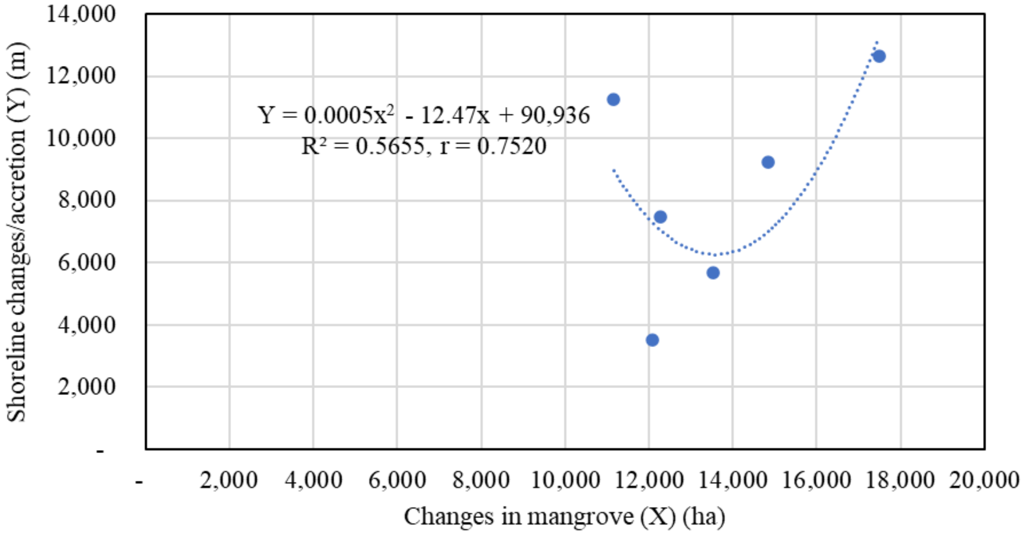

Figure 9. Polynomial regression of the relationship between the change in mangrove extent and accretion at Kojadoi Island, eastern Maumere Bay (1995-2025) (strong correlation between X and Y).

The polynomial regression equation ($Y = 0.0005X^2 - 12.47X + 90{,}936$, $R^2=0.5655$, $r = 0.7520$) indicates that variable X (change in mangrove extent) can explain 56.55% of the variation in variable Y (accretion), while 43.45% of the variation in variable Y cannot be explained by variable X. The correlation coefficient (r) value of 0.7520 indicates a strong correlation between variables X and Y.

Zone B (Talibura Subdistrict). The relationship between abrasion and changes in mangrove extent was calculated after quadratic transformation of the data from 1995 to 2025, as shown in Figure 10.

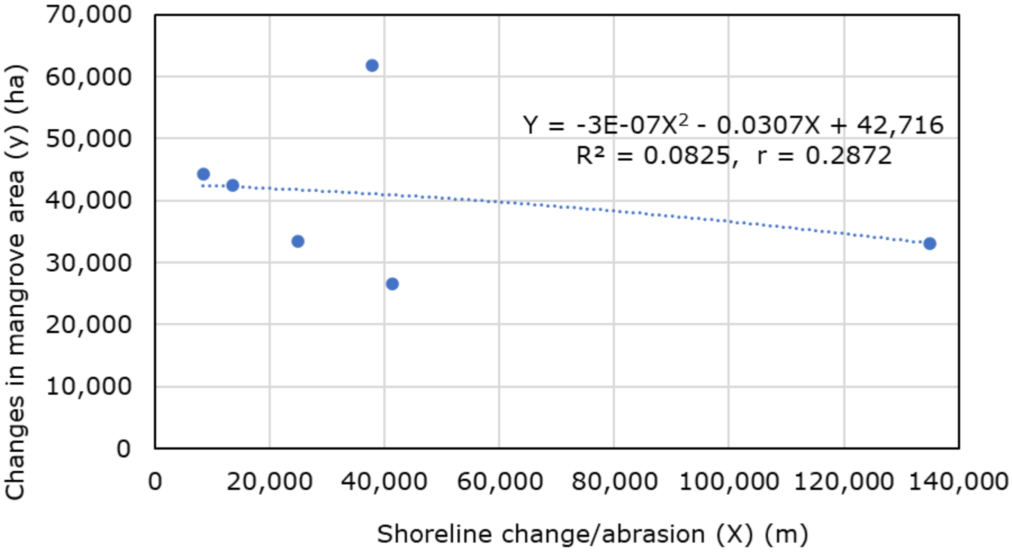

Figure 10. Polynomial regression of the relationship between coastal abrasion and the change in mangrove extent in Talibura District, eastern Maumere Bay (1995-2025)

Regression analysis produced a polynomial equation ($Y = -3E\text{-}07X^2 - 0.0307X + 42{,}716$, $R^2 = 0.0825$, $r = 0.2872$). The low R^2 value shows that variable X can only explain about 8.25% of the variation in variable Y. This indicates that the regression model used has a very weak ability to explain the variation in the dependent variable and that other factors affect the dependent variable but are not included in this model, for example, anthropogenic factors, calling for further analysis. Meanwhile, the regression analysis of the relationship between mangrove extent and accretion produced a polynomial regression equation, as shown in Figure 11.

The polynomial regression equation ($Y = -4E\text{-}05X^2 + 3.5665X - 51{,}734$, $R^2 = 0.4857$, $r = 0.6969$) had an R² value of 0.4857, indicating that approximately 48.57% of the variation in variable Y (accretion) can be explained by variable X (change in mangrove extent). The correlation coefficient (r) of 0.6969 indicates a fairly strong correlation between variables X and Y.

These results show that mangroves play an important role in maintaining the balance of coastal ecosystems; however, their ability to increase beach accretion is limited. Previous studies have also shown that mangroves can enhance coastal accretion by trapping sediment and reducing wave energy (Giri et al 2011). However, when mangroves cover too large an area, they can cause a decline in coastal accretion due to excessive retention of sediment in areas of the mangrove ecosystem that do not result in a change in shoreline (Barbier 2012).

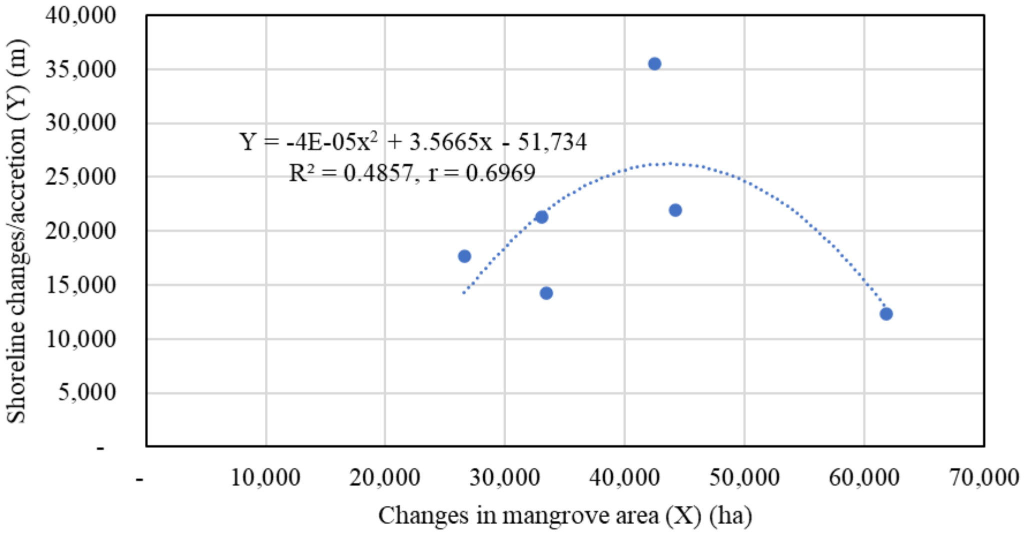

Figure 11. Polynomial regression analysis of the relationship between the change in mangrove extent and accretion in Talibura District, eastern Maumere Bay (1995-2025) (fairly strong correlation between X and Y).

Anthropogenic factors

Satellite image analysis results. The NDVI (Normalized Difference Vegetation Index) analysis of the spatial patterns of anthropogenic objects (LULC) in the eastern part of Maumere Bay from 1995 to 2025 found that there had been a conversion of mangrove land to non-mangrove land, such as cleared or unvegetated (open) land, other vegetation, dryland agriculture, scrub, mixed gardens, rice fields, and built-up land, as presented in Table 6. Based on the data in Table 6, considerable areas of the mangrove ecosystems in the eastern reaches of Maumere Bay were converted to non-mangrove classes during the period 1995-2025. Mangrove ecosystems covering 32.67 hectares (10.4% of the total mangrove extent in 1995) were converted into cleared areas (open land). Mangrove ecosystems covering 70.02 hectares (22.29% of the 1995 extent) were converted to other vegetation, 6.48 hectares (2.06%) to dry land agriculture, 2.43 hectares (0.77%) to scrubland, 38.34 hectares (12.21%) to mixed gardens, 29.34 hectares (9.34%) to rice fields, and 18 hectares (5.73%) to built-up land.

Table 6

Conversion of mangrove land into anthropogenic objects in eastern Maumere Bay (1995-2025)

Years	*Area of mangrove forest converted to anthropogenic objects (ha)*							
	Open land	*Other vegetation*	*Dryland farming*	*Scrub*	*Mixed farms*	*Rice fields*	*Developed land*	*Total*
1995-2000	12.69	23.22	0.09	1.17	15.03		3.24	55.44
2000-2005		8.46	0.27	1.08	0.45	15.12	9.54	34.92
2005-2010	0.27	6.39			0.99		0.18	7.83
2010-2015	18.72	24.66	6.03	0.18	3.51	1.44	4.05	58.59
2015-2020		3.51			0.36		0.81	4.68
2020-2025	0.99	3.78	0.09		18	12.78	0.18	35.82
Total	32.67	70.02	6.48	2.43	38.34	29.34	18	197.28

These anthropogenic factors contribute to changes in the coastline (abrasion and accretion) described by the mathematical equations above. The conversion of mangroves to non-mangrove land uses can cause environmental degradation and loss of biodiversity within and around the mangrove ecosystems (Giri et al 2011). Mangroves play an important role in maintaining the balance of coastal ecosystems, such as protecting beaches from abrasion, providing habitats for marine species, and reducing the impact of climate change (Barbier 2012). Therefore, there is a need for better management of the mangrove ecosystems and human activities in the coastal environments to reduce the negative impacts on mangrove ecosystems.

Results of interviews with respondents. The respondents interviewed mostly (86%) strongly agreed that climate change and anthropogenic factors contribute to the reduction of mangrove cover in the eastern reaches of Maumere Bay. The vast majority (88%) of respondents strongly agreed that climate change has caused an increase in temperature, changes in rainfall patterns, and an increase in the frequency of natural disasters (tidal flooding), which have affected the growth and survival of mangroves. Human activities such as infrastructure development, agriculture, and urbanization have also caused mangrove habitat destruction, pollution, and environmental changes that have affected mangrove growth and survival (90% of respondents strongly agreed). Mangrove cover has declined in recent years, especially in densely populated coastal areas (78% of respondents strongly agree). The interview results show that climate change and anthropogenic factors have contributed to the reduction in mangrove cover, and that there is high awareness of these phenomena. Economic motives also play a role in the reduction of mangrove cover, as human activities are often driven by economic interests, such as property development, agriculture, and industry (Barbier 2012). However, this can lead to environmental degradation and loss of mangrove biodiversity. Therefore, better management of the mangrove environment and human activities is needed to reduce the negative impact on mangrove ecosystems. This can be achieved by raising public awareness not only about the importance of mangrove conservation, but also how this can be achieved, developing policies that support sustainable mangrove management, and increasing community participation in mangrove management (Giri et al 2011).

Conclusions. The results of this study reveal the dynamics of coastline shifts over the period 1995-2025 in eastern Maumere Bay, specifically Kojadoi Island and Talibura Subdistrict. Abrasion and accretion could occur simultaneously due to interactions between natural factors, such as climate change, and anthropogenic factors due to human activities. Abrasion by ocean waves and currents results in a landward shift or retreat of the coastline in some areas, while accretion, the process of coastal expansion caused by sedimentation, results in a seaward shift or advance of the coastline in others. Spatio-temporal dynamics (changes in space and time) on the coastline were clearly visible through DSAS analysis of Landsat satellite imagery.

Factors contributing to coastline change include coastal bathymetry, with isobaths generally parallel to the coastline, sediment resuspension, wind speed and direction, wave action, and tidal currents. The sea and coasts in the eastern reaches of Maumere Bay (Kojadoi Island and Talibura Subdistrict) are influenced by monsoonal weather patterns, with the strongest winds predominantly from the west and south.

At Kojadoi Island, changes in mangrove extent in eastern Maumere Bay were significantly related to coastline changes (abrasion and accretion). The regression equations indicate very strong correlations between the variables at this site. In Talibura Subdistrict, the correlation between changes in mangrove extent and abrasion was very weak, indicating the need to explore other factors not included in this model, such as anthropogenic factors. There was a fairly strong correlation between changes in mangrove extent and accretion at this site.

Anthropogenic factors, such as land use, also contribute to changes in mangrove extent and coastline advance or retreat. There has been extensive conversion of mangrove ecosystems since 1995, with large areas becoming cleared (bare or open) land or covered in scrub and other vegetation, as well as conversion to various agricultural uses and built-up land. There is high awareness among the local community that human activities and climate change can cause damage to mangrove habitats and result in environmental changes that can affect mangrove growth and survival. Better management of the mangrove environment and human activities is needed to reduce the negative impacts on mangrove ecosystems. This can be done by developing policies that support sustainable mangrove management, raising public awareness of and capacity for mangrove conservation, and increasing community participation in the management of coastal resources, especially mangrove ecosystems.

Acknowledgements. The authors would like to thank the Director of Research, Technology, and Community Service (DRTPM) and his team at the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia for funding this research in 2025-2026 through the Directorate General of Higher Education, Research, and Technology.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Adame M. F., Connolly R. M., Turschwell M. P., Lovelock C. E., Fatoyinbo T., Lagomasino D., Goldberg L. A., Holdorf J., Friess D. A., Sasmito S. D., Sanderman J., Sievers M., Buelow C., Kauffman J. B., BryanBrown D., Brown C. J., 2021 Future carbon emissions from global mangrove forest loss. Global Change Biology 27(12):2856-2866.

Akhrianti I., Nugraha M. A., Gustomi A., Arizona M. O., 2024 The mapping of shoreline change caused by accretion and abrasion as an impact of tin minning in Pangkalpinang. Jurnal Kelautan: Indonesian Journal of Marine Science and Technology 17(3):243-251.

Alesheikh A. A., Ghorbanali A., Nouri N., 2007 Coastline change detection using remote sensing. International Journal of Environmental Science & Technology 4(1):61-66.

Alongi D. M., 2002 Present state and future of the world's mangrove forests. Journal Environmental Conservation 29(3):331-349.

Arifanti V. B., Sidik F., Mulyanto B., Susilowati A., Wahyuni T., Subarno, Yulianti, Yuniarti N., Aminah A., Suita E., Karlina E., Suharti S., Pratiwi, Turjaman M., Hidayat A., Rachmat H. H., Imanuddin R., Yeny I., Darwiati W., Sari N., Hakim S. S., Slamet W. Y., Novita N., 2022 Challenges and strategies for sustainable mangrove management in Indonesia: a review. Forests 13(5):695.

Barbier E. B., 2012. The blue economy: a report to the European Commission. European Commission, Brussels.

Barbier E. B., 2016 The protective service of mangrove ecosystems: a review of valuation methods. Marine Pollution Bulletin 109(2):676-681.

Barbier E. B., Hacker S. D., Kennedy C., Koch E. W., Stier A. C., Silliman B. R., 2011 The value of estuarine and coastal ecosystem services. Ecological Monographs 81(2):169-193.

Beck M. W. & Lange G. M., 2016 Managing coasts with natural solutions: guidelines for measuring and valuing the coastal protection services of mangroves and coral reefs. WAVES. Wealth Accounting and the Valuation of Ecosystem Services. World Bank Group. Washington DC 167 p. www.wavespartnership.org

Bengen D. G., 2001 Technical guidelines for the introduction and management of mangrove ecosystems. PKSPL, Coastal and Marine Resources Research Center. Bogor: Institut Pertanian Bogor.

Bhokaleba B. P., Erfin E., 2022 [Perceptions of the northern coastal community of Sikka Regency regarding the function of mangroves as tsunami barriers]. Papalele: Journal of Social and Economic Research on Fisheries and Marine Affairs 6(2):68-74. [in Indonesian]

Bird E. C. F., Ongkosongo O. S. R., 1980 Environmental changes on the coasts of Indonesia. The United Nations University. United Nations University Press, Japan, 52 p.

Blaber S. J. M., 2007 Mangroves and Fishes: Issues of Diversity, Dependence, and Dogma. First International Symposium on Mangroves as Fish Habitat Keynote Address. Bulletin of Marine Science 80(3):457-472.

Darmiati, Nurjaya I. W., Atmadipoera A. S., 2020 [Analysis of coastline changes in the west coast region of Tanah Laut Regency, South Kalimantan]. Jurnal Ilmu dan Teknologi Kelautan Tropis 12(1):211-222. [in Indonesian]

Datta D., Chattopadhyay R. N., Guha P., 2012 Community based mangrove management: a review on status and sustainability. Journal of Environmental Management 107:84-95.

Egnankou W. M., 2010 [Rehabilitation of mangroves between Fresco and Grand-Lahou in Côte d'Ivoire: Important fishing areas. The importance of mangrove forests for fishing, wildlife and water resources in Africa]. Nature and Faune 24(1):85-143. [in Franch]

Field C. D., 1995 Impact of expected climate change on mangroves. Hydrobiologia 295(1):75-81.

Fitriana D., Oktaviani N., Khasanah I. U., 2019 [Tidal harmonic analysis using the admiralty method at stations less than 50 km away]. Jurnal Meteorologi Klimatologi dan Geofisika 6(1):38-48.

Gedan K., Kirwan M., Wolanski E., Barbier E., Silliman B., 2011 The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. Climatic Change 106(1):7-29.

Giri C., Ochieng E., Tieszen L. L., Zhu Z., Singh A., Loveland T., Masek J., Duke N., 2011 Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20(1):154-159.

Halim M. P., Setiawan B., 2023 The potential of mangrove ecotourism as a sustainable ectourism product in the mangrove extent of Kss Beach, Tangerang District. Journal Syntax Transformation 4(11):146-158.

Hamza A. J., Esteves L. S., Cvitanovic M., Kairo J. G., 2024 Global patterns of mangrove resource utilization: a systematic review. Frontiers in Sustainable Resource Management 3:1395724.

Hauhouot C., 2010 [The Assinie coastline in Ivory Coast: coastal dynamics and tourism development]. Les Cahiers d'Outre-Mer. Revue de géographie de Bordeaux 63(251):305-320. [in Franch]

Hazazi G., Sasmito B., Firdaus H. S., 2019 [Analysis of shoreline changes on mangrove existence using remote sensing and digital shoreline analysis system (DSAS) applications in 2014-2018 (Case Study: Kendal Regency)]. Jurnal Geodesi Undip 8(1):19-27. [in Indonesian]

Himmelstoss E. A., Henderson R. E., Kratzmann M. G., Farris A. S., 2018 Digital shoreline analysis system (DSAS) version 5.0 user guide: U.S. Geological Survey Open-File Report 2021-1091, 104 p.

Huete A., Didan K., Miura H., Rodriguez E. P., Gao X., Ferreira L G., 2002 Overview of the radiometric and biophysical performance of the MODIS vegetation indices. remote sensing of environment 83(1-2):195-213.

Jhonnerie R., Siregar V. P., Nababan B., Prasetyo L. B., & Wouthuyzen S., 2014 Mangrove coverage change detection using Landsat imageries based on hybrid classification in Kembung River, Bengkalis Island, Riau Province. Jurnal Ilmu dan Teknologi Kelautan Tropis 6(2):104671.

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.

Kasim F., 2012 [A multi-method approach to monitoring shoreline changes using Landsat remote sensing datasets and GIS]. Jurnal Ilmiah Agropolitan 5(1):620-635.

Koch E. W., Barbier E. B., Silliman B. R., Reed D. J., Perillo G. M. E., Hacker S. D., Granek E. F., Primavera J. H., Muthiga N., Polasky S., Halpern B. S., Kennedy C. J., Kappel C. V., Wolanski E., 2009 Non-linearity in ecosystem services: Temporal and spatial variability in coastal protection. Frontiers in Ecology and the Environment 7(1):29-37.

Kuenzer C., Bluemel A., Gebhardt S., Quoc T. V., Dech S., 2011 Remote sensing of mangrove ecosystems: a review. Remote Sensing 3(5):878-928.

Monsef A. H., Smith S. E., 2017 A new approach for estimating mangrove canopy cover using landsat 8 imagery. Computers and Electronics in Agriculture 135:183-194.

Noor Y. R., Khazali M., Suryadiputra I. N. N., 2012 [An introduction guide to mangroves in Indonesia]. PHKA/Wetlands International Indonesia Programme. Bogor. Indonesia, 220 p. [in Indonesian]

Parera G. R. J., Siregar V. P., Agus S. B., 2024 Mangrove land cover and coastline changes using multi-spectral imagery in Talibura, Sikka District. Journal of Fisheries and Marine Technology 15(1):57-67.

Pariwono J. I., 1999 Oceanographic conditions of Lampung Coastal Waters. Technical Report, Coastal Resources Center, University of Rhode Island. Pp. 3-5.

Poerbandono D., Djunarsjah E., 2005 [Hydrographic survey]. Bandung: Refika Aditama. Refika Aditama, xiv + 166 p. [in Indonesian]

Polidoro B. A., Carpenter K. E., Collins L., Duke N. C., Ellison A. M., Ellison J. C., Farnsworth E. J., Fernando E. S., Kathiresan K., Koedam N. E., Livingstone S. R., Miyagi T., Moore G. E., Nam V. N., Ong J. E., Primavera J. H., Salmo S. G., Sanciangco J. C., Sukardjo S., Wang Y., Yong J. W. H., 2010 The loss of species: mangrove extinction risk and geographic areas of global concern. Plos ONE 5(4):e10095.

Pujiono E., Kwak D. A., Lee W. K., Kim S. R., Lee J. Y., Lee S. H., Park T., Kim M. I., 2013 RGB-NDVI colour composites for monitoring the change in mangrove extent at the Maubesi Nature Reserve, Indonesia. Forest Science and Technology 9(4):171-179.

Sasmito B., 2020 [Analysis of coastline changes due to sea level rise in Demak Regency Coast]. Elipsoida: Jurnal Geodesi dan Geomatika UNDIP 3(2):178-184. [in Indonesian]

Shumway C. A., 1999 Forgotten waters: freshwater and marine ecosystems in Africa, strategies for biodiversity conservation and sustainable development. Boston: Boston University.

Suhana M. P., Nurjaya I. W., Natih N. M., 2016 [Vulnerability analysis of the east coast of Bintan Island using digital shoreline analysis and the coastal vulnerability index]. Jurnal Teknologi Perikanan dan Kelautan 7(1):21-38. [in Indonesian]

Triatmodjo B., 1999 Coastal engineering (teknik pantai). Yogyakarta: Beta Offset.

Ukkas M., 2009 [Abrasion study and sedimentation in the water of Bua-Passimarannu, East Sinjai District, Sinjai Regency]. AKUATIK: Jurnal Sumberdaya Perairan 3(1):20-29. [in Indonesian]

Vincentius A., Nessa M. N., Jompa J., Saru A., Nurdin N., Rani C., 2018 Influential factors analysis towards mangrove cover and production of demersal fish in Maumere Bay, Indonesia. AACL Bioflux 11(3):810-822.

Vincentius A., Parera G. R. J., Woda M. R. R., 2024 [Estimation of mangrove carbon biomass stock using Sentinel-2A satellite images in western Maumere Bay]. Acropora: Jurnal Ilmu Kelautan dan Perikanan Papua 7(2):30-41.

Vincentius A., Parera G. R. J., Woda M. R. R., 2025 Mangrove carbon biomass potency through satellite image analysis in the eastern area of Maumere Bay. Jurnal Teknologi Perikanan dan Kelautan 16(4):370-383.

Walters B. B., Ronnback P., Kovacs J. M., Crona B., Hussain S. A., Badola R., Primavera J. H., Barbier E., Dahdouh-Guebas F., 2008 Ethnobiology, socio-economics and management of mangrove forests: a review. Aquatic Botany 89(2):220-236.

Ward R. D., Friess D. A., Day R. H., and MacKenzie R. A., 2016 Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosystem Health and Sustainability 2(4):e01211.

Winarso G. J., Judijanto, Budhiman S., 2001 The potential application remote sensing data for coastal study. In Proc. 22nd. Asian Conference on Remote Sensing, Singapore. Pp. 1-5.

Winarso G., Joko H., Arifin S., 2009 Study of the use of remote sensing data for coastline mapping (Case study of the North Coast of Jakarta). Jurnal Penginderaan Jauh dan Pengolahan Data Citra Digital 6(1):65-72.

*** BSN [National Standardization Agency], 2010 [Hydrographic Survey]. Jakarta. Available at: https://sni.bsn.go.id. Accessed at: July 2025.

*** FAO (Food and Agriculture Organization), 2007 The World's Mangrove 1980-2005. Rome (IT): FAO. Available at: https://www.fao.org/4/a1427e/a1427e00.pdf?utm_source=chatgpt.com. Accessed at: July 2025.

*** NASA (National Aeronautics and Space Administration), 2022 Climate change: how do we know?. Available at: https://climate.nasa.gov/evidence/. Accessed at: July 2025.

*** UNFCCC (United Nations Framework Convention on Climate Change), 2021 The science of climate change. Available at: https://www.ipcc.ch/report/ar6/wg1/?utm_source=chatgpt.com. Accessed at: July 2025.

Received: 19 November 2025. Accepted: 07 January 2026. Published online: 07 April 2026.

Authors:
Angelinus Vincentius, Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: angelinusvincentiustonda@gmail.com
Guido Roberto Jerun Parera, Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: guidoparera0306@gmail.com
Erfin, Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: laerfin@gmail.com
Yuliana Onang, Management Study Program, Faculty of Economics and Business, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: yulianaonangdalopez@gmail.com
Yakobus Nong Randi, Student of Aquatic Resources Management Study Program, Faculty of Food Technology, Agriculture and Fisheries, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: rudyis133@gmail.com
Oktavianus Dje Lali Laru, Student of Management Study Program, Faculty of Economics and Business, Nusa Nipa University, Health Road No. 3, 86111 Maumere, Indonesia, e-mail: djevicky50@gmail.com

How to cite this article:
Vincentius A., Parera G. R. J., Erfin, Onang Y., Randi Y. N., Laru O. D. L., 2026 Spatio-temporal dynamics of mangroves in Eastern Maumere Bay (Indonesia) in relation to climate change and anthropogenic pressures. AACL Bioflux 19(2):607-628.