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Research Article

Analysis of Coastline Changes in West Leihitu District Using Landsat Imagery

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Abstract

Coastal areas are currently facing serious threats from changes to the coastline driven by natural forces such as waves, tides, and ocean currents, as well as human activities such as coastal reclamation, development, and mangrove deforestation. Changes in the coastline can directly impact coastal ecosystems and the lives of surrounding communities, especially in areas where economic activity depends on coastal resources. One area experiencing such dynamics is the West Leihitu District in Central Maluku Regency. Field observations indicate that the coastline in this area generally shows a tendency toward shoreline advance (accretion), presumed to be driven by sedimentation processes associated with terrestrial sediment supply and local wave and current dynamics. This condition highlights the importance of conducting a quantitative spatial–temporal analysis of shoreline changes in the area. This study aims to analyze coastline changes in the West Leihitu District from 2015 to 2024 using Landsat 9 satellite imagery and the Geographic Information System (GIS)-based Digital Shoreline Analysis System (DSAS) method. The analysis was conducted spatially and temporally to determine the extent of shoreline shifts, both forward and backward. The image data were processed through radiometric and geometric correction, land-sea boundary delineation, shoreline digitization, and inter-year overlay. The Net Shoreline Movement (NSM) and End Point Rate (EPR) methods were used to calculate the distance and rate of shoreline change. The results of the study show that the coastline varied across five coastal villages: Larike, Wakasihu, Allang, Liliboy, and Hatu. Larike Village experienced the greatest coastline advance, with an average change of 7.05 meters and a rate of 0.78 meters/year, followed by Wakasihu Village, with an average change of 6.69 meters and a rate of 0.74 meters/year. Meanwhile, Allang and Liliboy villages showed a tendency for shoreline retreat, with average changes of 4.25 meters and 0.85 meters, respectively. Hatu village experienced relatively small changes and remained stable.



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Introduction

Coastline changes can have far-reaching impacts, especially for communities dependent on coastal ecosystems. In West Leihitu District, coastal areas are not only residential but also centers of economic activity, such as fishing, tourism, and trade. However, changing environmental conditions due to abrasion, sedimentation, and other external factors have threatened the sustainability of coastal ecosystems and the livelihoods of local communities. If coastline changes are not properly monitored, negative impacts can include the loss of productive land, damage to infrastructure, and the loss of natural habitat for coastal flora and fauna, which are crucial for ecosystem balance. Therefore, continuous monitoring is necessary to detect and understand changes, enabling the implementation of mitigation and adaptation measures. (Pratama and Hermawan, 2021).

The use of remote sensing technology, particularly satellite imagery, has become one of the most effective and efficient methods for monitoring coastal change. Satellite data offers advantages in terms of wide coverage, frequent monitoring, and lower costs compared to conventional field surveys. Landsat satellites, launched in 1972 and continuously updated with cutting-edge technology, provide consistent, long-term data for analyzing changes in Earth's surface. With the launch of Landsat 9, the latest generation in the Landsat satellite series, coastline change analysis can be conducted with improved spectral and temporal resolution, enabling more detailed change detection at local to regional scales (Wahyuni & Ramadhan, 2020).

This study aims to analyze shoreline changes in the West Leihitu District using Landsat 9 satellite imagery data. Through this study, it is hoped that a deeper understanding of the factors influencing shoreline changes in the region can be gained, so that the results can serve as a basis for policymakers in formulating more adaptive and sustainable coastal management strategies. In addition, this study is expected to contribute to a better understanding of the environmental and social impacts of shoreline changes, so that coastal communities can be better prepared to face the environmental changes occurring around them.

Research Method

The research was conducted in West Leihitu District, Central Maluku Regency, with a coastline of approximately 31 km, encompassing five coastal villages: Hatu, Liliboy, Allang, Wakasihu, and Larike. Geomorphologically, this coastal area is dominated by rocky coastlines composed of weathered rock and gravel, with wave abrasion. However, in certain segments, sandy beaches with fine- to medium-grained sediment deposits are found, which generally accumulate in small bays or areas with relatively low wave energy. This variation in beach type influences vulnerability to shoreline changes: sandy beaches tend to be more responsive to wave and current dynamics, while rocky beaches are relatively more stable but still experience changes due to long-term weathering and abrasion. The research situation, conditions, and location are shown in Figures 1-4.

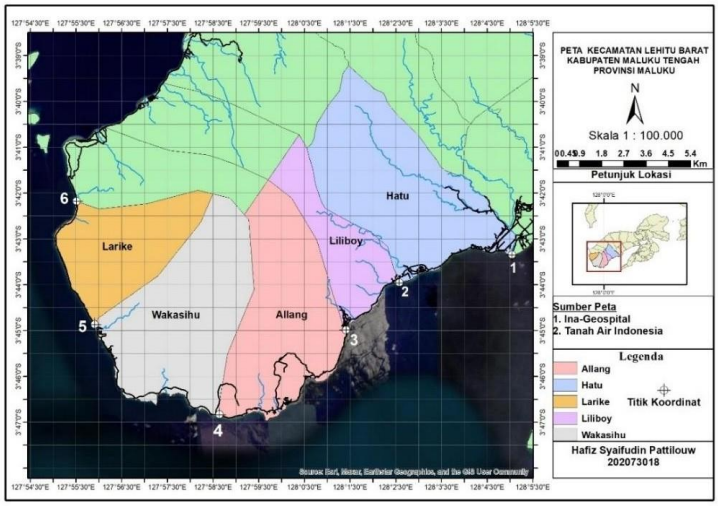


Figure 1. Map of West Leihitu District



Figure 2. Allang Village Beach



Figure 3. Wakasihu Village Beach



Figure 4. Liliboi Village Beach

Data Collection

Landsat 9 imagery was downloaded from USGS EarthExplorer (https://earthexplorer.usgs.gov/) with a cloud-cover threshold of less than 10% to ensure data quality. Data were collected annually from 2015 to 2024, focusing on the dry season (June–September) to minimize cloud interference. Additional data, including 1:50,000-scale topographic maps from the Geospatial Information Agency (BIG) and field data from observations in five villages, were used for validation.

Image Processing

The image processing stages include

1. Image Cropping
   Image cropping is carried out to minimize computer processing time. Data processing is performed entirely on a computer or laptop. The relatively heavy processing power of computer processors is the reason for cropping images. Furthermore, image cropping also aims to maximize the coverage of the research data, particularly in the West Leihtu District.
2. Radiometric Correction
   Image processing is highly susceptible to errors, necessitating further correction. This is crucial because images serve as the baseline for obtaining coastline data. Radiometric correction identifies spectral features of the soil related to image appearance. This is a mandatory part of the data processing process to ensure high-quality visual images and to correct erroneous pixels in the actual object recording.

3. Geometric Correction
   Geometric is a spatially oriented term. Geographical positioning includes latitude and longitude data, known as coordinates. Coordinates on a map reflect the actual location on the ground. With regard to image processing, errors are also possible.
4. Image Sharpening
   Image sharpening begins by selecting an appropriate combination of bands to clearly display coastline features. In this case, a combination of Band 4 (Red), Band 5 (Near Infrared), and Band 6 (Shortwave Infrared 1) from Landsat 9 imagery was used. This combination is chosen because it provides good visual contrast between land and sea.
5. Shoreline Digitization
   Next, the shoreline is manually digitized using onscreen digitizing techniques. Digitization is performed by tracing the boundary between land and water directly on the image, and the results are stored in vector format as the basis for shoreline change analysis.
6. Vector Data Storage
   The digitized shoreline is stored in vector (polyline) format and subsequently used for shoreline change analysis.

DSAS Analysis

Shoreline change analysis was conducted using DSAS version 5.0 software integrated with ArcGIS 10.8. The steps included:

1. Transect Creation: Transects were automatically created every 50 m along the shoreline, perpendicular to a manually defined baseline. A total of 620 transects were generated for the study area.
2. NSM and EPR Calculation: Net Shoreline Movement (NSM) was calculated as the distance of shoreline change between 2015 and 2024, while the End Point Rate (EPR) was calculated as the annual rate of change (NSM divided by the number of years).
3. Interannual Overlay: Annual imagery was overlaid to identify patterns of advance and retreat, with visual validation using Google Earth 2015 and 2024.

Calculation of Change Area

The area of shoreline advance and retreat was calculated by creating change polygons between the 2015 and 2024 images using geoprocessing functions in QGIS. Results were measured in hectares and validated with field data to ensure accuracy of up to 90%.

Validation and Limitations

Validation was conducted by comparing the digitized results with field observations at six points in each village, as shown in Figure 1, using a GPS with 5 m accuracy. Limitations of the study include the spatial resolution of Landsat 9 (30 m), which may limit the detection of small changes, and potential bias from tidal variations during image acquisition.

Results and Discussion

This processing was carried out using the Digital Shoreline Analysis System (DSAS) software. The statistical method used in this study is Net Shoreline Movement (NSM). The zero-point reference line, or baseline, is the 2015 coastline. The 2024 coastline will be used to calculate shoreline changes. The change in distance at each point is analyzed using the Net Shoreline Movement (NSM) and End Point Rate (EPR) methods. Net Shoreline Movement (NSM) is used to calculate the distance of shoreline change, defined as the distance between beach data from the initial and final years on each transect, in meters. Meanwhile, the End Point Rate (EPR) is used to calculate the rate of shoreline change, calculated by dividing the distance of shoreline change between the initial and final shorelines by time. Each computational calculation result can have a (-) or (+) sign. The (+) sign indicates that the shoreline has advanced, while the (-) sign indicates that the shoreline has retreated. Analysis of shoreline changes in the West Leihitu District during 2015–2024 reveals significant variation across villages and time periods. Table 1 summarizes the average NSM and EPR per village based on the DSAS analysis.

Table 1. Average NSM and EPR of Shoreline Change in West Leihitu District (2015–2024)

Village	Type Change	NSM (m)	EPR (m/year)
Larike	Forward	+7,05	+0,78
Wakasihu	Forward	+6,69	+0,74
Allang	Backward	-4,25	-0,47
Liliboy	Backward	-0,85	-0,09
Hatu	Stable	~0	~0

Spatial Change Analysis

Spatially, Larike Village recorded the largest shoreline advance with an average NSM of +7.05 m and EPR of +0.78 m/year, followed by Wakasihu with an NSM of +6.69 m and EPR of +0.74 m/year. Conversely, Allang experienced a significant shoreline retreat with an NSM of -4.25 m and EPR of -0.47 m/year, while Liliboy recorded a smaller shoreline retreat with an NSM of -0.85 m and EPR of -0.09 m/year. Hatu Village exhibited stability with near-zero change, likely due to its more sheltered coastal topography. Shoreline changes along the coast in the West Leihitu District can be seen in Figure 5.

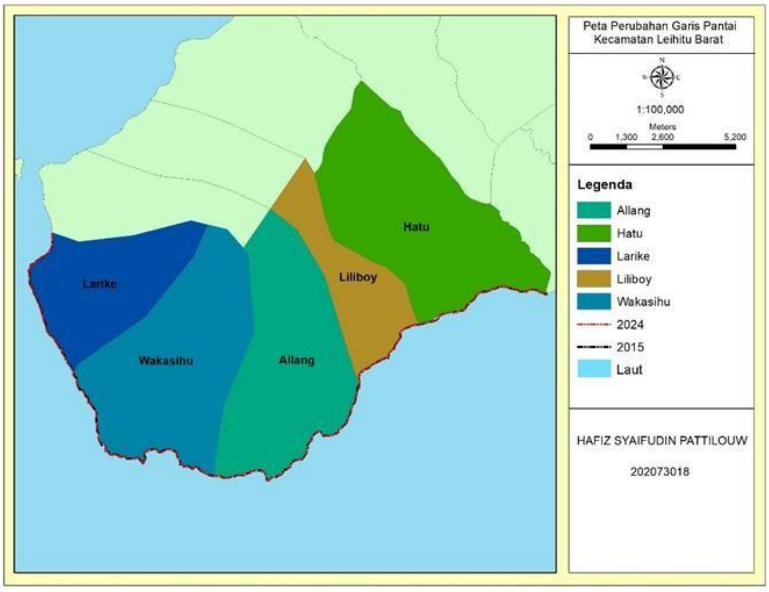


Figure 5. Map of Coastline Changes in West Leihitu District (2015–2024)

Temporal Change Analysis

Temporal analysis shows significant annual fluctuations. Table 2 summarizes the annual shifts in the dominant area of retreating shoreline (Liliboy).

Significant shoreline retreat in 2022–2023 (-20.70 m) at Liliboy is suspected to be due to a combination of strong waves. In contrast, Wakasihu recorded the largest shoreline advance in 2020–2021 (NSM +32.86 m), likely due to intense sedimentation driven by ocean currents. Table 3 shows the annual shifts at Wakasihu.

Table 2. Average Annual Shoreline Shift in Liliboy (2015–2024)

Period	NSM (m)	Description
2015–2016	-0,50	Backward
2016–2017	-0,30	Backward
2017–2018	+0,20	Forward
2018–2019	-0,40	Backward
2019–2020	-0,60	Backward
2020–2021	+0,10	Forward
2021–2022	-0,70	Backward
2022–2023	-20,70	Significant Backward
2023–2024	-0,50	Backward

Table 3. Average Annual Shoreline Shift in Wakasihu (2015–2024)

Period	NSM (m)	Description
2015–2016	+1,50	Forward
2016–2017	+2,10	Forward
2017–2018	-0,80	Backward
2018–2019	+3,20	Forward
2019–2020	+4,50	Forward
2020–2021	+32,86	Significant Forward
2021–2022	+2,30	Forward
2022–2023	-17,07	Significant Backward
2023–2024	+1,80	Forward

Source: Results of processing Landsat 9 satellite image data, 2015–2024

Transect Analysis

Transect analysis in the predominantly retreating shoreline area (Liliboy) showed the highest shoreline retreat rate in Transect 6 (EPR -3.22 m/year), followed by Transect 4 (-3.14 m/year). In the predominantly advancing shoreline area (Wakasihu), Transect 2 recorded an EPR of +6.29 m/year, followed by Transect 5 (+4.08 m/year). This pattern indicates strong oceanographic dynamics in the east/southeast (dominantly retreating) and west/northwest (dominantly advancing), as confirmed by image overlays on Google Earth 2015 and 2024 (Wahyuni & Ramadhan, 2020). This can be seen in Figures 6 and 7.

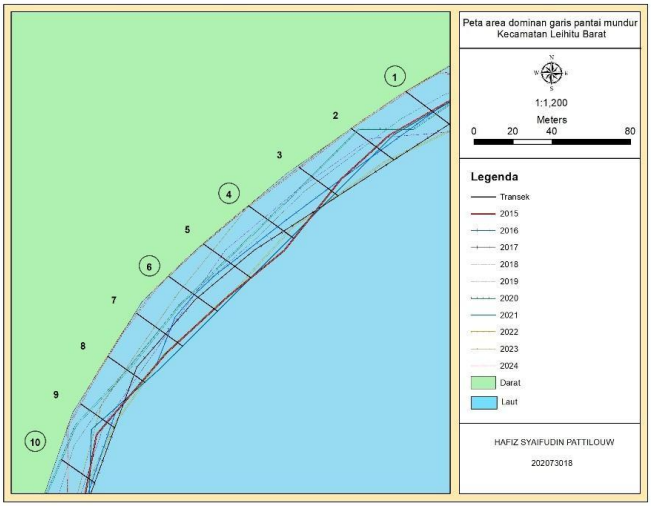


Figure 6. Map of the dominant area of the retreating coastline in west leihitu district

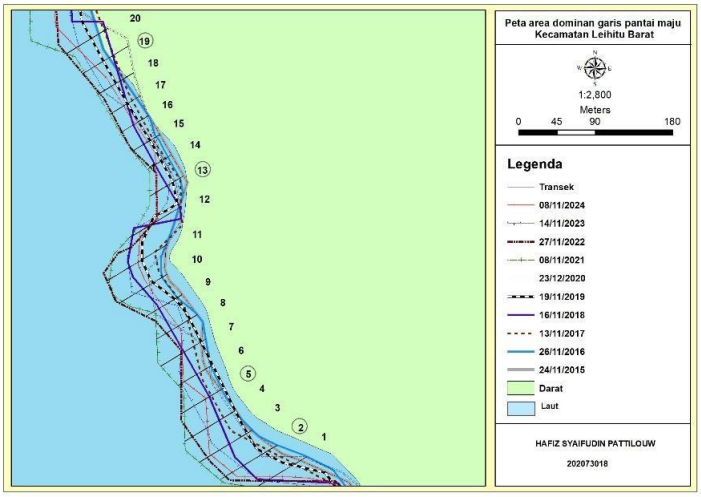


Figure 7. Map of the dominant area of the developed coastline of the West Leihitu District

Extent of Shoreline Change

Calculation of the area of change using GIS shows a total change of 32.29 ha, with 19.65 ha of advancing shoreline (the largest in Wakasihu (10.12 ha) and 12.64 ha of retreating shoreline (the largest in Liliboy (6.45 ha). The advancing shoreline is more pronounced, indicating strong sedimentation in the western region, likely driven by longshore currents. Anthropogenic factors, such as mangrove deforestation and land-use change, are accelerating shoreline retreat in Allang and Liliboy (Setyawan et al., 2021). Figure 8 and Table 4 show the extent of shoreline change from 2015 to 2024.

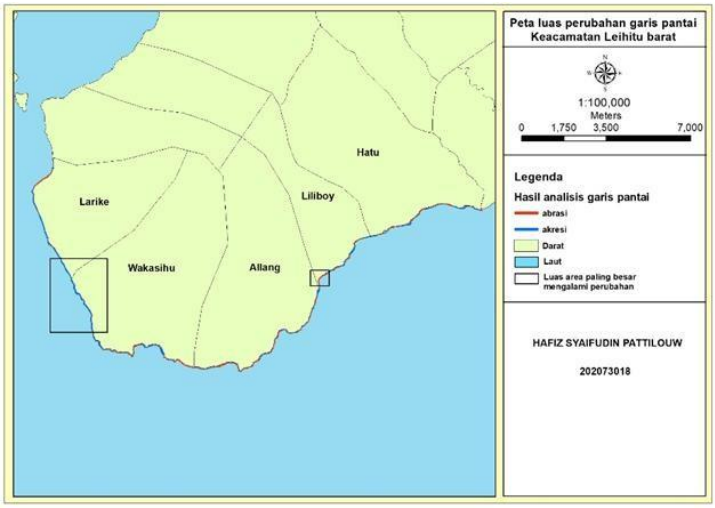


Figure 8. Map of the Area of Coastline Change in the West Leihitu District

Table 4. Area of Coastline Change 2015-2024

Setback (ha)		Polygons	Polygon Forward (ha)		Polygons
Largest	0,947428	108	Smallest	7,022782	116
Largest	0,000026	176	Smallest	0,000019	181
Total	12,644218	184	Total	19,64772	197
Average	0,1355		Average	0,2117	

Source: Landsat 9 satellite imagery data processing, 2015–2024

Comparison with Previous Research

The results of this study indicate the dynamics of shoreline change, characterized by advancement (accretion) and retreat (abrasion), across several coastal segments in West Leihitu District. This finding aligns with research by Setyawan et al. (2021) in Kuala Pesisir District, which showed that shoreline change is generally influenced by a combination of natural factors such as waves, currents, and sedimentation, as well as human activities in coastal areas. Furthermore, Indrawati and Supriyadi (2019) reported that Landsat satellite imagery is effective for mapping shoreline change in tropical regions, with high accuracy for regional-scale analysis. However, this study is unique among previous studies because it uses Landsat 9 imagery, which offers improved radiometric quality and data continuity over earlier generations, such as Landsat 8. This allows for temporal analysis of shoreline change with more consistent resolution, allowing for more detailed identification of annual fluctuations. To strengthen the validity of the research results, these findings were also compared with field conditions and information from coastal communities, as well as secondary data from relevant agencies. Based on field observations and information from local communities, several coastal areas, such as Larike and Wakasihu Villages, are experiencing gradual land subsidence due to sedimentation. This condition aligns with the results of image analysis, which indicates a trend of coastline advance in these areas.

Meanwhile, in several coastal segments of Liliboy and Allang Villages, local residents also reported coastal erosion during the high-wave season, supporting the research findings on the trend of shoreline retreat in the area. Thus, the agreement among the results of satellite image analysis, field observations, community information, and secondary data sources indicates that the remote sensing method used in this study is quite representative of the dynamics of shoreline change in West Leihitu District.

Implications for Coastal Management

Shoreline change in West Leihitu requires specific management strategies for each village. In Allang and Liliboy, protective structures such as breakwaters or groins are recommended to mitigate shoreline retreat that could threaten productive land and infrastructure. In Wakasihu, sediment management is necessary to prevent the negative impacts of excessive shoreline retreat, such as changes to the mangrove ecosystem and coastal flooding. Regular monitoring using satellite imagery is recommended to detect early changes, supported by field data for validation (Pratama & Wibowo, 2021).

Conclusion

Shoreline changes in the West Leihitu District from 2015 to 2024 varied spatially and temporally. Larike and Wakasihu experienced shoreline advance with an average shift of 7.05 m (0.78 m/year) and 6.69 m (0.74 m/year), while Allang and Liliboy experienced shoreline retreat with an average of 4.25 m (0.47 m/year) and 0.85 m (0.09 m/year), while Hatu remained relatively stable. The total area of change was 32.29 ha, with 19.65 ha of shoreline advance and 12.64 ha of shoreline retreat. These results can be the basis for adaptive coastal management, including regular monitoring and the construction of protective structures in areas prone to shoreline retreat.

Conflicts of Interest

The authors declare no conflict of interest.

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