The Impact and Prediction of Shoreline Dynamics in Pekalongan, Indonesia

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Abstract

Shoreline in Pekalongan has changed and impacted land use significantly. This research investigates historical changes in shoreline dynamics and their impact on land use from 2003–2021. This research also examines the trend of shoreline prediction for 2031–2041. Multitemporal SPOT5 and SPOT6 satellite images were used as primer data to detect shoreline and land use changes. The DSAS (Digital Shoreline Analysis System) analyzes the shoreline change and generates shoreline prediction. This research shows that the coastal areas of Pekalongan have been impacted by erosion, with 528.08 hectares of area and 56.33 hectares of accretion. The North Pekalongan sub-district is the worst area hit by erosion. The shoreline has retreated 2405.8 meters with a 353.3 m/year erosion rate. Several areas of land use were heavily affected by erosion trends, such as ponds, rice fields, and open land. Shoreline predictions generated by DSAS were heavily reliant on historical rates of shoreline change dynamics. The predicted area of the shoreline is estimated to retreat 49.9–466.2 meters from the existing position in the next 10 and 20 years. This research is expected to provide information to local governments for evaluating the maintenance and development planning of the coastal area

Keywords: Shoreline Dynamic, Shoreline Prediction, DSAS, Land Use, Geospatial Analyst

INTRODUCTION

Coastal area is a transition area between land and marine ecosystems. Coastal areas can be used for development purposes such as settlement, industry, ports, and tourism; and the presence of natural resources such as fishery, aquaculture, mangrove forests, and coral reefs (Kwong and Gunasiri, 2014). However, the coast constantly adapts to new developments, encouraging shoreline dynamics to have a natural balance (Arief *et al.,* 2011)

City and Pekalongan Regency shorelines, which have sandy beach coastal typologies, are constantly changing (Marfa'i *et al.,* 2011). The shoreline dynamic is related to coastal characteristics such as morphology, material, and the processes which directly occur in the shoreline dynamic. These processes include natural factors (hydrodynamic processes), human factors (anthropogenic), and their interaction (Ongkosongo, 1982). On the other hand, the Coastal City area and Pekalongan Regency experience rapid land use development in various sectors each year (Kartika *et al.,* 2019). The shoreline dynamic impacts land use in coastal areas (Kwong and Gunasiri, 2014; Dewi and Bijker, 2019).

Therefore, a study that uses multitemporal data to monitor and predict shoreline dynamics and their impact on land use is required. This research also examines the shoreline trend projections for 2031-2041, which are expected to provide data for local governments and can be used for evaluation of management and development planning in coastal area.

MATERIAL AND METHODS

Study area includes the districts of Siwalan, Wonokerto, Tirto (Pekalongan Regency), and North Pekalongan (Pekalongan City) in Central Java, Indonesia. Primary data includes SPOT5 with a resolution of 5mx5m from 2003 and 2009 and SPOT6 with a resolution of 6mx6m from 2016 and 2021. Secondary data consists of a land use map at

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a scale of 1:10.000 in 2017 from the Development Planning Agency at the Sub-National Level in Pekalongan; base maps also include administrative boundary maps and transportation road maps (road) from the Development Planning Agency at the Sub-National Level in Pekalongan City and Regency, hourly tidal data for Pekalongan Station from the Geospatial Information Agency for April 2021 - March 2022, and re-analyzed wind data for ERA-5 at an hourly resolution of 25km from 2003–2021 from the European Center for Medium-Range Weather Forecasts (ECMWF).

Tidal Data Processing

Tidal data was processed using the UTide program on a Matlab application using the least squares method. This program can analyze the tides in a multi-temporal context while considering accurate nodal corrections (Codiga, 2022). UTide is made up of two program codes: ut_solv, which analyzes the tidal elevation and generates 59 tidal harmonic components, and ut_reconstr which reconstructs (predicts) the tidal elevation. Tidal reconstruction (prediction) was performed in years where tidal data were unavailable. This elevation prediction will be used to determine the tidal conditions during satellite image recording.

Wind Data Processing

The wind data was converted into tabular data using Ocean Data View software. This form data is hourly wind speed data for the u (eastward) and v (northward) components from 2003 to 2021. The following calculations are used to determine the wind speed and direction (Himran, 2002):

$$c = \sqrt{x^2 + y^2} \qquad (1)$$

$$\theta = tan^{-1}\frac{v}{u} \qquad (2)$$

Note: c = wind speed resultant (meters/second); u = wind speed in vector x direction (meter/second); v = wind speed in vector y direction (meter/second)

The results are presented in the wind rose using WRPlot software to determine the dominant direction of the wind data in each period of the year.

Image Processing

The first step for image processing is image cropping and image restoration. Image cropping reduces the image size and focuses on the study area. Image recovery is performed by radiometric correction and image sharpening (Houlès *et al.*, 2006; Xiaoke *et al.,* 2009; Ahuja and Biday, 2013). Geometric correction uses the rectification method to restore the position of the object in the image to match the coordinates of their actual position on the earth (Kardoulas *et al.,* 1996; Octariandy *et al.,* 2016). A roadmap dataset can be used as a base map for a reference position.

Shoreline Mapping

Digitized on-screen was performed to obtain shoreline data (Thieler *et al.,* 1994; Moore, 2000; Tirkey *et al.,* 2005). Scale of 1:10,000 is used by considering the data source specifications, where the determination of the scale is 1: (2000 x image resolution) (Tobler, 1987).

Land Use Mapping

The 2017 Land Use Map from the Development Planning Agency at the Sub-National Level is used for land use mapping. The reference data is updated (processed to obtain the most recent results) and outdated (processed to obtain previous results) at a scale of 1:10,000 using the digitization method (Tobler, 1987; Khamala and Ottichilo, 2002; Lisna *et al.,* 2007).

Historical Shoreline Change Dynamic Analysis

The historical dynamics of the shoreline were analyzed to determine which areas have a shoreline dynamic, either through erosion or accretion processes. Shoreline data in the form of polylines is then converted into polygons using the “feature to polygon” tools. The shoreline polygons are processed using “symmetrical difference” tools to determine shoreline dynamics. The results of the symmetrical difference process are overlaid with shoreline polylines to facilitate the shoreline dynamics observation. The erosion process is indicated by the location of the newest shoreline behind the oldest shoreline and vice versa for the accretion process.

Shoreline Trend Dynamic Analysis

The DSAS (Digital Shoreline Analysis System) is used on ArcGIS 10.8.1 software to perform the shoreline dynamics trend analysis (Thieler *et al.,* 2009; Himmelstoss *et al.,* 2018). A baseline is required for this analysis in order to calculate transect lines with intersecting shorelines. The baseline runs parallel to the shoreline, while the transect line runs perpendicular to the baseline, intending to divide the area into sections of the shoreline. The analysis results inform the distance changes in the calculation of the Net Shoreline Movement (NSM), the rate of change in the calculation of the End Point Rate (EPR), the total distance changes in the calculation of the Shoreline Change Envelope (SCE), and the Linear Regression Rate (LRR).

Shoreline Prediction Analysis

Shoreline projection analysis was performed to determine the future description of the shoreline based on dynamic trends over time using the Kilman Filter method (Long and Plant, 2012). This method can improve the estimation of the modeled shoreline position through the uncertainty factor (Himmelstoss *et al.,* 2018). This method is an advanced analysis of calculations (EPR and LRR). The shoreline prediction model of the Kilman Filter method requires an initial analysis of the LRR (linear regression rate) value to be carried out. The value can be obtained if there are three or more shoreline datasets. As a result, predicting shorelines with less than four shorelines cannot be carried out.

Shoreline Dynamics Impact on Land Use Analysis

Shoreline dynamics analysis (erosion and accretion) on land use data was performed to determine the impact of shoreline dynamics. The method used is by overlapping through "spatial analyst" tools such as clip, erase, merge, symmetrical difference, and intersect (Kwong and Gunasiri, 2014; Dewi and Bikjer, 2019; Tirkey *et al.,* 2005; Yin *et al.,* 2010).

RESULTS AND DISCUSSION

Shoreline Conditions 2003 - 2021

Satellite image data is acquired simultaneously with the same water level elevation condition, high or low tide. Four shorelines were obtained based on the dataset with a distance of 6-7-5 years for each period. The use of a long period data is intended to determine the pattern and trend of shoreline dynamics that occur on the coast of Pekalongan City and Regency regularly. The dominant condition of the water's elevation at each time of image recording is around MSL. Nevertheless in 2003, tide condition at the peak of HWL that leads shoreline position distorted by 1.73 meters.

Historical Shoreline Change Dynamics

For the past 18 years, the coast of Pekalongan City and Regency has seen a variety of shoreline dynamics, both in terms of pattern and area. In the erosion process, the trend of increasing change occurred from 2009 to 2016, and the trend of decreasing change occurred from 2016 to 2021. The erosion that occurred between 2009 and 2016 was the most significant, covering an area of 364.78 ha. On the other hand, the accretion process tends to decrease each year, especially between 2009 and 2016. The greatest accretion occurs between 2016 and 2021, with an area of 43.86 Ha. However, the accretion that occurred was not the result of the sedimentation process but instead of the ponds that were repaired and builtin flooded land areas.

Each year, erosion, and accretion (the shoreline dynamic) happen differently in each region, but erosion has been the most common change to the shoreline. In 2003-2009, the trend of shoreline dynamics was quite diverse along the coast. A very high erosion trend occurred in Tirto and Wonokerto sub-districts. The shoreline in these sub-districts had retreated by 112.73 m (with an erosion rate of 17.3 m/year) and 74 m (with an erosion rate of 11.4 m/year). While the very high accretion trend happened in North Pekalongan and Wonokerto sub-districts, the coast has moved as far as 89.4 m (at a rate of 13.73 m/year) and 73.6 m (at a rate of 11.3 m/year) in these sub-districts.

Table 1. Image recording time and tidal conditions

Satellite	Resolution	Acquisition Date	Time (GMT+7)	Elevation (m)	Condition	MSL	LWL	HWL
SPOT5	5m	03/25/2003	11:40:57	1.47	High tide	1.11	0.77	1.51
SPOT5	5m	09/29/2009	11:41:02	1.30	High tide	1.29	0.96	1.75
SPOT6	6m	07/16/2016	11:20:32	1.58	High tide	1.51	1.12	1.81
SPOT6	6m	07/25/2021	11:18:50	1.7	High tide	1.68	1.25	2.09

Table 2. Impacted Areas by Shoreline Dynamics from 2003 – 2021

No.	City/Regency	Subdistrict	2003 – 2009		2009 – 2016		2016 – 2021	
			Accretion	Erosion	Accretion	Erosion	Accretion	Erosion
1	Pekalongan City	North Pekalongan	3.88	8.71	0.71	233.40	27.63	34.91
2	Pekalongan Regency	Siwalan	0.22	2.88	0.02	2.18	0.15	0.41
3	Pekalongan Regency	Tirto	0.34	3.82	0.46	72.91	15.26	23.54
4	Pekalongan Regency	Wonokerto	5.57	12.53	1.28	56.29	0.83	76.49
	Total		10.00	27.94	2.46	364.78	43.86	135.35

Table 3. Total Impacted Areas

No	City/Regency	Subdistrict	2003 - 2021	
			Accretion	Erosion
1	Pekalongan City	North Pekalongan	32.21	277.01
2	Pekalongan Regency	Siwalan	0.40	5.47
3	Pekalongan Regency	Tirto	16.05	100.28
4	Pekalongan Regency	Wonokerto	7.67	145.32
		Total	56.33	528.08

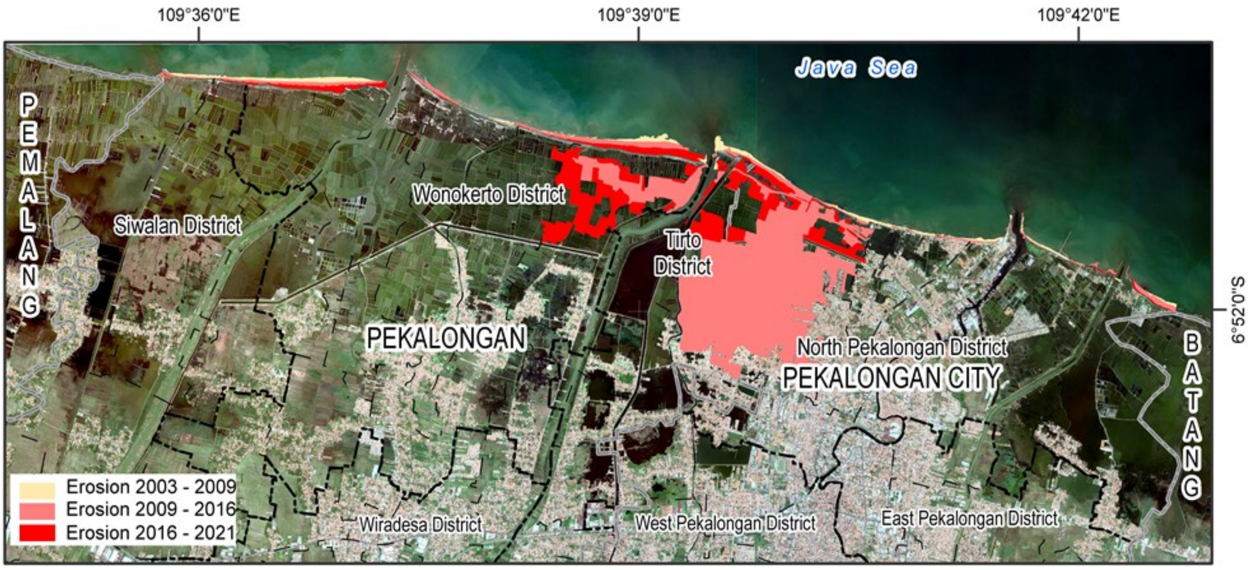


Figure 1. Spatio-Temporal of Erosion 2003 – 2021

From 2009-2016, there was a dominant trend of erosion along the coast of Pekalongan City and Regency, in contrast to the previous period, where there was still an accretion trend in addition to the erosion trend. The furthest retreat of the shoreline is in North Pekalongan District, as far as 2405.8 meters, with an erosion rate of 353.9 meters per year. The erosion trend also occurred in Wonokerto District, where the erosion rate increased to 12.7 m/year, and the shoreline

Figure 2. Spatio-Temporal of Accretions 2003 – 2021

Shoreline Trends Dynamic

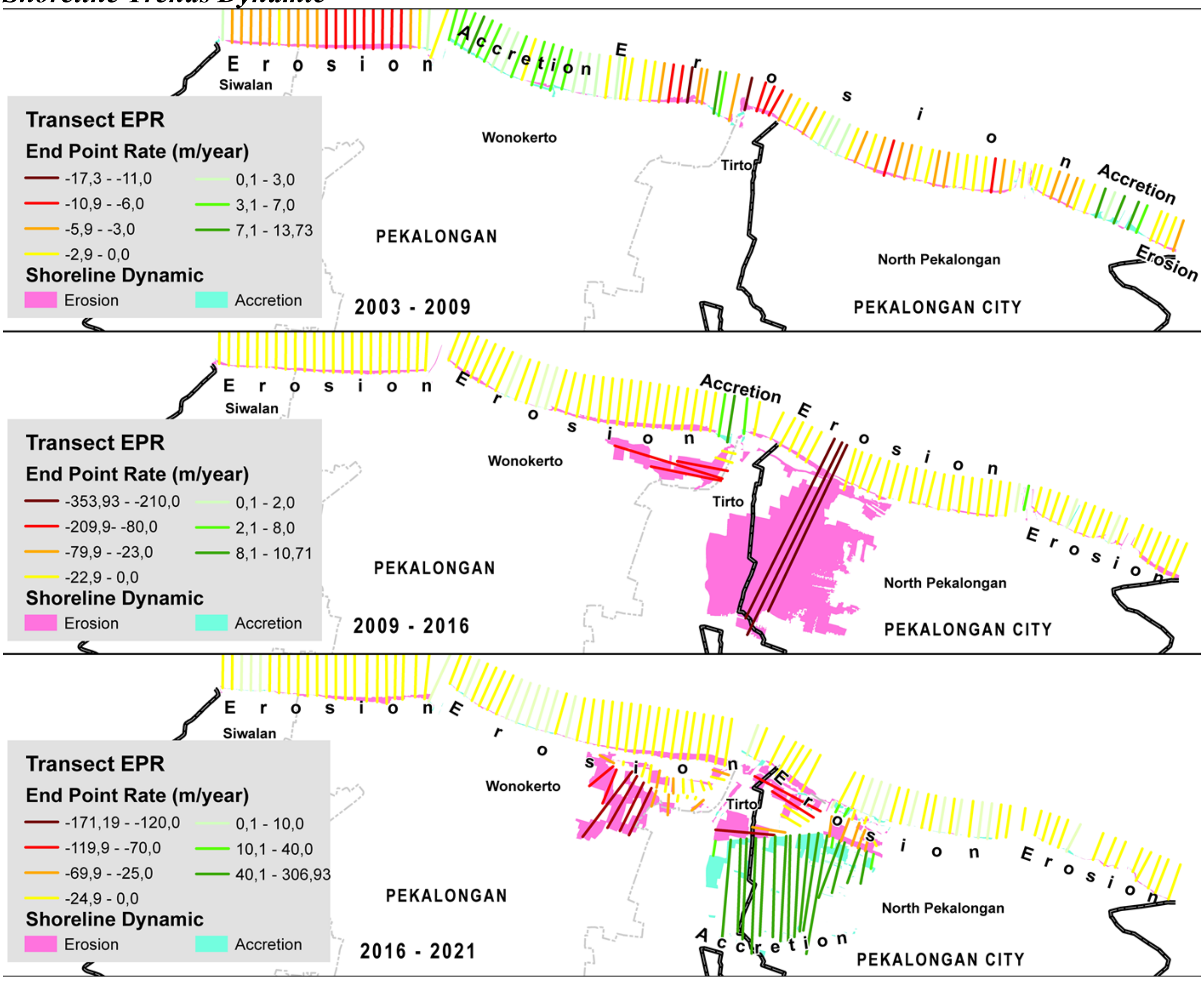


Figure 3. Shoreline Trends Dynamic on DSAS Transects in Each Period of Change

retreated as far as 86.2 meters during this period. A large amount of erosion in North Pekalongan District is thought to have been caused by both hydrodynamic factors and a tidal flood that happened around the same time.

In 2016–2021, the shoreline dynamics trend along the coast of Pekalongan City and Regency showed an erosion trend. The high erosion trend is in Wonokerto District, where the shoreline has retreated as far as 890.6 m in this period with an erosion rate of 171.2 m/year. There is also an accretion trend in North Pekalongan District. But the accretion trend is not caused by the process of sedimentation. Instead, it is caused by a permanent, huge embankment that forces the coast to line up with it.

Wind Characteristic

The average wind speed increases in each period. The highest average wind speed was 2.77 m/s from 2009 to 2016. The wind rose; figure 4, shows the dominant wind direction. The wind is blowing from the east-southeast at all times. Waves and currents are formed by the speed and direction of the wind, which makes the waves and currents move westward.

Land Use Condition

Every year, land use develops in a spatial-temporal pattern. The progress is visible in the rice fields and ponds. Rice field area decreased gradually; in 2003, rice field area was 2238.17 Ha, and in 2021, rice field area was 375.41 Ha. The land in the rice fields was converted into ponds. The area of rice fields decreased significantly between 2009 and 2016. In 2016, a new type of flooded land use appeared; this type did not exist in the previous year (2003 and 2009). Inundated land existed in 2016 due to tidal flooding, which converted land from ponds and rice fields to inundated areas. The flooded land area in 2016 was 778.03 Ha and is expected to grow to 1240.33 Ha by 2021.

Historical Shoreline Dynamics Impact on Land Use

The erosion process has heavily affected ponds and rice fields, with respective areas reduced by 247.89 Ha and 177.66 Ha between 2003 and 2021. The accretion process affects the increasing area of open land (sand beaches) due to sedimentation along the coast, which totals 18.02 Ha. The largest accretion impact was found in pond-type land covering an area of 35.53 hectares; however, the impact of accretion on the pond was caused by exertion to convert inundated land into ponds rather than a sedimentation process. The following table shows the results of the land use area affected by historical shoreline dynamics (erosion and accretion).

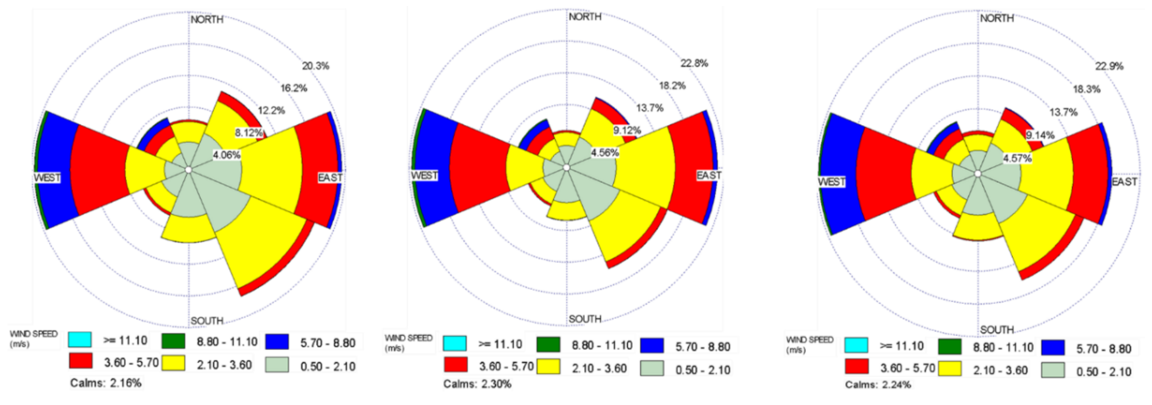


Figure 4. Wind Rose of Dominant Wind Direction from 2003 – 2009 (a), 2009 – 2016 (b), and 2016 – 2021

Table 4. Dominant Wind Speed and Direction from 2003 – 2021

Period	Average Speed (m/s)	Direction
2003 - 2009	2.66	East
2009 - 2016	2.77	East
2009 - 2021	2.74	East

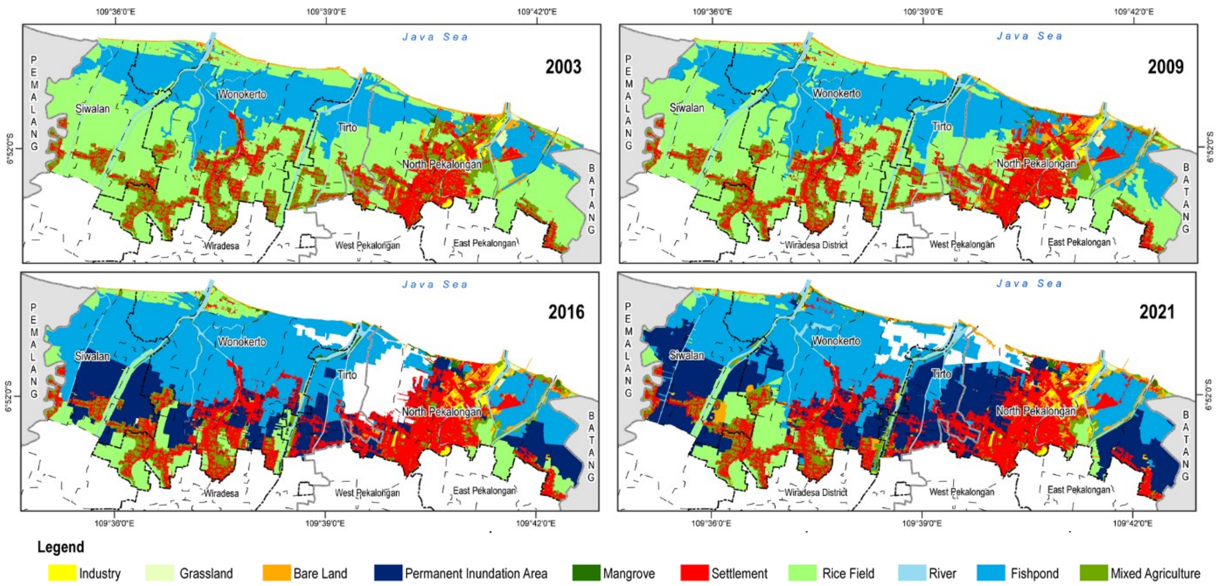
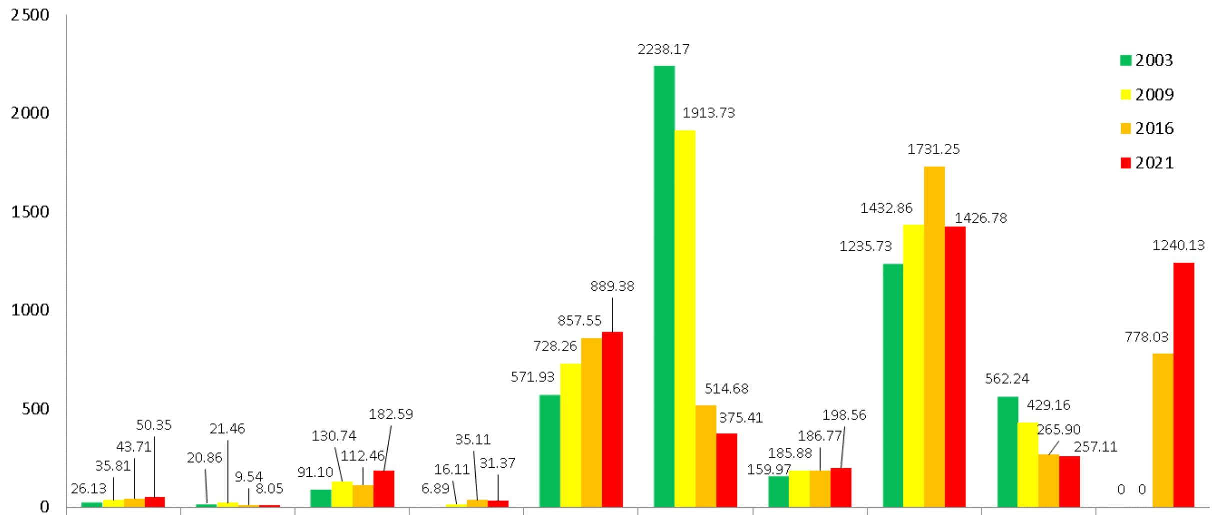


Figure 5. Land Use 2003 (a), 2009 (b), 2016 (c), and 2021(d)



	Industry	Grassland	Bare Land	Mangrove	Settlement	Rice Field	River	Fishpond	Mixed Agriculture	Permanent Inundation Area
2003	26.13	20.86	91.10	6.89	571.93	2238.17	159.97	1235.73	562.24	0
2009	35.81	21.46	130.74	16.11	728.26	1913.73	185.88	1432.86	429.16	0
2016	43.71	9.54	112.46	35.11	857.55	514.68	186.77	1731.25	265.90	778.03
2021	50.35	8.05	182.59	31.37	889.38	375.41	198.56	1426.78	257.11	1240.13

Figure 6. Land Use Graph of Development Areas in 2003, 2009, 2016, and 2021

Shoreline Prediction in 2031 – 2041

The shoreline prediction shows that the shoreline will be behind the existing shoreline position in the next 10 and 20 years; this means that the three sub-districts in Pekalongan Regency will experience continuous erosion in the future if no action is taken to stop it. Figure 7 shows the results of the shoreline projection.

The shoreline projection results are quite diverse, unlike the North Pekalongan District case. Shoreline projections tend not to change in Jeruksari and Bandengan Sub-district. This is due to the construction of a permanent embankment in this area. The presence of a permanent embankment is intended to mitigate the tidal flood disaster, which is becoming more severe by the year. Panjangbaru Sub-district, Panjang Wetan Sub-district, Krapyak Sub-district, and Degayu Sub-district are examples of shoreline projections in the North Pekalongan District that will retreat (erosion) in the coming year. Degayu Sub-district has accretion shoreline projections. Table 6 shows each change in shoreline projection distance.

Reviewing the erosion and accretion areas predicted by shoreline projections for the next 10 and 20 years. In the year 2031, the potential erosion area is 122.18 ha and the potential accretion area is 1.66 ha, while in 2041, the potential erosion area is 192.44 ha and the potential accretion area is 2.22 ha. The potential rendered by the projection of shoreline dynamics will impact the use of pond land, rice fields, mangroves, open land, and even settlements.

Coastal City and Pekalongan Regency's shorelines changed from 2003 to 2021, with 528.08 ha of erosion and 56.33 ha of accretion. The shoreline dynamics trend shows an erosion trend, particularly from 2009 to 2016, which experienced the highest erosion dynamics compared to other periods. North Pekalongan District was the most affected during that period, as evidenced by a land loss of 233.40 ha due to erosion. The shoreline in this area has retreated as much as 2405.8 meters in just seven years (2009–2016), with an erosion rate of 353.9 m/year. Several factors have contributed to the significant change in the shoreline caused by erosion.

Table 5. Land Use Impacted by Shoreline Dynamics

No	Impacted Land Use	Area (Hectares)							
		2003 - 2009		2009 - 2016		2016 - 2021		Review	
		Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Total Accretion	Total Erosion
1	Industry	0.11	-	-	0.01	0.04	-	0.15	0.01
2	Open Field	9.31	20.31	1.34	28.47	7.37	7.09	18.02	55.86
3	Mangroves	0.45	-	0.87	0.79	0.34	4.00	1.66	4.79
4	Rice Field	0.05	5.94	-	168.06	-	3.67	0.05	177.66
5	River	0.03	0.01	-	0.68	0.00	0.03	0.03	0.72
6	Pond	0.00	1.48	0.23	165.79	35.30	120.22	35.53	287.49
7	Mixed Plants	0.05	0.06	0.02	0.87	0.00	0.13	0.07	1.06
8	Moor Field	-	0.11	0.01	0.01	0.00	-	0.01	0.11
9	Settlement	-	0.04	-	0.11	0.80	0.21	0.80	0.36
TOTAL		10.00	27.94	2.46	364.79	43.86	135.35	56.33	528.08

Table 6. 10 and 20-year Projection Shoreline Change

Point	Subdistrict	2031	2041	Description
A	Siwalan	-45.9	-80.1	Erosion
B	Wonokerto	-105.6	-202.8	Erosion
C	Wonokerto	-23.4	-51.9	Erosion
D	Wonokerto	-199.2	-466.2	Erosion
E	Wonokerto	-1266.5	-1266.5	Erosion
F	North Pekalongan	-35.7	-64.2	Erosion
G	North Pekalongan	-19.1	-34.6	Erosion
H	North Pekalongan	-17.6	-30.4	Erosion
I	North Pekalongan	+39.4	+56.5	Accretion
J	North Pekalongan	-73.9	-128.2	Erosion

Figure 7. Shoreline position in 2031 and 2041

Natural shoreline changes can be caused by ocean waves, currents, winds, sedimentation, and tides (Ongkosongo, 1982). According to Table 3, the highest average wind speed was obtained between 2009 and 2016, with a value of 2.77 m/s. An increase in average wind speed can affect the height of the generated waves. The generating factor, namely the local wind, which is influenced by the monsoon, strongly influences waves and currents on the north side of the Java Sea (Setyawan and Pamungkas, 2017). The most important process in coastal dynamics is longshore currents. Longshore sediment transport is determined by the wave height and the wave incidence angle (Triatmodjo, 1999; Opa, 2011).

The presence of an alternate river in Pekalongan City is also an anthropogenic factor that contributes to the dynamics of the shoreline in Pekalongan City and Regency. The Loji River is a river channel constructed by the Pekalongan City Government to manage and control floods in the city area if a river overflow occurs (Sebastian, 2008). However, the presence of an alternate river reduces the balance of sediment supply, resulting in an imbalance in longshore sediment transport. In its initial state, sediment from the estuary was carried westward by a longshore current to explore the coast (because the dominant wind direction came from the east). Next, the sediment is distributed and deposited on the beach. However, if the river's sediment supply decreases, the West Coast will erode due to an imbalance in the transport of sediment that was initially supplied by the river (Triatmodjo, 1999; Direktur Jendral Pesisir dan Pulau-Pulau Kecil, 2004). The following image shows the visualization of the above description.

Other anthropogenic factors cause high erosion processes is land subsidence. The rate of land subsidence in Pekalongan Coastal City reached 7.7 to 10.5 cm/year based on monitoring satellite imagery SAR-1 (Chaussard *et al.,* 2013). This land subsidence causes coastal land areas to experience tidal flooding. Land subsidence factors can affect shoreline dynamics indirectly. There is a reasonably connected correlation between land subsidence and shoreline dynamics. The greater value of land subsidence, the greater area affected by coastal erosion (Aniendra *et al.,* 2019). Areas that experience land subsidence often experiences tidal flooding that overflows inland, damaging the shoreline. This has happened in Pekalongan City, precisely in Bandengan Sub-district, North Pekalongan District, which has retreated as far as 2405.8 meters with an erosion rate of 353.9 m/year within seven years (2009–2016). The phenomenon of tidal flooding, which is influenced by land subsidence, also affected land use, namely the emergence of inundated areas in 2016. The inundated area is a water column previously an area of rice fields and ponds. As a result, paddy fields and ponds can no longer be used as intended. In order to restore the function of land in damaged rice fields and ponds, a study of the suitability of pond land in permanently inundated areas to be used as ponds to revitalize new land uses can be implemented (Rachmansyah *et al.,* 2010).

Reconsidering the generated impact by the shoreline dynamics, which in this case is the erosion process on land use, The use of paddy fields and ponds is the most affected land use among other land uses, each of which has an affected area of 247.89 ha and 177.66 ha during 2003–2021. This is caused by the ponds and paddy fields having a longitudinal distribution pattern along the shoreline (Bintarto, 1977). Therefore, when shoreline erosion occurs, these two types of land use are more likely to experience a reduction than other types of land use. Open land is a type of land use that is highly affected, in addition to the types of ponds and rice fields. The total area that the erosion process has lost is 55.86 ha. The intended open land is a sandy beach area without any beach protections.

In general, some data are needed to predict the shoreline in the future, considering the very complex processes that occur in the shoreline dynamics. These data can be in the form of hydrodynamic parameters such as wind, waves, currents, and sediments, as well as their coastal structures, to simulate 2/3-dimensional line predictions. However, in this study, shoreline prediction using DSAS (Digital Shoreline Analysis System) processing highly depends on the historical rate of

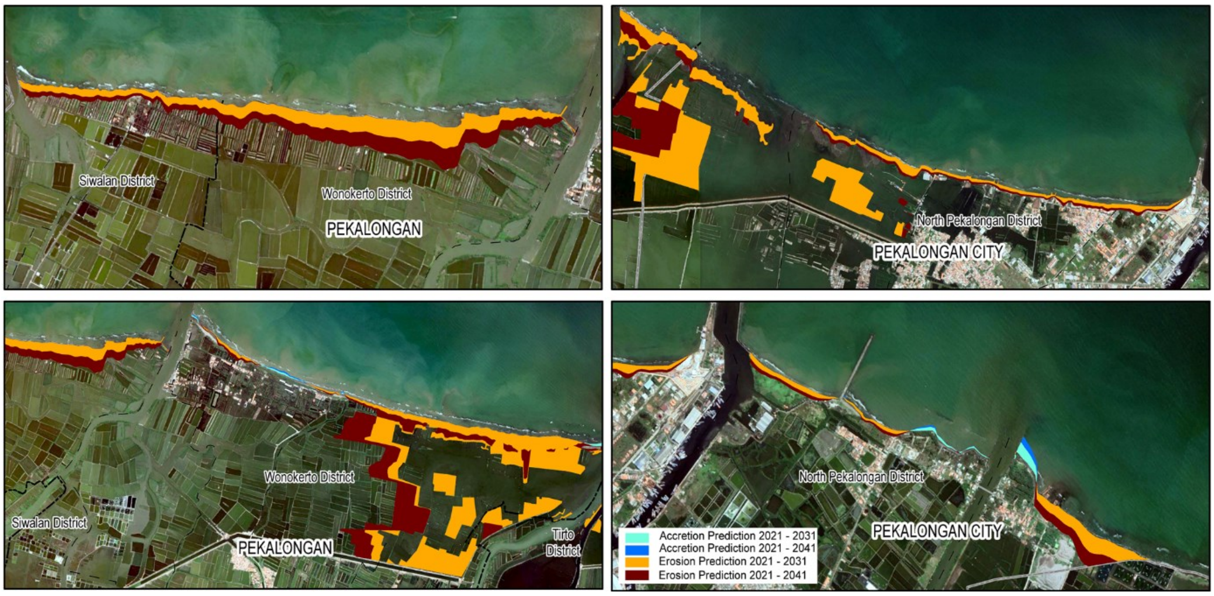


Figure 8. Projected area of accretion and erosion in 2031 and 2041

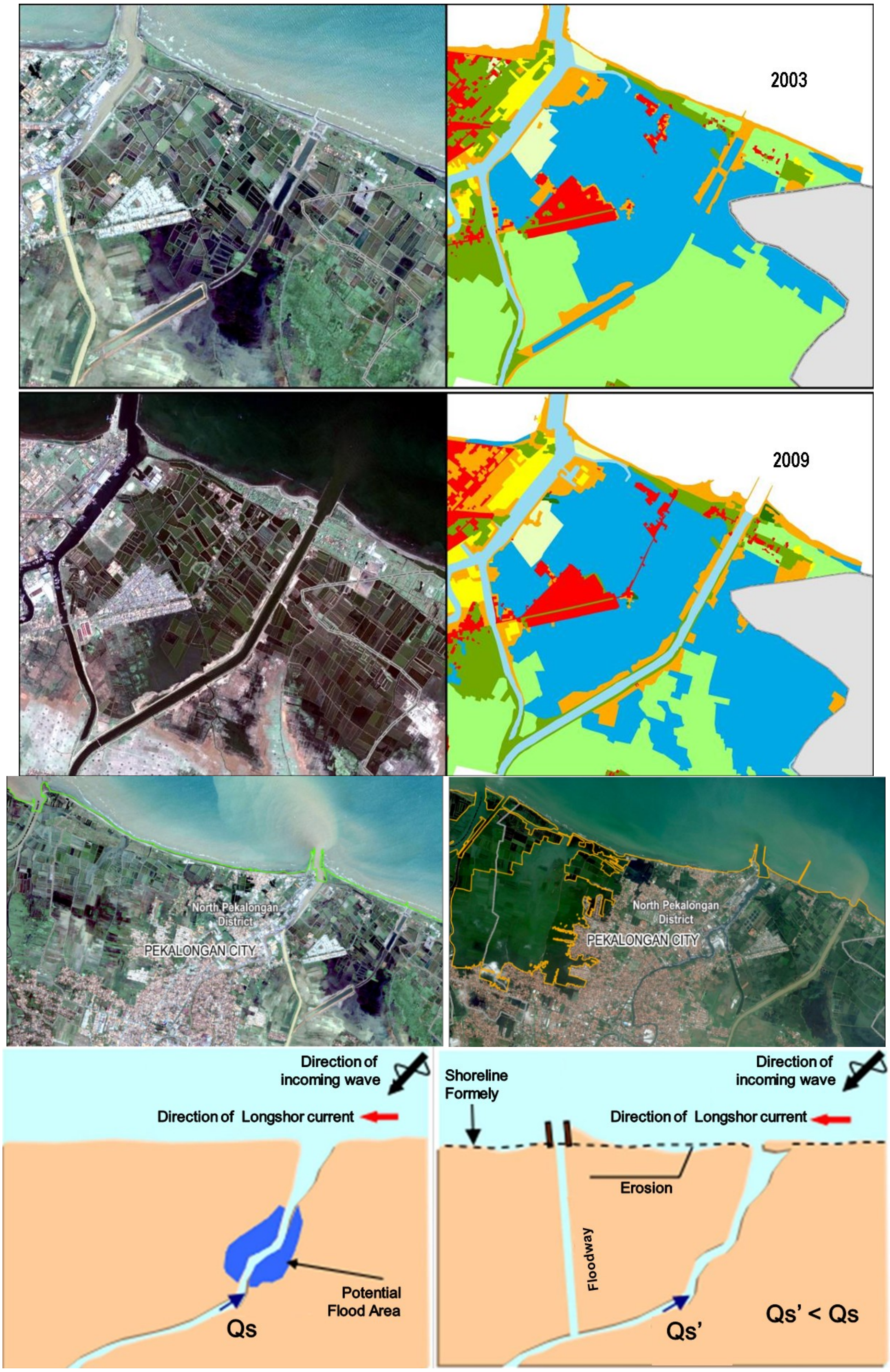


Figure 9. River Flow in Coastal Pekalongan City in 2009 Transfer of Function from Ponds in 2003 which disturbs the balance of sediment transport

Figure 10. Beach Characteristics and Shorelines Projection in Pekalongan Regency (a) and Pekalongan City (b)

shoreline dynamics. This is undoubtedly a weakness in the DSAS (Digital Shoreline Analysis System), which subjectively predicts the shoreline based on the data usage period. On the other hand, the shoreline prediction process in DSAS is relatively easy and efficient. The DSAS result can be used as initial information for researchers and stakeholders to conduct further and more complex studies related to highly dynamic areas that show shoreline projections in the form of erosion (Esmail *et al.,* 2019). The shoreline predictions are compared more closely using a method called "visualization," based on the field survey results and can explain the coast characteristics in figure 10.

Most of the coast in Pekalongan Regency is natural and does not have any protection from the sea (ii-iv in Figure 9a). These conditions may erode the shoreline in the next 10–20 years. Although there is a breakwater in the form of a rocks pile that serves to reduce the impact of waves, shorelines that are predicted to retreat can occur because the breakwater has been separated from the mainland, so the function is no longer effective.

On the other hand, the coast characteristics in Pekalongan City tend to have coastal protection (Regions v, vii, and ix). The presence of severe erosion history in Bandengan Sub-district does not push the projection of the shoreline in the area

(Region V) any further backward but instead maintains it. This is due to the existence of a giant sea wall structure to stop the tidal waves and stabilize the shoreline.

The coast in Panjangbaru and Panjangwetan Sub-districts (region vii) is protected by a sea wall along with a revetment in the form of rock piles that should be able to withstand erosion. However, the shoreline prediction results show erosion, as in Krapyak Sub-district (region ix). As mentioned, this is one of the problems with the DSAS shoreline prediction model. The results of the DSAS shoreline prediction are very dependent on the rate of erosion and accretion occurred in the past, and they do not consider the shoreline dynamics that are caused by humans (such as building sea walls).

CONCLUSIONS

The city and Regency of Pekalongan have been impacted by erosion with 528.08Ha areas and 56.33Ha area of accretion over 18 years. The North Pekalongan District is the greatest erosion area. The shoreline has retreated 2405.08 meters with a 353.3 m/year erosion rate. Several land use areas were heavily affected by erosion trends, such as fishponds (287.49 ha), rice fields (117.66 ha), and bare land/sandy beaches (55.86 ha). Shoreline retreat is expected to be 49.9-1266.5 meters in 10-20 years primarily in Wonokerto District.

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