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Shoreline change detection in Jepara regency, Indonesia, using multitemporal Landsat imagery from 1994 to 2024

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ABSTRACT

This research examines the dynamics of shoreline changes in Jepara Regency, Indonesia, by utilizing multitemporal Landsat images spanning from 1994 to 2024.The coastal areas of Jepara face significant challenges due to erosion and accretion, exacerbated by anthropogenic activities and climate change. Previous studies in the region have been limited to single image analysis without examining long-term shoreline dynamics. To address this knowledge gap, this research integrates multitemporal Landsat imagery with the digital shoreline analysis system (DSAS) to reveal erosion-accretion patterns and predict future shoreline changes. The study area encompasses eight coastal sub-districts in Jepara Regency, stretching from Kedung in the west to Donorojo in the east. Shoreline data extraction was performed using the normalized difference water index (NDWI) and Otsu's thresholding method. DSAS was employed to calculate shoreline change rates, including net shoreline movement (NSM), end point rate (EPR), and linear regression rate (LRR). The results indicate varying shoreline dynamics across the sub-districts, with Donorojo experiencing significant accretion with an average LRR value of 1.23 m/year and an average EPR of 0.86 m/year. Conversely, Kedung is facing critical erosion with an average LRR value of -9.67 m/year and an average EPR of -9.75 m/year. Predictions using the Kalman filter suggest increasing trends of erosion and accretion in several sub-districts over the next 10 to 20 years. In 2034 and 2044, erosion occurred on the Kedung Malang coast with NSM values of -301.39 m and -440.37 m, respectively. Meanwhile, the highest accretion in the same years occurred on the Ujungwatu coast, with NSM values of 263.67 m and 353.48 m, respectively. The findings highlight the need for responsive strategies to mitigate the adverse impacts of shoreline changes and utilize the potential of accreting areas for sustainable coastal management in Jepara regency.

Keywords: shoreline change, DSAS, shoreline prediction, Landsat.

INTRODUCTION

Coastal regions hold substantial ecological, economic, and social significance, playing an essential role in biodiversity, resource provision, and community livelihoods. The distinctive environments within coastal zones, such as estuaries, beaches, mangroves, and coral reefs, rank among the most biologically productive areas globally. These regions support a rich diversity of life and serve as vital habitats for numerous marine organisms, while also offering ecosystem services including carbon sequestration, nutrient cycling, and protection from storm surges (Zenati et al., 2024; Ramanujam et al., 2024; Rumahorbo et al., 2023; Singh, 2023). Furthermore, these areas perform critical functions such as water filtration and habitat provision for both marine and terrestrial species, and they act as buffers against coastal erosion and flooding (McClenachan et al., 2020). The role of mangroves in mitigating erosion and enhancing biodiversity is well-documented, demonstrating how coastal habitats protect inland areas while supporting a multitude of life forms (Chawalit et al., 2025; Fajri et al., 2024). The importance of this protective function is becoming increasingly critical as coastal areas face numerous global threats.

Coastal regions are currently confronted with a multitude of global threats arising from both natural and anthropogenic sources. Among these, coastal erosion represents one of the most pressing challenges, affecting approximately 80% of the world's coastlines, with erosion rates varying from 1 cm/year to as severe as 30 m/year in certain areas (Boye et al., 2022). This issue is further intensified by the increased frequency and severity of coastal storms and rising sea levels attributable to climate change, leading to significant modifications in coastal morphology and potentially severe socioeconomic repercussions (Abd-Elhamid et al., 2023; Chettiyam Thodi et al., 2023). The Intergovernmental Panel on Climate Change (IPCC) projects sea level rise to range from 0.43 meters to 0.84 meters by the century's end, further endangering these areas by exacerbating erosion and potentially resulting in coastal submergence (Komi et al., 2022). It is imperative that coastal management strategies incorporate these dynamics to mitigate risks and promote sustainable development.

Shoreline alterations represent a significant global challenge, with Indonesia being one of the most affected nations. As one of the largest archipelagic countries, Indonesia comprises approximately 17,508 islands and possesses an extensive coastline measuring around 95,181 kilometers (Qurniati et al., 2017). The coastal regions of Indonesia are particularly susceptible, with approximately 60% of the nation's population, equating to around 250 million individuals, residing in these areas (Mutaqin et al., 2020). The study location in the coastal area of Jepara, situated in Central Java, Indonesia, is distinguished by a diverse ecosystem comprising mangroves, seagrasses, and coral reefs, which are vital components of its marine biodiversity (Suryanti et al., 2025). This region faces numerous environmental challenges, including coastal erosion and alterations in sediment dynamics, exacerbated by anthropogenic activities and climate change. In the Jepara coastal area, climate change poses a significant threat, with rising sea levels endangering both coastal ecosystems and human settlements. Research indicates that elevated sea levels will alter sediment transport, complicating the management of erosion issues (Maslukah et al., 2019; Mu et al., 2024). Since 1980, mangrove areas along the northern coast of Jepara regency have been threatened by coastal erosion and land use changes (Hayati et al., 2022). Approximately 7.6 km of the 72 km coastline in Jepara, Central Java, has suffered damage, primarily due to coastal erosion, adversely affecting adjacent settlements, aquaculture ponds, agricultural land, and high-value tourist areas (Wahyudi and Adi, 2018).

Geographic information systems (GIS) and remote sensing technology, particularly through satellite imagery, have significantly advanced the monitoring of coastal dynamics. The use of Landsat imagery enables researchers to detect and analyze changes in shoreline positions over extended periodsn (Zahir et al., 2021). GIS enhances remote sensing by offering analytical capabilities for modeling and interpreting spatial data related to shoreline changes. The application of the DSAS, as highlighted in a study, facilitates the calculation of shoreline change rates and the prediction of future configurations based on historical data (Daswin, 2023; Gopinath et al., 2023). The integration of these technologies not only enables the identification of erosion hotspots but also supports the development of strategic responses to coastal erosion risks, thereby allowing policymakers to implement timely mitigation measures (S. et al., 2024; Nicu et al., 2020).

Previous research conducted in Jepara regency has predominantly focused on single-image analyses. These studies have included assessments of shoreline extraction accuracy using the NDWI, MNDWI, and AWEI indices with Landsat 8 OLI imagery in 2018, as well as evaluations of the impact of tidal correction on shoreline position, without addressing long-term shoreline dynamics (Wicaksono et al., 2018; Wicaksono and Wicaksono, 2019). To date, no studies have employed multi-decade, cross-sensor Landsat time series in conjunction with quantitative analysis using the DSAS to elucidate erosion–accretion patterns and forecast shoreline changes. This study addresses this gap by integrating multitemporal Landsat imagery from 1994 to 2024 with DSAS in a multitemporal framework, while also projecting shoreline changes for the next 10 and 20 years. This methodology is anticipated to offer a comprehensive spatial overview of historical shoreline dynamics, current conditions, and potential future changes, thereby providing a scientific foundation for sustainable coastal area planning and management.

STUDY AREA

Jepara Regency, situated in the coastal region of Central Java Province, Indonesia, serves as the focal area for this study due to its dynamic and complex coastal ecosystem, as illustrated in Figure 1. The regency comprises several Sub-Districts with coastal boundaries, including Donorojo, Keling, Kembang, Bangsri, Mlonggo, Jepara, Tahunan, and Kedung. The study area extends from Kedung Sub-District in the west to Donorojo Sub-District in the east. The coastal region of Jepara has experienced substantial transformations, particularly where wave action interacts with adjacent coral reefs. This interaction exemplifies the dynamic relationship between the shoreline and marine structures, influencing both sediment transport and ecological stability. It underscores the critical role of coral reef systems in maintaining ecological equilibrium (Suryono et al., 2021). The waters surrounding Jepara are characterized by dynamic variations in currents and wave patterns, which shape the region's ecological framework (Rochaddi et al., 2021). This intricate interplay between topography and coastal features also highlights the regency's susceptibility to natural phenomena such as landslides, particularly evident in Keling Sub-District due to its distinct geological and hydrological conditions (Feisal et al., 2020). Furthermore, land-use changes have significantly impacted Jepara's coastline, notably through urbanization and agricultural expansion. The conversion of coastal habitats for agricultural and urban purposes has resulted in considerable habitat loss, affecting local biodiversity and exacerbating coastal erosion (Hayati et al., 2022; Sui et al., 2020).

METHODOLOGY

Data collection

This study employs Landsat imagery as a reference for identifying the location and condition of the shoreline. The Landsat images were acquired via the Google Earth Engine platform, which provides access to multitemporal satellite imagery. The utilization of Google Earth Engine enables batch processing over extensive geographic areas, thereby facilitating widespread and convenient access to the The analysis of shoreline changes was conducted over a 30-year period, with monitoring intervals every 10 years, encompassing the years 1994, 2004, 2014, and 2024. Landsat archive (Arjasakusuma et al., 2021). Furthermore, this imagery offers a long historical data record and adequate spatial resolution for analyzing shoreline changes. The Landsat satellite images utilized are of various types, as detailed in Table 1, and were selected based on the availability of data from each satellite image, including: Landsat 5 TM (Thematic Mapper), Landsat 7 ETM+ (Enhanced Thematic Mapper Plus), and Landsat 8/9 OLI (Operational Land Imagery).

Shoreline data extraction and analysis

The delineation of boundaries between terrestrial and aquatic environments is effectively achieved through the application of the normalized difference water index (NDWI). This technique facilitates the precise derivation of shorelines by utilizing specific spectral bands and threshold methodologies (Pujianiki et al., 2021). NDWI enhances the distinction between water bodies and land in Landsat satellite imagery by employing the green band in conjunction with the near-infrared band (NIR). Subsequently, the Otsu method is applied to extract the boundary between sea and land, which has been previously segregated using the NDWI method, resulting in a binary classification that accurately represents shoreline positions (Dewi, 2019). The analysis of shoreline changes in this study employs the DSAS, an effective tool for detecting coastal accretion and erosion based on multitemporal satellite imagery (Pratikto et al., 2021). In utilizing DSAS, a baseline is established as necessary to facilitate effective monitoring of shoreline dynamics, drawn parallel to the observed shoreline. Additionally, the analysis of the rate of shoreline change necessitates the creation of transects. These transects are constructed perpendicular to the shoreline at 50-meter intervals to ensure high accuracy in analyzing the rate of shoreline change. In Jepara regency, 3.160 transect data points were generated for this purpose. Transects enable the measurement of shoreline change metrics, such as the NSM, EPR, and linear regression rate (LRR), which are calculated based on the intersections of transects with historical shoreline positions. These metrics provide quantifiable indicators of erosion and accretion processes, ultimately informing coastal management strategies.

EPR is a valuable method for assessing shoreline change by measuring the distance between the intersection points of the earliest and most recent shoreline data, based on the time elapsed since these measurements were taken. In contrast, the LRR offers a more comprehensive analysis, as

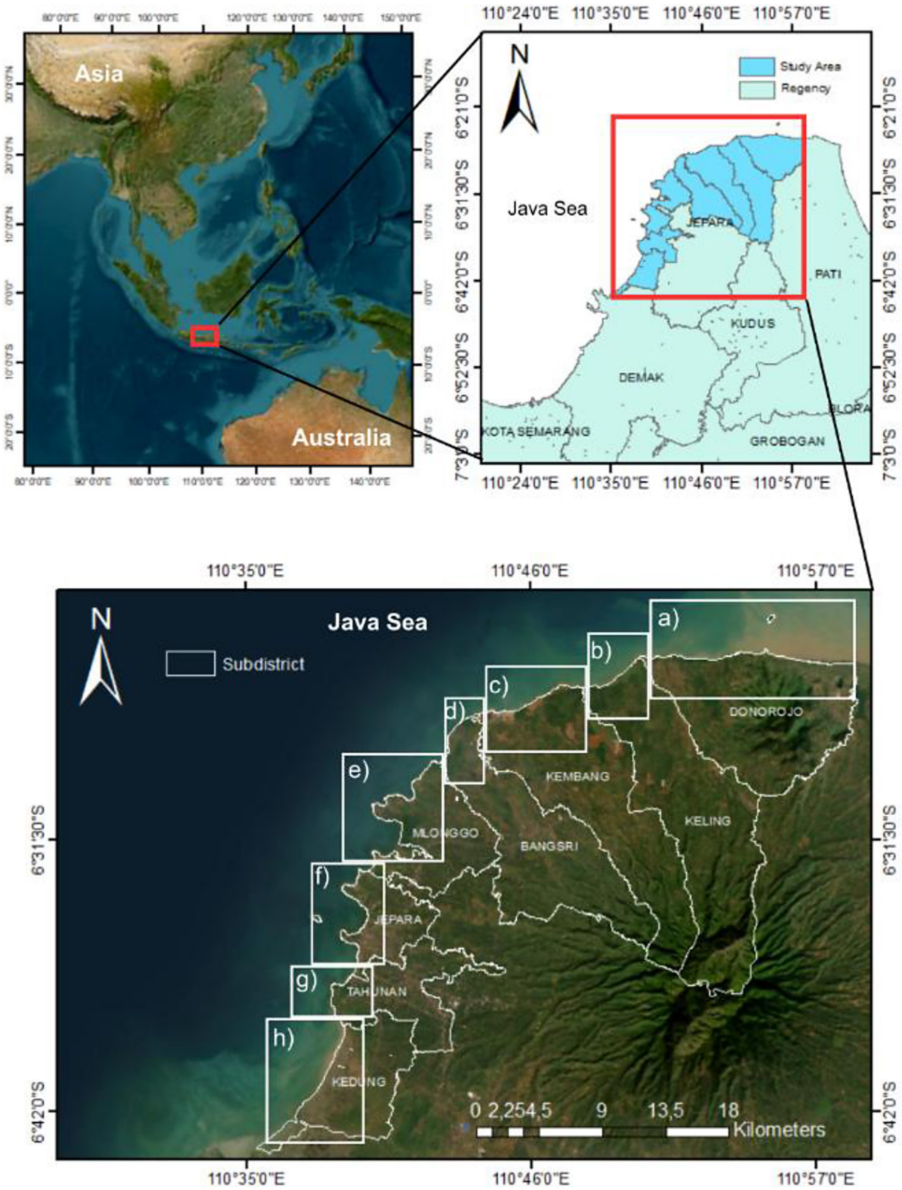

Figure 1. Study area

Table 1. Satellite data utilized in the shoreline change study

No	Satellite	Data acquisition	Resolution
1	Landsat 5 TM	1994-05-28	30 m
2	Landsat 7 ETM+	2004-03-28	30 m
3	Landsat 8 OLI	2014-02-28	30 m
4	Landsat 8 OLI	2024-03-27	30 m

it can be applied over an extended period across multiple shoreline positions. This technique employs statistical regression to examine gradual and historical trends in shoreline movement. The LRR method calculates the average rate of shoreline change, rendering it particularly suitable for long-term assessments (Fatunmibi et al., 2023). In contrast, NSM is utilized to calculate the total distance between the oldest and most recent coastline positions without considering the temporal rate of change (Grottoli et al., 2023). To classify erosion and accretion in this study, a reference is required to determine the levels of erosion and accretion along the coastline; this reference is provided in Table 2.

Prediction of future shorelines

Shoreline prediction was conducted utilizing DSAS version 5.1, employing a Kalman filter methodology. The Kalman filter, which is predicated on previously calculated LRR data, serves

Table 2. Classification of EPR and LRR for shoreline changes

NO	Classification	Shoreline change rate (m/year)
1	Very high erosion	< -4
2	Moderate erosion	-4 to -1
3	Stable shoreline	-1 to 1
4	Moderate accretion	1 to 4
5	Very high accretion	> 4

as an effective technique for forecasting the rate of shoreline change and determining the future position of the shoreline.(Natarajan et al., 2021).

RESULTS

This study delineates its scope by categorizing the results into eight distinct zones, corresponding to the number of sub-districts within the coastal region of Jepara Regency. The study area encompasses the sub-districts of Donorojo, Keling, Kembang, Bangsri, Mlonggo, Jepara, Tahunan, and Kedung. The statistical outcomes pertaining to shoreline changes are presented in Table 3.

Donorojo

Donorojo sub-district, a coastal region, is experiencing notable shoreline expansion primarily due to the predominance of accretion processes along most segments of its coast. The findings of the study, as illustrated in Figure 2, reveal an average LRR of 1.23 meters per year and an average EPR of 0.86 meters per year. These metrics substantiate the ongoing sedimentation processes in this area. The maximum NSM recorded is 195.11 meters. The area exhibiting the highest rate of accretion is located along the coast of Ujungwatu Village, where the highest LRR and EPR values are 8.94 meters per year and 6.54 meters per year, respectively. However, certain points are identified as experiencing erosion at a higher rate, with an LRR of -4.80 meters per year, an EPR of -4.66 meters per year, and the lowest NSM of -138.95 meters. Despite this, erosion does not predominate the shoreline change events in this region, as accretion events are more prevalent. In study locations with the highest rate of accretion, the primary driving factors are oceanographic dynamics, particularly currents parallel to the shoreline, and fluvial factors, both of which foster conditions conducive to sedimentation. These significant shoreline changes have been adaptively utilized by the local community, who have converted the newly formed land into new aquaculture areas.

Keling

The dynamics of shoreline changes in Keling sub-district exhibit relative stability, with a tendency toward mild erosion. Statistical calculations, as depicted in Figure 3, reveal an average LRR of -0.11 m/year and an average EPR of -0.14 m/year, indicating that the majority of the shoreline in Keling sub-district remains relatively stable. Despite the overall stability observed over 30 years of monitoring, certain locations remain susceptible to erosion. The area experiencing the highest erosion rates is characterized by a minimum LRR of -2.04 m/year, a minimum EPR of -2.31 m/year, and a minimum NSM of -69.01 m. This location is Bringin Beach, located in Bumiharjo Village, where the shoreline is notably dynamic due to the interaction with a river running parallel to the coast. This interaction results in significant dynamism in the river channel and

Table 3. Summary statistics of shoreline change parameters for each sub-district

Sub-district	LRR			EPR			NSM	
	Average	Max	Min	Average	Max	Min	Max	Min
Donorojo	1.23	8.94	-4.80	0.86	6.54	-4.66	195.11	-138.95
Keling	-0.11	1.85	-2.04	-0.14	1.72	-2.31	51.35	-69.01
Kembang	0.09	1.82	-2.65	-0.01	1.81	-3.10	53.94	-92.58
Bangsri	-0.37	2.11	-4.33	-0.68	1.19	-5.18	35.41	-154.55
Mlonggo	0.75	7.85	-5.81	0.55	6.54	-6.05	195.10	-180.36
Jepara	0.56	6.41	-8.93	0.53	5.73	-8.18	171.03	-244.09
Tahunan	0.27	3.42	-2.39	0.20	3.48	-2.28	103.88	-67.91
Kedung	-9.67	-0.52	-22.90	-9.75	-0.59	-23.73	-17.46	-707.98

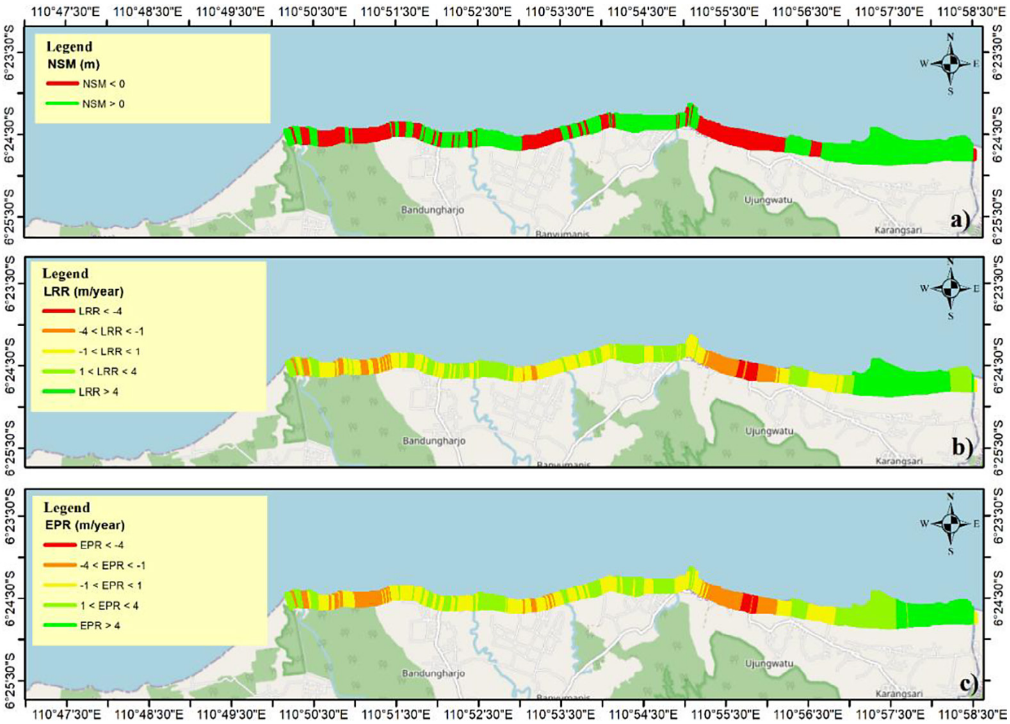

Figure 2. Shoreline changes at Donorojo sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

morphology, influenced by ocean current energy capable of eroding the riverbank, thereby directly impacting the stability of both the river and the adjacent shoreline. Additionally, there are areas experiencing accretion, with a maximum LRR of 1.85 m/year, a maximum EPR of 1.72 m/year, and a maximum NSM of 51.35 m. This accretion occurs at Karangwiro Beach, which is characterized by a rocky, cape-like formation conducive to sedimentation processes that extend the shoreline.

Kembang

The results of the shoreline change analysis, as depicted in Figure 4, reveal that in the Kembang sub-district of Jepara regency, the average LRR is 0.09 m/year, indicating a general stability in this area. Additionally, the average EPR is -0.01 m/year, further suggesting shoreline stability. Notably, there is significant variability, with maximum LRR and EPR values of 1.82 m/year and 1.81 m/year, respectively, and minimum values of -2.65 m/year and -3.10 m/year, respectively. These average and extreme values highlight a disparity, suggesting that while the overall coastline of the Kembang sub-district is relatively stable, certain locations have experienced substantial changes, either through erosion or accretion. This is corroborated by NSM values, which range from a maximum of 53.94 m to a minimum of -92.58 m. The pattern of significant shoreline change at specific sites is closely associated with anthropogenic impacts over the past 30 years, particularly in areas that have been developed into a coal-fired power plant and a fishing harbor. Anthropogenic factors significantly influence the characteristics of shoreline change in this sub-district.

Bangsri

The coastal region of Bangsri sub-district exhibits diverse characteristics, as illustrated in Figure 5, yet it predominantly experiences shoreline erosion. The conducted calculations reveal an average LRR of -0.37 m/year and an average EPR of -0.68 m/year. These findings indicate a consistent shoreline retreat over the past three decades, classifying the area as experiencing low erosion. The most severe erosion is observed on the eastern coast of Keling sub-district, particularly at the Tanjung Jati steam power plant. This location recorded a minimum LRR of -4.33 m/year, a minimum EPR of -5.18 m/year, and a shoreline retreat with a minimum NSM value of -154.55 m. Conversely, the identification results indicate a maximum LRR of 2.11 m/year, a maximum EPR of 1.19 m/year, and

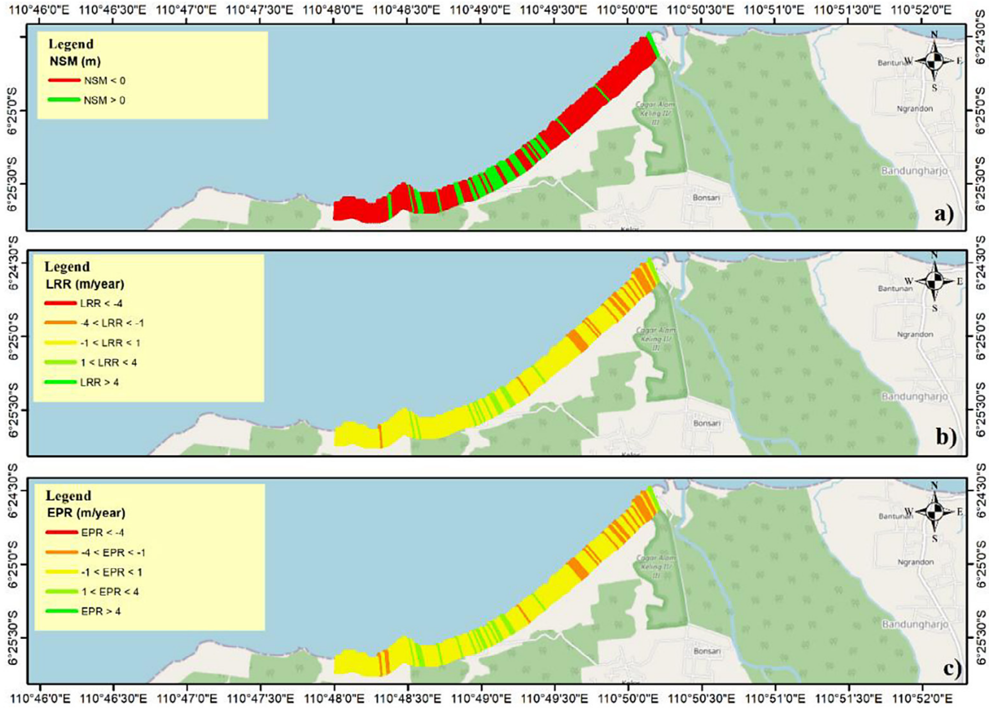

Figure 3. Shoreline changes at Keling sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

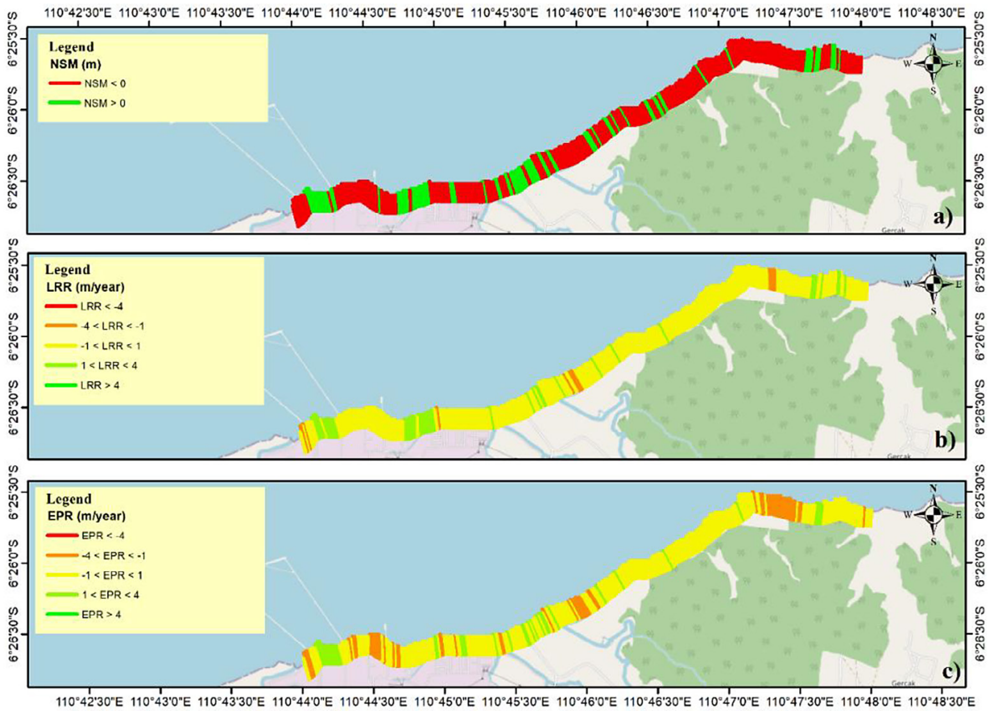

Figure 4. Shoreline changes at Kembang sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

a maximum NSM of 35.41 m. The site with the highest accretion is identified at Bondo Beach, situated in the eastern part of the Bangsri sub-district coastal area, specifically in Bondo village.

Mlonggo

As illustrated in Figure 6, statistical analysis utilizing DSAS reveals that the coastal region of the Mlonggo sub-district under investigation

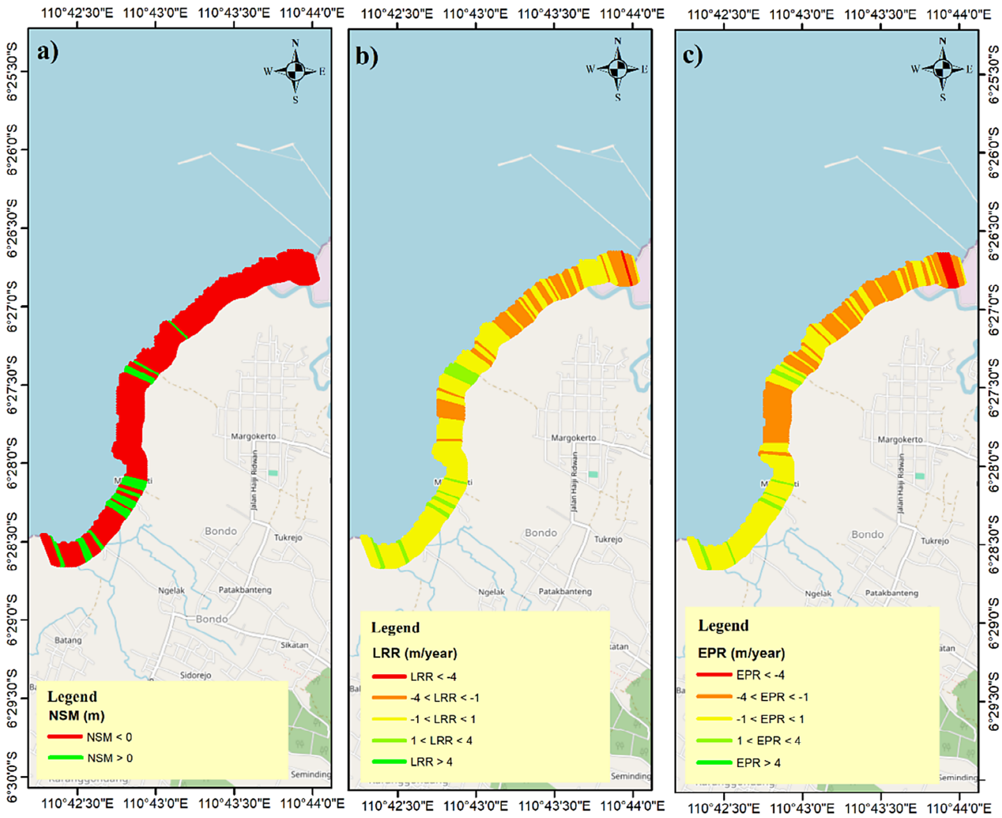

Figure 5. Shoreline changes at Bangsri sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

predominantly exhibits shoreline changes characterized by accretion. This is evidenced by an average LRR value of 0.75 m/year and an average EPR of 0.55 m/year, suggesting that the shoreline changes in this area are classified as stable. The analysis recorded the highest accretion with a maximum LRR value of 7.85 m/year, an EPR of 6.54 m/year, and an NSM of 195.10 m. The area experiencing the most significant accretion was identified as the Blebak Beach area, located in Sekuro village. Conversely, other locations demonstrated the highest erosion rates, with minimum LRR values of -5.81 m/year, an EPR of -6.05 m/year, and an NSM of -180.36 m. This area was identified at Selayar Beach, Jambu village, which was previously a pond area that has undergone a land use change to become a mangrove area.

Jepara

The coastal region of the Jepara sub-district exhibits a generally stable shoreline, as evidenced by the results of DSAS analysis processing, depicted in Figure 7. The parameters LRR and EPR reveal average values of 0.56 m/year and 0.53 m/year, respectively, indicating that the majority of the shoreline in the Jepara sub-district is undergoing accretion. Nevertheless, there are notable variations between the maximum and minimum values in shoreline change parameters over the past 30 years. The area experiencing the highest accretion is characterized by an LRR value of 6.41 m/year, an EPR of 5.73 m/year, and an NSM of 171.03 m. This area is located at Kartini Beach, which has been significantly impacted by anthropogenic activities related to coastal development involving hard structures, thereby contributing to an increase in the shoreline. Conversely, the area experiencing the most severe erosion has an LRR value of -8.93 m/year, an EPR of -8.18 m/year, and an NSM of -244.09 m. The phenomenon of the highest erosion is observed in the Kartini Beach area, where erosion is attributed to anthropogenic factors resulting from land use changes over the past 30 years.

Tahunan

The analysis of shoreline changes over a 30-year period indicates that the coastal area of the Tahunan sub-district is characterized by a low level of accretion, as illustrated in Figure 8. This conclusion is supported by the calculation of the

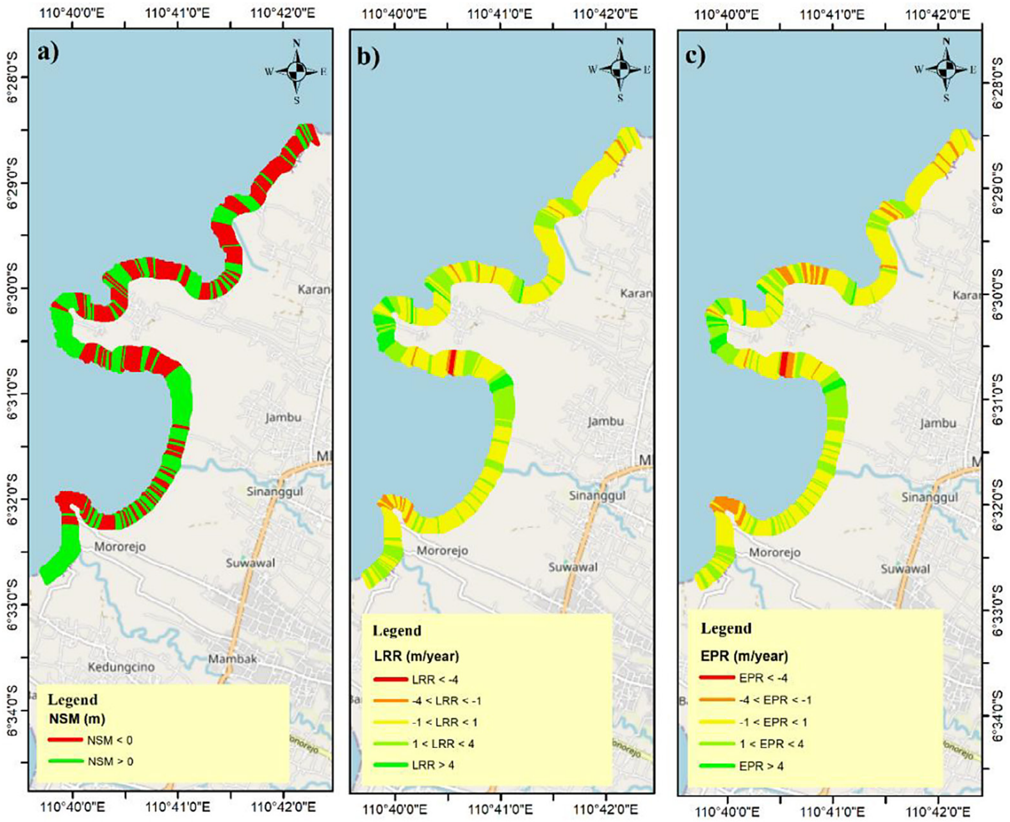

Figure 6. Shoreline changes at Mlonggo sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

average LRR value of 0.27 m/year and the average EPR value of 0.20 m/year, suggesting that, on average, the area is experiencing accretion. Despite the general trend of accretion, certain locations within the Tahunan sub-district have recorded significant erosion events, with an LRR value of -2.39 m/year, an EPR value of -2.28 m/year, and a NSM value of -67.91 m/year. Notably, this high erosion is observed at Kali Buntung Beach, located in Semat Village. Conversely, other areas exhibit the highest levels of accretion, as determined by DSAS calculations, which reveal a maximum LRR value of 3.42 m/year, a maximum EPR value of 3.48 m/year, and a maximum NSM value of 103.88 m. This pattern is evident in the Teluk Awur beach area, where sedimentation is occurring due to the influence of longshore currents on suspended sediments, leading to substantial sediment distribution (Subardjo et al., 2020).

Kedung

The analysis of the Kedung sub-district reveals pervasive coastal erosion, with no evidence of accretion, as depicted in Figure 9. The calculated average LRR is -9.67 m/year, indicating a rapid and consistent shoreline retreat. Furthermore, the average EPR of -9.75 m/year corroborates the LRR findings, underscoring the persistent erosion along the Kedung Sub-District coastline over the past 30 years, with no signs of recovery. Detailed spatial analysis identifies the highest erosion rate in the pond area near the Serang Estuary, with an EPR of -23.73 m/year and an LRR of -22.90 m/year. Additionally, NSM value reached an extreme of -707.98 m over the 30-year period. These findings suggest that anthropogenic factors significantly contribute to the erosion, as the presence of ponds increases the coastal area's vulnerability. Moreover, the proximity of residential zones along riverbanks and the coastline exacerbates the area's susceptibility to disasters (Setiadi et al., 2023).

Prediction of future shoreline change (2034 and 2044)

Utilizing the Kalman filter method, predictive modeling has been conducted to forecast shoreline changes in Jepara Regency for the years 2034

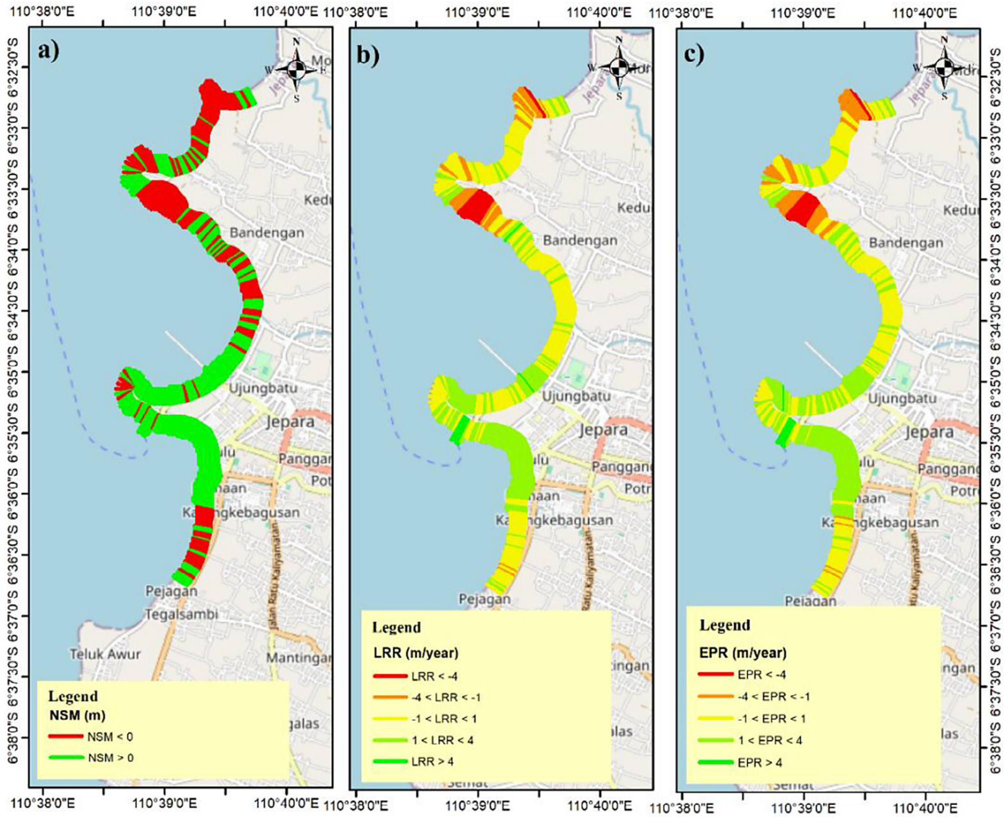

Figure 7. Shoreline changes at Jepara sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

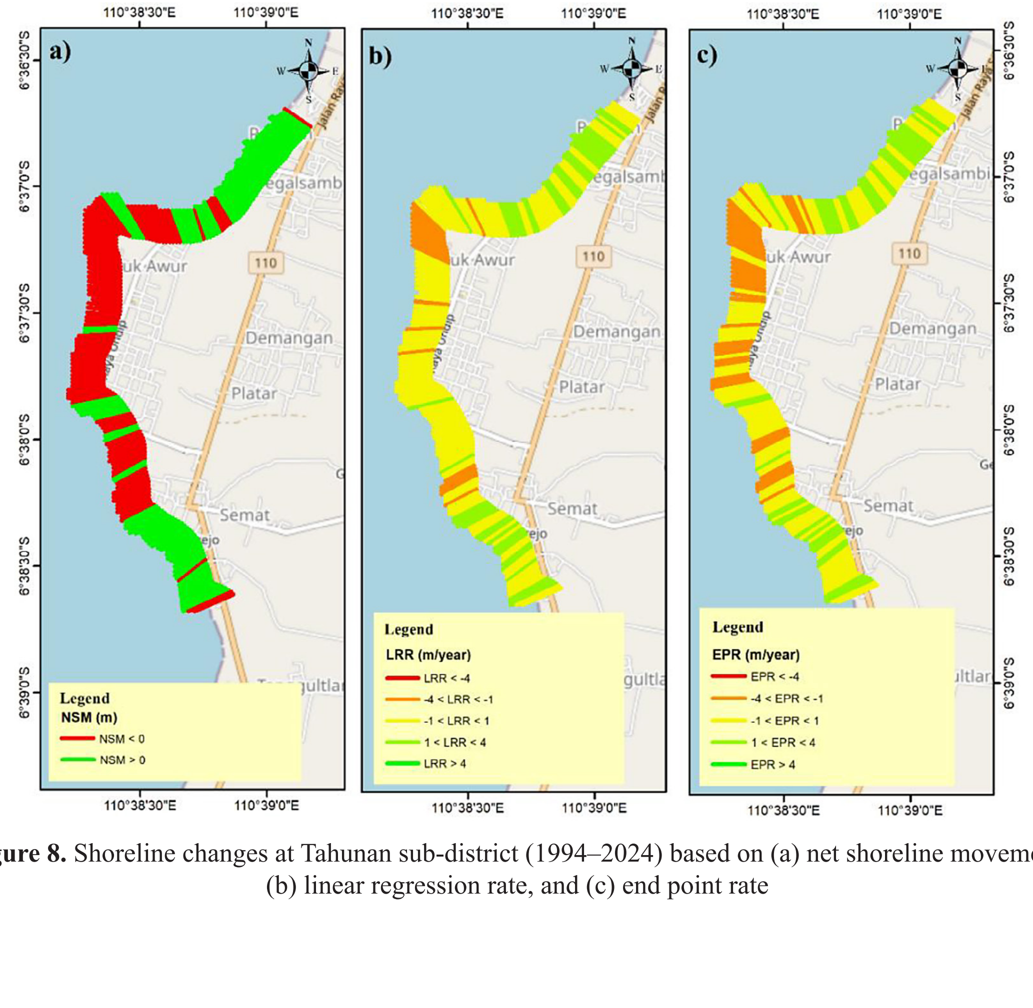

Figure 8. Shoreline changes at Tahunan sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

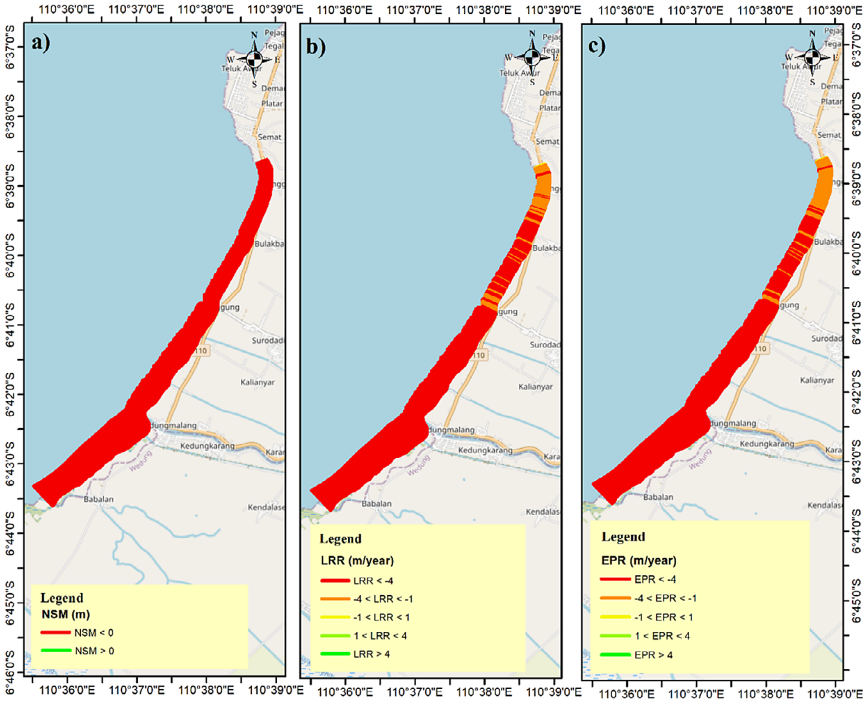

Figure 9. Shoreline changes at Kedung sub-district (1994–2024) based on (a) net shoreline movement, (b) linear regression rate, and (c) end point rate

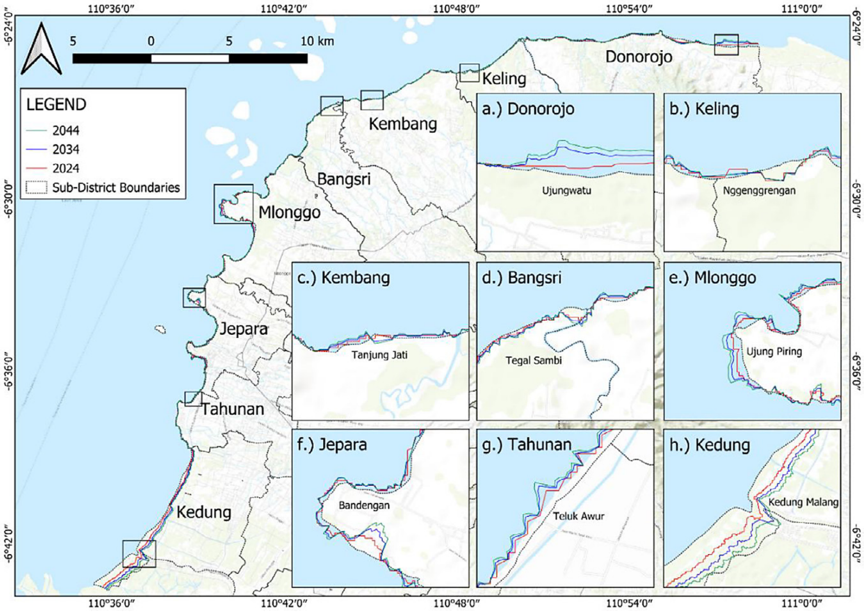

Figure 10. Prediction shoreline change at Jepara regency: (a) Donorojo, (b) Keling, (c) Kembang, (d) Bangsri, (e) Mlonggo, (f) Jepara, (g) Tahunan, (h) Kedung, for 2034 and 2044, derived from three decades of historical change

and 2044. The prediction outcomes, illustrated in Figure 10, reveal a trend of significant erosion and accretion across several sub-districts. The Kedung sub-district is projected to experience the most severe erosion, with values of -301.39 meters in 2034 and -440.37 meters in 2044. Similarly, the Jepara sub-district is anticipated to face a critical erosion rate of -128.47 meters in 2034 and -229.08 meters in 2044. Conversely, the Donorojo sub-district is expected to undergo the most pronounced accretion, with values of 263.67 meters in 2034 and 353.48 meters in 2044, followed by the Mlonggo sub-district, which is projected to have accretion values of 129.38 meters in 2034 and 192.48 meters in 2044. Additionally, other sub-districts are also predicted to experience significant levels of erosion and accretion. For instance, the Keling sub-district is expected to undergo erosion of -42.24 meters in 2034 and -41.63 meters in 2044, with accretion reaching 24.1 meters in 2034 and 35.7 meters in 2044. The Kembang sub-district is forecasted to experience erosion of -55.78 meters in 2034, increasing to -75.35 meters in 2044, while accretion is projected to reach 55.22 meters in 2034 and 58.68 meters in 2044. The Bangsri sub-district is anticipated to exhibit extreme erosion levels of -43.1 meters in 2034, increasing to -74.76 meters in 2044, with accretion rising from 52.16 meters in 2034 to 72.26 meters in 2044. The Tahunan sub-district is predicted to experience extreme erosion of -48.4 meters in 2034 and -60.33 meters in 2044, along with accretion from 44.04 meters in 2034 to 70.18 meters in 2044. This uneven shoreline pattern suggests an imbalance in sediment transport dynamics within the coastal area, potentially threatening the stability of ecosystems and the region's spatial planning.

CONCLUSIONS

The multitemporal analysis of shoreline changes in Jepara Regency from 1994 to 2024 reveals significant variations in shoreline dynamics. The analysis was conducted by categorizing the area according to the administrative sub-districts within Jepara Regency. The sub-districts of Keling, Kembang, Bangsri, Mlonggo, Jepara, and Tahunan exhibited stable shoreline conditions, as indicated by average LRR and EPR values within the stable range of -1 to 1 m/year. Conversely, Kedung sub-district experienced a tendency towards erosion, with average LRR and EPR values both below -4 m/year, classifying the shoreline change in this sub-district over the past 30 years as very high erosion. In Donorojo sub-district, the average LRR value ranges from -1 to 1 m/year, while the average EPR value ranges from 1 to 4 m/year. The LRR value suggests a relatively stable long-term trend in Donorojo, whereas the EPR indicates a moderate accretion trend. Thus, the coastal area of Donorojo sub-district can be generally categorized as experiencing moderate accretion, as the EPR reflects the actual positional change of the shoreline, while the small LRR value indicates a relatively stable long-term trend, albeit leading to shoreline accretion.

Shoreline change predictions using the Kalman Filter indicate significant variations along the Jepara Regency coast. The coastal area of Ujungwatu Village in Donorojo sub-district exhibits the highest level of accretion, with the shoreline increasing by 263.67 m in 2034 and 353.48 m in 2044. Nggenggrengan Beach experiences erosion of -42.24 m in 2034 and -41.62 m in 2044. The coastal area of Tanjung Jati regresses by -55.78 m in 2034 and -75.35 m in 2044. Tegal Sambi Beach experiences erosion of -43.10 m in 2034 and -74.76 m in 2044. Ujung Piring Beach sees accretion of 129.38 m in 2034 and 192.49 m in 2044. Bandengan Beach undergoes erosion of -128.47 m in 2034 and -229.08 m in 2044. Teluk Awur Beach experiences accretion of 44.04 m in 2034 and 70.18 m in 2044. The coast of Kedung Malang is the area with the most significant erosion among all locations, with values of -301.39 m in 2034 and -440.37 m in 2044. The study underscores the necessity for responsive strategies to address both natural and anthropogenic shoreline dynamics to mitigate severe adverse impacts on affected areas and to harness the potential of regions experiencing accretion.

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