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RESEARCH PAPER

Shoreline change analysis and its impact on coastal communities using remote sensing and GIS in the Kedungsepur Metropolitan area

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Abstract. Shoreline mapping plays an important role in sustainable coastal management, particularly in strategic areas such as the Kedungsepur Metropolitan area. This study aims to analyzes shoreline changes and identifies their impact on coastal communities. Shoreline extraction was conducted using remote sensing data from Landsat satellite imagery, while the analysis of shoreline changes was performed using the Digital Shoreline Analysis System (DSAS) within a Geographic Information System (GIS) environment. The results reveal that shoreline changes – both erosion and accretion – occurred across Kendal Regency, Semarang City, and Demak Regency. The most severe coastal erosion was identified in Bedono Village (Demak Regency), while the highest accretion occurred in Pidodo Kulon Village (Kendal Regency). When analyzed by watershed units, the highest accretion was found in the Bodri Watershed, one of the priority areas for revitalization. These findings highlight the need for integrated policy approaches that connect coastal and watershed management to ensure long-term sustainability.

Keywords: Shoreline change mapping; Remote sensing; Geographical Information System; Digital Shoreline Analysis System; coastal community

1. Introduction

Java Island, Indonesia, is renowned for being one of the most densely populated islands globally, characterized by its significant economic and cultural importance. The island stretches longitudinally, bordered by the Java Sea to the north and the Indian Ocean to the south (Setyawan & Pamungkas, 2017). This geographic position places the northern coast of Java in a highly strategic role within the Indonesia's economy. Major urban center –including Jakarta, Bekasi, Cirebon, Pekalongan, Semarang, and Surabaya– are situated along this shoreline, serving as critical hubs for trade, industry, and population density (Andreas et al., 2018; Ondara et al., 2020). However, this economically strategic coastal zone is increasingly threatened by serious

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environmental challenges. In recent decades, the northern coast of Java has experienced a significant rise in tidal flooding and coastal erosion. These environmental issues are driven by a combination of natural processes and anthropogenic activities (Andreas et al., 2018; Solihuddin et al., 2021). Coastal erosion, also referred to as abrasion, refers to the process by which wave action gradually wears away the shoreline, leading to land loss. Tidal flooding, on the other hand, involves the inundation of land areas due to rising sea levels and increased frequency of high tides. Both of these issues have become alarmingly frequent and severe along the northern coast of Central Java. Moreover, they are projected to worsen as development activities in the region continue to escalate (Handayani et al., 2019; Mahendra et al., 2017; Marfai et al., 2021; Rahman et al., 2021).

The impact of this environmental challenge is far-reaching, particularly because the north coast of Central Java is home to the Kedungsepur Metropolitan area, which serves as a key center of regional economic growth. This metropolitan area plays a vital role in Central Java's economic stability, accommodating a dense population and hosting numerous industrial activities (Hanifah et al., 2023; Indrayati et al., 2023). Consequently, the adverse effects of coastal erosion and tidal flooding in this region may lead to serious repercussions not only for local communities but also for the broader economy. Potential consequences include infrastructure damage, loss of property, and the disruption of critical economic activities, all of which underscore the urgency of addressing coastal degradation.

Addressing these issues requires a comprehensive and well-informed approach to coastal planning and development. Implementing sustainable management practices are essential to mitigate the effects of coastal erosion and tidal flooding. In this context, accurate and up-to-date data on shoreline changes play a critical role. Shoreline change mapping is a vital tool for monitoring how coastal boundaries evolve over time and for assessing the potential consequences for coastal areas (Barzehkar et al., 2021; Mbezi et al., 2024). Through the analysis of shoreline changes, researchers and policymakers can gain deeper insights into coastal dynamics, detect emerging trends, and forecast future transformations, thereby enabling more effective and proactive decision-making.

The urgency of studying shoreline changes cannot be overstated. The shoreline represents sensitive interface between land and sea, where any alterations in its shape or position can significantly impact coastal ecosystems, infrastructure, and the communities that inhabit these areas. Accurate shoreline mapping is essential for identifying patterns of change, predicting the risks associated with natural disasters such as tidal flooding and coastal erosion, and developing targeted adaptation strategies to safeguard both human populations and natural habitats. For instance, the early detection of erosion hotspots can prompt the timely implementation of protective measures, such as sea walls, dune reinforcement, or vegetation planting, to help stabilize and preserve the shoreline (Hernández-Delgado, 2024).

Despite the critical importance of shoreline change studies, research in this area remains relatively sparse in Indonesia (Arjasakusuma et al., 2021). The lack of comprehensive and systematic investigations into shoreline dynamics constrains our ability to effectively address the challenges posed by coastal erosion and tidal flooding. Strengthening research efforts and investing in advanced monitoring technologies are necessary steps to fill this knowledge gap. Remote sensing techniques, such as the use of satellite imagery, over valuable insights into shoreline changes and can support the development of more accurate models of coastal processes.

Shoreline mapping studies generally use Geographic Information System (GIS) and remote sensing approaches. The remote sensing data typically used are medium-resolution satellite images, such as those from Landsat and Sentinel (Alharbi et al., 2023; Arjasakusuma et al., 2021; Hossen & Sultana, 2023; Novellino et al., 2020). Studies utilizing remote sensing for shoreline change mapping have been widely applied along the northern coast of Central Java, such as studies by Kurniawan and Marfai (2020), Muskananfola and Febrianto (2020), Dewi and Bijker (2020), [Astuti et al (2021)](), [Manik and Wijayanto (2023)](). However, these studies have yet to describe the spatio-temporal impacts of shoreline changes in detail. In fact, understanding the impact of shoreline changes in this area is crucial for formulating effective policies related to the sustainable planning and development of coastal areas. [Mishra et al. (2020)]() also highlight an ongoing challenge in shoreline mapping studies - namely, the limited integration of physical shoreline data into social science frameworks. Therefore, the presents study aims to map shoreline changes along the northern coast of Central Java, with a specific focus on the Kedungsepur Metropolitan area. It also seeks to identify the environmental impacts resulting from these changes. Shoreline changes not only reflect the physical characteristics of the coastal environment, but also reveal interactions between socio-economic development, ecological transformation, and coastal policy [(Li et al., 2018)]().

2. Material and method

2.1. Study locations

The Kedungsepur Metropolitan area is an urban area surrounding the capital of Central Java Province, Semarang City. This area includes Kendal Regency, Demak Regency, Semarang Regency, Semarang City, Grobogan Regency. The Kedungsepur Metropolitan area is envisioned as a large-scale economic hub with an international orientation, focusing on trade in goods and services, various industries including maritime sectors, marine resources, tourism, and the development of the creative economy. This study specifically focuses on the coastal zones within the Kedungsepur Metropolitan area, covering Kendal Regency, Semarang City, and Demak Regency ([Figure 1]() and [Table 1]()).

Figure 1. Study location

Table 1. Geographical scope of the study

Area	District
Kendal regency	Rowosari, Kangkung, Cepiring, Patebon, Kota Kendal, Kaliwungu
Semarang city	Tugu, Semarang Barat, Semarang Utara, Genuk
Demak regency	Sayung, Karangtengah, Bonang, Wedung

2.2. Satellite image data

Shoreline changes in this study were identified using remote sensing techniques. The remote sensing data utilized consist of medium-resolution satellite imagery, specifically Landsat satellite imagery. Landsat satellite imagery is characterized by its use of multiple spectral bands, each capturing different wavelengths of light to reveal various features of the Earth's surface. The Landsat satellites include several bands ranging from visible light to infrared, enabling detailed analysis of features such as vegetation, water bodies, and urban areas. For example, Near Infrared (NIR) bands are very useful for assessing vegetation health, while Thermal Infrared (TIR) bands effective for monitoring surface temperatures. By combining data from these spectral bands, researchers can obtain a comprehensive understanding of environmental dynamics, including shoreline changes. This makes Landsat imagery a powerful and widely used tool for Earth observation.

The Landsat image data from the years 1997, 2007, 2017, and 2023 were used in this study (Table 2). According to Irfan and Suprayogi (2012), the most significant erosion along the shoreline of Semarang City occurred between 1997 to 2003. Notably, in 1997, the hamlets in Timbulsloko Village, Demak Regency, were lost due to severe coastal disaster events (KIARA, 2021; Wirasatriya et al., 2017). Therefore, 1997 was designated as the baseline year for shoreline change mapping. Additionally, a medium-term mapping interval was adopted, consistent with (van Rijn, 2011), who suggests that shoreline changes of up to 100 meters can occur over a 10-yearperiod.

Satellite image data were obtained from the Google Earth Engine (GEE) platform, utilizing Surface Reflectance products that have been atmospherically corrected. The first stage in the image selection process was to filter acquisition dates to the dry season (June – September). The second stage is pre-processing through masking using the Quality Assurance (QA) band. This process ensures that the selected satellite images used are representative of actual ground conditions. Additionally, masking using QA bands is intended to eliminate pixels affected by cloud cover and cloud shadow, thereby enhancing the accuracy of the imagery (Amalia et al., 2024; Wang et al., 2020).

2.3. Shoreline extraction and shoreline change analysis

Shoreline extraction was performed using a combination of band ratio and histogram threshold methods. The band ratio involved the NIR band and Green bands, as the NIR band provides strong separability between vegetation and water bodies, while the Green band enhances the detection of land-water boundaries obscured by vegetation (Astuti et al., 2021; Sunny et al., 2022). The resulting band ratio produced a raster image, which was then subjected to histogram threshold to classify pixels into land and water categories. Once classified, the raster data were converted into vector line format to delineate the shoreline.

Shoreline change analysis was conducted using a GIS-based approach, specifically the Digital Shoreline Analysis System (DSAS). DSAS is an extension of the ArcGIS software designated to analyze shoreline changes over time. The analysis requires the creation of a baseline, which serves as the zero-reference point for measuring shoreline position, and transects that divide the shoreline into segments for systematic analysis. DSAS offers several statistical methods, including Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR) (Kılar, 2023; Lazuardi et al., 2022; Natarajan et al., 2021). NSM calculates the distance of shoreline move-

Table 2. Satellite image data used

Year	Data
1997	Landsat 5, surface reflectance product
2007	Landsat 5, surface reflectance product
2017	Landsat 8, surface reflectance product
2023	Landsat 8, surface reflectance product

ment between the earliest and latest shoreline positions, while EPR divides this distance by the length of the time period analyzed (Astuti et al., 2021). LRR applies a least squares regression line through all shoreline positions along a transect to estimate the rate of change over time (Ayalke et al., 2023).

The EPR parameters typically reflects the overall shoreline change between the earliest and most recent shorelines, providing a general overview of the change over the analysis period. However, it is limited to to comparisons between two shorelines positions. For analyses involving multiple shorelines datasets, the LRR yields more precise and objective results (Quang et al., 2021). According to Hossen and Sultana (2023), LRR outperforms both EPR and NSM in long-term shoreline changes due to its ability to apply a least squares regression line across all shoreline positions from oldest to most recent. Therefore, this study adopts LRR method for shoreline change analysis, following approaches used by Velsamy et al. (2020) and Rojahan et al. (2022). The resulting LRR values are then classified to differentiate between shoreline erosion, accretion, and stability. The classification follows Hossen and Sultana (2023), where negative LRR values indicate erosion, positive values indicate accretion, and values near zero represent relatively stable shorelines (Table 3).

2.4. Identify impacts on coastal communities

The results of the shoreline change analysis are described, followed by a discussion of their impact on coastal communities. Assessing these impacts encompasses a multi-step approach involving a literature review, field observations, and in-depth interviews. Data collection began with a thorough review of existing literature to establish a theoretical framework. Field observations were then conducted in areas undergoing the most sever coastal erosion and accretion. Additionally, in-depth interviews were carried out with key respondents, including local residents, to capture firsthand experiences and insights. The data were analyzed using a descriptive qualitative method, which involved systematically organizing and interpreting and the qualitative information to reveal patterns and themes related to the impacts of shoreline changes on coastal communities.

3. Result and discussion

Shoreline changes are divided into two main types: coastal erosion and accretion. Coastal erosion is the process where waves and currents remove sediment from the shoreline, leading to land loss. This phenomenon is often driven by storm surges, high-energy wave action, and anthropogenic activities. Conversely, accretion occurs when sediment is deposited by waves and currents, gradually extending the shoreline. This process is influenced by factors such as changes in wave patterns, sediment supply, and coastal management practices. Shoreline change analysis was conducted using data from 1998 to 2023. The results, derived from shoreline change maps, clearly illustrate the dynamics of the shoreline within the study area. Kendal Regency, Semarang City, and Demak Regency each experienced both coastal erosion and accretion over the observation period (Figure 2).

In the study location, coastal erosion is observed across Kendal Regency, Semarang City, and Demak Regency. As shown in Table 4, the average rate of shoreline change is predominantly negative, indicating that shoreline is dominant process in the region. However, accretion is clearly visible in Semarang City, particularly in areas undergoing land reclamation. A relatively stable

Table 3. Shoreline classification based on LRR.

Rate of shoreline change (m/year)	Shoreline classification
< -1	Erosion
-1 until +1	Quite stable
> +1	Accretion

shoreline is found in the western part of Kendal Regency, specifically Rowosari. The shoreline in this area remains stable due to it is controlled by coastal erosion and accretion processes of nearly equal magnitude (Astuti et al., 2021). Additionally, certain segments of the shorelines in Cepiring also exhibit relative stability. According to Table 4, the lowest average rate of shoreline changes in the study area, approximately 1.47 m/year, is recording along the stretch from Rowosari to Kangkung between 1997 to 2023.

3.1. Coastal erosion

The highest rate of coastal erosion in the study area, reaching -236.27 m/year, is found in Bedono Village, Sayung District, Demak regency. Between 1997 to 2023, the shoreline in this area retreated by approximately 5.74 km (Figure 3). According to interviews results, coastal erosion has been occurred since 1997 and has significantly impacted local livelihoods. Previously, the residents of Bedono Village primarily worked as pond fishers, however, all fishponds were submerged due to coastal erosion. In response the community has adapted by shifting to alternative sources of income, including construction work, shellfish cultivation, retail, and tourism (Haloho & Purnaweni, 2020).

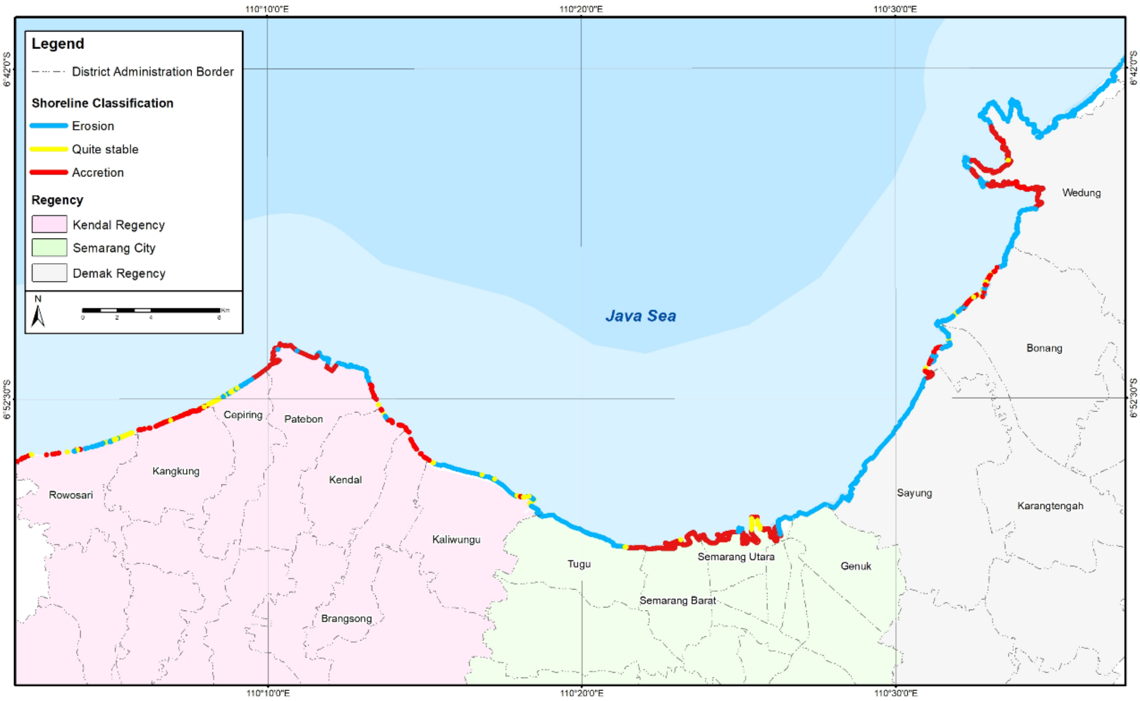

Figure 2. Shoreline change map

Table 4. Highest rate of shoreline change (m/year)

Area	Segment		Highest rate of shoreline change (m/year)		
			Coastal erosion	Accretion	Average
Kendal Regency	I	Rowosari - Kangkung	-5.84	10.64	1.47
	II	Cepiring – Patebon – Kota Kendal	-26.50	73.50	1.92
	III	Brangsong - Kaliwungu	-131.81	15.30	-16.01
Semarang City	IV	Tugu – Semarang Barat	-88.72	64.04	-10.14
	V	Semarang Utara - Genuk	-97.43	29.69	-9.12
Demak Regency	VII	Sayung - Karangtengah	-236.27	13.11	-39.58
	VII	Bonang - Wedung	-88.34	97.84	-7.09

Bedono Village is also home to a religious tourism site, the tomb of Sheikh Muzakir (Figure 3). Despite severe coastal erosion that has submerged much of the village, the Sheikh Muzakir Tomb remains intact. According to interview results, Sheikh Mudzakir was a respected cleric known for his healing abilities, which earned great reverence within the community. In ther response to environmental challenges, the local community has taken adaptive mesures to preserve the tomb site. These include constructing protective structures and expanding the site to withstand coastal erosion and tidal flooding (Kusyanto et al., 2023).

Significant coastal erosion is also found in Kendal Regency, specifically in Mororejo Village, Kaliwungu District (Figure 4). This area experiences a shoreline retreat rate of -131.81 m/year, resulting in a total shoreline loss of approximately 4.01 km between 1997 to 2023. According to Putri et al (2024), this coastal erosion is partly attributed to the construction of a port in the Kendal Industrial Park, which has triggered hydro-oceanographic changes in the area. The erosion has caused considerable damage to local fishponds. However, the residents of Mororejo Village have adapted by implementing a silvofishery, which integrates aquaculture with mangrove cultivation to enhance ecological and economic resilience (Perwitasari et al., 2020).

Even though it does not experience the highest rate of coastal erosion, Semarang City has been significantly affected, with a shoreline retreat of approximately 2.2 km between 1997 and 2023. The most affected area is Terboyo Kulon Village in Genuk District, which has a coastal erosion rate of around -97.43 m/year. According to interview results, residents have observed the effects of coastal erosion since 1997, with the severity increasing over time. By 2005, the fish auction facility located at the border between Terboyo Kulon Village and Tanjung Mas Village had completely disappeared (Figure 5). The severe erosion in Semarang City is caused by several factors, such as coastal reclamation activities (Hadi, 2017; Marques & Khakhim, 2016).

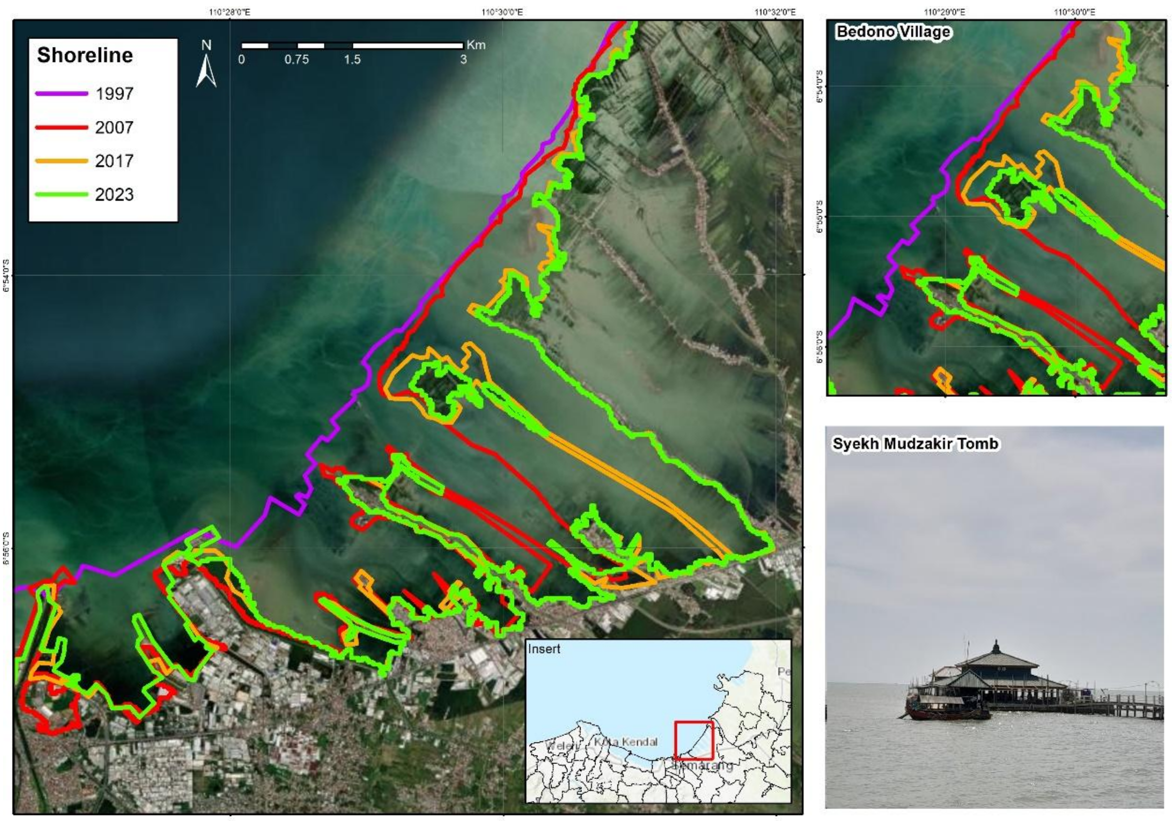

Figure 3. Shoreline changes in Bedono Village, Sayung, Demak Regency

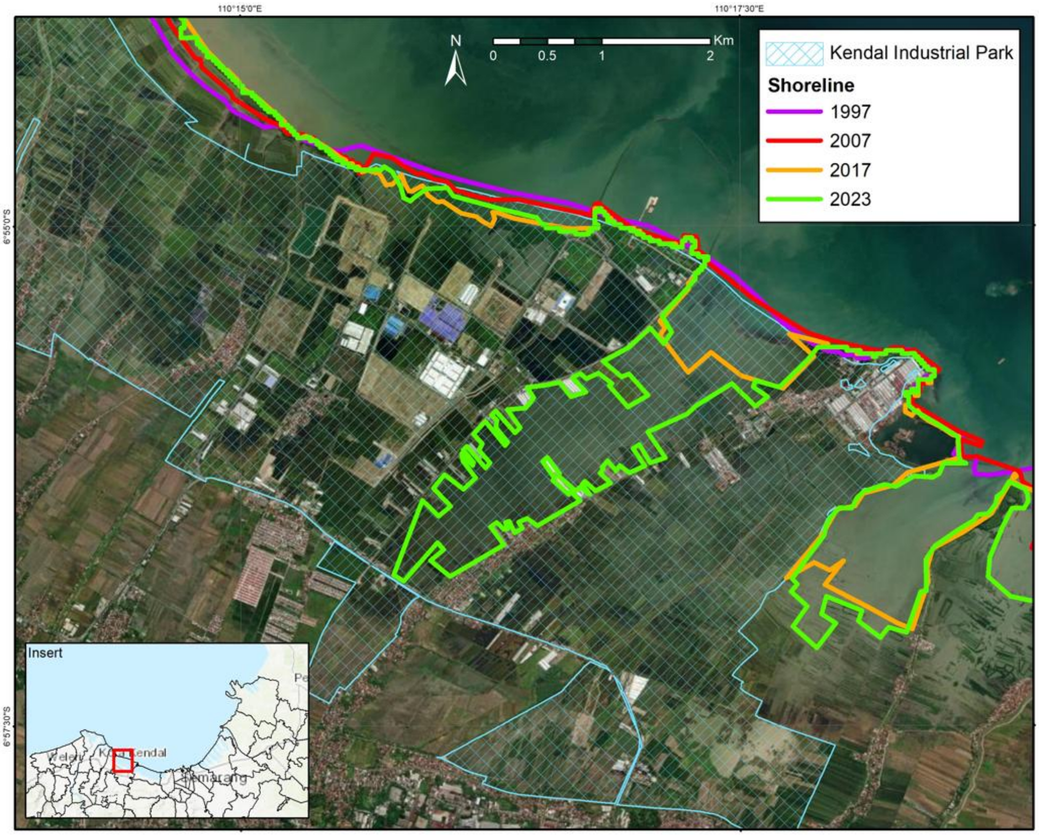

Figure 4. Shoreline changes in Mororejo Village, Kaliwungu, Kendal Regency

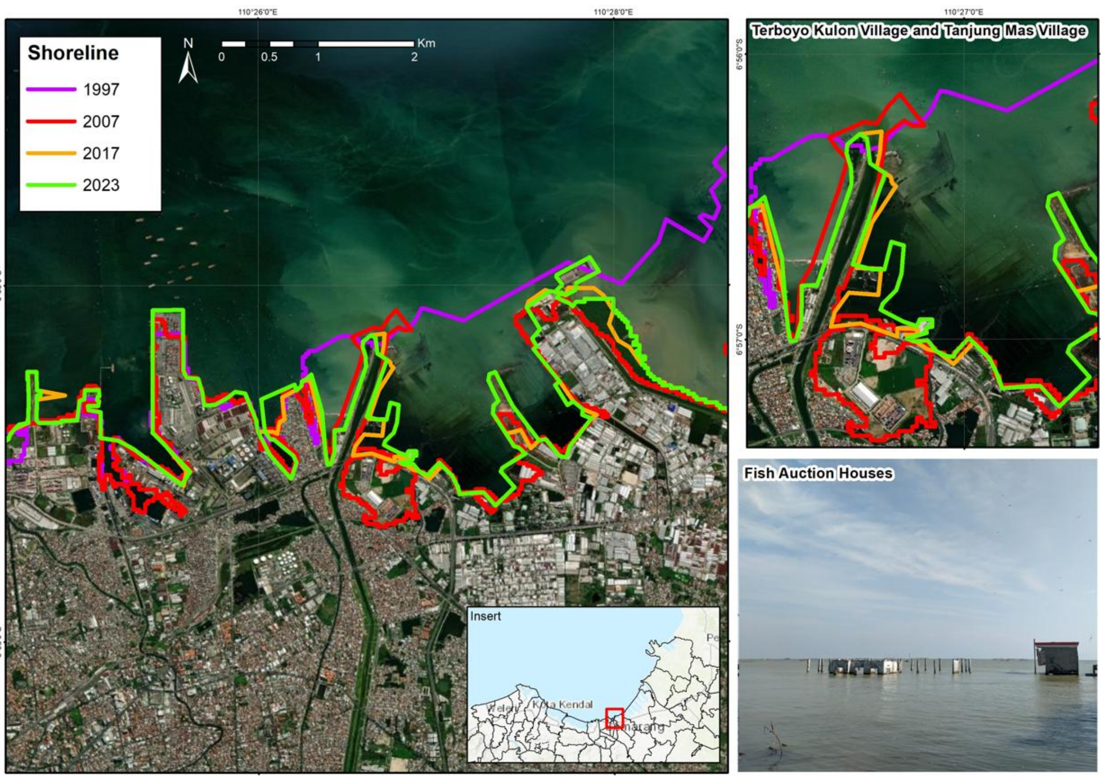

Figure 5. Shoreline changes in Terboyo Kulon, Genuk, Semarang City

3.2. Accretion

In the study area, the highest rate of accretion is found in Kendal Regency, specifically in Pidodo Kulon Village, Cepiring District (Figure 6). This region has experienced shoreline advancement of approximately 1.99 km between 1997 and 2023, with an average accretion rate of around 73.5 m/year (Table 5). The area is part of the Bodri Delta, which is known for its rapid growth compared to other deltas along the northern coast of Java (Sanjoto et al., 2019). One of the main contributing factors to this high accretion rate is the high sedimentation from the Bodri River (Antari et al., 2020). Another notable area of accretion is located in Semarang City, precisely in Tambakharjo, North Semarang District. However, in this case, the shoreline expansion –approximately 1.4 km– is the result of land reclamation rather than natural sedimentation.

According to Marsudi and Lufira (2021), coastal sedimentation is strongly influenced by land cover within the watershed. Reduced vegetation in upstream areas leading to increased erosion, which in turn leads to greater sediment deposition in estuaries zones. The Bodri Watershed, showing the highest accretion rate of 73.50 m/year, has been identified as a key priority for revitalization in the Central Java Regional Plan (Gubernur Jawa Tengah, 2023). Similarly, the Tuntang and Serang Watershed –also prioritized for revitalization– demonstrate significant

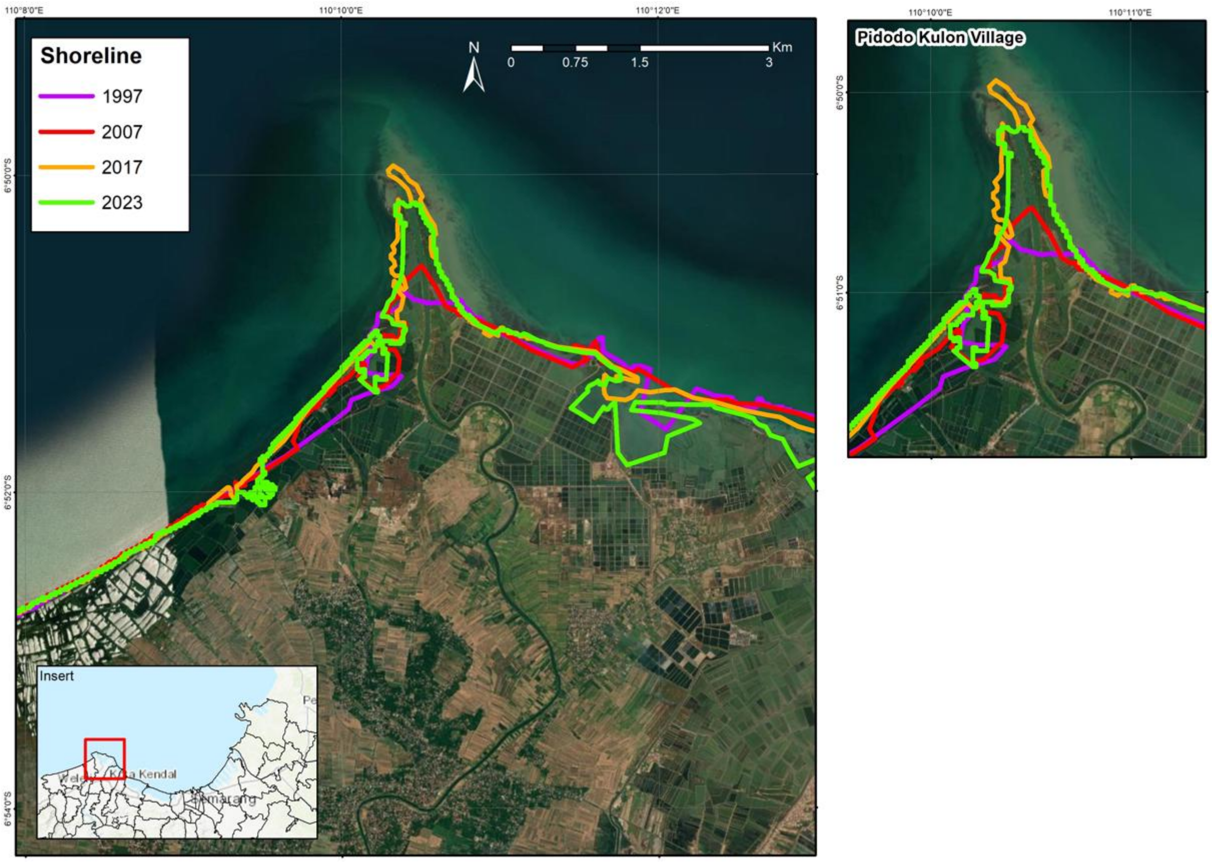

Figure 6. Shoreline changes in Pidodo Kulon, Kendal Regency

Table 5. Shoreline changes based on watershed area

Area	Highest rate of shoreline change (m/year)		
	Coastal erosion	Accretion	Average
Bodri Watershed	-26.50	73.50	0.76
Tuntang Watershed	-10.29	10.44	-1.27
Serang Watershed	-88.34	97.84	-9.68

accretion rates of 10.44 m/year and 97.84 m/year, respectively. These findings highlight the urgent need for erosion control and watershed conservation efforts. Enhancing vegetation cover and implementing sustainable land management practices in upstream areas can significantly reduce erosion and regulate sediment transport. Such measures are essential for maintaining coastal stability and ensuring the ecological health of the estuarine environments.

3.3. Future work

An analysis of shoreline changes in the Kedungsepur Metropolitan area shows that coastal erosion is the most dominant trend. However, shoreline accretion is also observed in certain areas, caused by sedimentation at river mouths and land reclamation activities. These findings underscore the urgent need for effective mitigation strategies, particularly for addressing coastal erosion. Consistent with the recommendations of Irsadi et al (2022), active involvement from communities, government agencies, and private organizations is essential for the success of these efforts. One promising strategy is mangrove restorations which not only helps stabilize shorelines but also support coastal biodiversity.

Mangrove ecosystems play a crucial role in mitigating coastal erosion by serving as natural buffers against wave action and storm surges. Effective mangrove restoration depends on comprehensive data current mangrove distribution, coastal land cover, and their changes over time. Detailed mapping and continuous monitoring are vital for understanding the condition of mangrove forests and their interactions with shoreline dynamics (Besset et al., 2019). Such data is indispensable for planning restoration initiatives and evaluating their effectiveness. integrating shoreline change analysis with mangrove mapping changes mapping is play an important role for coastal area management (Thakur et al., 2021), asit enables a better understanding of how shoreline dynamics influence mangrove ecosystem and how, in turn, mangroves effects shoreline stability.

In shoreline change mapping studies, GIS and remote sensing technologies have become indispensable tools. These technologies provide valuable insights into shoreline dynamics by enabling the analysis of spatial and temporal changes across extensive areas. However, the effectiveness of these technologies highly dependent on the quality and resolution of the data used. Currently, medium-resolution satellite imagery, such as that provided by Landsat, is commonly employed in shoreline studies. Despite its long historical record and has been freely available since 1972, its spatial resolution poses limitations which can hinder the level of detail in shoreline analysis (Apostolopoulos & Nikolakopoulos, 2020).

The relatively coarse resolution of Landsat imagery often fails to capture fine-scale shoreline changes accurately, potentially leading to data inaccuracies. While high-resolution satellite imagery can address these weaknesses regarding accuracy, such data is often expensive and not readily available, posing a significant barrier for developing countries like Indonesia. To address this limitation, integrating satellite imagery with radar data is recommended, as it enhances change detection accuracy and provides a more reliable assessment of erosion and accretion processes (Apostolopoulos & Nikolakopoulos, 2020; Arjasakusuma et al., 2021). Radar data is particularly due to its ability to penetrate cloud cover and provide surface texture information, further enhance the reliability of shoreline studies (Pradhan et al., 2018). Additionally, advanced shoreline mapping techniques using machine learning from GEE, as demonstrated by Sidiq et al. (2025), should be implemented in the future to further improve the precision and efficiency of shoreline analysis.

Beyond technological advancements, there is a critical need to strengthen the social and environmental dimensions of shoreline change research. Effective policy recommendations and adaptation strategies must consider not only the immediate impacts on coastal areas but also the broader environmental context. Integrated coastal and watershed management policies are essential for address the complex interactions between land and sea processes. In this study, the largest occurred in the downstream priority watersheds, specifically Bodri and Tuntang, which was associated with activities in the upstream watersheds targeted for revitalization. This highlights the need for a holistic approach that encompasses both coastal and inland areas. Such integrated management strategies are aligned with national climate resilience development plans, which emphasize the importance of adapting to climate change by strengthening the resilience of both coastal zones and watershed.

Integrating coastal and watershed management requires coordinated efforts across various sectors and scales. For instance, policies that regulate land use and reducing sediment runoff in upstream areas can help mitigate the impacts of erosion and accretion downstream. Such integrated approach can enhance the sustainability of both coastal and watershed ecosystems, ensuring the resilience of natural and human systems to environmental changes. Future research should prioritize the development and refinement of these integrated management strategies. This includes assessing the effectiveness of current policies, identifying gaps in existing practices, and exploring innovative solutions to emerging challenges. Collaboration among researchers, policymakers, and local stakeholders are crucial for advancing this field and achieving sustainable outcomes (Singh, 2024).

4. Conclusion

The shoreline extraction results were analyzed over the observation period from 1998 to 2023. The shoreline changes map reveals notable changes across the study area, with Kendal Regency, Semarang City and Demak Regency all experiencing both coastal erosion and accretion. The most severe coastal erosion occurred in Demak Regency, specifically in Bedono Village. In contrast, the most significant accretion was observed Pidodo Kulon Village, Kendal Regency. When analyzed by watershed units, the highest accretion was found in the Bodri Watershed, which is one of the priority watersheds targeted for revitalization. These findings underscore the importance of integrating coastal and watershed management to address interconnected land-sea process effectively.

Future work should leverage advanced technologies such as the integration of satellite imagery with radar data and the application of machine learning methods to enhance the accuracy of shoreline change detection and improve assessments of erosion and accretion processes. However, technological advancement alone is not sufficient, they must be complemented by the integration of social and environmental dimensions into policy recommendations for more effective management. Adopting integrated coastal and watershed management policies will enable stakeholders to better address the impacts of shoreline changes and promote the sustainability of coastal and watershed ecosystems. Coordinated efforts across sectors to manage land use and reduce sediment runoff are essential. Future research should prioritize evaluating existing policies, identifying gaps, and exploring innovative solutions that align with national climate resilience development goals. Such comprehensive approaches will not only improve management practices but also contribute significantly to long-term sustainability and climate resilience efforts.

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