Journal of Geographical Research : Geoeducasia
2025, Volume 1, Number 2, Pages 76-86

https://doi.org/xxx

Coastal Morphodynamics Under The Influence Of Climate Change And Anthropogenic Activities In The Last Decade: A Study In Jepara Area, Indonesia

Rizqya Putri Sani Nurussolikhin[1*] Muhamad Ervin[1] Audyana Putri[1] Shafaa Lubnaa Tsabita An Nafi[1] and Arif Ashari[1]

[1]Department of Geography Education, Universitas Negeri Yogyakarta, Indonesia
(*)corresponding author: audyanaputri.2022@student.uny.ac.id

Submitted	:	2 March 2025
Accepted	:	4 April 2025
Published online	:	30 December 2025

Abstract

Coastal areas in Jepara region have received much attention due to their unique geomorphology and long-standing human history. In recent years, the coastal areas of Jepara and Demak have gone viral on social media due to floods that recalled public memories of the Muria Strait, which disappeared several centuries ago. In this paper, we studied coastal morphodynamics under the influence of climate change and anthropogenic activity, such as land-use changes, coastal development, and resource exploitation. This study aims to find the actual morphodynamic conditions currently under the issue of climate change and increasingly massive anthropogenic activities. This study uses primary and secondary data. Data collection is based on literature study, documents, observation, and interpretation of remote sensing imagery. Data analysis was conducted using descriptive analysis supported by remote sensing analysis. Descriptive analysis was carried out using a geomorphological approach and causal thinking patterns. Meanwhile, remote sensing analysis was conducted using Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI) analysis. The results of this study show that Jepara Coastal Area has been influenced by a combination of climate and anthropogenic activities such as land-use changes, development, and resource exploitation, in the coastal area. The climate element in question is wind, which correlates with the characteristics of waves and ocean currents. In the west season, the climate is destructive, while in the east season, it is constructive. This condition causes the formation of beaches with pocket beaches. Anthropogenic activities trigger the formation of the Wulan Delta, which has an impact on the patterns that exist in the region. In the last decade, strong marine erosion has mainly occurred on the south shore. Erosion in the north also occurs but at a limited intensity. In summary, this study offers new insights into the current morphodynamics of the Jepara Coastal Area.

Keywords: Anthropogenic activities; climate change; coastal morphodynamics; Jepara coastal

Introduction

The coastal area is geomorphologically unique, as it is a confluence of land and sea systems. Moreover, coastal areas are areas where many people live. Bird (2008) explains that more than half of the world's population lives in coastal regions, and many people visit the coast frequently. In this regard, coastal dynamics controlled by a combination of land and sea processes are urgent to study. The study of coastal morphodynamics will add insight into geomorphology while providing vital information to support the benefit of human life.

In Indonesia, a coastal area that has been of interest for a long time is Jepara, Central Java. Central Java. This coastal area has emerged in connection to both geomorphological history and human life. Geomorphologically, this area is the former Muria Strait that still existed in the 10th century and began disappearing in the 17th century (Daliman, 2012; Sunarto, 2004). The disappearance of this strait is a legendary chronicle and has become a viral discussion in recent years. Concerning human history, the Demak region was an important area of trade and international relations during medieval times, and so it also appears on ancient European charts.

The coastal area of Jepara continues to experience dynamics over time because of the operation of various geomorphic agents. One of the coastal dynamics in Jepara that needs attention is morphodynamics. Sunarto et al. (2014) explain that morphodynamics is related to landscape formation and development. Geology and climate impact these processes in coastal areas (Bird, 2008). Geological factors are related to rock types and tectonism, while climatic factors are related to wind, waves, and weathering processes (Sunarto et al., 2014). Along with the much-discussed issue of climate change, coastal morphodynamics in the Jepara area must be monitored to provide helpful information to support productivity and avoid negative adverse impacts.

Previous studies on the dynamics of the Jepara coast have been relatively extensive (Sunarto, 2004; Sunarto et al., 2014; Marfai & Permana, 2014). However, further studies are needed to provide up-to-date, accurate information about climate change issues. The massive anthropogenic activities in the last decade further strengthen the concern. Anthropogenic activities are believed to have affected the morphodynamics of the coast in Jepara. Compared to natural factors, the influence of anthropogenic activities have not been widely discussed in previous literature. This suggests a gap that needs to be filled with further research emphasizing the combined aspects of climate and anthropogenic activities.

We present a study on the morphodynamics of Jepara coastal area in the last decade under the combined influence of climatic factors and anthropogenic activities. Jepara region is not the Jepara Regency's administrative area but is along the Muria Volcano's coast, west of the former Muria Strait. There are three more specific objectives in this paper. First, we present a description of the morphodynamic chronicle of the Jepara coast based on a review of previous literature. Second, we present an evaluation of the morphodynamics that have occurred in the last decade, along with the impacts of climatic and anthropogenic activities. Finally, we present the results of a typology analysis of the Jepara coastal area generated by climatic and anthropogenic influences in the last decade. This paper provides alternative information on coastal morphodynamics in Jepara.

Method

Data Collection and Analysis

This study is characterized by using geographic approaches to analyze problems. The approach used is a spatial approach, especially the analysis of spatial interactions, with linkages and interactions among the various variables (Yunus, 2010). This research also implemented the themes of geography, namely location, place, human-environment interaction, movement, and region. In addition to the geography approach, this research also implemented the geomorphology approach. Between the two geomorphological issues described by Urban (2013), this study uses a physical systems perspective where geomorphology is a quasi-experimental science in which hypotheses are tested separately in a short period and detailed observations are obtained and recorded with great precision and accuracy. The working hypotheses in this study state that (1) morphodynamic changes along the Jepara coast are primarily influenced by climatic factors such as wind direction and wave dynamics, and (2) anthropogenic activities, including land use change and canal construction, intensify these natural processes and modify erosion–sedimentation patterns.

Referring to Huggett (2016), this study uses a process geomorphology approach, where observations are made of short-term coastal dynamics rather than landscape reconstruction as in historical geomorphology. The research focused on morphodynamic changes along the Jepara coast during the last decade (2013–2023) to describe active geomorphic processes. The steps carried out in this study included (1) collecting data from Landsat-8 OLI satellite imagery and field observations, (2) processing the imagery to calculate the Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI), (3) comparing the results from 2013 and 2023 to identify erosion and deposition areas, and (4) verifying these changes through field observation. The temporal scale used in this study was graded time, representing short-term events within the dynamic equilibrium cycle, while the spatial scale used was third order, following the area of this study which covers approximately 103 km² (Millar, 2013).

This research uses primary data and secondary data. Primary data was obtained from field observations. Meanwhile, secondary data were obtained from remote sensing image interpretation, literature studies, and documentation. Field observations were conducted using a combined analytical geomorphologic and synthetic geomorphologic survey. Remote sensing image interpretation was applied using Landsat-8 imagery. Documentation was carried out to obtain data from published documents, including the Geological Map of Kudus sheet, the Indonesian Topographical Map, and publications from the Central Bureau of Statistics. The literature study was used to obtain data from previous studies by Sunarto (2004) and Sunarto et al. (2014).

The data that has been obtained is then analyzed using descriptive analysis supported by remote sensing analysis. Descriptive analysis was based on a geomorphological approach and causal thinking to explain how natural and human factors shape the Jepara coast. The analysis followed four levels of explanation in explanatory descriptive research, namely (1) descriptive, (2) comparative, (3) associative, and (4) causal levels (Sunarto, 2004). In practice, this process was carried out through four main steps: (1) describing the geomorphic features and identifying visible changes from maps and satellite imagery, (2) comparing the differences between the 2013 and 2023 datasets to detect spatial and temporal variations, (3) analyzing the relationships between these changes and influencing factors such as climate and human activities, and (4) determining the causal mechanisms that explain the observed morphodynamic patterns. Meanwhile, remote sensing analysis was conducted using Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI) analysis. NDWI analysis was already used by Ihsan et al. (2023) for coastal area monitoring using Landsat Imagery, and in this study, NDWI and NDBI were applied to detect coastline shifts, erosion, deposition, and built-up area changes in the Jepara coastal area.

The Study Area

This study was conducted in the Jepara Coastal Area, Central Java. The area in question is not within the administrative boundaries of Jepara Regency. Still, it refers to the west coast starting from the change in orientation of the Central Java coast from the relative direction of W-E to SW-NE to the edge of the Muria Volcano on the north side. Administratively, most of the study area falls within the Jepara Regency, and a small part falls within the Demak Regency. The total area of the study area is 1386 km2, covering a land area of 639 km2 and a sea area of 747 km2. 58.2% of the study area is in Jepara district and 41.8% in Demak district. See Figure 1.

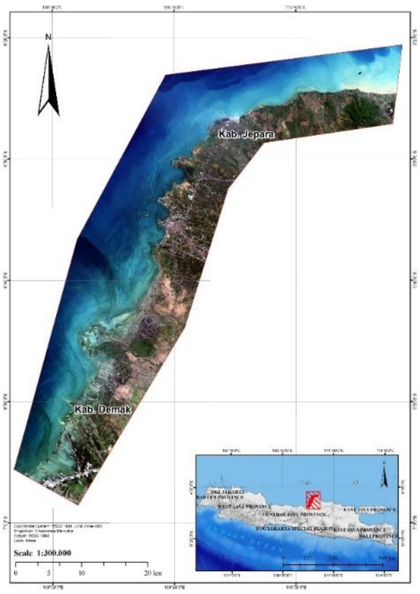

Figure 1. The Study Area

The Geological Map of the Kudus Sheet shows that the surface of this coastal area is covered by alluvium. This material is the product of geomorphic processes that have taken place in recent times. In the south, the alluvium material was deposited on top of the Bulu Formation and the Ngrayong Formation, both related to laguna-marine products as described by Sunarto (2004). In the north, the alluvium material was deposited on top of the Muria Tuff formed from the Middle Pleistocene to early Holocene. Geomorphologically, the landforms in this region are very diverse, including shale beds, swales, coral reef beach terraces, pocket shales, and tidal flats (Sunarto et al., 2014). These landforms are categorized as marine landforms. In addition, there are also other landforms in coastal areas, namely fluvial. See Figure 2.

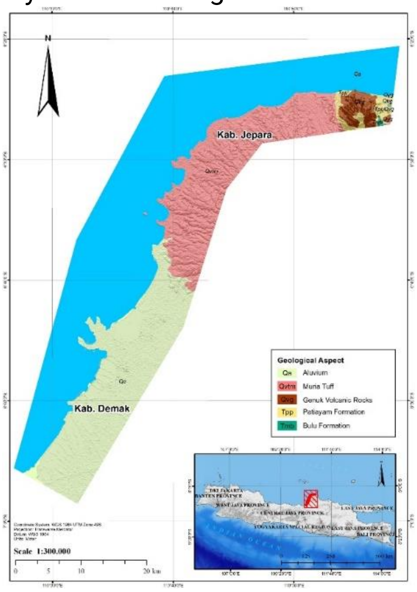

Figure 2. Geological Formation of the Study Area

In general, the Jepara coastal area is strongly influenced by the sedimentation process and volcanic activity of Mount Muria and Genuk. The landscape of the Jepara coastal area has two types of constituent materials: muddy coastal areas and sandy coastal areas. The findings of a study conducted by Yuniastuti (2016) show that this area, especially the area included in Demak Regency, is mostly mud, while the Delta Wulan area is sand. The deposition of the material forms gentle scarp slopes.

The average annual rainfall in 2021 was 3109 mm, with 177 rainy days yearly (Badan Pusat Statistik, 2024). Although the rainfall in 2021 is relatively high, in the span of 10 years (1987-1996), the Jepara area is classified as type E (relatively dry) according to the Scmidt-Ferguson climate classification, with some areas classified as type D (moderate) (Sunarto et al., 2014). Vegetation in the coastal part of Jepara is mostly mangrove (Rhizophora) and Nipah (Nypa fruticans) mangroves that have been damaged. In addition to mangroves, vegetation that grows in this coastal area is Avicennia, Sonneratia, Pandanus tectorius, and Acanthus ilicifolius. Especially in the northern shoals, the vegetation includes goat's foot grass (Ipomoea pes-caprae) and widuri (Calotropis gigantea).

From a socio-economic perspective, most residents work in the agriculture, processing industry, services, and trade sectors. In the agricultural sector, the focus of the population's work is classified into capture fisheries, rice, plantations, secondary crops, and livestock (Sunarto et al., 2014). From the agriculture sector, the potential for rice farming is substantial, especially in alluvial plain landform areas rich in water resources. In addition, there are also capture fisheries and salt pond farmers located on the coast.

Result

The Chronicle of Morphodynamics in jepara Coastal Area: A Review

The Jepara coastal area has long experienced morphodynamic evolution. The palaeogeomorphological study conducted by Sunarto (2004) succeeded in finding several events related to morphodynamics in the Jepara Coastal Area, including (1) morphological changes of the Wulan Delta and (2) evolution of coastal irregularities west of the Muria Volcano. The Wulan Delta is a curious example of anthropogenic-geomorphologic phenomena, where the formation of this delta cannot be separated from anthropogenic activities. Ancient maps made by Westerners show that there is no delta on the south side of the town of Iapara (Jepara) on the island of Iava Mazor (Java). The coast in the region is a flat beach. This is known based on maps made by Giacomo Gastaldi in 1548, Gerrard Mercator in 1569, Peter van der Aa in 1714, and Gerard van Keulen in 1728. In 1892, the Wulan Canal was built for irrigation purposes. The development of the canal caused the deposition of mud that initially occurred in the plain to move to the mouth of the Wulan Canal, which then expanded to form the Wulan Delta.

Sunarto (2004) further explains that the delta embryo began to form after the construction of the Wulan Canal in 1892. Furthermore, the 1925 topographic map shows the Wulan Delta with an arcuate shape. The 1946 topographic map even depicts the Wulan Delta with a cuspate shape. The Delta continued to develop seaward until it became a bird's foot or digitate shape in the '90s. The area of the delta increased from 1.9 km2 in 1925 to 9.15 km2 in 1992. Changes in the morphology of the Wulan Delta cannot be separated from the influence of seasons, ocean waves, ocean currents, tides, and seabed topography.

Marfai & Permana (2014) explained that the maximum daily wind direction during the 2002-2012 decade mostly came from the east or land, then from the northwest, north, and west. The most minor frequency is from the southwest, south, and southeast in the western season, which occurs during December-February. The dominant wind direction comes from the west and northwest. During the first transitional season from March to May, the wind direction is more variable from the east, north, southeast, and northwest. From June to August, the wind moves from the east in the eastern season. In the second transitional season, from September until November, the wind direction is still dominant from the east. Generally, wind events that affect marine conditions come from the northwest, west, and north. Winds moving from the east are onshore winds that do not generate waves.

Wind is related to ocean waves. Sunarto (2004), in his findings, showed that in the east season, waves in Jepara waters are constructive, so they do not cause coastal erosion but instead build the coast. Meanwhile, in the western season, the wind generates destructive waves. This finding is reinforced by the explanation from Marfai and Permana (2014) that the waves formed are more significant during the western season. Wind is also related to ocean currents. Sunarto (2004) explains that the pattern of currents in the Java Sea changes completely twice a year by seasonal changes. In the west season, there is a west current that flows eastward. In the first transitional season, the west current begins to weaken and even begins to reverse direction. In the eastern season, the current moves from east to west. Meanwhile, in the second transitional season, the currents are often erratic but dominated from the west because the eastern currents begin to weaken. In addition to waves and currents, tides also play a role in the coastal dynamics in this region. Tides in this region are included in the microtidal because the range is less than 2 meters. Tides of this type are very supportive of the development of delta morphology.

Beaches in the Jepara region (west side of Mount Muria) generally have wave conditions that alternate between destructive and constructive. This is very different from the east coast of Mount Muria, which continues to be constructive, both during the west and east seasons. Because it is continuously constructive, the east coast of Mount Muria can develop extensive shoals. Meanwhile, very different conditions are found on the west coast of Mount Muria, Jepara region, where the waves are destructive in the west season and constructive in the east season. Because these destructive-constructive conditions alternate, this area sometimes experiences marine erosion, i.e., in the west season, and sometimes experiences marine deposition in the east season. As a result, coastal irregularities are characterized by the presence of pocket beaches (Sunarto, 2004).

Morphodynamics of Jepara Coast in the Last Decade

In this section, we present the results of an analysis of the morphodynamics of the Jepara coast in the past decade. These morphodynamics occur under the influence of climate change and increasingly massive anthropogenic activities. In recent decades, climate change has proven to have widespread impacts, including on coastal dynamics. Several studies have shown that in recent decades, marine forces have grown stronger. Waves, currents, and tides have become more extreme, causing a massive impact on morphological evolution in coastal areas (Chowdury et al., 2023; Hansen et al., 2025; Lobeto et al., 2024; Pang et al., 2023).

The results of the NDWI transformation analysis show that the Jepara coast has been transformed over the past decade (2013-2023). The deposition process on the coast of Jepara and Demak shows an increase in deposition material, especially in the Wulan River Delta area. Areas with sedimentation experienced a gradual shift from 2013-2023, which, based on this study, is associated with changes in seasonal wind direction and wave intensity that reflect climatic variability during the last decade. These conditions are considered part of the local manifestation of climate change, which alters wind and wave patterns and consequently affects coastal sediment transport. This finding is consistent with the explanation by Choliq et al. (2015), who stated that the coastal areas of Demak to Jepara receive a lot of wave runoff in the form of waves due to wind, sea level fluctuations, and currents along the coast, supporting the influence of climate related processes on coastal morphodynamics.

In general, the coastal dynamics that occurred in the Jepara region over the past decade are characterized by the expansion of the Wulan Delta and the change in the position of the eroded area from the north of the Wulan Delta to its south. The Wulan Delta continues to expand seaward because of sediment deposition due to the construction of the Wulan Canal, which has occurred over the past few decades. This process appears to be a continuation of the previous process. In other words, the same process is still ongoing today. In the past decade, the Wulan Delta has shown an increase in land area of about 5.39 km2.

An exciting finding was found in the south of the Wulan Delta based on the NDWI analysis and field observations conducted in this study. In the last decade, this area has experienced intense marine erosion. This contrasts with Sunarto's (2004) findings that the northern side of the Wulan Delta has experienced much marine erosion in the past. It is suspected that in the last decade, there has been a modification of winds and ocean currents in the region so that the area experiencing turbulence is south of the Wulan Delta rather than north of the delta. The coastal area that experienced massive marine erosion then became inundated by seawater. Sedimentary material from the marine erosion in this area was probably deposited to the north.

Massive marine erosion that has caused many coastal areas to sink was been identified by Marfai and Permana (2014) about a decade ago. Marine erosion has reached above 70%. Natural factors and anthropogenic activities cause this marine erosion. The high rate of marine erosion on this beach cannot be separated from the destructive influence of ocean waves. The height of the dominant waves from the west and northwest ranges from 1.21 to 2.63 meters, so the range causes erosion. In addition, anthropogenic activities such as coral theft on the beach also accelerate this erosion process. Land use change has also become more massive over the past decade, putting pressure on coastal areas. Until now, erosion caused by marine forces controlled by the respective west monsoon continues. Land mass reduction due to marine erosion is also still found on the northern side of the study area, although not as severe as the condition on the southern side adjacent to the Wulan Delta. See Figure 3 and 4.

Over the past ten years, there is no significant increase or decrease in land that has occurred due to erosion and marine deposition. In other words, the land area between 2013 and 2023 is not significantly different. The morphodynamics of the coastal area, especially those controlled by erosion and marine deposition, are more likely to be the demolition of material by the erosion process and then the building of another location by the deposition process. Marfai & Permana (2014) also explained that sedimentation occurs in all coastal areas, especially river estuary areas

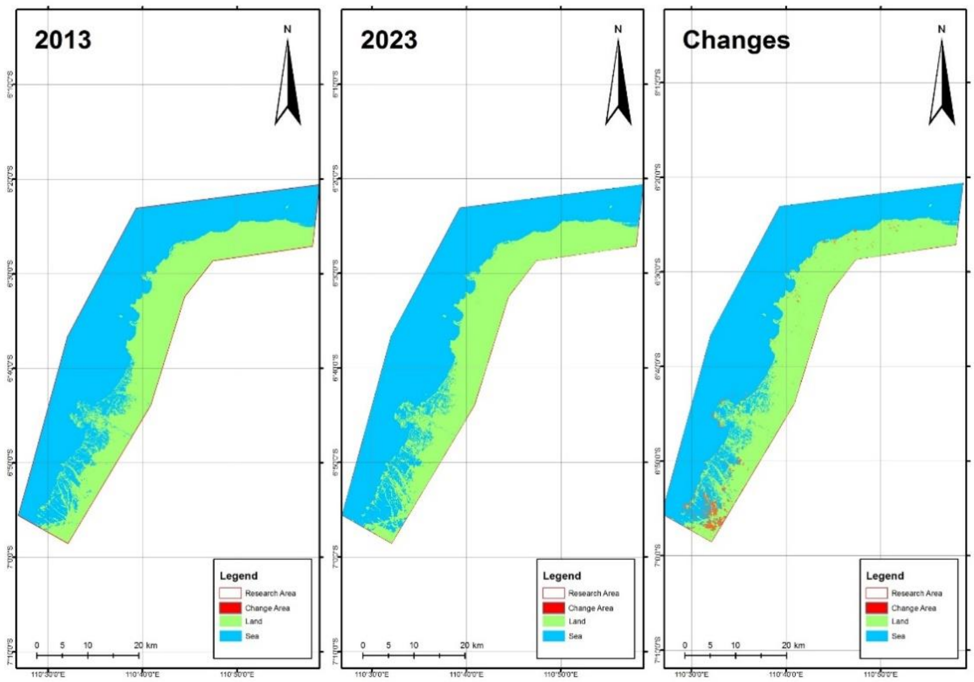

Figure 3. Erosion and Deposition in the Jepara Coast in the Last Decade

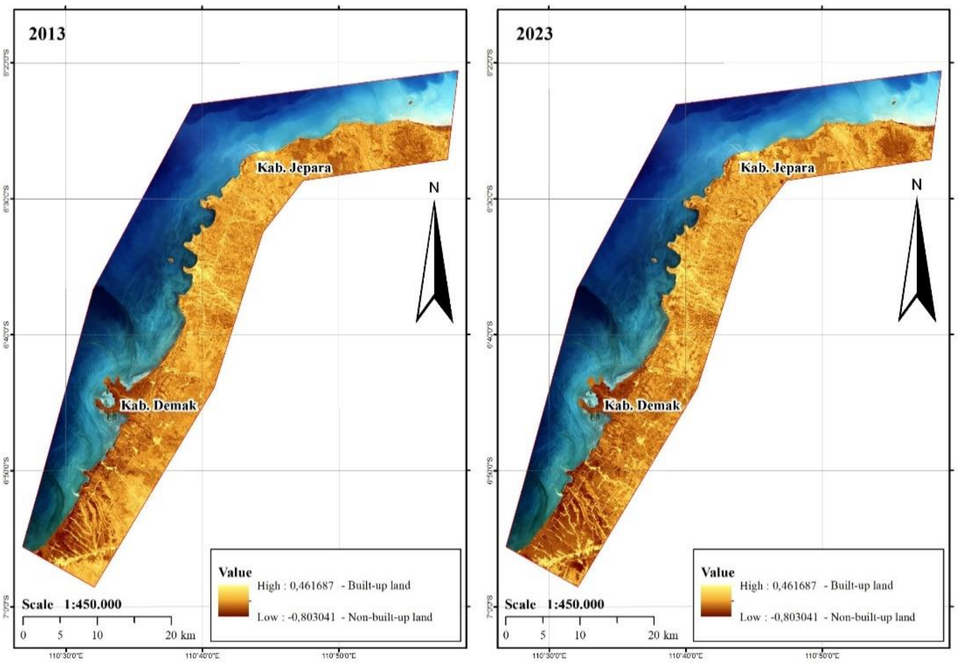

Figure 4. Land Use Change of the Jepara Coastal Area in the Last Decade

Typology of Jepara Coastal Area

Many previous authors have developed typologies of coastal areas, including Cotton, Johnson, Valentin, and Shepard (Pramono & Ashari, 2014). In this study, the typology analysis was carried out to describe the present geomorphic condition of the Jepara coast as the result of recent morphodynamic processes. Referring to C.A. Cotton's classification, the Jepara Coastal Area, based on the interpretation in this research, is entirely included in the coast of stable region category because it develops in the north of Java Island, which is relatively stable tectonically. Meanwhile, in the sub-type of category, the Jepara Coastal Area is currently divided into two categories, namely the southern side, which is dominated by the appearance of submergence, and the northern side, which is dominated by the appearance of emergence, namely in the form of pocket beaches. This typology analysis is relevant to the objective of this paper, which is to explain how climate and anthropogenic factors have shaped the coastal morphology of Jepara in the last decade.

Referring to the classification made by D.W. Johnson, the Jepara Coastal Area is currently included in the coastal submergence, neutral coastal, and combined coastal categories. Submergence coasts are typical for the southern side, which experienced intense marine erosion and was subsequently inundated by seawater. The Wulan Delta represents a neutral coastal category formed by alluvium deposition in marine waters. Meanwhile, the area to the north of the Wulan Delta belongs to the combined coastal type, where some appearances are products of submergence due to marine erosion activities, and others are products of emergence in the form of limited marine deposition to form pocket beaches and the like.

In the coastal classification, according to H. Valentin, the Jepara coast consists of two types: the coast that has advanced and the second that has retreated. The first type is more explicitly included in the prograde coast sub-type, either formed by organic activity from mangroves and coral or by inorganic deposition in the form of deltas and tidal flats. The area included in the prograde coast is the Wulan Delta and the area to its north. Meanwhile, the area south of the Wulan Delta belongs to the second type, specifically the retrograded coast sub-type, eroded by marine erosion. Interestingly, this retrograded coast type is solely due to marine erosion without the eroded cliff morphology commonly found in retrograded coasts.

Finally, in F. Shepard's classification, the coastal area of Jepara is based on the results of morphodynamics in the last decade, some of which are included in the primary coast and others in the secondary coast. Primary coasts are coasts that are dominated by terrestrial processes. In the study area, this type of coast is found in the Wulan Delta, which more specifically falls into the category of sub-aerial deposition coast. In contrast to primary coasts, secondary coasts are dominated by marine processes. This type is found in the north and south of the Wulan Delta. The northern area is categorized as a marine deposition coast. It is formed by sediment deposition by marine forces, whereas the southern area of the delta is classified as a wave erosion coast because it experiences intense marine erosion.

Discussion

The issue of climate change is related to many aspects of the balance of natural systems, including marine energy consisting of waves, currents, and tides. Changes in the characteristics of these marine forces can affect the morphodynamics in coastal areas. At this time when human activities have an increasingly massive influence on environmental conditions, the role of anthropogenic factors in morphodynamics cannot be ignored. Here, we present the current state of morphodynamics in the coastal area of Jepara over the past decade under the issue of climate change and increasingly massive anthropogenic activities.

Studies on the influence of climate change and anthropogenic activities on morphodynamics in coastal areas have been carried out by several previous authors. Javier et al. (2015) conducted a study on the effects of climate change on coastal evolution. The study explained that changes in morphodynamics are highly dependent on climate change, including (1) wind waves are governed by the displacement of cyclones, whose latitude and size follow climate change, thus affecting the wave gradient at the coastline; (2) temperature changes significantly affect the speed of rock weathering and cliff dissolution processes. If rainfall conditions change considerably, it will affect the rate of sediment reaching the shore. Thus, erosion and shoreline accretion occur because of climate change. Shorelines can shift landward or seaward because of changes in sea level. In the context of this research, the results of NDWI and field observations indicate a similar phenomenon, where the coast south of the Wulan Delta is currently sinking. Therefore, the issue of climate change in recent decades has directly impacted the coastal areas of Jepara through the mechanism of shoreline retreat and sea level rise, which aligns with the global scale processes described by Javier et al. (2015).

Wright & Thom (2023) in their study on coastal morphodynamics and climate change, showed that climate change is causing sea level rise, tidal surges, and tropical storms to become more frequent and severe. As a result, many of the world's coasts are affected by climate change, including the Pacific West Coast, the East Coast of the Americas, and the Australian Coast. The study also provides validation and confirmation that with climate change, many extreme weather conditions, such as increased frequency of tropical storms, and combined events such as storm surges combined with heavy rainfall. These events are triggered primarily by rising ocean temperatures. As a result, marine erosion processes are becoming more robust and intensive in the Jepara Coastal Area.

Lastly, anthropogenic activities cannot be ignored in their impact on the morphodynamics of the coastal area. Our study shows that anthropogenic activities take the form of land use change and resource extraction that pay little attention to environmental conditions. Concerning this condition, Deng & Yu (2023) explained that anthropogenic activities have influenced the morphogenetic evolution of coasts and estuaries. Human activities have become an essential external force for predicting the future of morphological evolution in ecosystem health. In a study conducted in the Pearl River Estuary, China, it is known that human activities influenced morphodynamic evolution in recent decades. Human activities such as land reclamation, dam construction, and reduction of sediment supply to beaches and estuaries have affected morphodynamic evolution.

Conclusion

The Jepara Coastal Area is an area that has received a lot of attention for a long time. Studies on the coastal morphodynamics that occur in this region have also been conducted. Here, we follow up on previous studies by further uncovering the morphodynamics that have taken place in the last decade under the issue of climate change and increased anthropogenic activities. Our findings show that the general morphodynamic characteristics are still the same as in the previous decade. However, there is a significant new finding of massive erosion on the south side of the Wulan Delta. As a result, a lot of land has been inundated by water for the past decade.

Of course, this study is also not free from limitations. The impact of anthropogenic activities is relatively limited in this paper. Based on our evaluation of these limitations, future studies are highly recommended to focus on the effects of anthropogenic activities on morphodynamics in coastal areas. Additionally, future studies are highly recommended to reveal in detail the bio-morphodynamics of anthropogenic activities.

Acknowledgement

The authors express their gratitude to the Department of Geography Education, Universitas Negeri Yogyakarta, for the academic and facility support, as well as to all parties who assisted in data collection, analysis, and provided valuable input during the research and writing process of this article. The authors also extend their appreciation to those who offered professional feedback that contributed to improving the quality of this article. The authors likewise acknowledge the contribution of everyone involved, which greatly supported the successful completion of this research.

References

Badan Pusat Statistik. (2024, September 13). Jumlah Curah Hujan (mm) dan Jumlah Hari Hujan (hari) Menurut Bulan di Kabupaten Jepara, 2021. Badan Pusat Statistik. https://jeparakab.bps.go.id/id/statistics-table/1/OTQzIzE=/jumlah-curah-hujan--mm--dan-jumlah-hari-hujan--hari--menurut-bulan-di-kabupaten-jepara--2021.html

Bird, E. (2008). Coastal Geomorphology: An Introduction (2nd ed.). Wiley.

Choliq, A., Pimay, A., & Anas, A. (2015). Pemberdayaan Pesantren untuk Penanggulangan Abrasi di Pantai Demak dan Jepara. Dimas: Jurnal Pemikiran Agama Untuk Pemberdayaan, 15(2), 53. https://doi.org/10.21580/dms.2015.152.746

Chowdury, P., Lakku, N.K.G., Lincoln, S., Seelam, J.K., Behera, M.R. (2023). Climate change and coastal morphodynamics: Interactions on regional scales. Science of the Total Environment 889, 166432. https://doi.org/10.1016/j.scitotenv.2023.166432

Daliman, A. (2012). Islamisasi dan perkembangan kerajaan-kerajaan Islam di Indonesia. Ombak.

Deng, J., & Yu, H. (2023). Modelling Coastal Morphodynamic Evolution under Human Impacts: A Review. In Journal of Marine Science and Engineering (Vol. 11, Issue 7). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/jmse11071426

Hansen, J. E., Kharecha, P., Sato, M., Tselioudis, G., Kelly, J., Bauer, S. E., … Pokela, A. (2025). Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed? Environment: Science and Policy for Sustainable Development, 67(1), 6–44. https://doi.org/10.1080/00139157.2025.2434494

Hugget, R. (2016). Fundamentals of Geomorphology (4th ed.). Routledge.

Ihsan, K. T. N., Harto, A. B., Sakti, A. D., & Wikantika, K. (2023). Monitoring coastal areas using ndwi from landsat image data from 1985 based on cloud computation google earth engine and apps. International Archives of the Photogrammetry, Remote Sensing and Spatial

Information Sciences - ISPRS Archives, 48(M-3–2023), 109–114. https://doi.org/10.5194/isprs-archives-XLVIII-M-3-2023-109-2023
Javier, D. J., Veiga, E. M., & Esteban, V. (2015). Effects of Climate Change on Coastal Evolution. In Engineering Geology for Society and Territory - Volume 1: Climate Change and Engineering Geology (pp. 395–399). Springer International Publishing. https://doi.org/10.1007/978-3-319-09300-0_75
Lobeto, H., Semedo, A., Lemos, G., Dastgheib, A., Menendez, M., Ranasinghe, R., Bidlot, J-R. (2024). Global coastal wave storminess. Scientific Reports 14, 3726. https://doi.org/10.1038/s41598-024-51420-0
Marfai, M. A., & Permana, K. (2014). Erosi dan Sedimentasi Kawasan Pesisir Jepara. In Geomorfologi dan Dinamika Pesisir Jepara (pp. 62–67). Gadjah Mada University Press.
Millar, S. W. S. (2013). Spatial and Temporal Scales in Geomorphology. In Treatise on Geomorphology (Vol. 1). https://doi.org/10.1016/B978-0-12-374739-6.00009-9
Pang, T., Wang, X., Nawaz, R.A., Keefe, G., Adekanmbi, T. (2023). Coastal erosion and climate change: A review on coastal-change process and modeling. Ambio: Journal of Environment and Society 52, 2034-2085
Pramono, H., & Ashari, A. (2014). Geomorfologi dasar. UNY Press.
Sunarto. (2004). Perubahan fenomena geomorfik daerah kepesisiran di sekeliling Gunungapi Muria Jawa Tengah (kajian paleogeomorfologi). Universitas Gadjah Mada.
Sunarto, Marfai, M. A., & Setiawan, M. A. (2014). Geomorfologi dan dinamika Pesisir Jepara (1st ed.). Gadjah Mada University Press.
Urban, M. A. (2013). Philosophy and Theory in Geomorphology. In Treatise on Geomorphology (Vol. 1). Elsevier Inc. https://doi.org/10.1016/B978-0-12-374739-6.00008-7
Wright, L. D., & Thom, B. G. (2023). Coastal Morphodynamics and Climate Change: A Review of Recent Advances. In Journal of Marine Science and Engineering (Vol. 11, Issue 10). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/jmse11101997
Yuniastuti, E. (2016). Identifikasi tipologi dan dinamika, potensi dan permasalahan, dan strategi pengelolaan wilayah kepesisiran di wilayah Kepesisiran Demak. Jurnal Geografi, 8(1), 31–46.
Yunus, H. S. (2010). Metode penelitian wilayah kontemporer. Pustaka Pelajar.