Coastal vulnerability level and beach handling priorities in Serang District Banten Province

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Abstract. Coastal erosion and accretion have altered the shorelines of various Indonesian coastal areas, endangering the lives and livelihoods of coastal populations. Damage to beaches in coastal areas affects the community's daily activities, the transportation system, industry, and trade, as well as the environment and public health. Based on this occurrence, the initial stage of disaster management study resulting from coastal damage is to identify the coast's vulnerability to threatening harm. To assess coastal vulnerability, field observations and measurement from the research location were carried out to obtain visual damage observation, land use, lithology, tidal range, and beach slope. Coastline data from satellite imagery and wind data from the government agencies were carried out to obtain the rate of shoreline change, width of damage, length of damage, and wave height. The purpose of this research is to look at changes in the coastline of Serang, Banten Province, and analyse the amount of beach damage to set priorities for coastal management. The beaches explored were Karangantu Beach, Domas Beach, Lontar Beach, and Tengkurak Beach. Karangantu Beach's level of vulnerability is classified as very high, so dealing with it is a top priority. Domas and Lontar Beaches are extremely vulnerable, so dealing with them is a key priority. Tengkurak Beach has a moderate level of vulnerability, hence the priority for managing is rather high. This can be utilized as a model for overcoming coastal damage in Serang District, Banten Province, by constructing coastal protection buildings based on the shore's vulnerability and management priority.

1. Introduction

The coastline of Indonesia faces significant risks from both natural and man-made sources. These elements include the possibility of tsunamis occurring in coastal areas and rising sea levels brought on by climate change [1]. Furthermore, Indonesia faces a serious problem with coastal erosion, with roughly 40% of the nation's coastline already harmed [2]. In addition, the fast expansion and urbanization of the coastal areas caused pollution, destroyed habitats, and engaged in illegal sand mining [3]. As a result, Indonesia must collect critical information about the damage caused by coastal inundation [4]. Effective disaster management and mitigation strategies depend on an understanding of the extent of coastal inundation damage in Indonesia. It will support the development of focused plans to lessen vulnerability and increase resilience in coastal communities, as well as the prioritization of locations for intervention and resource allocation.

Determining the priority of coastal countermeasures is a crucial step in effectively managing and safeguarding coastal areas. To achieve this, a systematic strategy should be implemented that considers the level of damage to the shore and the importance of various locations. This approach allows for the identification of urgent concerns that require immediate attention, while also considering the long-term importance and strategic value of different areas along the coast. This strategy should incorporate a thorough analysis of how risks affect the coastal region in order to develop effective adaptation plans that minimize potential harm [5].

Natural influences as well as human activities of sand mining (seabed sand extraction) affected morphological changes such as coastal alteration and bathymetry change in Serang District, Banten Province [3]. Natural and human factors contribute to shoreline changes in Serang City, Banten Province [6]. The shoreline morphology on Banten Province's North Coast is likewise changing rapidly. Reclamation, accretion, and abrasion were terms used to describe changes in the morphology of the shore [7]. While sea sand mining and the conversion of mangrove swamps into fishery ponds are variables causing abrasions in Pontang Cape, Serang Regency, Banten Province, the most likely sources of changes in the shorelines are the rivers that feed into the bay and sediment transports that affect Banten Bay accretions [8]. Sea level rise, abrasion/erosion, and large waves are causes for concern since they can destroy infrastructure and incur losses. For this reason, managing coastal zones at Anyer Beach, Banten Province, requires a vulnerability review. The biggest influences on Anyer Beach's vulnerability are elevation and wave height [9].

The goals of this significant study are to assess coastal alterations and assess the shoreline's vulnerability in Banten Province's Serang District. This study concentrated on Karangantu Beach, Domas Beach, Lontar Beach, and Tengkurak Beach in Serang, Banten Province. The Serang District, Banten Province, prioritized beach management can then be retrieved. Whether they are hard structures (beach wall structures, breakwater structures, etc.) or soft structures (mangrove planting), creating structures for coastal protection is a top priority for coastal management.

2. Materials and Methods

2.1. Study Area

In Java Island, the westernmost province is called Banten. North of the province is the Java Sea, south is the Indian Ocean, west is the Sunda Strait, and east are the Special Capital Region of Jakarta and West Java Province. The beaches of Karangantu, Domas, Lontar, and Tengkurak in Serang, Banten Province, are included in the study area. Figure 1 shows the location of this investigation.

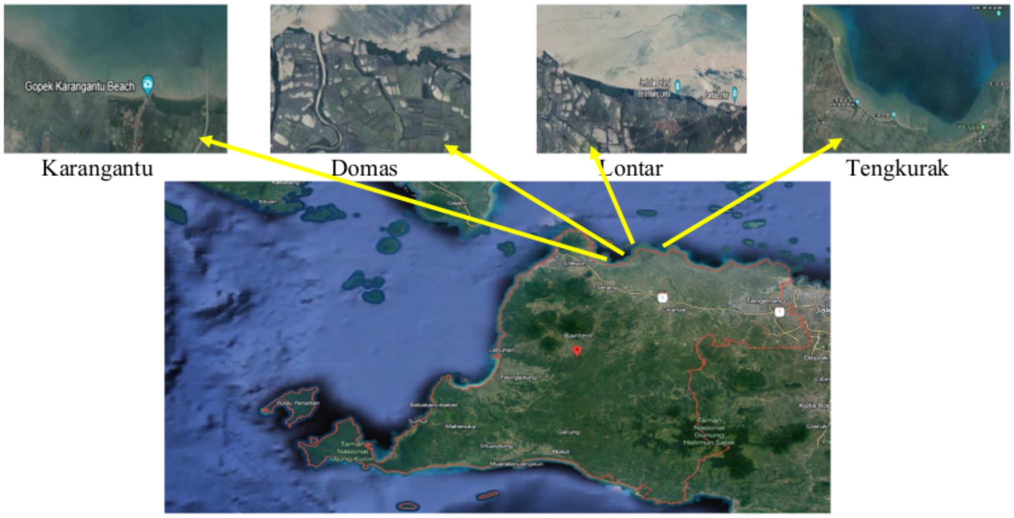


Figure 1. Examination of a location using Google Earth Engine

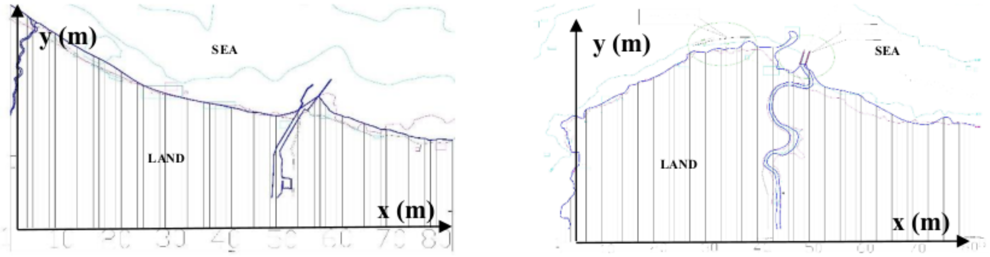
2.2. Data Collection

Sea level information gathered at the time of generation is used to calculate wind data for wave forecasting. Direct observations above sea level or readings acquired on land near to the expected site and converted to wind data at sea were both used to gather this information. Utilizing statistical analysis data and wind information from the Serang wind recording station, the hour and direction of wind deception between 2010 and 2021 were identified. The waves caused by the wind were identified via hindcasting [10]. This method's main goal is to calculate wave height using wind data, which can be efficiently collected using empirical techniques. The calculation used the greatest wind speed in order to examine the extreme wave conditions. The design wave height is the wave height at the research coastal point where the wave has changed during its propagation from the deep sea. The period and wave height were calculated using 12-year wind data hindcasting as the wave data. The wave height for the 10-year return period will be predicted using SMADA software [11], and different return dates for each direction were also used for extreme wave analysis [12].

Studying the marine physical phenomenon known as tides is also necessary to fully understand the circulation pattern of saltwater masses. Depending on the type of tide in these rivers, this tidal parameter often regulates the water flow from noon until the end of the daily period. To determine the tidal range based on the observational data, tide measurements are also used. For a period of fifteen days, tides were measured at every location under investigation.

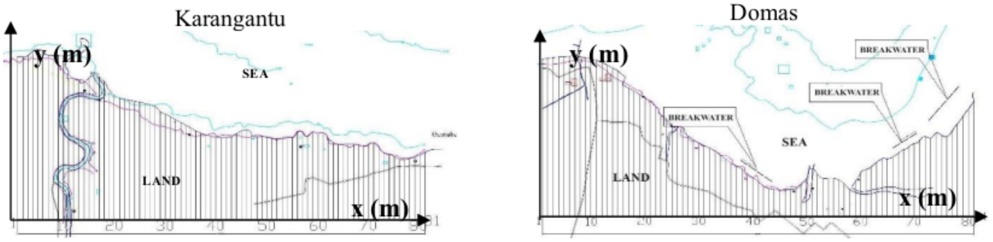
The majority of the Serang district is known to be composed of fire rocks with surface deposits, which are predominantly found on the north coast and eastern half of the region. The north shore comprises a level area with a slope of 0-5%, according to the morphology. Aside from that, the north shore's soil is primarily sandy and gravelly. Soil data is required to assess a soil's condition, type, and mechanical properties.

Topographic maps are needed to specify the starting location of the coastline that has to be studied. By creating 81 grids at a certain distance based on the length of the coastline to be replicated, the beginning position of the shorelines of Karangantu, Domas, Lontar, and Tengkurak is utilized as an input. The Google Earth Pro engine may provide information regarding the locations of the shorelines of Karangantu, Domas, Lontar, and Tengkurak, which can then be loaded into the AutoCAD program [13]. The distance between grids is 30 m for Karangantu Beach, 52.3 m for Domas Beach, 49 m for Lontar Beach and 64 m for Tengkurak Beach.



Karangantu

Domas



Lontar

Tengkurak

Figure 2. Grid of the Karangantu, Domas, Lontar, and Tengkurak coastline

The coastal grids for Karangantu, Domas, Lontar, and Tengkurak are shown in Figure 2, where the x-axis is the distance to the location being studied and the y-axis is the position of the coastline. A numerical method can be used to forecast changes in coastlines over time. A computer model called GENESIS [14] estimates changes in coastline produced primarily by sea waves. This view is supported by the one-line theory, which asserts that the beach profile remains constant and allows shoreline change to be specifically described in terms of coastal position. This model's major application is to mimic shoreline response.

2.3. Coastal Vulnerability Index

The degree of vulnerability of shore regions to natural disasters is measured using the Coastal Vulnerability Index (CVI). It offers a numerical evaluation of the vulnerability that a coastal region might experience because of various factors. To identify and allocate resources for coastal adaptation and mitigation measures, planners, researchers, and policymakers are helped by the CVI [15, 16]. The CVI considers several physical, biological, and socioeconomic factors that affect a coastal area's vulnerability, such as the rate at which the shoreline changes, the length and width of visual damage observations, the lithology of the damage, the wave height, the tidal range, the land usage, and the coastal slope. Each of the parameters has data collected. Data collection and analysis frequently contain the usage of remote sensing and Geographic Information Systems (GIS) [17, 18, 19, 20]. Satellite imagery, topographic maps, hydrological data, and demographic information are integrated to create a comprehensive assessment [21]. To make sure that all the data are on the same scale, each factor's data is frequently normalized. This is significant because different factors may have varying ranges or units. Each factor is given a weight after normalization, which is determined by how important it is in relation to vulnerability. Table 1 displays the ranking of the Coastal Vulnerability Index variables [22].

Table 1. Ranking of coastal vulnerability index parameters

Variable	Ranking of Coastal Vulnerability Index				
	Very Low	Low	Moderate	High	Very High
	1	2	3	4	5
Shoreline change rate (m/year)	0	0-1	1-5	5-10	>10
Observations visual damage	Visible symptoms of damage	Looks scours but still stable	Scours occurs and will happen collapse	Scour and debris occur but not jeopardize facilities or infrastructures	Scour and debris occur and endangering facilities or infrastructure
Length of damage (km)	<0.5	0.5-2	2-5	5-10	>10
Width of damage (m)	0	1-10	10-50	50-100	>100
Lithology	Igneous, sedimentary and metamor-phic, compact and hard	Fine-grained sedimentary rocks, compact and soft	Gravel and coarse sand, rather compact	Sand, silt, clay, rather compact	Sand, silt, clay, mud, loose
Wave height (m)	<0.5	0.5-1	1-1.5	1.5-2	>2
Tidal range (m)	<0.5	0.5-1	1-1.5	1.5-2	>2
Land use	Moor, mangrove forests, vacant land and bogs	Domestic tourist areas and traditional farms	Rice fields and intensive ponds	Settlements, ports, offices, schools and provincial roads	Cultural heritage, international tourist areas, industry, country roads, and national defense
Coastal slope (%)	0-2	2-5	5-10	10-15	>15

The index quantifies the relationships between the nine (9) physical factors. The coastal vulnerability index is calculated after assigning a risk value to each piece of coastline based on each unique data variable [23], as follows:

$$\mathrm{CVI} = \left(\frac{a\times b\times c\times d\times e\times f\times g\times h\times i}{9}\right)^{1/2} \quad (1)$$

where a represents the rate of shoreline change, b represents the recorded visual damage, c the length, d the width, e the range of lithology, f the wave height, g the range of tidal waves, h the use of land, and i the coastal slope. Based on the value of the coastal vulnerability index, Table 2 categorizes various levels of coastal vulnerability [24].

Table 2. Classification of coastal vulnerability level

CVI	0-25	25-50	50-75	>75
Potential Damage	Low	Medium	High	Very High

3. Results and Discussions

The shoreline at Karangantu, Domas, Lontar, and Tengkurak beaches has changed due to wave action. Figure 3 shows the change in shoreline at Karangantu beach. Shoreline alterations occur on average once a year. The greatest change in coastline was recorded at 18.3 m/year (grid 77). Shoreline changes at Karangantu Beach demonstrate that grids 41-72 are eroding, while grids 2-40, 73-80 are sedimenting. This conclusion is explained by the numerical output from the GENESIS software, which results in shoreline modifications in the form of silt build up with a volume of 35,400 m^3. This indicates that sedimentation is occurring at Karangantu Beach.

Figure 4 shows the shift in shoreline at Domas' coastal area. The largest annual change in shoreline was found to be 84.8 m (grid 38). Grids 11-19, 23-24, 26-38, 41-42, and 62-80 were eroded, while grids 2-10, 20-22, 39-40, and 43-61 were sedimented. These findings are supported by the numerical output data from the GENESIS program, which shows erosion-related changes in the shoreline with a volume of 216,000 m^3. This demonstrates that Domas Beach is eroding.

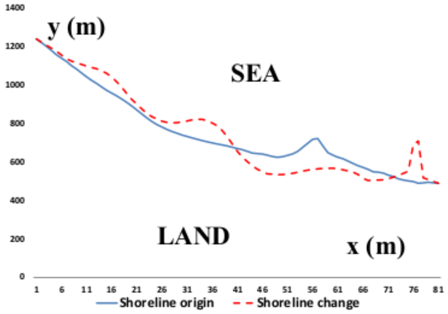


Figure 3. Changes on the coastline of Karangantu

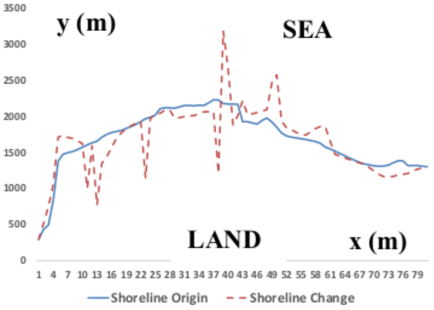


Figure 4. Changes in the coastline of Domas

Figure 5 describes the change in shoreline along the Lontar coast. The greatest annual rate of change in coastline is 19.3 m. Erosion affects grids 11-15, 18-40, 72-80, while sedimentation affects grids 2-10, 16-17, 41-71. According to the numerical calculations, the shoreline of Lontar encountered sedimentation with a volume of 163,000 m^3 and a length of 3.579 km. The maximum forward/retreat movement of the shoreline determines the width of Lontar's coastal damage. On grid 77, there was coastal damage, with a maximum sedimentation value over the ensuing 12 years of 231.4 m.

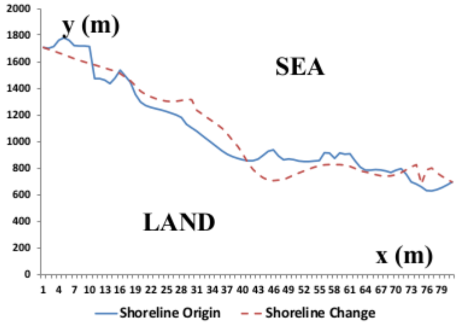


Figure 5. Changes in the coastline of Lontar

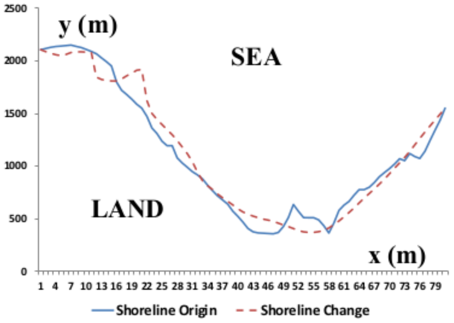


Figure 6. Changes in the coastline of Tengkurak

Tengkurak Beach's coastline has changed as shown in Figure 6. The greatest change in coastline was discovered to be 30.6 meters per year (grid 21). The results of changes in the shoreline at Lontar Beach demonstrate that grids 2-15, 33-34, and 50-72 underwent erosion, while grids 16-32, 35-49, and 73-80 experienced sedimentation. These results are clarified by the numerical output results obtained by changes in the shoreline in the form of sediment buildup with a volume of 463,000 m^3. This indicates that Tengkurak Beach is experiencing sedimentation. Grid 21 has the widest coastal damage, and the highest sediment deposition value for the next 12 years is 366.6 m. Tengkurak Beach has 4.032 kilometers of beach damage.

Table 3 shows the results of the study and observation of nine CVI variables in the coastal areas of Karangantu, Domas, Lontar, and Tengkurak. Domas Beach has the greatest rate of shoreline alteration and the greatest width of damage. The biggest length of damage, on the other hand, occurs along the Karangantu shore. The highest wave height occurs near the Domas coast area.

Table 3. Result of analysis and observation of CVI variables at coastal area in Serang District

Variable	Coastal Area			
	Karangantu	Domas	Lontar	Tengkurak
Shoreline change rate (m/year)	18.3	84.8	19.3	30.6
Observations visual damage	Occurs scouring but still stable	Occurs scouring but still stable	Occurs scouring but still stable	Occurs scouring but still stable
Length of damage (km)	5.88	3.084	3.579	4.032
Width of damage (m)	219.6	1,018.2	231.4	366.6
Lithology	Sand, silt, clay	Sand, silt, clay	Silt, clay	Silt, clay
Wave height (m)	1.84	3.06	4.2	1.8
Tidal range (m)	0.86	0.73	0.89	0.92
Land use	Ports, offices, and schools	Mangrove plant, pond	Settlements, mangrove plant, pond, wharf	Mangrove forests, vacant land, and bogs
Coastal slope (%)	0-5	0-5	0-5	10-15

The CVI rating is determined from the study's findings and observations of the CVI characteristics listed in Table 3. Table 4 illustrates the ranking of CVI variables in Karangantu, Domas, Lontar, and Tengkurak's coastal areas. Table 5 shows the level of damage based on CVI. The coastal area of

Karangantu is severely dammed. The coastal areas of Domas and Lontar have sustained significant damage. Tengkurak's coastal area had moderate damage.

Table 4. Rangking of CVI variables at coastal area in Serang District

Variable	Coastal Area			
	Karangantu	Domas	Lontar	Tengkurak
Shoreline change rate (m/year)	5	5	5	5
Observations visual damage	2	2	2	2
Length of damage (km)	4	3	3	3
Width of damage (m)	5	5	4	5
Lithology	4	4	4	4
Wave height (m)	4	5	5	4
Tidal range (m)	2	2	2	2
Land use	4	2	4	1
Coastal slope (%)	2	2	2	2

Table 5. Damage assessment based on CVI in Serang District's coastal area

Coastal Area	CVI	Potential damage
Karangantu	75.4	Very high
Domas	51.6	High
Lontar	73.0	High
Tengkurak	32.7	Medium

Construction of both soft and hard coastal protection structures along the coast of Karangantu is strongly preferred, although priority coastal management is also an option. These results are in accordance with the analysis of the vulnerability of demersal fisheries in Karangantu Harbor which shows that the social and institutional dimensions have high vulnerability [25]. Based on the research results [8], there are two coastline segments that experience different coastline change phenomena, namely Banten Bay-Domas (accretion) and Tanjung Pontang-Lontar (abrasion). The most likely cause of changes in the coastline is sedimentation from rivers that empty into the bay and sediment transport which influences the accretion of Banten Bay, while sea sand mining and the conversion of mangrove swamps into fish ponds are factors that influence abrasion in Tanjung Pontang. Particularly suitable for the installation of weak or robust coastal protection systems are the coastlines of Domas and Lontar. The widest level of accretion occurred in Tengkurak Village covering an area of 57.9 ha in 2015 and increasing to 143.5 ha in 2019 [7] so that Tengkurak's coastline has been chosen for the development of a soft or hard coastal protection structure.

4. Conclusions

The coastal vulnerability index is used to assess coastal vulnerability. The coastline change rate, observed visible damage, length, width, lithology, wave height, tidal range, land use, and coastal slope are the elements affecting the coastal vulnerability index value in Serang, Banten Province, Indonesia. Due to the highly high coastal vulnerability index for Karangantu, it is strongly suggested that coastal management be implemented while building the soft and hard coastal protection structure. Due to the high coastal vulnerability indices of Domas and Lontar, the development of a soft or hard coastal protection system is strongly suggested. Tengkurak's medium coastal vulnerability score suggests that priority coastal management be given while constructing a soft or hard coastal protection structure. More research is required to calculate the coastal vulnerability index with the variable coastal green belt. More research can be done to determine the ideal site for coastal protection structures in order to reduce coastal vulnerability.

Acknowledgments

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