Jurnal Geografi Gea 24 (2) (2024) 124-137

Jurnal Geografi Gea

Journal homepage: https://ejournal.upi.edu/index.php/gea

JURNAL UPI

JURNAL GEOGRAFI Gea

Strategy on Reducing Coastal Vulnerability at Pekalongan Coastal Area, Central Java

Desri Wahyuni[1], Widiyana Riasasi[2], Ivan Ardiansyah[3], Siti Meliyani[4]

[1,2,3,4]Universitas Amikom Yogyakarta, Jl. Ring Road Utara, Ngringin, Condongcatur, Depok, Sleman, DI Yogyakarta, 55281, Indonesia

Correspondence e-mail: [1]melani.desri@gmail.com

ABSTRACT

Coastal Vulnerability Index (CVI) indicates the physical level of a coastal area in encountering hazards occurred in the area, such as erosion, land subsidence, and inundation flood. Pekalongan lies directly facing the Java Sea, and has been experiencing coastal hazards that are triggered by human activities, such as land use change, or natural processes, like sea level rise. Moreover, the areas are massively developed regarding socio-economic activities. This study aims to measure the coastal vulnerability index (CVI) level in Pekalongan and to identify strategic planning to reduce the coastal vulnerability level. The parameter scope of CVI measured in this study includes geomorphology, shoreline change rate, coastal slope, tidal range average, sea level rise, and significant wave height, by weighted and scoring method. The results show that the vulnerability index on the north coast of Pekalongan is classified as very high. Spatially, the highest index values are located in Tirto and North Pekalongan. The index value is dominantly influenced by the characteristic of its material formed of sedimentation material transported through Loji and Banger Rivers. Pekalongan had been implementing mangrove planting and installed concrete infrastructure, such as seawalls and jetties to reduce the impact of the coastal hazards. However, advanced actions are important to strengthen the efforts towards coastal sustainability, including the participation of all parties. This study could be an initial assessment of sustainable coastal management by presenting the existing coastal condition through physical parameters.

ARTICLE INFO

Article History:
Submitted/Received 08 November 2023
First Revised 08 October 2024
Accepted 30 October 2024
First Available online 31 October 2024
Publication Date 31 October 2024

Keyword:
coastal vulnerability index,
coastal hazards,
strategic actions,
Pekalongan

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

1. INTRODUCTION

One of the strategic development areas of Indonesia is northern coast of Java Island, includes Central Java Province (Marfai et al., 2021). Socio-economic activities i.e., trade, industry, and migration, evolve rapidly in those areas. The impact of the human activities triggers in increasing of natural resources needs. Therefore, the coastal area, which is very dynamic, is potentially affected (Addo, 2013; Marfai et al., 2008; Riasasi, 2019).

The northern coast of Java is influenced by a complex proccesses from sea, river, and wind. Compounded by its characteristic which is formed by sediment deposition, the coastal area has been experiencing multi-hazard. The hazards of land subsidence, inundation flooding, and coastal erosion threats the northern coast of Java (Marfai et al., 2008; Solihuddin et al., 2021). Coastal area also highly affected by tidal activities and will affect people that lives on the shoreline (Hanif et al., 2021).

In the last few decades, coastal area of Pekalongan, including the city and regency, has been undergoing natural events that caused economic and health losses, namely coastal erosion and inundation flood. Data states Pekalongan is the area with the highest level of land subsidence, which up to 20 cm/year (Pratami et al., 2021). Pekalongan experiences tidal floods almost everyday for 3-5 hours (Sauda et al., 2019). Moreover, coastline change occurred due to natural and man-made events. In average, coastal erosion in Pekalongan reached 3.98 meter – 5.07 meter long per year from coastline because of damaged mangrove ecosystem (Nugroho & Indra, 2022; Widada et al., 2022).

The coast of Pekalongan acts as a multi-function area, namely the shipping route, fisheries, and maritime tourism area (Maramis et al., 2022). The coastal area is formed by sedimentation of material that was transported through the Loji River and Banger River, hence it has rich nutrition from the upper stream. The upper sediment layer is dominated by river channel deposits and floodplain with sand with a thickness of approximately 5 meters. This layer was deposited during a low sea level. Below it lies the Nearshore Marine Deposit, consisting of sand, swamp deposits, and river channels with a thickness of around 6 meters, deposited during a sea-level drop.

Beneath this layer is the Offshore Marine Deposit, comprising sand containing coral fossils and mollusk shells, with a thickness of approximately 3 meters, deposited during a sea inundation (Moechtar et al. 2013). The resources in the coastal area of Pekalongan have to be managed well to keep it sustainable. Measuring the coastal vulnerability has been a part of a long assessment of integrated coastal area management (Handiani, 2022). Assessment of the coastal vulnerability index (CVI) has been done in many studies to complete advanced goals, i.e., to compose mitigation in Gunung Kidul tourism area (Widura & Mardiatno, 2022); to measure its influence on aquaculture productivity (Komah et al, 2017); or to assess coastal vulnerability (Dhiauddin et al, 2019; Husaini et al, 2021; Handartoputra et al, 2015). In terms of understood the disaster there are three important interrelated points, vulnerability and capability with the scale used based on the portion of the level, both at the state, district, city, and the local scale (Pamungkas et al, 2024). Based on the background, this article aims to measure the coastal vulnerability index (CVI) level in Pekalongan and to identify strategic planning to reduce the coastal vulnerability level. This study is expected to contribute to the integrated management of coastal areas in Pekalongan towards sustainability.

2. METHODS

2.1. Study Area

Pekalongan precisely is located at coordinates between 6° 0 ‘- 7° 23' South latitude and 109° 37’ - 109° 78' East longitude. Pekalongan regency and city administratively are included

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

in Central Java Province and four sub-districts directly bordered by the Java Sea on the north side (**Figure 1**), namely Siwalan, Wonokarto, Tirto and North Pekalongan. Approximately 18.86 km of coastline stretches from west to east with gentle topography.

The geomorphological conditions of sandy beaches and coastal erosion caused high vulnerability value (Dewadaru et al., 2014). Pekalongan lies on various slope areas, from flat to very steep. Most of the morphology is plains, particularly in the northern part, and hilly areas in the southern part. Almost all areas of Pekalongan are alluvium plains.

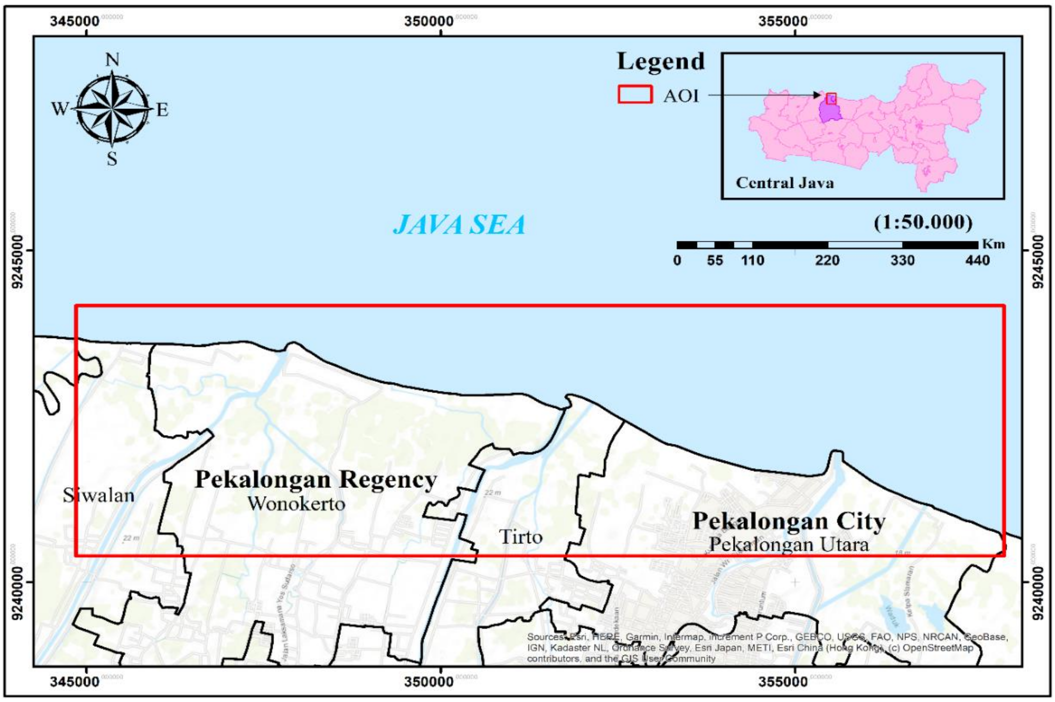

Figure 1. Study Area

2.1. Method

The coastal vulnerability index was measured by six parameters, namely geomorphology, shoreline changes rate, coastal slope, tidal range, relative sea level rise, and significant wave height. All data was secondary data collected from remote sensing data provider, i.e., Google Earth Engine, National DEM, Geospatial Information Agency, Aviso+, and Copernicus Weather Forecasts Center. Remote sensing technology provides convenience and efficiency in calculations and analysis (Ridwana & Himayah, 2020).

The combination of remote sensing and GIS technology in various aspects has proven to provide valuable data for certain scenarios (Parthasarathy & Deka, 2021). Geographical Information Systems provide a sufficient tools to assist in storing, processing, and modeling coastal vulnerability data (Chakraborty, 2021). Framework of this research can be seen in **Figure 2**.

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

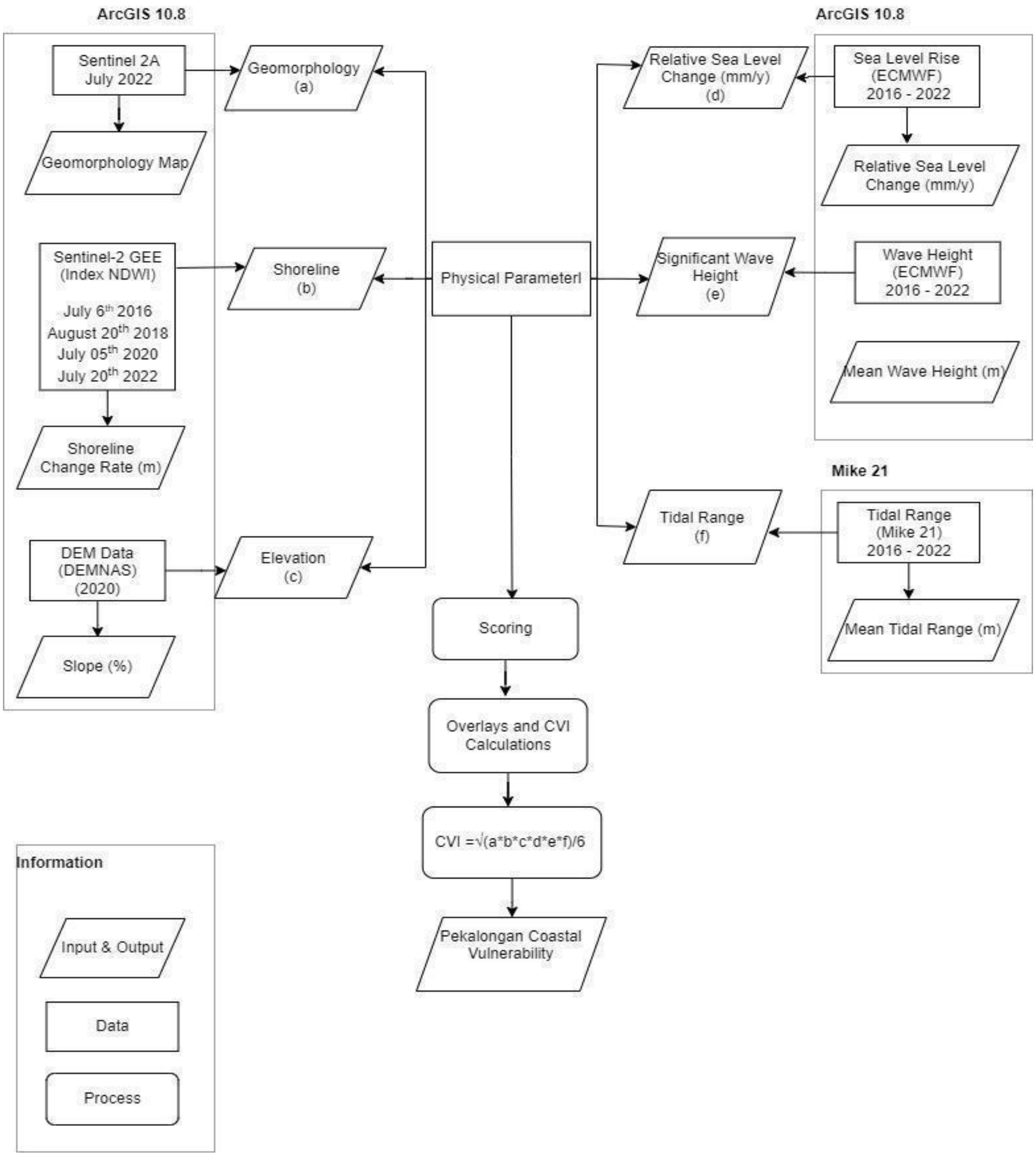

Figure 2. Flowchart

Scoring and weighted method was performed to calculate the value of Coastal Vulnerability Index (CVI). The index equation as follows:

$$CVI = \sqrt{\frac{(a * b * c * d * e * f)}{6}}$$

To determine the class of the index, Table 1 presents the classification of the vulnerability levels.

Table 1. Classification of Vulnerability Class

Vulnerability Class	CVI Value
Low	<4.75
Medium	4.75 – 10.64
High	10.64 – 19.66
Very High	>19.66

Source: Hammar-Klose et al. (2003)

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

3. RESULTS AND DISCUSSION

The discussion can be either in a separate subsection or integrated within the result section. The author should discuss the finding from the research with relevant literature.

3.1. Coastal Vulnerability Index

3.1.1. Geomorphology

The landscape is characterized by clear appearance expressions, specific structures, and physiographic distinctions (Sutikno et al, 2019; Sopandi et al, 2020). The geomorphology of the north coast of Pekalongan coastal areas is sandy beaches and mud flats. The process of marine sedimentation carried by ocean waves towards the coast formed the alluvial plains. That geomorphological conditions made the Pekalongan coast more vulnerable. Based on the geomorphological parameter, the area has a score of 5 or "very high" vulnerability.

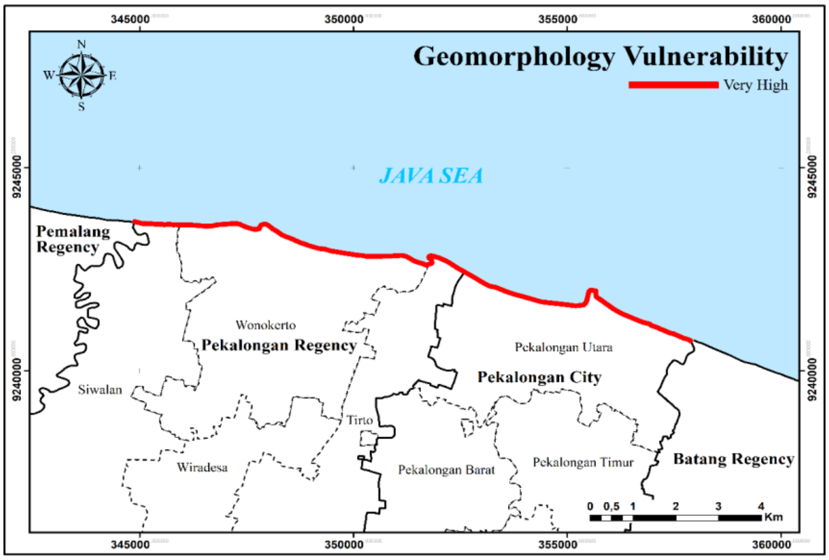

Figure 3. Geomorphology Vulnerability in Pekalongan Coastal Area

3.1.2. Shoreline Change Rate

Shoreline changes are indicated by forward (accretion) and backward (abrasion) shoreline changes. The total rate of shoreline changes in coastal area of Pekalongan from 2016 to 2022 was 21.26 meters and the average was 5.32 meters. The largest shoreline changes occurred in Wonokerto sub-district at (-9.54) meters and Tirto at (-6.92) meters. While the coastline of North Pekalongan sub-district was (-2.52) meters, and the smallest coastline change occurred in Siwalan sub-district at (-2.28) meters over 6 years.

The rate of shoreline change indicates that each year the Pekalongan coastal area had been experiencing abrasion. Abrasion caused the coastline retreat on the Pekalongan coast. Abrasion that happened in Pekalongan coast was affected by physical conditions. The calculation results show that the vulnerability parameter of the shoreline change rate on the north coast of Pekalongan Regency and Pekalongan City is "very high" vulnerability due to its score of 5.

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

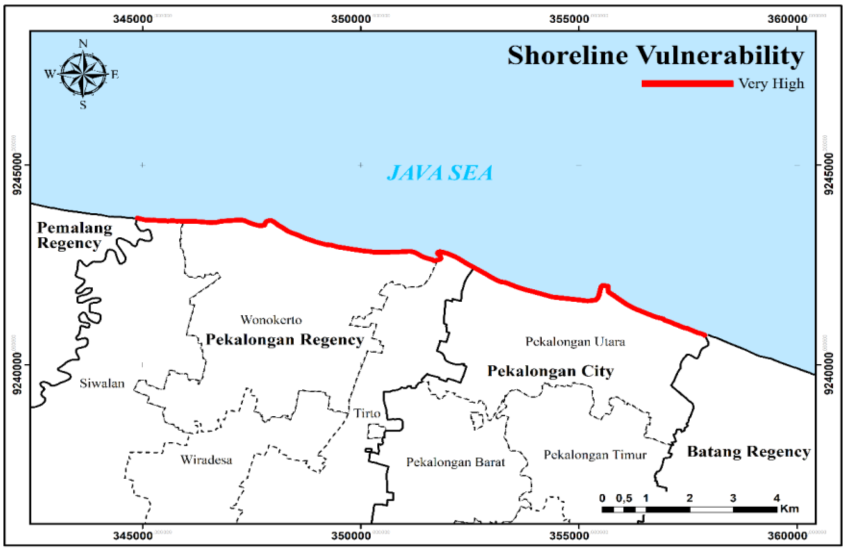

Figure 4. Shoreline Vulnerability in Pekalongan Coastal Area

3.1.3. Coastal Slope

The results of the classification of slope according to Van Zuidam (1985), Pekalongan have 6 slope classes. The slope obtained in coastal Pekalongan is flat or almost flat (0-2%), undulating (2-7%), undulating-rolling (7-15%), rolling-hilly (15-30%), hilly-steeply dissected (30-70%), steeply dissected-mountainous (70-140%) Most of the north coast of Pekalongan Regency and Pekalongan City is a low-lying area with a percentage of slope of 1.9% - 2% which is included in the flat category.

With relatively flat surface conditions and relatively low elevation, it is very vulnerable to sea tides so that (sea) water can rise inland (Sauda et al., 2019). The parameter of coastal slope shows results Pekalongan coastal area is "very high" vulnerability with a score of 5.

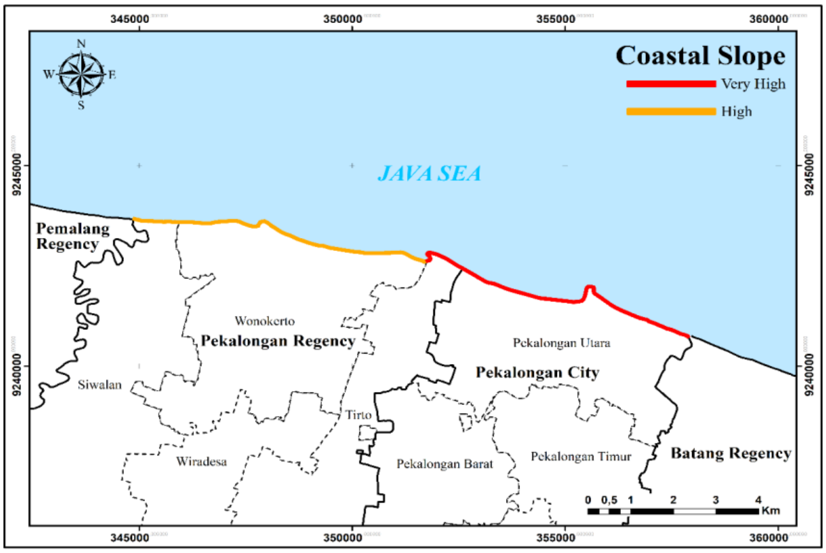

Figure 5. Coastal Slope Vulnerability in Pekalongan Coastal Area

3.1.4. Tidal Range Average

Tides are observed by the regular and repeated movement of the rise and fall of sea water from the surface to the seabed (Rangkuti et al., 2022). Tidal data from January 1, 2016 to December 31, 2022 has varying values. The average tidal value for the six years is 0.011 meters. The north coast of Pekalongan experienced low tidal events with values of less than

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

1m each year. Based on the weighting table, the tidal value is "very high" vulnerability with the score of 5.

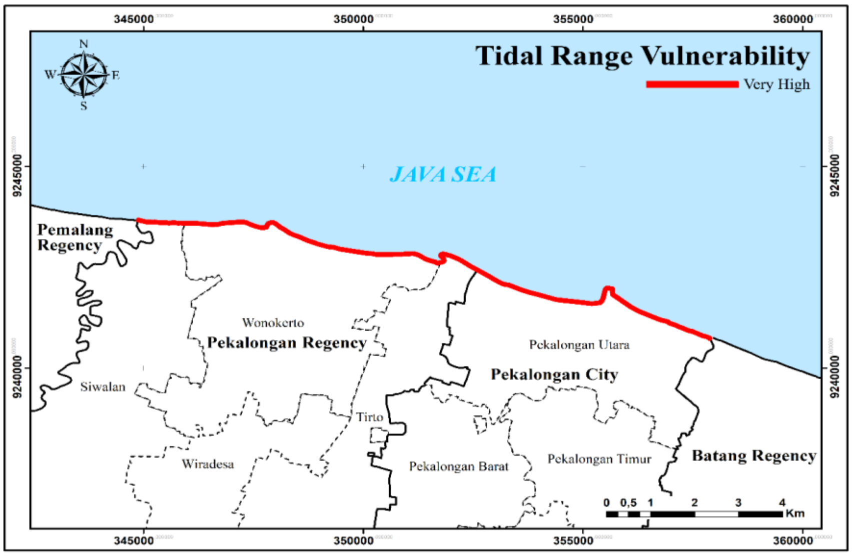

Figure 6. Tidal Range Vulnerability in Pekalongan Coastal Area

3.1.5. Sea Level Rise

Sea level rise is one of the issues impact of climate change triggered by thermal expansion, moreover in Indonesia in general, average sea level rise has reached 6 – 8 m/year and projected will be up to 15 cm/year in 2030 (ICCSR, 2010; Triana & Wahyudi, 2020). This study used the Jason 3 satellite from 2016 to 2022 recording that it resulted from the sea level change in Pekalongan coast was 4.30 mm/year. Therefore, the value is included in score of 6 and is categorized as "very high" vulnerability.

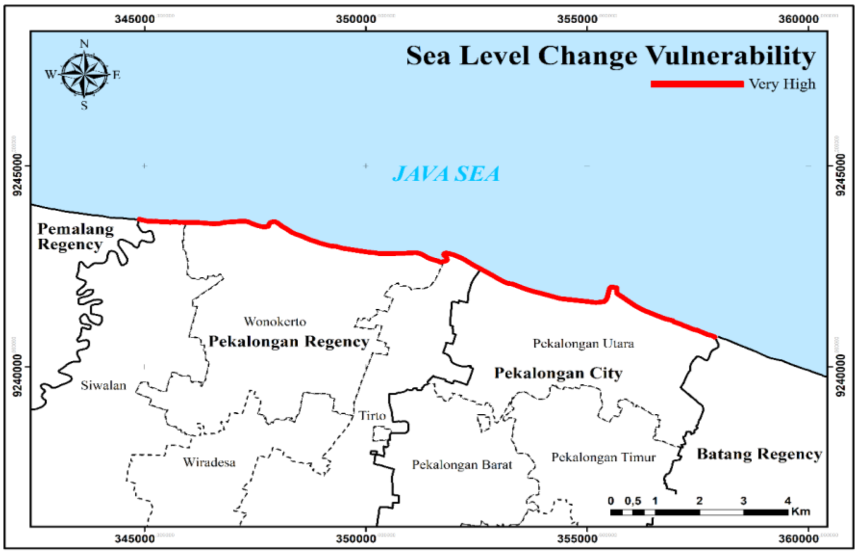

Figure 7. Sea Level Change Vulnerability in Pekalongan Coastal Area

3.1.6. Significant Wave Height

The significant wave height is obtained by the average wave height (from peak to valley) of one-third of the highest ocean waves that occurred in a particular time period (Muliati, 2020). Wave height values in coastal Pekalongan are taken per year, as shown in Table 2.

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

Table 2. Wave height values of the study area

Year	Wave Height (m)
2016	0.234
2017	0.433
2018	0.565
2019	0.552
2020	0.451
2021	0.544
2022	0.474

Source: Data Processing (2023)

The average significant wave height for 2016 - 2022 in coastal Pekalongan is 0.465 meters. This value identifies the coastal area is classified into the "very low" vulnerability category.

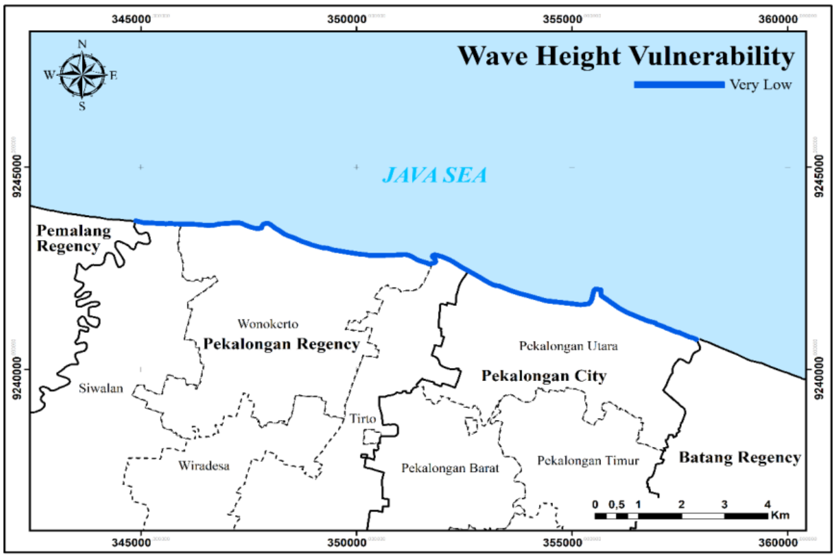

Figure 8. Wave Height Vulnerability in Pekalongan Coastal Area

3.1.7. Coastal Vulnerability Index (CVI)

Based on calculations and observations of variables that affect the vulnerability of coastal ecosystems: geomorphology; rate of shoreline change; coastal slope; tidal range average; relative sea level rise; and average wave height, the Coastal Vulnerability Index (CVI) value was determined. The results of the CVI calculation are presented in **Table 3**.

Table 3. CVI values of the study area

Sub-District	Siwalan	Wonokerto	Tirto	North Pekalongan
Coastal Geomorphology	5	5	5	5
Shoreline Change	5	5	5	5
Coastal Slope	4	4	5	5
Tidal Range Average	5	5	5	5
Sea Level Change	5	5	5	5
Wave Height	1	1	1	1
CVI	20.41	20.41	22.82	22.81
Category	Very High	Very High	Very High	Very High

Source: Data Processing (2023)

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

The results of the Pekalongan's coastal vulnerability index show a very high vulnerability value. The resulting CVI value is more than 19.66, and classified into very high vulnerability. Coastal geomorphology parameters, shoreline change, tidal range average, and significant wave height contributes to the very high CVI because those factors included in the class are very high. The slope factor has a score of four or "high" in Pekalongan Regency and has a score of five or "very high" in Pekalongan City. However, the significant wave height indicated a very low score.

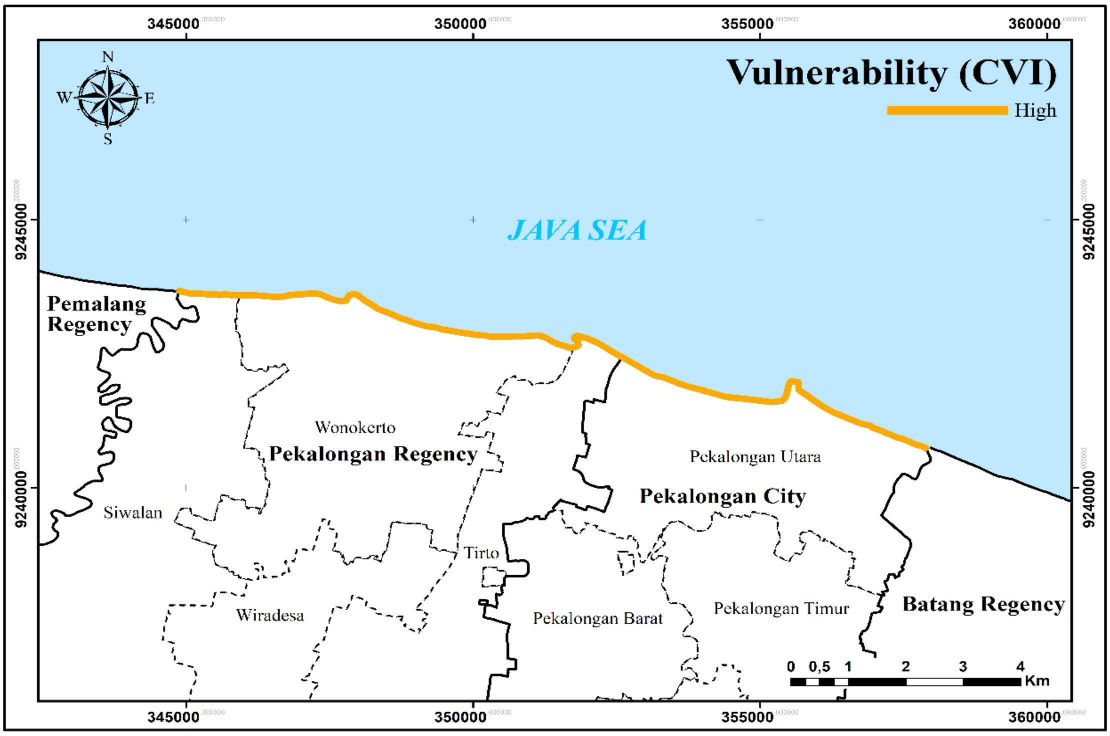

Figure 9. Coastal vulnerability in Pekalongan Coastal Area

3.2. Coastal Vulnerability Discussion

The north coast of Pekalongan is composed by coastal alluvial plains that dominated by material of sand. These landforms were shaped as a result of sea processes, wave energy, currents, and tides (Kurnianto, 2019). It makes the area have a relatively flat slope, approximately 0-7%. Community of Pekalongan City has been developing the coastal area into mangrove ecotourism and the community of Pekalongan Regency uses the coastal area for fisheries. Characteristic of the north coast of Java, that sediment formed area, added with massive land exploitation makes coastal areas more vulnerable. Shoreline change on the north coast of Pekalongan is classified as high, with abrasion value up to 9.54 meters in Wonokerto sub-district. Waves and ocean currents are vital trigger of erosion on the north coast of Pekalongan.

The presence of high and low tides potentially inundated the coast. The classification shows that the smaller the tidal value, the higher the vulnerability value. It is because an area with a long tidal range (high value) will increase the range of influence of sea level rise to land and can cause coastal erosion (Tiraska, 2017). Areas with large tidal values most likely are prone to permanent inundation (Sulma, 2012). High relative water level changes also affect coastal vulnerability. Research by Iskandar et al, (2020) in Pekalongan City shows a relative sea level rate of 4.3 mm/year. This value has led to the land subsidence rate of 16.74 cm/year.

As the water level rises, the area subject to inundation will extend further inland, affecting the stability of the coast itself. Meanwhile, the wave height of the north coast of Pekalongan,

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

located in the north of Java Island, is lower than the wave height of the south coast of Java Island (Setyawan & Pamungkas, 2017).

Based on the results of the coastal vulnerability index (CVI), the north coast of Pekalongan is very vulnerable. The parameters resulted a very high level of vulnerability, indicating that the coast is potentially threatened by the variables. Shoreline erosion is one of the hazards that caused high impact to the land. Therefore, it is urgent to reduce the rate of shoreline erosion. By maintaining the stability of the coastline, the value of the tidal range to changes in sea level can be smaller. Some efforts can be applied to reduce abrasion, i.e., planting mangroves, building seawalls, groins, and breakwaters along the coast, and building Jetties for eroded areas around river mouths.

Protection to the north coast of Pekalongan is necessary, otherwise the value of coastal vulnerability will get worse, especially if the built-up increased in the coastal areas. A high coastal vulnerability index indicates the hazards will harm living creatures and the environment. The results of this study can be used as a reference and guideline in setting policies in coastal zone management. Communities should increase their awareness of the coastal hazard and the vulnerability that might cause damages to their properties.

3.3. Management Strategy for Reducing Vulnerability in Pekalongan Coastal Area

The direct impact of sea level rise is an inundation flood on the low elevated area (Ondara et al., 2018). The high coastal vulnerability on the north coast of Pekalongan signifies the area needs precise prevention actions. Moreover, the Pekalongan coastal area is getting busier with economic activities in small ports built around the area. Appropriate actions could reduce the impacts of erosion and sea level rise. Seawalls, revetment, bulkheads, and jetties are kinds of infrastructure buildings installed in river mouths to prevent sediment siltation.

In Pekalongan coastal area has been installed seawall and breakwater to protect the coast. By far, mitigation efforts performed in the area have been successful to reduce the erosion impact, even the material turned into solid sediment deposition that forms a plain land behind the breakwater (Kusli. M, 2017). Compared to the other side of the coast that had not been installed yet, the area has a stable form. Moreover, it is essential to perform further study on the type of erosion in the area to arrange precise planning to stabilize the coastline. Nonetheless, offshore breakwater still is considered the most effective infrastructure to prevent erosion and hold the sediment supply.

One of the ecological-based efforts to reduce coastal vulnerability is mangrove planting. The northern coast of Java borders directly with the Java Sea which is suitable for mangrove's habitat (Wijaya et al., 2023). Mangroves play a role in protecting the coast from waves, wind and storms, and have ecological functions to regulate microclimates (Huda, et al., 2019). Besides being environmentally friendly, mangrove forest is also relatively low-cost in its development. However, strategic planning on non-infrastructure also needs to be improved. Policy-making and participation from related stakeholders, i.e., government, community, and public institutions, should be integrated to enforce, maintain, and monitor the action for coastal sustainability.

4. CONCLUSIONS

The north coast of Pekalongan indicates a high vulnerability index. With an abrasion value of 9.54 meters, it leads to a very high shoreline change rate. The high index was also triggered by factors of geomorphology of alluvial plains with sedimentation materials, relatively plain slopes, very high tidal range and sea level rise, although the wave height was classified as very low. Strategic actions to reduce the coastal vulnerability combine infrastructure and non-infrastructure development. Especially in Pekalongan, the actions consist of policy-making by

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

compatible stakeholders for mangrove forests and concrete seawall development. Community participation is also necessary to strengthen strategic actions.

5. RECOMMENDATIONS

Coastal vulnerability at Pekalongan Coastal Area, Central Java is classified as high and very vulnerable. Therefore, it is urgent to reduce the coastal vulnerability from the beginning. The vulnerability map can be used as a reference and guideline for policy setting in coastal zone management. Community capacity should be strengthened in areas with high vulnerability.

6. REFERENCES

Addo, K. A. (2013). Shoreline morphological changes and the human factor. Case study of Accra Ghana. *Journal of Coastal Conservation*, 17(1), 85–91. https://doi.org/10.1007/s11852-012-0220-5

Chakraborty, S. (2021). Remote sensing and GIS in environmental management. *Environmental Management: Issues and Concerns in Developing Countries* (Pp. 185-220). Springer, Cham., 188–220.

Dewadaru, ida P., Hariadi, & Saputro, S. (2014). Kajian Morfologi Pantai di Pantai Slamaran Kabupaten Pekalongan. *Journal Of Oceanography*, 3(1), 105–123.

Dhiauddin, R., Gemilang, W. A., Ondara, K., Wisha, U. J., Rahmawan, G. A., & Kusumah, G. (2019). Integrated Method of Smartline Approach and CVI (Coastal Vulnerability Index) In Assessing Pangandaran West Coast Vulnerability. *Jurnal Segara*, 15(2), 109–118. https://doi.org/10.15578/segara.v15i2.7001

Hammar-Klose, E. S., Pendleton, E. A., Thieler, E. R., Williams, S. J., & Norton, G. A. (2003). *Coastal vulnerability assessment of Cape Cod National Seashore (CACO) to sea-level rise*. US Geological Survey, Open File Report, 02-233.

Handartoputra, A., Purwanti, F., Hendrarto. (2015). Penilaian Kerentanan Pantai Di Sendang Biru Kabupaten Malang Terhadap Variabel Oseanografi Berdasarkan Metode Cvi (Coastal Vulnerability Index) Coastal Vulnerability Assessment at Sendang Biru Beach, Malang Regency towards Oceanography Variables Based on CVI (Coastal Vulnerability Index) Method. *Diponegoro Journal of Maquares*, 4(1), 91–97. http://ejournal-s1.undip.ac.id/index.php/maquares

Handiani, D. N., Heriati, A., Suciaty, F., & Putih, J. P. (2022). Coastal Vulnerability Assessment Along The North Java Coastlines-Indonesia. *Journal Segara*, 18(1), 1–12.

Huda, A. C., Pratikto, I., & Pribadi, R. (2019). Karakteristik Lahan terhadap Kerentanan Pesisir Pantai Kabupaten Rembang, Jawa Tengah. *Journal of Marine Research*, 8(3), 253-261.

Husaini, R. R., & Darfia, N. E. (2021). Analisis Kerentanan Pantai Pulau Rupat Provinsi Riau Berdasarkan Metode Indeks Kerentanan Pantai. *Jurnal Teknik Sipil Institut Teknologi Padang*, 8(1), 6-6. https://doi.org/10.21063/jts.2021.V801.06

Hanif, M., Graha Putra, B., Atthori Hidayat, R., Ramadhan, R., Shafrina Wan Moh Jaafar, W., Hermon, D., & Suhana Mokhtar, E. (2021). Impact Of Coastal Flood On Building, Infrastructure, And Community Adaptation In Bukit Bestari Tanjungpinang. *Jurnal Geografi GEA*, *21*(2).

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

ICCSR. (2010). *Scientific basis: analysis and projection of sea level rise and extreme weather events*. In Ministry of National Development Planning or National Development Planning Agency, Republic of Indonesia.

Iskandar, S. A., Helmi, M., Widada, S., & Rochaddi, B. (2020). Analisis Geospasial Area Genangan Banjir Rob dan Dampaknya pada Penggunaan Lahan Tahun 2020-2025 di Kota Pekalongan Provinsi Jawa Tengah. *Indonesian Journal of Oceanography*, 2(3), 3–15.

Komah, S., Purwanti, F., & Churun Ain. (2017). Hubungan Tingkat Kerentanan Pantai Dan Produksi Tambak Di Kecamatan Juwana Kabupaten Pati, Jawa Tengah. *Journal Of Maquares*, 6, 525–529.

Kurnianto, F. A. (2019). Keberagaman Bentuk Lahan Di Wilayah Pesisir Dan Kaitannya Dengan Karakteristik Proses Geomorfologi. *Majalah Pembelajaran Geografi*, 2(2), 197–209.

Kusli. M. (2017). *Kajian Efektifitas Bangunan Pantai Kota Pekalongan*. (Unpublished master's thesis) Institut Teknologi Bandung, Bandung, Indonesia.

Maramis, M., Widada, S., & Handoyo, G. (2022). Pengaruh Influks Sedimen dari Sungai Terhadap Distribusi Ukuran Butir Sedimen Dasar di Perairan Slamaran, Pekalongan, Jawa Tengah. *Indonesian Journal of Oceanography*, 04(02), 1–11. https://ejournal2.undip.ac.id/index.php/ijoce

Marfai, M.Aris, Wijayanti, H., Triyani, A., & Riasasi, W. (2021). *Pengurangan Resiko Bencana Berbasis Ekosistem di Pesisir Utara Jawa Tengah*. UGM Press.

Marfai, M. A., Almohammad, H., Dey, S., Susanto, B., & King, L. (2008). Coastal dynamic and shoreline mapping: Multi-sources spatial data analysis in Semarang Indonesia. *Environmental Monitoring and Assessment*, 142(1–3), 297–308. https://doi.org/10.1007/s10661-007-9929-2

Moechtar H., Lumbanbatu, M.U., Subiyanto, Poedjoprajitno S., Cita, A. (2013). *Geodinamika Kuarter Daerah Pantura Antara Semarang Cirebon*. Pusat Survei Geologi Badan Geologi KESDM.

Muliati, Y. (2020). *Rekayasa Pantai (1st ed.)*. Penerbit Itenas.

Nugroho, K., & Indra, T. (2022). *Identifikasi Perubahan Garis Pantai Menggunakan Citra Satelit Landsat Dengan Metode Digital Shoreline Analysis System (DSAS) (Studi Kasus : Kota Pekalongan , Jawa Tengah)*. FTFP Series, 340–345.

Ondara, K., Rahmawan, G. A., & Pitri, Y. A. (2018). Kerentanan Pesisir Kota Pariaman, Sumatera Barat Menggunakan Pemodelan Numerik Hidro-Oseanografi. *In Prosiding Seminar Nasional Kelautan dan Perikanan IV* (pp. 13-24).

Pamungkas, T. D., Somantri, L., Aliyan, S. A., & Firdaus, R. A. Determination of Physical and Social Vulnerability Zones In Cisarua District, West Bandung Regency, Using Remote Sensing and Geographical Information Systems. *Jurnal Geografi Gea*, 24(1), 56-66.

Parthasarathy, K. S. S., & Deka, P. C. (2021). Remote sensing and GIS application in assessment of coastal vulnerability and shoreline changes: a review*. In ISH Journal of Hydraulic Engineering* 27(S1), pp. 588–600). Taylor and Francis Ltd.

Pratami, B. D., Larasati, R., Ratna Intan, S. R., & Kamalludin, I. (2021). Status Hukum Tanah Musnah Berdasarkan Permen ATR/BPN No. 17 Tahun 2021. *Jurnal Officium Notarium*, 1(2), 218–229. https://doi.org/10.20885/jon.vol1.iss2.art2

Rangkuti, A. M., Cordova, M. R., Rahmawati, A., & Adimu, H. E. (2022). *Ekosistem Pesisir & Laut Indonesia* (S. B. Hastuti & R. Damayanti, Eds.; 1st ed.). Bumi Aksara.

Riasasi, W. (2019). Identifikasi Garis Pantai Kawasan Pesisir Kabupaten Brebes Berbasis Penginderaan Jauh dan Sistem Informasi Geografis. *Geomedia: Majalah Ilmiah Dan Informasi Kegeografian*, 17(1), 47–53.

Ridwana, R., & Himayah, S. (2020). Utilization of remote sensing technology and geographic information systems for tourism development. *International Journal of Applied Sciences in Tourism and Events*, 4(2), 158-169.

Sauda, R. H., Nugraha, A. L., & Hani'ah. (2019). Kajian Pemetaan Kerentanan Banjir Rob Di Kabupaten Pekalongan. *Jurnal Geodesi Undip*, 8(1), 466–474. https://doi.org/10.14710/jgundip.2019.22777

Solihuddin, T., Husrin, S., Salim, H. L., Kepel, T. L., Mustikasari, E., Heriati, A., Ati, R. N. A., Purbani, D., Mbay, L. O. N., Indriasari, V. Y., & Berliana, B. (2021). Coastal erosion on the north coast of Java: Adaptation strategies and coastal management. *IOP Conference Series: Earth and Environmental Science*, 777(1).

Sopandi, A., Dewi, W. R., Nurjanah, A., Rohman, M. F., Ilham, R., Sugandi, D., & Ridwana, R. (2020). Analisis Bentuk Lahan Pangandaran Berbasis Citra Satelit Landsat 08 OLI. *Jurnal Georafflesia: Artikel Ilmiah Pendidikan Geografi*, 5(1), 49-57.

Sulma, S. (2012). *Kerentanan Pesisir Terhadap Kenaikan Muka Air Laut (Studi Kasus: Surabaya dan Daerah Sekitarnya)*. (Unpublished master's thesis), Universitas Indonesia, Jakarta, Indonesia.

Sutikno, Dibyosaputro, S., & Haryono, E. (2019). *Geomorfologi Dasar Bagian 1* (Nadilah, Ed.; 1st ed.). Gadjah Mada University Press.

Setyawan, W. B., & Pamungkas, A. (2017). Prosiding Seminar Nasional Kelautan dan Perikanan III. *Seminar Nasional Kelautan Dan Perikanan III*, 191–202. https://tides.big.go.id/

Tiraska, A., Gaol, J. L., & Natih, N. M. N. (2017). *Analisis Kerentanan Wilayah Pesisir Palabuhan ratu terhadap Kenaikan Muka Laut menggunakan pendekatan SIG*. IPB University.

Triana, K., & Wahyudi, A. J. (2020). Sea level rise in Indonesia: The drivers and the combined impacts from land subsidence. *ASEAN Journal on Science and Technology for Development*, 37(3), 115–121. https://doi.org/10.29037/AJSTD.627

Widada, S., Ismanto, A., Priambodo, I. B., & Siagian, H. (2022). Perubahan Garis Pantai dan Dampaknya Terhadap Banjir Rob di Kota Pekalongan, Provinsi Jawa Tengah. *Jurnal Kelautan Tropis* 25(1), 121–130.

Widura, E., & Mardiatno, D. (2022). Assessment of the Coastal Vulnerability Index (CVI) for disaster mitigation strategies in some coastal tourism areas in Gunungkidul, Yogyakarta-Indonesia. *IOP Conference Series: Earth and Environmental Science*, 989(1).

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529

Wijaya, M. S., Kamal, M., & Widayani, P. (2023). Mapping of Mangrove Composition in Ratai Bay, Lampung Province Using Pleiades-1 Satellite Imagery. *Jurnal Geografi Gea*, *23*(2), 107–122. https://doi.org/10.17509/gea.v23i2.59612

DOI: https://doi.org/10.17509/gea.v24i2.63996
p-ISSN 1412-0313 e- ISSN 2549-7529