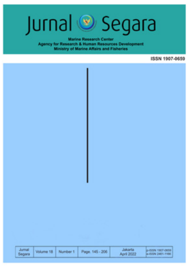

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COASTAL VULNERABILITY ASSESSMENT ALONG THE NORTH JAVA COASTLINES-INDONESIA

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ABSTRACT

The north coast of Java is an area with very diverse maritime activities. These high activities threaten the ecosystem and environmental sustainability. Several areas already experience environmental degradation and most of the threats come from ocean pollution, coastal erosion, continuous tidal flood (rob), and coastal land subsidence. Furthermore, the coastal degradation is worsened by climate change which may cause the area more vulnerable to disaster. This study aims at evaluating the coastal vulnerability using weighted coastal vulnerability index (CVIw). The method calculates coastal vulnerability by weighting physical coastal parameters using Analytical Hierarchy Process (AHP). CVIw calculation result shows that the vulnerability is dominant at high (39%) and very high (51%) classes. The high vulnerability occurs in Tangerang, Bekasi, Brebes, Demak, Jepara, Pati, and Rembang Regencies. Meanwhile, very high vulnerability takes place in several regencies: Serang, Karawang, Subang, Indramayu, Cirebon, Tegal, Kendal, Semarang, and Gresik. The parameters of relief, coastal features, tidal range and shoreline give contribution more in coastal vulnerability besides lithology, sea level change, and wave height. Identifying vulnerability in these areas might help local governments to prioritize their action plan in coastal disasters mitigation.

Keywords: Disaster, mitigation, coastal vurnerability, North Java.

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INTRODUCTION

The north coast of Java Island is an area faced with coastal shoreline problems (Solihuddin *et al.*, 2019). Erosion and abrasion are natural processes in the coastal area, but these processes have increased excessively as human activities increase in the area (Kepel *et al.*, 2019). A significant and growing number of people are on the island of Java, Indonesia, where more than 140 million people live in the area. Most of these people reside in the flat and low-lying northern coastal plains (Willemsen *et al.*, 2019). Although, the area is not being exposed to intensive natural hazards, such as storms, hurricanes, and tsunamis the north Java coastlines are vulnerable to sea-level rise (Kulp & Strauss, 2019). This condition leads to coastal ecosystems and people who benefit from coastal services vulnerable to potential sea-level rise (SLR).

Coastal vulnerability is a spatial concept that explains in various ways by experts from different disciplines. The concept identifies people and places that are susceptible to disturbances resulting from coastal hazards, such as coastal storms, erosion, and inundation. The hazards cause significant threats to coastal physical, economic, and social systems (Bevacqua *et al.*, 2018). The Coastal Vulnerability Index (CVI) is a popular index in literature to assess the coastal vulnerability of climate change (Contestabile & Vicinanza, 2020). The CVI uses similar assessments along the ocean coastline, which all the coastal parameters are assumed to contribute equally to the coastal vulnerability (Gornitz, 1991), Thieler & Klose (2000)). However, another coastal assessment study is integrating CVI with multi-criteria evaluation, the Analytic Hierarchy Process (AHP) method (Saaty, 1977). The AHP is used to calculate the weighting coastal parameters and then it incorporates the weighted into each parameter under a set of equations. The index is called the coastal vulnerability index (CVIw) (Bagdanavičiūtė *et al.*, 2015).

In this study, the CVIw was used as a basis for the vulnerability assessment along the north coast of Java. The study makes a quantitative assessment as a response to progressive change in the dynamic of the coastal zone around the study area. The result of the assessment can help the coastal managers and decision-makers, which usually have limited resources and also questions of where to invest. To create a rational decision, the vulnerability analysis along the study area is necessary and it also indicates the relative vulnerability of different areas.

METHODOLOGY

The northern part of Java in this study is from the western part of the Cilegon City in Banten Province to the eastern part of the Situbondo City in East Java Province (Figure 1). The selected coastal features are dominated by alluvium deposit, which consists of silt, sand, clay, gravel, and organic matter. The materials were deposited by rivers and usually most extensive in the lower part of a river (deltas and floodplains) (Ongkosono, 1979). In other areas can be found a large intertidal flat, few mangroves, sea wall and riprap revetments as a protection from erosion.

This research uses parameters that require a large amount of data from different sources. They are developed from remote sensing and numerical model data, also the Geographic Information System (GIS) (Table 1). The study uses seven physical coastal parameters and these parameters are assessed in the weighted coastal vulnerability index (CVIw). The parameters are coastal relief and features, lithology,

Figure 1. Study area.

Table 1. Field observation results

Parameters	Resolution	Data Source
Relief (m)	8.25 m	DEMNAS (Digital Elevation Model Nasional); http://tides.big.go.id/DEMNAS
Lithology/geology	1: 100.000	Geology/lithology map from Geological Research and Development Centre, Republic Indonesia (1996)
Coastal features	1: 400.000	Coastal features map from Marine Research Center, Ministry of Marine Affairs and Fisheries Republic of Indonesia (MoMAF)
Mean tidal range (m)		http://tides.big.go.id (Geospatial Information Agency)
Shoreline change rate (m/year)	1:400.000	Shoreline change map from Landsat satellite at year 1998, 2008, and 2018 from Coastal features map from Marine Research Center, Ministry of Marine Affairs and Fisheries Republic of Indonesia (MoMAF)
Relative sea level change (mm/year)	Lat. = 1°; Long.=3°	Jason-2 satellite July 2008 to September 2017 from Aviso+ https://www. aviso.altimetry.fr/
Mean wave height (m)	0.08°	Ocean Model Global from Copernicus Marine Service Information website (CMEMS; https://resources.marine.copernicus.eu/)

Source: Data Processing, 2021

mean tidal range, shoreline change rate, relative sea-level change, and wave height (Shaw *et al.*,1998; Handiani *et al.*, 2019).

These physical coastal parameters are ranked into five categories of vulnerability scores. The scores are categorized on a scale of 1–5 (low risk to high risk) by breaking the range into five divisions (Table 2). Then, Analytic Hierarchy Process (AHP) method was applied to derive the relative weights for the parameters. The weights are incorporating expert judgment. In this present study, the expert judgment was modified and adapted from (Koroglu *et al.*, 2019), and Solihuddin *et al* (2021). This judgment is used in AHP calculation. The weights for the parameters are coastal relief =0.34, lithology/geology= 0.27, coastal features= 0.23, tidal range= 0.04, shoreline change= 0.05, relative sea-level change = 0.04, and wave height= 0.03 (Purbani *et al.*, 2019). Furthermore, the formula equation of the weighted coastal vulnerability index (CVIw) is based on Bird & Ongkosongo (1980):

$$CVI_{w=} \sum_{j=1}^{n} w_j * v_{ij} \quad \text{.. 1)}$$

where wj is the weight of parameter j; vij is the

Table 2. Vulnerability Ranking for the Study Area

Parameters	Vulnerability rank				
	1 very low	2 low	3 Moderate	4 high	5 Very high
Relief (m)[a,b]	>30	21-30	11-20	6-10	0-5
Lithology/geology[a,c]	Plutonic, volcanic, high-medium metamor phics	Sand-stones and conglomerates, metamorphics	Most sedimen tary rocks	Coarse poorly sorted, unconsolidated sediment	Fine, consolidated sediments
Coastal features[a,c]	Rocky, cliffed coasts, Fiords, Fiards	Medium cliffs, Indented coasts	Alluvial plains, Low cliffs, Glacial drift	Cobble beaches, Estuary Lagoon;	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mang-roves, Coral reefs; coast construction
Mean tidal range (m)[a]	>6.0	4.1–6.0	2.0– 4.0	1.0–1.9	<1.0
Shoreline change rate (m/yr)[a,c]	≥2.1	1.0–2.0	-1.0–1.0	-1.0– -2.0	≤-2.1
Relative sea level change (mm/yr)[c]	<-1.21	-1.21–0.1	0.1–1.24	1.24–1.36	>1.36
Mean wave height (m)[c]	<1.1	1.1–2.0	2.0–2.25	2.25-2.60	>2.60

Source: Data Processing, 2021; [a)]Gornitz 1991, [b)]Shaw *et al.*, 1998, [c)]Thieler & Hammar-Klose 2000 vulnerability rank of area i under parameter j and n is the total number of parameter. At the end, the vulnerability categories were represented with percentile ranges as 0 - 25%, 25 - 50%, 50 - 75%, and 75 - 100% (Koroglu *et al*., 2019).

RESULTS AND DISCUSSION

The overall ranking distribution of the parameters is shown in Figure 2 to Figure 8. Parameter vulnerabilities vary based on their coastal condition.

Coastal Parameters Vulnerabilities

Coastal relief is used to characterize the vulnerability of coastal regions due to inundation. The north coast of Java is a coastal plain with only small area of rocky and cliffs. Most of the coastal relief in the area is low contours and is relatively flat (< 25 m), also formed in several bird's-foot deltas around the estuary leaving the bays with relatively small rivers far behind. The Digital Elevation Model (DEM) from Geospatial Information Agency Republic of Indonesia is used to determine the relief condition of the study area. Based on this relief condition which is between 0 - 11 m, the study area is classified into low contours and it has moderate to very high vulnerability (Figure 2).

Coastal geology or lithology characteristics of the north coast of Java are formed by alluvial river deposits and volcanic sediments in the hinterland consisting of gravel, sand, silt, and clay. This parameter expresses the relative erodibility of different landform types. Our study used a lithology map from Geological Research and Development Centre, Republic Indonesia. Based on the map, the north coast of Java is classified as a rocky coastline, which a rank of 1 (one) representing the lowest vulnerability for erodibility and a ranking of 5 (five) representing the highest vulnerability. The vulnerability classification of lithology in the area study is shown in Figure 3.

Based on the map, the coastal features are sandy and muddy coasts (i.e. mangrove, tidal mudflats, salt marshes), gravelly coast, as well as coastal protection

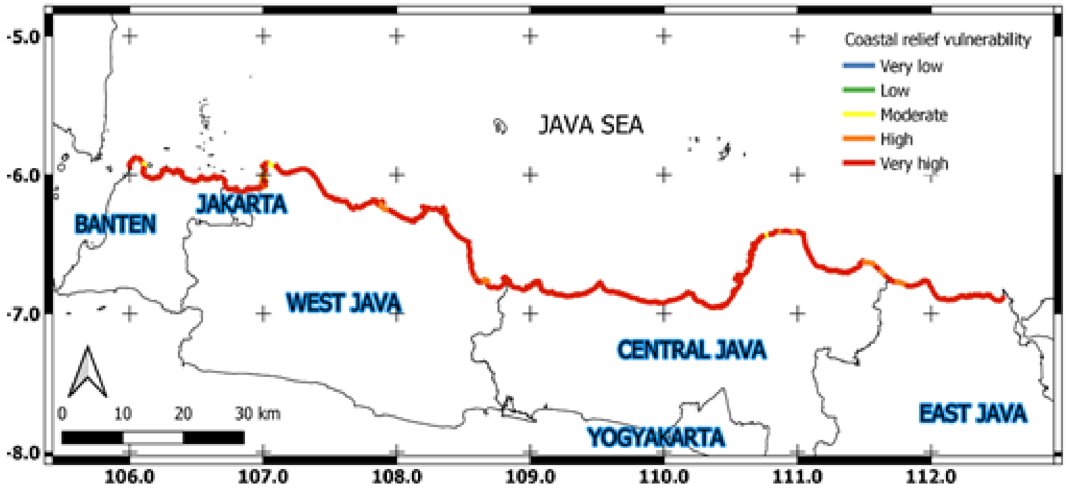

Figure 2. Vulnerability rank for coastal relief.

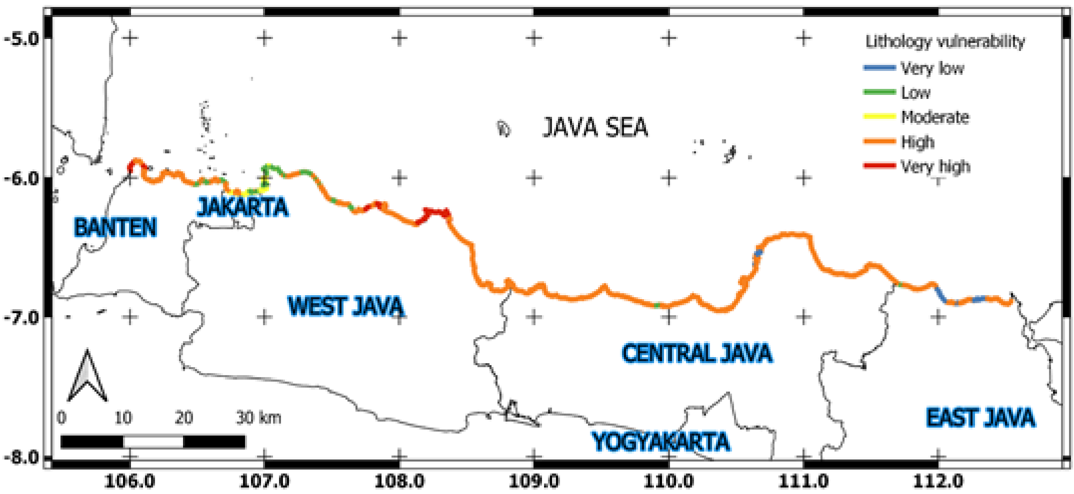

Figure 3. Vulnerability rank for lithology/geology.

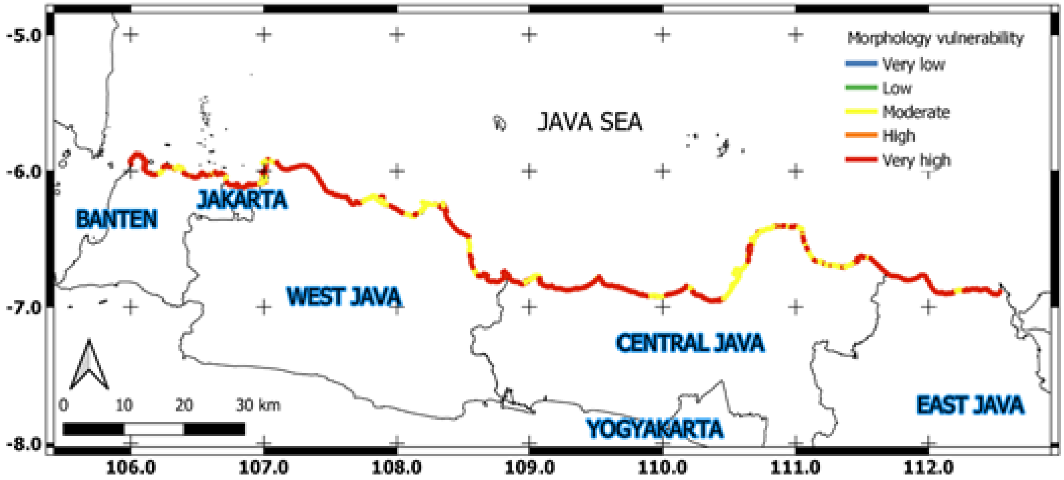

Figure 4. Vulnerability rank for coastal features.

and infrastructures (e.g. seawall, jetties, seaports, sea-dike, groin, rock armors, etc.). Then, the map is classified into vulnerability rank and the result is shown in Figure 4. Most of the coastal feature vulnerability is from moderate to very high rank. Low cliff is ranked as moderate vulnerability, estuary and lagoons are high vulnerability, also the coastal protection and infrastructures are rank as very highest vulnerability.

Tide type in the north coast of Java is mostly mixed tide prevailing diurnal, but in few areas are mixed tide prevailing semi-diurnal. These results are based on several tide prediction stations in the study area from several predicted locations along the coast estimated from the Geospatial Information Agency, Indonesia. The average tidal range is between range 0.8m - 0.9m or less than 1 m along the coast and this condition is in line with earlier studies. Therefore, the study area is classified as a very high vulnerability [Figure 5]. Tidal range rank in our study classified micro-tidal coasts in to high vulnerability and macro-tidal coasts to be of low vulnerability.

The study used the trend of shoreline changes observed in three sets of images. The images are a comparison of images from Landsat satellites in recent decades from 1998 to 2018 and the Landsat TM/ETM+ images were analyzed to assess shoreline changes following the Digital Shoreline Analysis System (DSAS) calculation. The results of the shoreline change analysis indicate that some areas have been subject to significant accretion and erosion during the time. A higher erosion rates at a specified shoreline location indicate a more vulnerable coastline at the study area and assigned as a higher ranking. The highest abrasion shows in Demak Regency (Central Java) within abrasion rate around 279.1 m/year, while the highest accretion shows in Bekasi Regency (West Java) within accretion rate around 154 m/year. In consequence, based on the shoreline change parameter, the area was categorized between very low to very high vulnerability (Figure 6).

Sea level changes is a long and gradually process and the sea-level change of the north coast of Java was retrieved from Jason-2 satellite altimetry.

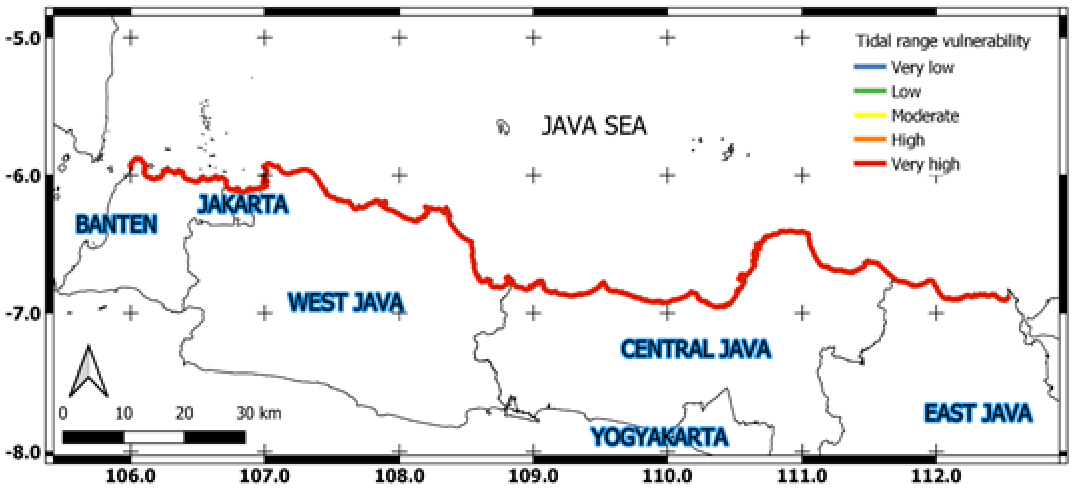

Figure 5. Vulnerability rank for mean tidal range.

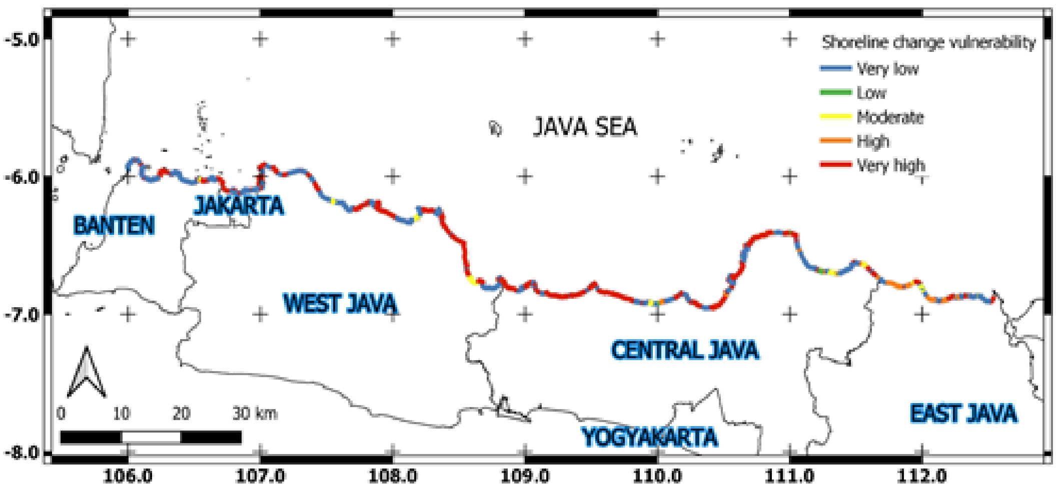

Figure 6. Vulnerability rank for shoreline change.

The altimetry estimation of sea level usually make only a small spatial variation unless the study area is really large. According to the satellite, the sea level rate of change in the study area is between 1.2 mm/year and 1.36 mm/year. Within this value, the area has a varying result of vulnerability, from very low to very high sea-level change. The vulnerability is shown in Figure 7. The higher sea level rise contributed more in vulnerability of particular shoreline, thus was assigned with a higher ranking value.

Wave height along the study areas are from 0.27 m to 0.43 m and it is categorized with very low vulnerability (rank = 1), in Figure 8. The wave in the north coast of Java has relatively low energy and it is developed mostly by local wind monsoon. Around Indramayu Regency, the wave height is around 0.02 m – 0.75 m in West Monsoon, while in East Monsoon the wave height is smaller (around 0.008 m - 0.63 m). The higher wave height is deemed to make the shoreline more vulnerable to erosion, so the ranking was higher compared to lower wave heights at a shoreline.

Coastal vulnerability

The coastal vulnerability distribution in the north coast of Java is summarized in Figure 9. The vulnerability is distributed into equal 4 classes (low, moderate, high, and very high). The area with low risk-level occurred in East Bekasi dan Central Jepara Regencies. The moderate risk is found in West Bekasi, Pekalongan, Tuban, and Lamongan Regencies. Furthermore, high-risk regencies are in Tangerang, Bekasi, Brebes, Demak, most of Jepara, Pati, and Rembang Regencies. Meanwhile, very high vulnerability takes place in several regencies namely Serang, Karawang, Subang, Indramayu, Cirebon, Tegal, Kendal, Semarang, and Gresik.

Furthermore, our study found that percentages of the values (based on total coastline segments n_{total}=471) in CVIw are 1%, 9%, 39%, and 51%, respectively from low to very high (Figure10). These percentages were calculated based on comparison between number of segments in each vulnerability and total number of coastline segments. The coastline segments were

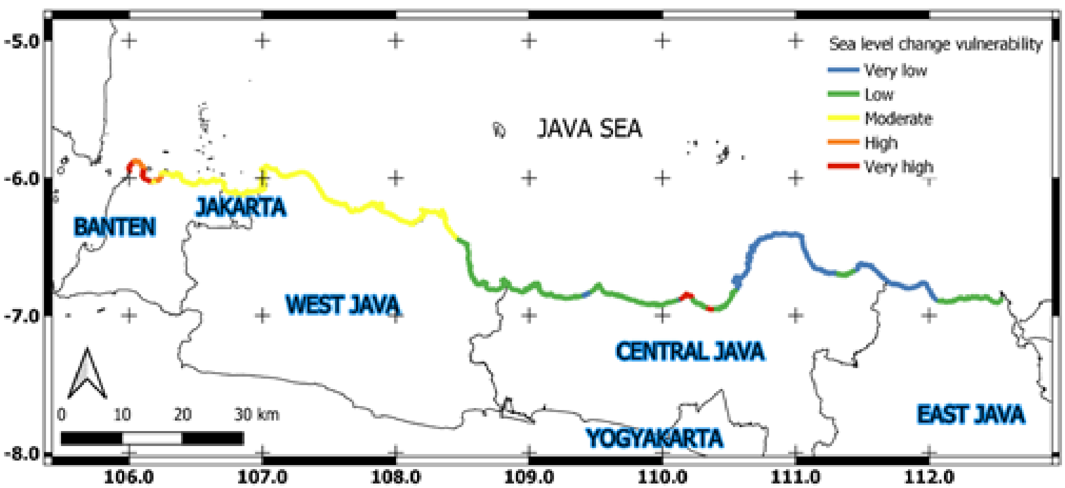

Figure 7. Vulnerability rank for sea level change.

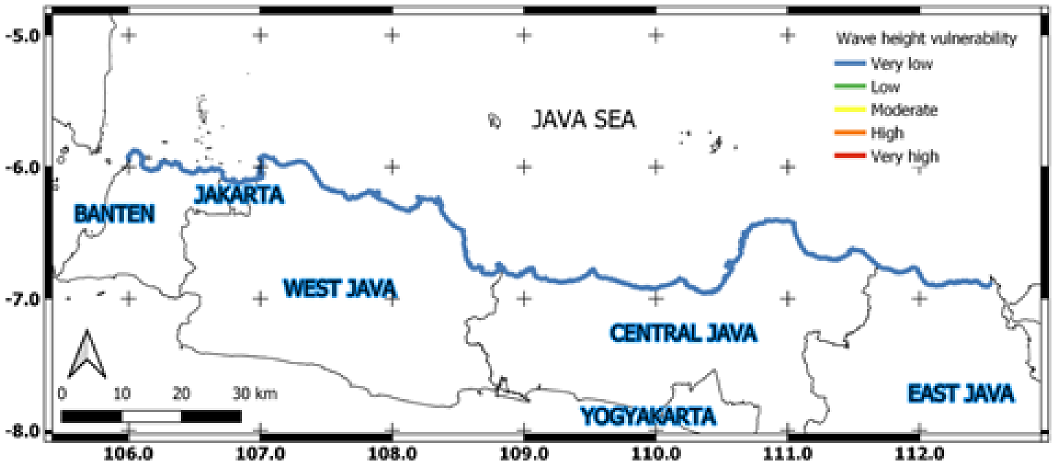

Figure 8. Vulnerability rank for wave height.

Figure 9. Vulnerability map of CVIw distribution.

divided based on coastline changes parameter in the north coast of Java and it was used as base calculation of the vulnerabilities. As an example, 1% of low vulnerability is comparison between 5 (five) segments of low vulnerability and 471 segments of total coastline. The detail total number of segments in each class are showing in Table 3. Based on this percentages, we concluded that most of the study area experience very high vulnerability.

Each coastal parameter has its own contribution to the coastal vulnerability index. Using radial graphs (Figures 11 to 14), we identified which coastal parameter contributes to each coastal vulnerability assessment. The coastal parameter distribution identifies each parameter that contributes dominantly and have an effect on coastal vulnerability in the area. In low vulnerability area (Figure 11), the number of coastline segments in this class is five or n=5 (Table 1 and Figure 11) and the maximum number on radial graph of Figure 11 is five. It means that the low class is composed by five other segments of each coastal parameters, namely relief, lithology, coastal features, tidal range, shoreline change, sea level, and wave height. From these parameters, we can see in Figure 11 that each parameter has their own classification. As

Table 2. Vulnerability Ranking for the Study Area

Vulnerability class	Number of segments (n)
Low	5
Moderate	41
High	183
Very high	242

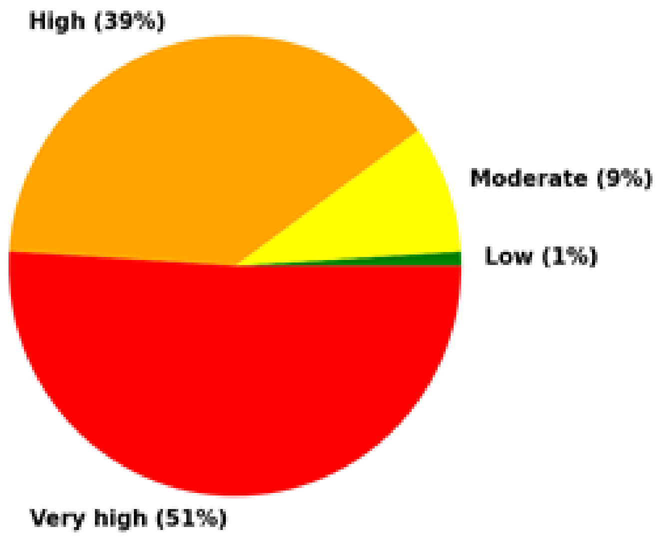

Figure 10. Vulnerability percentages of CVIw distribution.

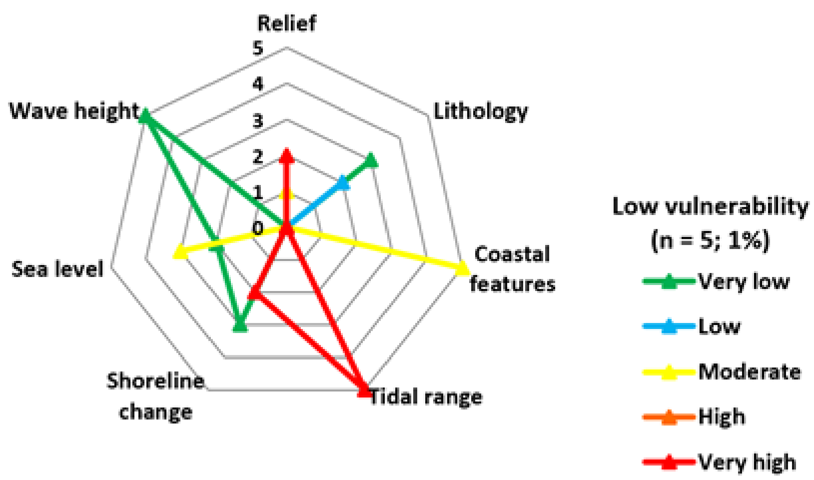

Figure 11. Vulnerability rank for sea level change.

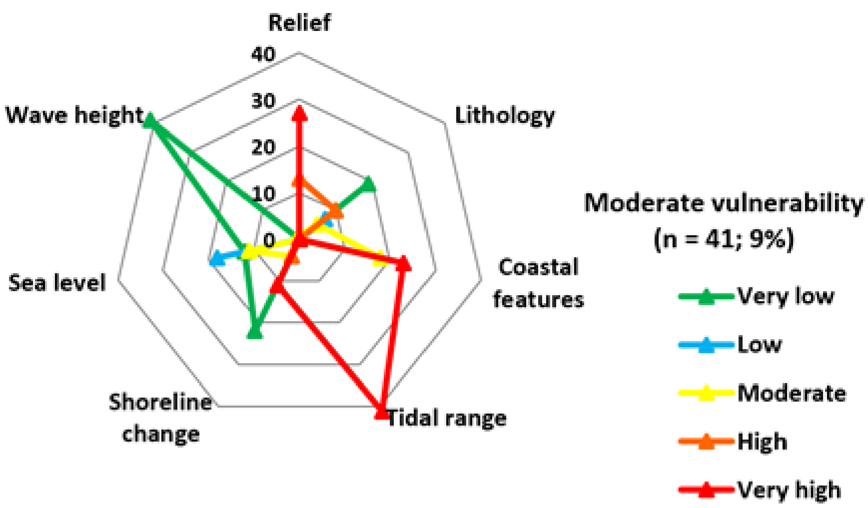

Figure 12. Vulnerability rank for sea level change.

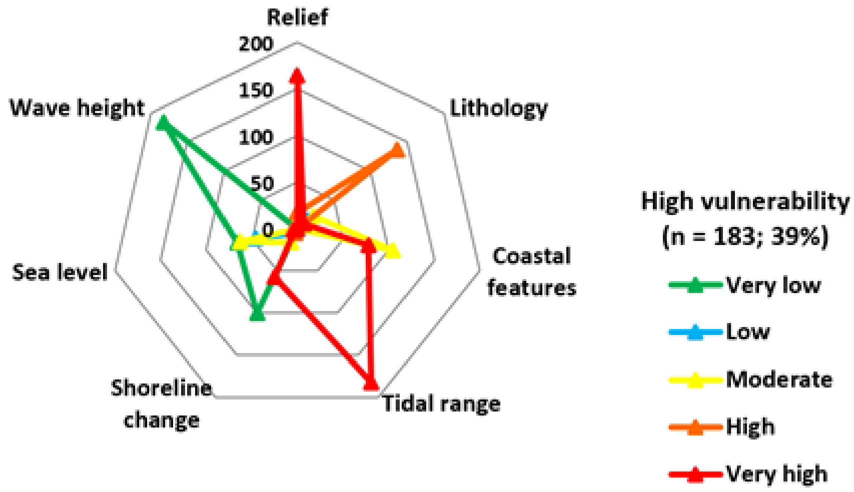

Figure 13. Radial graphs all parameters of high vulnerability.

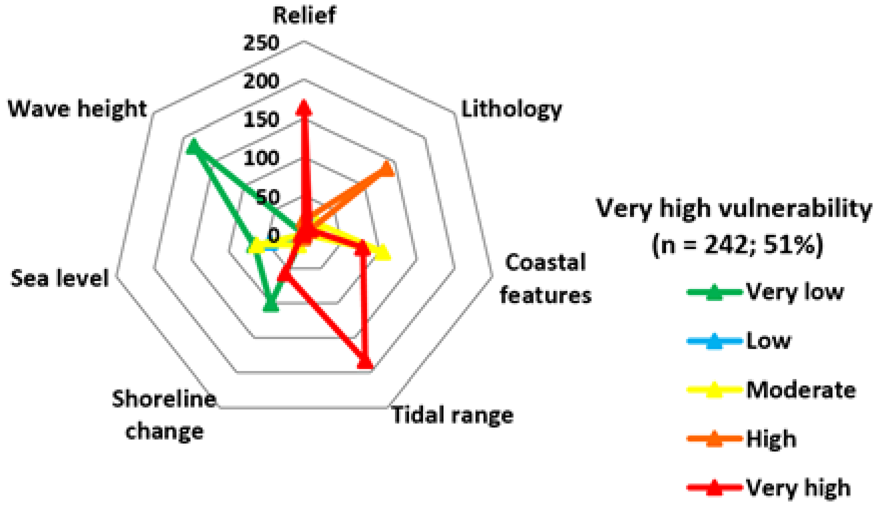

Figure 14. Radial graphs all parameters of very high vulnerability.

an example, relief parameter consists two segments of high and very high vulnerabilities and one segment of moderate vulnerability. The tidal range consists all (five) segments of very high vulnerability, while the wave height consists all segments of very low vulnerability. Others coastal parameters are described in the Figure 11 as an example earlier. From the Figure 11, we can conclude that parameter such as tidal range, shoreline change, and coastal relief are contributed in very high rank vulnerability. Wave height dominantly contributes in very low vulnerability and coastal features dominantly contributes in moderate vulnerability. In some parameters, such as sea level, shoreline change, relief, and lithology have more combination of vulnerabilities, although very high vulnerability becomes main concern in this study.

Coastal distribution parameters in moderate vulnerability have a similar pattern to low vulnerability, except the coastal feature contributes larger segments number of very high rank (Figure 12). Furthermore, the coastal distribution parameters pattern in high (Figure 13) and very high vulnerabilities are rather similar, but the very high vulnerability has more a large contribution of very high parameters: shoreline change, tidal range, lithology, and coastal feature (Figure 14). These results show that relief, coastal features, tidal range and shoreline change values are influencing coastal vulnerability in the northern part of Java Island larger than other coastal parameters. It because these parameters have dominant segment number in very high vulnerability. The very high vulnerability suggests that the area needs urgent action and assure not causing more environmental problems in the future.

CONCLUSION

A vulnerability index is a tool developed for coastal managers to show potential coastal risk and in supporting the decision makers. The tool is very helpful as an important part of the assessment in planning process for integrated coastal zone management

(ICZM). This study used seven physical coastal parameters (coastal relief, lithology, morphology, shoreline change, tidal range, sea-level change, and wave height) which are classified into very low to very high rank and calculated using the weighted index coastal (CVIw) within Analytical Hierarchy Process (AHP) approach.

CVIw calculation result shows that the vulnerability area in the northern Java is dominant at high (39%) and very high (51%) classes. The high vulnerability occurs in Tangerang, Bekasi, Brebes, Demak, Jepara, Pati, and Rembang Regencies. Meanwhile, very high vulnerability takes place in several regencies such as Serang, Karawang, Subang, Indramayu, Cirebon, Tegal, Kendal, Semarang, and Gresik. Furthermore, the results also show that relief, coastal features, tidal range and shoreline change values are dominantly influencing the value of coastal vulnerability besides lithology, sea level, and wave height. It means that those parameters should be taken into account in the mitigation process of the area, since they give more contribution to the vulnerability in the area. Identified the vulnerability in these areas might give recommendation to the local governments in prioritizing their action plan in coastal disaster mitigation to protect coastal environment and achieve the ICZM.

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REFFERENCE

Bagdanavičiūtė, I., Kelpšaitė-Rimkienė, T., & Soomere, T. (2015). Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. *Ocean & Coastal Management, 104*, 124-135. DOI:10.1016/j.ocecoaman.2014.12.011

Bevacqua, A., Yu, D., & Zhang, Y. (2018). Coastal vulnerability: Evolving concepts in understanding vulnerable people and places. *Environmental Science & Policy, 82*, 19-29. DOI:10.1016/j.envsci.2018.01.006

Bird, E.C.F., & Ongkosongo, O.S.R. (1980). *Environmental Changes on Coasts of Indonesia*. The United Nation University, Tokyo, pp.52.

Contestabile, P., & Vicinanza, D. (2020). Coastal Vulnerability and Mitigation Strategies: From Monitoring to Applied Research. *Water, 12*(9), 2594. DOI:10.3390/w12092594

Gordon, A., Susanto, R.D., & Vranes, K. (2003). Cool Indonesian throughflow as a consequence of restricted surface layer flow. *Nature, 425*(6960), 824-828. https://doi.org/10.1038/nature02038

Gornitz, V. (1991). Global coastal hazards from future sea level rise. *Glob. Planet. Chang, 89*(4), 379–398. https://doi.org/10.1016/0031-0182(91)90173-O

Handiani, D.N., Darmawan, S., Heriati, A., Aditya, Y.D. (2019, in Indonesian). Coastal vulnerability study to the sea level rise in Subang Regency-West Java. *Jurnal Kelautan Nasional, 14*(3), 145-154. http://dx.doi.org/10.15578/jkn.v14i3.7583.

Kepel, T.L., Heriati, A., Mbay, L.O.N., Ati, R.N.A.A., Jayawiguna, M.H., & Abida, R.R. (2019, in Indonesian). Mangrove rehabilitation as coastal abrasion defenses in North Coast Java. In: T. Solihuddin, M.H. Jayawiguna, Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir], AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Jakarta, p. 53-75. (Indonesian)

Koroglu, A., Ranasinghe, R., Jiménez, J.A., & Dastgheib, A. (2019). Comparison of Coastal Vulnerability Index applications for Barcelona Province. *Ocean & Coast. Manag, 178*, 1047992, 1-11. https://doi.org/10.1016/j.ocecoaman.2019.05.001.

Kulp, S.A. & Strauss, B.H. (2019). Vulnerability to sea-level rise and coastal flooding. Nature Communications. https://doi.org/10.1038/s41467-019-12808-z

Mahapatra, M., Ramakrishnan. R., & Rajawat, A.S. (2015). Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. *Nat Hazards, 76*, 139-159. https://doi.org/10.1007/s11069-014-1491-y

Ongkosongo, O.S.R. (1979). The Nature of Coastline Changes In Indonesia. *Workshop on Coastal Geomorphology*, UNESCO, Singapore-Malaysia,.

Purbani, D., Salim, H.L., Marzuki, M.I., Abida, R.F., Tussadiah, A., & Triyono. (2019, in Indonesian). Abrasion and accretion in the last decades case study: Serang, Indramayu, Brebes, Demak, and Gresik Districts In: T. Solihuddin, M.H.

Jayawiguna, Triyono, editors. *North Coast Java strategies based on coastal zone dynamic*. AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Jakarta. p.37-51.

Saaty, T.L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology, 15*(3), 234-281. https://doi.org/10.1016/0022-2496(77)90033-5

Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M.-H., & Solomon, S. (1998). Sensitivity of the coasts of Canada to sea-level rise. *Bull. Geol. Surv. Can. 505*, 1-79.

Solihuddin, T., Dhiadudin, R., Mustikasari, E., Rahayu, Y.P, & Husrin, S. (2019, in Indonesian). North Coast Java rehabilitation: issues, analysis, and challenges. In: T. Solihuddin, M.H. Jayawiguna, Triyono, editors. North Coast Java strategies based on coastal zone dynamic, AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Jakarta, p. 9-35.

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 Conf. Series: Earth and Environmental Science, 777*, 1-12. doi:10.1088/1755-1315/777/1/012035.

Thieler, E.R., & Hammar-Klose, E.S. (2000). National Assessment of Coastal Vulnerability to Sea-Level Rise; Preliminary Results for the US Pacific Coast; Technical Report; U.S. Geological Survey: Woods Hole, MA, USA.

Willemsen, P., Lelij A.C. van der, Wesenbeeck, B. van. (2019). Risk Assessment North Coast Java. Deltares, Report Project No. 1220476-002-ZKS-0007, p. 1-25.