Comparison of coastal vulnerability assessment for Subang Regency in North Coast West Java-Indonesia

Dian N. Handiani, Aida Heriat and Wina A. Gunawan

ABSTRACT
Coastal vulnerability is a spatial concept that can contributes to decision-making processes in managing the coast. Our study aims to compare and evaluate the coastal vulnerability index (CVI) and the weighted CVI (CVIw) along the Subang Regency coastline in northern part of Java Island-Indonesia. We use coastal parameters: coastal relief, morphology, shoreline change, tidal range, sea-level change, wave height, land subsidence, and land use. Then, vulnerability maps are prepared to highlight areas with low, medium, high, and very high vulnerability. The vulnerability parameters map showed that shoreline change, land subsidence, and land use are influencing the vulnerability more than other parameters. The CVIw appears to be more favourable to assess the Subang Coast vulnerability, in which the very high vulnerability (43%) is dominant compared to the CVI (21%). This will require urgent protective action from the coast managers. Both CVI and CVIw have a 21% of very high risk in the same areas (Mayangan, Legon Wetan, and Pangarengan Villages), and these areas need protection from the coastal land loss. Meanwhile, the authority has plans for aquaculture in the area, and we suggest that it should be planned thoroughly to ensure that the practice does not destruct the coasts any further.
**Introduction**

Most coastal environments around the world are experiencing the effects of climate change (Nicholls et al. 2018). Similarly, many of the Asian regions also experience these effects, and in recent years, climate-related disasters have also become prominent in these areas (Dulal 2019; Krampe and Mobjörk 2018). East and Southeast Asia are on top of the list of the regions affected and Indonesia is one of the countries that have significant annual growth rates of floods and storms (Thomas and López 2015). The floods and storms are affecting the vulnerability of the coastal area and with this conditions, Indonesian coasts are among the most vulnerable. As an archipelagic country and located on the equator within around 108,000 km coastline length (the second-longest coastline in the world), Indonesia is facing high pressure in the coastal area. Tropical cyclones (TCs) occurs around Indonesia seas may affect the weather pattern in Indonesia such as changes in the frequency and intensity of wind speed, increases in significant wave height, and higher ocean temperature and sea level rise. The dense population in the coastal area and the variety of activities making the coastal as an important area, but vulnerable due to natural processes and human activities (Ningsih et al. 2020; Zikra and Suntoyo 2015).

Northern coast of Java coastline extends from Serang Regency in Banten Province to Situbondo Regency in East Java Province (Solihuddin et al. 2019). The coastline is part of the coastal areas in Indonesia that is the most dynamic in economic activities for instance marine transportation, offshore industry, naval industry, and tourism. Coastal area is also a strategic area for development as they provide many resources for human livelihood such as agriculture, fishpond, captured fisheries, mining and other resource extraction (Solihuddin et al. 2019). At the same time, however, these coastal areas are also prone to environmental hazards such as erosion and sedimentation processes (Solihuddin et al. 2019; Willemsen et al. 2019). Studies have shown significant changes of coastline in the last decade (Purbani et al. 2019).

Subang Regency is located in north coast West Java. The regency experiences erosion along their coast and it is causing loss of coastal land and infrastructure and
building damages (Handiani et al. 2018). The Subang regency consists of four coastal
districts, namely Blanakan, Sukasari, LegonKulon, and Pusakanagara which is spread
among fourteen villages (Subang Statistics Agency 2021). The length of the coastline
in Subang regency is up to 48 km² (Handiani et al. 2018). Due to its strategic loca-
tion, Subang coast experiences rapid and advantageous economic growth but this is
unfortunately extending in parallel with environmental destruction (Handiani et al.
2018). Ultimately, this may lead to the displacement of people, significant damage to
properties and infrastructures, and considerable loss of coastal ecosystems in the area.
Therefore, it is clear that the assessment of coastal vulnerability for coastal zone man-
agement is crucial (Handiani et al. 2019).

Coastal vulnerability is a spatial concept that identifies people and places that are
susceptible to disturbances resulting from coastal hazards (Bevacqua et al. 2018). The
coastal vulnerability is also a popular assessment of the coastal environment prone to
significant hazards, such as coastal storms, erosion and inundation (Contestabile and
Vicinanza 2020). These hazards pose threats to the coastal physical, economic, and
social systems. Therefore, the effort to classify and analyze the coasts requires multi-
disciplinary information (Land-Ocean Interactions in the Coastal Zone-LOICZ 1995).
Since natural process of coastal area and aggravated by human activities, therefore
studies from various disciplines are needed to manage future condition. Simplified,
decision-centred, scenario-based planning methods can facilitate enhanced hazard
mitigation analysis and policy adoption in local master plans (Chaumillon et al. 2017;
Norton et al. 2019).

Our study focuses on the geophysical aspect of coastal vulnerability. This vulner-
ability can be used to distinguish the integrated coastal behaviour considering both
negative and positive responses to climate change induced conditions (i.e., resilience
and susceptibility). It is used to help facilitate coastal management assessment.

Coastal vulnerability index (CVI) is one of the favoured methods used to assess
costal vulnerability (Contestabile and Vicinanza 2020). This method addresses geo-
physical coastal vulnerabilities and is mostly adapted from Gornitz (1991). The physi-
cal–geological parameters include sea level rise (SLR), geomorphology, coastal slope
or regional relief/elevation, shoreline change, significant wave height, and tidal range
(Gornitz 1991; Shaw et al. 1998; Thieler and Hammar-Klose 2000; Pendleton et al.
2004). Natural processes combined with human activities are becoming significant
factors for coastal vulnerabilities. In considering the human activities, our study
added two parameters into the coastal vulnerability calculation. The parameters are
land subsidence (Husnayaen et al. 2018) and land use (Handayani et al. 2020). Then,
to take these parameters into account, the potential role of each parameter in each
costal area is assigned a value in the range of 1–5 (from very low to very high vul-
nerability, respectively). This quantification is mostly based on the potential magni-
tude of the contribution of the parameters to physical changes on the coast (Gornitz
1991; Gornitz and White 1992; Shaw et al. 1998; Thieler and Hammar-Klose 2000;
Pendleton et al. 2004; Rocha et al. 2020). Then, all parameters are assumed to con-
tribute equally to the coastal vulnerability. The CVI is evaluated as the square root of
the product of the ranked parameter divided by the total number of parameters
(Gornitz 1991).
However, analytic hierarchy process (AHP) method can be used to evaluate the coastal vulnerability. The AHP, developed by Saaty (1977, 2001), is used to calculate the needed weighting coastal parameters with the help of preference matrix, where all identified and relevant parameters for a particular study are compared against each other with reproducible preference parameters. The preference parameter is chosen by incorporating expert judgment. The judgment is used to estimate dominance in making comparisons between parameters, particularly when the parameters of the comparisons are intangible (Saaty 2008). The opinion of various experts in our study here is collected by reviewing literatures and discussing in internal group meeting of coastal specialist at Marine Research Centre, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF). The AHP weight parameters are used to estimate weighted coastal vulnerability index (CVIw) by incorporating the vulnerability score of each parameter under a set of equations (Bagdanavičiūtė et al. 2015).

Both indices, CVI and CVIw, are divided into four vulnerability ranking classes—low, moderate, high, and very high (Koroglu et al. 2019), in order to highlight the different levels of vulnerability. These indexes are calculated each using different approaches, the CVI is calculated by assuming all parameters contribute equally to the coastal vulnerability while the CVIw is used by assigning different weights for each parameter and therefore each parameter will have different importance to the coastal vulnerability. Different approaches and parameters contribution to the index can result into distinct vulnerability in the coast. This also means that the index selection process can be used to identify regions where risks may be relatively high.

The present research aims to compare the sensitivity of selected method of coastal vulnerability index (CVI and CVIw) for the regional characteristics. We would then select the most robust method to guide coastal managers on making policy processes. This assessment is applied to a coastal stretch characterized by sensitive human-influence of northern coast of Java coastline conditions, i.e., the Subang Regency coastal region. The research result is then visualized using a vulnerability map.

Materials and methods

Study area

Indonesia is a country known to have the second longest coastline in the world (Baietti et al. 2013) and is endowed with abundant natural resources and biodiversity. However, the country is facing many environmental problems including in its coastal zones, due to numerous pressures caused by rapid and unplanned or poorly planned industrial and economic development (Yoo et al. 2014; Rudiarto et al. 2018; Glaeser 2019). The northern coast of Java Island is one of the many coasts in Indonesia reported to be susceptible to environmental shocks such as floods, rising sea level, and other natural disasters as well as to anthropogenic pollution (Solihuddin et al. 2019).

The geographical coastline of our study area is situated in 107°39’E to 107°55’E in longitudes and 6°13’S to 6°15’S in latitudes (Figure 1, village territories of Subang Regency). The selected coast features are dominated by sandy beach, although large intertidal flat can be found in some areas. Other areas have muddy beach with few
mangroves, as well as sea wall and rip-rap as a protection from erosion that has already been worsening the coastal damage (Taofiqurohman and Ismail 2012; Handiani et al. 2018; Kalther and Itaya 2020). A few surviving mangrove areas are found in the estuaries or as river delta, such as Ciasem and Blanakan Estuaries, also in Cipunegara delta (Figure 1, symbol R1 to R3). These areas are around Blanakan, Langensari, Muara, and Patimban Villages (Handiani et al. 2018). Estuary and mangroves are natural ecosystems that have been used intensively and have been changing dramatically in the Subang Regency coast. Most of these changes are caused by degradation in these ecosystem functions, such as mangrove forest transformation into aquaculture (Handiani et al. 2018; Kepel et al. 2019).

**Data**

Most of the parameters used in this research are dynamic in nature and require a large amount of data from different sources. They are derived from remote sensing, numerical model data, and Geographic Information System (GIS) (Table 1). The present approach is comparable to the one used by (Ramdhani et al. 2012; Handiani et al. 2019). Here, eight physical coastal parameters are used to assess the coastal vulnerability indexes (CVI and CVIw). These parameters are coastal relief/elevation, geomorphology/coastal features, mean tidal range, shoreline change rate, relative sea level change, wave height, land subsidence, and land use (Gornitz 1991; Gornitz and White 1992; Shaw et al. 1998; Thieler and Hammar-Klose 2000; Pendleton et al. 2004; Husnayaen et al. 2018; Rocha et al. 2020).

The parameters described as physical processes such as the shoreline change, relative sea level change, and wave height (Gornitz 1991; Shaw et al. 1998; Thieler and Hammar-Klose 2000; Pendleton et al. 2004) are included due to the specific hydrodynamic regime of the study area and because of their relatively high importance in
the particular situation. The historical shoreline change patterns indicate the dynamics of the coast, forming different types of coastal landforms including beaches, tidal flats, deltas, cliffs, and barrier islands with varying responses to erosion/accretion. Coastline changes rate occurred in Subang Regency is high enough compared to other coastal areas in the West Java province. Based on Solihuddin et al. (2019) observation, the accretion rate in Muara Curug, Subang Regency is 25 m/year, on the other hand, the erosion rate in Pamanukan, Subang Regency is 52 m/year. Shoreline changes in Legon Kulon-Subang constituting maximum rates of shoreline retreat up to 150 m/year for the last two decades (from 2000 to 2020) and 7.4 km² inundated. (Solihuddin et al. 2021b) The shoreline change is used as an indicator for the potential impact of climate change, and it can be considered as a resilience capacity of the coast. Meanwhile, the geologic parameter is a combination of features of geomorphology and the type of lithology. The manifestation of coastal dynamics is manifested

| Parameter                      | Data source                                                                 | Resolution | Data format   |
|-------------------------------|----------------------------------------------------------------------------|------------|---------------|
| Coastal relief (m)            | DEMNAS (Digital Elevation Model Nasional); [http://tides.big.go.id/DENMAS and Elevation map from MoMaF](http://tides.big.go.id/DENMAS and Elevation map from MoMaF) | 8.25 m     | Raster        |
| Geomorphology/coastal features | Geology/lithology map and Coastal features map | 1: 100.000 and 1: 400.000 | Vector (polygon and line) |
| Mean tidal range (m)          | [http://tides.big.go.id](http://tides.big.go.id) (Geospatial Information Agency) |           | Vector (point) |
| Shoreline change rate (m/year) | Shoreline change rate map from Landsat Satellite at year 1998, 2008 and 2018 | 1: 400.000 | Vector (line) |
| Relative sea level change (mm/year) | Jason-2 Satellite July 2008 to September 2017 from Aviso + at [https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/products-and-images-selection-without-saral-old.html](https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/products-and-images-selection-without-saral-old.html) | Latitude =1°; Longitude = 3° | Raster |
| Wave height (m)               | Ocean Model Global from Copernicus Marine Service Information website (CMEMS) yearly averaged in 2019 simulation of CMEMS-GLO-PUM model and Simulating WAves Nearshore (SWAN) Indonesia area from MetOceanView System (MOV) Hindcasting data form January 1979 to January 1 2017 | 0.08°; 0.15° | Vector (point) |
| Land subsidence (mm/year)     | SAR Sentinel-1 data provided by European Space Agency (ESA) | 10 m       | Raster        |
| Land use                      | Land use map from Geospatial Information Agency, Republic of Indonesia (2018) and Google Maps | 1:250.000 1: 50:000 | Raster |

Jayawiguna et al. (2019). Geological Research and Development Centre (1996). Solihuddin et al. (2019). Purbani et al. (2019). Ardhun et al. (2010). Boudière et al. (2013). Meteorological Service of New Zealand Ltd (2021). Sidiq et al. (2021).
in the form of morphology and coastline changes or coastal evolution which is strongly influenced by bedrock lithology (geology), coastal relief including beach front slope and width (morphology), shoreline characteristics such as the material that composes coastal (sand, mud or rocky plains), as well as coastal processes such as abrasion and sedimentation (Sulaiman and Soehardi 2008). The coastal features are more related to the vulnerability of the particular coastal sections and should be easily observable or measurable using remote sensing technique. Both primary and secondary data obtained from authorized institutions in the form of raster and vector, then processed using GIS software to attain thematic maps needed in the analysis process. In addition, satellite data from Google Earth is used to see the actual condition of observed area. Some of features are mapped (shoreline change and coastal landforms) by researchers under the Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF) and the lithology map was made by researchers in the Geological Research and Development Centre, Republic of Indonesia (Table 1).

The land subsidence is a distinct parameter in North Coast Java which can influence the coastal vulnerability (Husnayaen et al. 2018). The Subang Regency is a smaller city, in terms of population size and area, compare to Bandung (West Java province’s capital) or Jakarta (Indonesia’s capital), but the city can be considered as a growing region. The population had increased to 1.6 million inhabitants in 2019 based on recorded data from the Central Agency on Statistics (Subang Statistic Agency 2021). Hence, coastal urban grows and the city is vulnerable to land...
Table 2. Vulnerability ranking of the parameters.

| Parameter                              | Very low | Low | Moderate | High | Very high |
|----------------------------------------|----------|-----|----------|------|-----------|
| Coastal relief (m)\(^{a,b}\)           | >30      | 21–30 | 11–20    | 6–10 | 0–5       |
| Geomorphology/coastal features and lithology\(^{a,c}\) | Rocky, cliffed coasts, Fiords, Fiards; Plutonic, Volcanic, High-medium grade metamorphics | Medium cliffs, Indented coasts; Low grade metamorphics, Sand-stones and conglomerates, Metamorphic rocks | Low cliffs, Glacial drift, Alluvial plains; Most sedimentary rocks | Cobble beaches, Estuary Lagoon; Coarse, poorly sorted, unconsolidated sediments | Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangroves, Coral reefs; Fine, consolidated sediment, ice; 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/year)\(^{a,c}\) | >2.0     | 1.0–2.0 | (–1.0)–(+1.0) | (–1.1)–(–2.0) | <–2.0 |
| Relative sea level change (mm/year)\(^{c}\) | <–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 | 2.25–2.6 | >2.60 |
| Land subsidence (mm/year)\(^{d}\)      | <–1.0    | Land rising | 1.0–2.0  | 2.1–4.0 | >1.0    |
| Water bodies, sparse vegetation, swamp or bare rock, mangrove | Forest | Coastal sands, local tourism, and traditional fishpond | Agriculture and intensive fishpond | Urban and industrial infrastructures |

\(^{a}\)Gornitz (1991).
\(^{b}\)Shaw et al. (1998).
\(^{c}\)Thieler and Hammar-Klose (2000).
\(^{d}\)Gornitz and White (1992).
\(^{e}\)Rocha et al. (2020).
\(^{f}\)Department of Marine Affairs and Fisheries (DMAF) (2005).
subsidence too. As the urban expansion has taken place in the eastern part of coastal Subang Regency (Susman et al. 2021), the utilization of coastal areas into fish ponds took place and causes destructions, such as abrasion, accretion, seawater intrusion, and the decreasing number of mangrove forests (Handiani et al. 2018; Nandi et al. 2016). These changes are one of the reasons in using land use parameter in the coastal vulnerability calculation. Overall, these eight parameters were selected, stored and manipulated within a geographic information system (Table 1).

**Methodology**

In this study, the CVI method (Gornitz 1991; Shaw et al. 1998; Thieler and Hammar-Klose 2000; Pendleton et al. 2004) and the CVIw method (Koroglu et al. 2019; Mahapatra et al. 2015) were used as a basis for the vulnerability assessment in the study area. The detailed workflow of the study (Figure 2) consists of the following major steps:

1. Collection, storage, and pre-processing of data.
2. Evaluation of vulnerability criteria according to the vulnerability rank (Table 2)
3. Calculation of CVI
4. Applying the AHP framework
5. Calculation of CVIw

Before the parameters were calculated, each of them was added into a line that resembled the coastline of the Subang Regency (extending to ≈ 48 km) and it was divided into village areas in Subang Regency. The villages are the main concern in coastal management of Subang Regency Coast (Handiani et al. 2018). Then, all the required parameters were ranked into five categories on a scale of 1–5 (low risk to high risk). Datasets for each parameter were implemented as attribute tables, and vulnerability scores were calculated according to each selected methodology. All processes and calculation used Geographic Information System (GIS) method.

Then, the CVI method was defined as (equation 1):

\[
CVI = \sqrt{(a*b*c*d*e*f*g*h)/8}
\]  

(1)

where \(a, b, c\), etc. are the estimated parameter of the different criteria to the vulnerability (Table 2). This method followed earlier studies by Gornitz (1991), Thieler and Hammar-Klose (2000), Pendleton et al. (2004) and Shaw et al. (1998).

Meanwhile, the CVIw method used AHP for weighting the parameters. The AHP method was used as evaluation of the relative weights for the parameters (Saaty 1977, 2001). The procedure for calculating the weights for CVIw is as follows. First, pairwise comparisons were carried out for all parameters considered, and the matrix was completed using scores based on their relative importance. In the construction of a pairwise comparison matrix, each parameter was rated against every other factor by assigning a relative dominant value between 1 and 9. Scale 1 refers to equal importance of two parameters to the object, whereas scale 9 means extreme importance of the evidence of favouring one over the other of the highest possible validity. Even scale of 2, 4, 6, 8 were used when compromise is needed. The significance of the
dominant scale values is given in Table 3 and it includes the expert judgement. In this present study, the expert judgement was modified and adapted from (Mahapatra et al. 2015; Handiani et al. 2019) also after an internal discussion with coastal specialist at MoMAF.

In order to indicate the likelihood that the matrix judgments were generated randomly, an index of consistency known as consistency ratio ($CR$) was used in the process of synthesis of the AHP (Saaty 1977). The $CR$ was computed using equation (2). If $CR$ satisfies this condition (less than 10%), then we conclude that the matrix is consistent; if otherwise, the matrix needs to be re-evaluated with different pairwise comparisons (Table 4) and the consistency is tested again.

$$CR = \left( \frac{CI}{RI} \right) < 10\%$$ (2)
Table 5. Physical parameters normalized matrix.

|                  | Coastal relief | Geomorphology/coastal feature | Shoreline change rate | Mean tidal range | Relative sea level change | Wave height | Land sub-sidence | Land use | Sum | Mean |
|------------------|----------------|------------------------------|-----------------------|-----------------|--------------------------|------------|-----------------|---------|-----|------|
| Coastal relief   | 0.45           | 0.52                         | 0.45                  | 0.38            | 0.42                     | 0.37       | 0.23            | 0.28    | 3.10| 0.39 |
| Geomorphology/coastal feature | 0.22 | 0.26                         | 0.37                  | 0.34            | 0.37                     | 0.33       | 0.23            | 0.28    | 2.41| 0.30 |
| Shoreline change rate | 0.07 | 0.05                         | 0.07                  | 0.17            | 0.09                     | 0.12       | 0.26            | 0.16    | 1.00| 0.13 |
| Mean tidal range | 0.05           | 0.03                         | 0.02                  | 0.04            | 0.02                     | 0.02       | 0.01            | 0.01    | 0.20| 0.03 |
| Relative sea level change | 0.05 | 0.03                         | 0.04                  | 0.02            | 0.05                     | 0.08       | 0.14            | 0.09    | 0.51| 0.06 |
| Wave height      | 0.05           | 0.03                         | 0.02                  | 0.02            | 0.02                     | 0.04       | 0.09            | 0.09    | 0.37| 0.05 |
| Land subsidence  | 0.06           | 0.03                         | 0.01                  | 0.01            | 0.01                     | 0.01       | 0.03            | 0.06    | 0.22| 0.03 |
| Land use         | 0.05           | 0.03                         | 0.01                  | 0.01            | 0.02                     | 0.01       | 0.01            | 0.03    | 0.18| 0.02 |
where CI means consistency index and RI means random index for different values of \( n \). Values of RI with \( n = 8 \) is equal to 1.41 (Saaty and Vargas 1991). CI can be expressed as (equation 3),

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\] (3)

where \( \lambda_{\text{max}} \) is the largest or principal eigenvalue of the matrix and \( n \) is the order of the matrix.

When the CR satisfies the condition imposed by equation (2), the weights of each physical parameter are determined by dividing the sum of the components and the total number of parameters (Table 5). The final percentage weight of physical vulnerability parameters were: coastal relief = 39%, geomorphology = 30%, tidal range = 13%, shoreline change = 2%, relative sea level change = 6%, wave height = 5%, land subsidence = 3%, and land use = 2%. Finally, the weighted coastal vulnerability index (CVI\(_w\)) is estimated according to the formula equation (4) (Bagdanavičiūtė et al. 2015):

\[
CVI_w = \sum_{j=1}^{n} w_j \times v_{ij}
\] (4)

where \( w_j \) is the weight of parameter \( j \); \( v_{ij} \) is the vulnerability rank of area \( i \) under parameter \( j \) and \( n \) is the total number of parameter.

The calculated CVI and CVI\(_w\) values were ranked into four categories to highlight the different levels of vulnerability. Subsequently, the vulnerability categories were represented with percentile ranges as 0–25%, 25–50%, 50–75%, and 75–100% (Koroglu et al. 2019) and it represents a value of low, moderate, high and very high vulnerabilities. The two methods led to vulnerability map as the final output of the coastal vulnerability assessment. The map was examined with statistical analysis by way of skewness and the mean values of each method to examine the reason behind the difference of the vulnerability calculation and to help with selecting the most realistic approach for future planning.

Findings and discussions

Coastal parameters vulnerabilities

Figure 3 shows the overall ranking distribution of coastal properties, such as: coastal relief, geomorphology, shoreline change, tidal range, sea level change, wave height, land subsidence, and land use. This study used coastal parameters similar to the study by Gornitz (1991), Shaw et al. (1998), Thieler and Hammar-Klose (2000), Gornitz and White (1992), Rocha et al. (2020) and Husnayaen et al. (2018). These parameters were used to characterize the physical vulnerability of coastal regions.

Coastal relief

The elevation of the north coast of Java is less than 25 m (Solihuddin et al. 2021a) and Subang Coast is part of Java’s north coast. Coastal relief in the Subang Coast
Figure 3. Vulnerability rank for coastal physical parameters: (a) Coastal relief, (b) Geomorphology, (c) Shoreline change, (d) Tidal range, (e) Sea level change, (f) Wave height, (g) Land subsidence, and (h) Land use.
indicates a very high vulnerability (Figure 3a). This conclusion holds in most of the areas, except Cilamaya Girang and Rawameneng where we found high vulnerability. Based on the elevation map of Digital Elevation Model National (DEMNAS) which was provided by the Geospatial Information Agency and the elevation map from Marine Research Center, MoMAF, Subang coast area has low relief contours of less than 10 m. The villages in eastern part of Subang has relief contour between 0 and 5 m and this value occurs in western villages, from Muara to Jayamukti villages, while the Cilamaya Girang and Rawameneng is larger than 5 m and less than 10 m. This means the coast has a high risk to inundation and it makes the area to score high and very high level of vulnerability.

**Geomorphology/coastal feature.** The geomorphology of the Subang Regency coast shows the major landforms consisting of sand beaches, mud flats, deltas, salt-marsh, mangroves, and some areas of coral reefs (Handiani et al. 2018). There are few coastal areas which function as estuary of rivers, such as in Blanakan River in Blanakan Village, Ciasem River in Muara Village, and Pusakanagara River in Patimban Village. Coastal sediment movement is different in each locations, the morphology of delta tends to develop to the west within sediment source coming from Cilamaya River and Ciasem River. The direction of displacement of coastal sediments tends to the west towards also occurred to Cilamaya Estuary. While in Pamanukan Subang, two deltas developed from two different river flows in the Cipunagara Delta and Muara Curug areas. The sediment source comes from Cipunagara River, Muara Curug, and Ciasem. Coastal sediments movement tends to the west towards Ciasem Estuary. (Solihuddin, et al. 2019) The estuary has a very high level of vulnerability and others
areas of sand beaches, mud flats, and mangroves also have a very high level of vulnerability (Figure 3b). In the eastern part of Subang Regency, around Patimban Village, geomorphology parameter has a very high level of vulnerability not only due to deltas and muds areas, but there are also groins and jetties constructed as prevention measures from erosion, which might contribute further to the vulnerability. Although, part of this area experiences quite high sedimentation as sand gets trapped and accumulated along the coast (Handiani et al. 2018; Taofiqurohman and Ismail 2012).

**Shoreline change rate.** Shoreline change has varying responses to accretion and erosion in the Subang Regency coastline. A positive or negative rate represent accretion or erosion processes (Figure 4). Here, the change is calculated based on the map of the shoreline change by Solihuddin et al. (2019) and Purbani et al. (2019). Their map was based on Landsat records of 1998, 2008 and 2018. The records were calculated using the Digital Shoreline Analysis System (DSAS) tool of Arc-GIS developed by U.S. Geological Survey. The DSAS uses a measurement baseline method (Leatherman and Clow 1983) to calculate rate-of-change for a time series of shorelines. From this map, we rectified and digitized the values. We then aggregated and attributed spatially to each village area. Dominant shoreline change was seen in areas of Cipunagara Delta, Muara and Blanakan Estuaries, Mayangan, Legon Wetan, also Pangarengan Villages. The delta and estuary mostly experiences accretion, hence has low level of vulnerability and villages indicate erosion were classified to have high vulnerability.

**Mean tidal range.** Subang Regency is part of the northern coast of Java, which has prevailing mixed diurnal tides. This type has one high and low tide in one cycle (24 hours
50 minutes) in some areas, while other areas have two high tides in one cycle. It is a common tidal type in the area of North Java Sea (Wyrtki 1961) and tidal range height in Java Sea is between 1.2 and 2 m, estimated based on model simulations (Indonesia Climate Change Sectoral Roadmap – ICCSR Team 2021). In this study, tidal range is in a range between 1 and 1.2 m, hence it is characterized as micro-tidal area (<2 m). These tidal records were derived from several predicted locations along the coast while the tidal prediction is estimated from the Geospatial Information Agency, Indonesia. Figure 5 shows an example of one cycle tide in several stations of the Subang Coast. Classification of tidal range rank in our study is based on (Thieler and Hammar-Klose 2000), that classified micro-tidal coasts to be of high vulnerability and macro-tidal coasts to be of low vulnerability. In consequence, based on the tidal range parameter, the area was categorized as having high vulnerability (Figure 3d).

**Relative sea level change.** The sea level change of the Subang Regency was retrieved from Jason-2 satellite altimetry, which has a coarse resolution. Data is observed from July 2008 to September 2017 and it covers the Subang Coast by four grid cells with values between 0.46 and 0.87 mm/year. The altimetry estimates of sea level usually make only a small spatial variation unless the study areas is really large. According to the satellite, sea level change in the study area is in the range of 0.1–1.24 mm/yr. With this value, the area is considered moderately vulnerable (Figure 3e).

**Wave height.** Furthermore, the waves are the foremost hydrodynamic force on the beaches and can induce morphodynamic changes. The parameter values for the wind-generated wave height in the study area is from a global ocean model (Ardhuin...
et al. 2010) and Simulating WAVes Nearshore (SWAN) in Indonesia area from MetOceanView System (MOV) Hindcasting data form January 1st 1979 to January 1st 2017 (Figure 6). The Subang Regency as part of the northern coast of Java has low wave energy and is mainly driven by local winds (east and west monsoon) (Wyrtki 1961; Gordon et al. 2003). The wave height significant in Java Sea reaches the highest in July to August (west monsoon), with a range about 0.6–1.2 m (Indonesia Climate Change Sectoral Roadmap – ICCSR Team 2021). In this context, the whole north Java coastline has a very low vulnerability with respect to wave energy. Meanwhile, the global and local ocean models used in this study shows that mean wave heights are 0.43–0.57 m along the coast study area (Ardhuin et al. 2010, Boudière et al. 2013, Meteorological Service of New Zealand Ltd 2021). Therefore, the whole coast is in very low vulnerability in terms of wave height parameter (Figure 3f).

Land subsidence. Many cities in the North Coast of Java are populated and developed. These areas are prone to the natural risk such as coastal flooding, mangrove loss, and coastal abrasion (Syvitski 2008; Solihuddin et al. 2021a). Not only those risks, land subsidence can also be found in the area (Sidiq et al. 2021), as been found in some of the cities such as Jakarta (Hoogeveen and Leeuwen 1995; Abidin et al. 2008), Semarang (Gumilar et al. 2013; Andreas et al. 2019), and Pekalongan (Sidiq et al. 2021). Land subsidence becomes a parameter that can enhance coastal vulnerability (Husnayaen et al. 2018). Our study makes use of a study by Sidiq et al. (2021) in land subsidence. Compare to coastal area such as Jakarta, Semarang, and Pekalongan, Subang Coast is not suffering as much as these cities. Land subsidence in Jakarta Coast is found to be continuing with cumulative displacement up to 15 cm, with a rate of 5 cm/year (Sidiq et al. 2021). While in Semarang Coast, the land subsidence rate is up to 12 cm/year according to Sidiq et al. (2021) and in a value range from 0 to 9.9 cm/year according to Husnayaen et al. (2018). The land subsidence in Subang Coast is in a range between 0 to 5 cm/year, and most of the villages area has less than 1 mm/year. The villages are from Cilamaya Girang (in the western part of Subang Coast) to Legon Wetan (in the eastern part of Subang Coast). Except these villages, the land subsidence in Pangarengan and Patimban Villages are more than 4 mm/year. Hence, most of the coasts are in low vulnerability except two villages which are in very high vulnerability in terms of land subsidence parameter (Figure 3f).

Land use. Most of the economic development activities in the northern coast of Java has strategic values as it has been, utilized as seaports, marine tourism, power plant, fisheries industries, agriculture, industrial area, public services, government offices, and many more (Solihuddin et al. 2021a). As a result, a significant number of people then live and reside in the area and this can influence the ranking of land use. In the present study, the coastline was divided following vulnerable ranks based on studies by Rocha et al. (2020) and Department of Marine Affairs and Fisheries (DMAF) (2005), which ranked according to value with direct benefit to human. The ranks are considering swap, mudflats and mangrove in low ranking, while urban and industrial in very high ranking. For the purpose of this study, we used the land use covers for
North Coast of West Java (Figure 7). The map is prepared by DMAF based on Indonesia topographic map (RBI) in 2019 and focused in West Java Coast in 1:25,000 scale. For detail results in each village land use, our study made use of satellite imagery from Google earth for making vulnerability classification suitable (Figure 7). Figure 7 demonstrate existing land use condition in the north coast of West Java Province (Subang as one of the coastal cities). The figure below shows detailed land use for each village in Subang where the west coast dominated by water bodies and vegetation, while urban and industrial areas are mostly found on the east coast of Subang. Data satellites from Google Earth are used to see the actual conditions from area observed. Tegalurung and Anggasari have a lot of intensive fishpond (A), Patimban with its urban and industrial areas (B), Blanakan and Tanjungtiga which have coastal sand (C), and Legonkulon and Mayangan as an urban area (D). The very low to very high vulnerabilities are found in the Subang Coast (Figure 3h)

Comparison of coastal vulnerability along the Subang Regency Coast

The overall vulnerability classes were distributed into an equal 4 percentage classes and the distribution is summarized in Figure 8. The distribution of vulnerability classes were examined through statistical analysis using skewness, mean and maximum values of each CVIs method (Figure 9). Then, Coastal vulnerability of CVI and
CVIw are mapped in Figure 10 and compared to the field photographs in similar figure.

The CVI and the CVIw of the study area were analyzed corresponding to the villages in the areas (Figure 1). The CVI values range from 7.75 to 53.03, whereas the CVIw values range from 3.58 to 4.62. So, the entire CVIs were divided into four equal parts. These values supposed that the lower range values indicate low risk, followed by moderate risk and high risk, and finally the upper range of the values indicates the coast at very high-risk level. Our study found that percentages of the values (based on villages area) in the CVI area are 43%, 7%, 29%, and 21%, respectively while in the CVIw area 14%, 36%, 7%, and 43% (low to very high risk) (Figure 8).

Based on these percentages, we found that the CVI has more low and high vulnerabilities compared to the CVIw method that has more moderate and very high vulnerabilities than the CVI. There is also a possibility that both methods have similar vulnerability for the same area. The statistical analysis of vulnerabilities skewness has different value in each method. The skewness of CVI is positive, and the CVIw is negative (Figure 9). The skewness value shows characteristic and location of the data set, in this study is the CVIs. If the skewness is between $-1$ and 1, then the data distribution is moderately skewed and any symmetrical data should have a skewness near zero. If the skewness is less than $-1$ and more than 1, then both distributions areas are highly skewed. The negative skewness indicated that the data distribution is left skewed, while the other way around showed positive skewness which indicates that the data is right skewed. The CVI is right skewed and it means data greater than mean value is more to the lower value. Meanwhile, the CVIw is left skewed and it means that the data lower than the mean value is more than the greater value. Although, the dense cell distribution in CVI are around the lower and the high vulnerability classes, which attempts evaluation of moderate vulnerability diffused in the low vulnerability. Whereas, the evaluation of very high vulnerability diffuses in the high vulnerability. The CVIw distribution is dense in moderate and very high, and it means the focus of assessment will be in these vulnerability areas. This can favour the very high vulnerability areas where management is needed urgently and thoroughly.

Figure 8. The overall CVI comparison for all methods.
But it may be challenging too for coastal manager to set up priority list of the coastal areas since, all the areas can be considered to be vulnerable hotspots.

The vulnerability values in both methods range from low to very high risk (Figure 10). The low risk-level in both calculations occurred in the western side of the regency and the areas are Cilamaya girang and Rawameneng Villages. The moderate risk in the CVI method was found in Tanjungtiga Villages and in the CVIw it was calculated in villages of Jayamukti, Blanakan, Langensari, Muara, and Tanjungtiga. Furthermore, both methods calculated high vulnerability in Patimban Village. In CVI, villages of Sukamaju Anggasari, Tegalurung Villages were calculated as high

Figure 9. The CVI distribution through statistical analysis.

Figure 10. The overall map of CVIs distribution and field photographs taken from Handiani et al. (2018), Hemawati et al. (2017), and Rianzani et al. (2018).
The very high vulnerability was predicted in Pangarengan, Legon Wetan, and Mayangan Villages by both methods. In CVIw, the high vulnerability was also found in Sukamaju, Anggasari, and Tegalurung Villages.

Our CVI and CVIw results were compared to several field locations (Figure 9). Land accretion was spotted in Blanakan and Patimban (point 1 and 5 in Figure 9), as seen in field photograph of Patimban where the sediment accretion led to trapping of the fishing boats. The land accretion formed in this village is in the average 159.32–538.50 m (Nandi et al. 2016). Although, the Patimban Village has very low shoreline change vulnerability, but other parameters in the area varies and most of them are moderate, high and very high vulnerabilities (Figure 3a–h). Hence, both the CVI and CVIw are in high vulnerability. We also found area related to accretion in Blanakan up to Muara Villages (Nandi et al. 2016; Kalther and Itaya 2020), shown in the field photograph point 5 and 4. There is a forming of land in the Blanakan area which was caused by excessive sediment runoff from Ciasem River (point 4 Figure 9). Strong stream toward the western generated by west and southwest winds carried the sediment up to Blanakan Village Coast, where it was trapped in the area (Nandi et al. 2016). In this area, the coastline had moved 1695.61 m seaward from 1990 to 2018 and adding a total area of 1856.62 ha (Kalther and Itaya 2020). The CVIs in the area is low to moderate vulnerabilities. The shoreline change in Blanakan Village also has very low vulnerability, similar to the one in Patimban Village and yet they have different CVI results. Comparing the vulnerability of each parameter in both areas showed that the land subsidence parameter differs in Blanakan and Patimban Villages. This different vulnerability shows the influence of land subsidence to the CVI and CVIw. Earlier study in area not far from Subang Regency, in Semarang area, shows that by adding the land subsidence parameter into CVI calculation, coastal vulnerability accuracy thus increased (Husnayaen et al. 2018).

The very high vulnerable areas are in Mayangan, Legon Wetan, and Pangarengan Villages where severe erosion occurred. The field photograph in these areas shows the coastal erosion of the study area (point 2 and 3 in Figure 9). Earlier study suggested decreasing number of mangrove forests with forests changed into fish ponds or used for the shrimp industry in Legon Wetan and Mayangan Villages (Handiani et al. 2018; Nandi et al. 2016). In Mayangan and Legon Wetan Villages, the shoreline change is very high vulnerability, and coastal relief, morphology, also land use are in very high vulnerability too. These areas have become urban and industrialized zones, hence many buildings can be found near the coastal area and it changes the physical coastal environment. Comparing these villages to near village (Mayangan), they have similar vulnerability in each parameter, but land subsidence and land use parameters are different (Figure 3g and h). Mayangan and Legon Wetan Villages have very high vulnerability in land use and low vulnerability in land subsidence. Pangarengan Village has moderate vulnerability in land use and very high vulnerability in land subsidence. And yet, at the end these areas have similar CVIs result. This shows that not only land subsidence influencing the CVIs, the land use is also affecting the coastal vulnerability.

In comparing CVI and CVIw, we also found that the CVIw calculation estimated higher vulnerability than the CVI. This shows in Jayamukti, Blanakan, Langensari,
and Muara Villages. Classified parameters vulnerabilities are similar in each area, where coastal relief and morphology are very high, shoreline change is very low, tidal range is high, sea-level change is moderate, wave height is very low, land subsidence is low, and land use is low. The CVI result is low and the CVIw is moderate in all these villages. This shows that the weighted parameter in the CVIw influences the calculation and the coastal vulnerability is one level higher in the CVIw than the CVI.

The results of the CVI and CVIw assessment highlighted the general preference of the CVIw due to greater value of very high vulnerability and higher level of vulnerability compared to similar area in the CVI. This difference is particularly important in regional studies where parameter variabilities are very high and one parameter may be more dominant in one coastal area than the other.

Spatial planning in Subang Regency Coast

Results indicate (Figure 11) that coastal vulnerability (the CVI and CVIw) is similar in Cilamaya Girang, Rawameneng, Tanjungtiga, Mayangan to Patimban Villages (in east part of Subang Regency). Meanwhile, coastal vulnerability differs in Jayamukti, Blanakan, Langensari, Muara, Sukamaju, Anggasari, and Tegalurung Villages. These result shows that both CVIs can be used to assess coastal vulnerability, but they give different facts. This information may lead different decisions in managing the coastal area.

Vulnerability index tools are used and developed for coastal managers to highlight potential coastal hotspots to a given set of environment condition. It is efficient because it simplifies a number of occurring processes at different scales. The tool is part of a vulnerability assessment in the regional scale (in cases here in Subang Regency, in north coast Java Island, Indonesia) which is an important step in planning and decision making for the integrated coastal zone management (ICZM). The Indonesia government implemented the sustainability policies for coastal areas (starts in year of 2007 and 2009), although the implementation of results were difficult and
poor due the local autonomy as central government transfers their jurisdiction to the local government (Nandi 2014). Hence, there is unparalleled understanding between the central government and local government because most of the local governments were focusing on increasing the government income by developing the land which in turn, affected the economy, and then led to ill-planned development rather than using sustainable development (Farhan and Lim 2010).

However, spatial planning of Subang Regency coast has been made and it is included in the West Java Province policy (Perda West Java Province No. 5, 2019). Based on that, Subang coast were divided into several zones, such as coastal conservation zone, tourism, harbour, aquaculture, capture fisheries and mining zone (Figure 11). Here, we compare the plan to the CVI and the CVIw. Patimban Port is planned to be built in the Patimban Village and the area has high vulnerabilities, (Figure 10, point 1). The high vulnerability (in both the CVIs) can be better used for planning and processing the port development efficiently. A recent study (Susman et al. 2021) in correlation to conflict land use showed that planning processes are inadequate and mismanaged. This condition leads to market failure, land abandonment, and overburdening the local communities with the costs of megaprojects. This means, high vulnerability in the area can lead to further government interference. This will reduce the conflict and continuing development of the port.

In regards to the east estuary of Ciasem River (Tajungtiga Village) where aquaculture is planned (Figure 11), we found that the area has moderate vulnerability (in both the CVIs). It can be developed as an aquaculture spot, although it has to be done efficiently. Since earlier study in near areas suggested decreasing number of mangrove forests as the they were converted into fish ponds for shrimp industry (Handiani et al. 2018; Nandi et al. 2016). These areas can experience severe coastal erosion harming the environment as well as peoples’ homes. Field photograph in point 3 Figure 10 is an evidence on destruction of coastal erosion in the Legon wetan and Mayangan Villages. In this matter, if the aquaculture is developed in Tanjungtiga Village, it should not shift the moderate vulnerability condition.

To discuss the coastal erosion, we would focus on Mayangan Village, where the area was characterized as having very high vulnerability (Figure 10). The Mayangan Village is part of Legon Kulon District and the area was identified by high changing coastal inundation (Solihuddin et al. 2021b). With these condition in the area, in Figure 11 shows that most of the coastal area plan is utilized in fisheries sector such as demersal pelagic capture fisheries and a marine aquaculture fishery zones (Yusrizal et al. 2018). In addition, the area also uses as a port zone known as Mayangan fishery port and the other part uses as a sub-zone of natural tourism (extended to Legon Wetan Village). Coastal development around the area must be carried out with comprehensive planning based on research. Future research should focus on how the environment in the area is shifting into less erosion or no erosion while maintaining sustainable aquaculture, ports, and tourism in the area. The local government suggested a technique of silvofishery system. Silvofishery is an integrated system, where mangrove is grown in fish pond area, either inside the pond or around the pond area. The system has been expected to be one of the alternative approaches to achieve sustainable management of extensive aquaculture and mangroves. One of the studies
that has evaluated the system was in Jayamukti Village, although the study suggested that the quality of environmental variables such as salinity, land elevation, tide and soil conditions could potentially limit the productivity and sustainability of the silvo-fishery (Tarunamulia et al. 2015).

Furthermore, in some areas where coastal conservation is planned (Jayamukti, Blanakan, Langensari, and Muara Villages), the CVIw vulnerability is categorized as moderate. And it is better to have low vulnerability in the coastal conservation zone area than moderate vulnerability. Furthermore, the land formation is found in this area (Nandi et al. 2016; Kalther and Itaya 2020), see also Figure 10, point 4 and 5. Hence, it is possible to have coastal conservation on mangrove forest for future planning.

With these examples, we showed it is possible to analyze the coastal vulnerabilities using the indexes. Earlier research conducted by Husnayaen et al. (2018) in Semarang, Indonesia showed that using the same method of coastal vulnerability assessment with more and less parameters had different accuracy. The CVI and Kappa coefficient results are 53% and fair agreement (0.30) for 6 parameters, whilst 93% and very good agreement (0.90) for 7 parameters. While in our study, by using the same number of parameters and different method of coastal vulnerability assessment has showed different dense distribution of coastal vulnerability. The CVIw method has dense distribution between moderate to high vulnerability, while the CVI method has dense distribution between low to high distribution. Hence, with these result we proposed that the coastal vulnerability assessment with more parameters and using the CVIw method may be used as a support tool in the decision-making of ICZM in other coastal region in Indonesia.

Moreover, our study using two CVI methods can contribute in identifying critical area within the existing Subang coastal zoning plan. Hence, the local government can immediate known the further treatment. This also helps local government as decision maker to prioritize the mitigation and adaptation programs to protect coastal area area based on funds availability.

Conclusions

We applied and compared the CVI and CVIw to study Subang Regency coastal vulnerability. The calculation used eight physical–geological coastal parameters which are coastal relief, morphology, shoreline change, tidal range, sea-level change, wave height, land subsidence, and land use. The result from the vulnerability parameters showed that the shoreline change, land subsidence, and land use are influencing the vulnerability more than other parameters. On the other hand, the most severe vulnerability class variations are seen in relief or elevation, geomorphology, shoreline change, tidal range, land subsidence, and land use parameters. These categorized vulnerabilities are reflected into overall CVIs computation, afterwards, the different calculations reflect different vulnerability categories for the villages coast.

Based on the analysis, CVIw result appears to be the more favourable approach to assess the vulnerability of the Subang coast. CVIw accounts dominantly the contribution of high vulnerability class, which led to a dense amount of very high-risk
vulnerability around 43% while it is 21% in the CVI. This can provide a more suitable and urgent protective action for the coastal managers. Around 21% in the same area of the Subang Coast (Mayangan, Legon Wetan, and Pangarengan Villages) is under very high risk in both CVI and CVIw. The area is losing some of its coastal lands to erosion and the authority plans to develop aquaculture there. The government should plan and assure thoroughly that it is not causing more environmental problems in the future.

This study shows that robust evaluation approaches, such as CVIs assessments, play a crucial role in facilitating future decision-making processes of coastal management strategies, given adaptation to the increasing threats posed by climate change. However, it is important to get sufficient data input and objective expert opinions in computing the CVIs. Eventually, making good use of the information provided by this paper would certainly help to support in decision-making of ICZM by local and national governance in Indonesia.

Acknowledgements

The authors gratefully acknowledged the informal supports and discussion from the colleagues in Marine Research Centre, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF)-Jakarta, Indonesia.

Disclosure statement

The authors declare no conflicts of interest.

Funding

This research was funded by the Institute of Research and Community Service (LPPM), Institut Teknologi Nasional (Itenas)-Bandung, Indonesia.

Data availability statement

Derived data supporting the findings of this study are available from the corresponding author [D.N.H.] on request.

References

Abidin HZ, Andreas H, Djaja R, Darmawan D, Gamal M. 2008. Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys. GPS Solut. 12(1): 23–32. http://doi.org/10.1007/s10291-007-0061-0

Andreas H, Abidin HZ, Gumilar I, Sidiq TP, Sarsito DA, Pradipta D. 2019. On the acceleration of land subsidence rate in Semarang City as detected from GPS surveys. E3S Web Conf. 94:04002. http://doi.org/10.1051/e3sconf/20199404002

Ardhuin F, Rogers E, Babanin AV, Filipot J-F, Magne R, Roland A, van der Westhuysen A, Queffeulou P, Lefevre J-M, Aouf L, et al. 2010. Semi empirical dissipation source functions for wind-wave models: Part I, definition and calibration and validation at global scales. J. Phys. Oceanogr. 40(9):1917–1941. http://doi.org/10.1175/2010JPO4324.1
Bagdanavičiūtė I, Kelpaitė L, Soomere T. 2015. Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. Ocean Coast. Manag. 104: 124–135. ISSN 0964-5691, http://doi.org/10.1016/j.ocecoaman.2014.12.011.

Baietti A, Roberto R, Shlyakhtenko A. 2013. Green infrastructure finance: green investment climate country profile - Indonesia. The World Bank. 1–53. http://doi.org/10.13140/RG.2.1.4211.8245

Bevacqua A, Yu D, Zhang Y. 2018. Coastal vulnerability: evolving concepts in understanding vulnerable people and places. Environ Sci Policy. 2018(82): 19–29. http://doi.org/10.1016/j.envsci.2018.01.006.

Boudière E, Maisondieu C, Ardhuin F, Accensi M, Pineau-Guillou L, Lepesqueur J. 2013. A suitable metocean hindcast database for the design of Marine energy converters. Int J Mar Energy. 3-4:e40–e52. http://doi.org/10.1016/j.ijome.2013.11.010

Chaumillon E, Bertin X, Fortunato AB, Bajo M, Schneider JL, Dezileau L, Walsh JP, Michelot A, Chauveau E, Créach A, et al. 2017. Storm-induced marine flooding: lessons from a multi-disciplinary approach. Earth Sci Rev. 165:151–184. http://doi.org/10.1016/j.earscirev.2016.12.005.

Contestabile P, Vicinanza D. 2020. Coastal vulnerability and mitigation strategies: from monitoring to applied research. Water. 12(9):2594. http://doi.org/10.3390/w12092594.

Department of Marine Affairs and Fisheries (DMAF). 2005. Guidance of Natural Hazards Mitigation in Coastal and Small Islands [Pedoman Mitigasi Bencana Alam di Wilayah Pesisir dan Pulau-Pulau Kecil]. 2nd ed. Indonesian.

Dulal HB. 2019. Cities in Asia: how are they adapting to climate change? J Environ Stud Sci. 9(1):13–24. http://doi.org/10.1007/s13412-018-0534-1.

Farhan AR, Lim S. 2010. Integrated coastal zone management towards Indonesia global ocean observing system (INA-GOOS): review and recommendation. Ocean & Coast. Manag. 53(8): 421–427. http://doi.org/10.1016/j.ocecoaman.2010.06.015.

Geological Research and Development Centre. 1996. Geology map of Indonesia. Indonesian.

Glaeser B. 2019. Sustainable coastal management for social-ecological systems—A typology approach in Indonesia. Coast. Manag. 2019:61–77. http://doi.org/10.1016/B978-0-12-810473-6.00006-6.

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

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

Gornitz VM, White TW. 1992. A coastal hazard data base for the U.S. East Coast, Tennessee: The University of Tennessee.

Gumilar I, Abidin HZ, Sidiq TP, Andreas H, Maiyudi R, Gamal, M, Fukuda Y, Y. 2013. Mapping And Evaluating The Impact Of Land Subsidence In Semarang (Indonesia). Indonesian J Geospatial. 2:26–41.

Handayani W, Chigbu UE, Rudiarto I, Putri IHS. 2020. Urbanization and increasing flood risk in the Northern Coast of Central Java—Indonesia: an assessment towards better land use policy and flood management. Land. 9(10):343. http://doi.org/10.3390/land9100343.

Handiani DN, Darmawan S, Hernawati R, Suryahadi MF, Aditya YD. 2018. Coastline change and coastal ecosystem identification in Subang Regency [Identifikasi Perubahan Garis Pantai dan Ekosistem Pesisir di Kabupaten Subang]. JRG. 2017(2):61–71. http://doi.org/10.26760/jrg.v201712.1765. Indonesian.

Handiyan DN, Darmawan S, Heriati S, Aditya YD. 2019. Coastal vulnerability study to the sea level rise in Subang Regency-West Java [Kajian Kerentanan Pesisir Terhadap Kenaikan Muka Air Laut di Kabupaten Subang-Jawa Barat]. J Kelautan Nasional. 14(3):145–154. http://doi.org/10.15578/jkn.v14i3.7583. Indonesian

Hernawati R, Handiyan DN, Darmawan S, Dita AV. 2017. Mangrove density identification in estuary Ciasem using multi-temporal landsat satellite [Identifikasi Kerapatan Mangrove Di Muara Sungai Ciasem Menggunakan Data Citra Satelit Landsat Multitemporal]. Bandung: National Seminar Proceedings Institut Teknologi Nasional (Itenas), Indonesian.
Hoogeveen R, Leeuwen BV. 1995. The large scale development of land subsidence in northwest Jakarta and north Tangerang, Indonesia. Proceedings of the Fifth International Symposium on Land Subsidence, The Hague. p. 433–438.

Husnayaen B, Rimba A, Oswa T, Nyoman Sudi Parwata I, Rahman As-syakur A, Kasim F. 2018. Ayu Astariini, I. 2018. Physical assessment of coastal vulnerability under enhanced land subsidence in Semarang, Indonesia, using multi-sensor satellite data. Adv Space Res. http://doi.org/10.1016/j.asr.2018.01.026.

Indonesia Climate Change Sectoral Roadmap – ICCSR Team 2021. Scientific basis: Analysis and Projection of Sea Level Rise and Extreme Weather Events. Policy paper of Deputy Minister for Natural Resources and Environment, Republic of Indonesia. [accessed 2021 July 4]. Available from: http://www.bappenas.go.id/index.php/download_file/view/14429/3971/.

Jayawiguna MH, Solihuddin, T, Triyono. 2019. North Coast Java: coastal dynamic and potential [Pantura Jawa: Potensi dan Dinamika Pesisir]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF). Indonesian. p. 1–13.

Kalther J, Itaya A. 2020. Coastline changes and their effects on land use and cover in Subang, Indonesia. J. Coast. Conserv. 24:1–16. http://doi.org/10.1007/s11852-020-00736-w

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

Koroglu A, Ranasinghe R, Jiménez JA, Dastgheib A. 2019. Comparison of coastal vulnerability index applications for Barcelona Province. Ocean Coast. Manag. 178: 104711.1–104799.2. http://doi.org/10.1016/j.ocecoaman.2019.05.001.

Krampe F, Mobjörk M. 2018. Responding to climate-related security risks: reviewing regional organizations in Asia and Africa. Curr Clim Change Rep. 4(4):330–337. http://doi.org/10.1007/s40641-018-0118-x.

Leatherman SP, Clow JB. 1983. UMD shoreline mapping project. IEE Geosci. Remote Sens. Soc. Newsl. 22:5–8.

Land-Ocean Interactions in the Coastal Zone-LOICZ. 1995. LOICZ typology: Preliminary version for discussion. LOICZ Reports and Studies No. 3. Texel, The Netherlands. p. 1–49. [accessed 2021 August 15]. Available from http://archive.iwlearn.net/loicz.org/imperia/md/content/loicz/. print/rsreports/report3.pdf

Mahapatra M, Ramakrishnan R, Rajawat AS. 2015. Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. Nat Hazards. 76(1):139–159. http://doi.org/10.1007/s11069-014-1491-y.

Meteorological Service of New Zealand Ltd 2021. MetOceanView Hindcast. [accessed 2022 March 8]. Available from: https://app.meteoceanview.com/hindcast-squared/.

Nandi. 2014. Coastal conservation policies and integrated coastal zone management (ICZM) in Indonesia. Int J Conserv Sci. 5(3):387–396. http://doi.org/10.1088/1755-1315/47/1/012017.

Nandi Meriana G, Somantri L. 2016. Monitoring The Land Accretion Development at Coastal Area of Blanakan, Subang Indonesia. IOP Conf. Series: Earth and Environmental Science 47. 2nd International Conference of Indonesian Society for Remote Sensing (ICOIRS). IOP Publishing. p. 1–10.

Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay JE, McLean RF, Ragoonaden S, Woodroffe CD, Parry ML, Canziani OF, et al. 2018. Coastal systems and low-lying areas. In Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working
Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. p. 315–356.

Ningsih NS, Hanifah F, Tanjung TS, Yani LF, Azhar MA. 2020. The effect of tropical cyclone Nicholas (11–20 February 2008) on sea level anomalies in Indonesian Waters. JMSE. 8(11): 948. http://doi.org/10.3390/jmse8110948.

Norton RK, Buckman S, Meadows GA, Rable Z. 2019. Using simple, decision-centered, scenario-based planning to improve local coastal management. J Am Planning Assoc. 85(4): 405–423. http://doi.org/10.1080/01944363.2019.1627237.

Pendleton EA, Thieler ER, Williams SJ, Beavers RS. 2004. Coastal vulnerability assessment of Padre Island National Seashore (PAIS) to Sea-Level Rise; US Geological Survey Open-File Report, U.S. Geological Survey, Woods Hole, MA, USA.

Purbani D, Salim HL, Marzuki MI, Abida RF, Tussadiah, A, Triyono. 2019. Abrasion and accretion in the last decades case study: Serang, Indramayu, Brebes, Demak, and Gresik Districts [Laju Abrasi dan Akresi Pantura Jawa dalam Satu Dekade Terakhir Studi Kasus: Kabupaten Serang, Indramayu, Brebes, Demak, dan Gresik]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Indonesian. p. 37–51

Ramdhan M, Husrin S, Sudirman N, Altanto T. 2012. 2012. Coastal Vulnerability Index Mapping due to Climate Change in West Sumatra [Pemetaan Indeks Kerentanan Pesisir Terhadap Perubahan Iklim Di Sumatera Barat dan Sekitarnya]. Jurnal Segara. 8(2):107–115. http://doi.org/10.15578/segara.v8i2.174. Indonesian.

Rianzani D, Darmawan S, Hernawati R, Maryanto TI. 2018. Mangrove Biomass Estimation Based on Remote Sensing (Case Study Subang Regency, West Java) [Estimasi Biomassa Mangrove Berbasis Pengindraan Jauh (Studi Kasus Kabupaten Subang, Jawa Barat. )]. National Seminar Proceedings Institut Teknologi Nasional (Iternas), Bandung. Indonesian. (accessed 2015 December 4). Indonesian.

Rocha C, Carlos A, Cristina C. 2020. Coastal vulnerability assessment due to sea level rise: the case study of the Atlantic Coast of Mainland Portugal. Water. 12(2):360. http://doi.org/10.3390/w12020360.

Rudiarto I, Handayani W, Sih Setyono J, Jawoto Sih Setyono 2018. A regional perspective on urbanization and climate-related disasters in the Northern Coastal Region of Central Java, Indonesia. Land. 7(1):34. http://doi.org/10.3390/land7010034.

Saaty TL. 1977. A scaling method for priorities in hierarchical structures. J Math Psychol. 15(3):234–281. http://doi.org/10.1016/0022-2496(77)90033-5. (77)90033-5

Saaty TL. 2001. Fundamentals of decision making and priority theory. Pittsburgh: RWS Publications.

Saaty TL. 2008. Decision making with analytical hierarchy process. Int J Sev Sci. 1(1):83–89.

Saaty TL, Vargas LG. 1991. Prediction, projection and forecasting: applications of the analytic hierarchy process in economics, finance, politics, games and sports. Boston: Kluwer Academic Publishers, p. 251.

Shaw J, Taylor RB, Forbes DL, Ruz M-H, Solomon S. 1998. Sensitivity of the coasts of Canada to sea-level rise. Bull Geol Surv Can. 505:1–79.

Sidiq TP, Gumaril I, Meilano I, Abidin HZ, Andreas H, Permana A. 2021. Land subsidence of Java North Coast Observed by SAR interferometry. IOP Conf Ser: Earth Environ Sci. 873(1):012078. IOP Publishing. http://doi.org/10.1088/1755-1315/873/1/012078.

Solihuddin T, Dhiadudin R, Mustikasari E, Rahayu YP, Husrin S. 2019. North Coast Java rehabilitation: issues, analysis, and challenges [Rehabilitasi Pantura Jawa: Isu, Analisis dan Tantangan]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF). p. 9–35. http://doi.org/10.1088/1755-1315/777/1/012035. Indonesian.
Solihuddin T, Husrin S, Salim HL, Kepel TL, Mustikasari E, Heriati A, Ati RNA, Purbani D, Mbay I, Indriasari VY, et al. 2021a. Coastal erosion on the north coast of Java: adaptation strategies and coastal management. IOP Conf Ser: Earth Environ Sci. 777(1):012035. http://doi.org/10.1088/1755-1315/925/1/012015.

Solihuddin T, Husrin S, Mustikasari E, Heriati A, Kepel TL, Salim HL, Risandi J, Dwiyanti D. 2021b. Coastal inundation and land subsidence in North Coast of West Java: A New Hazard? IOP Conf Ser: Earth Environ Sci. 925(1):012015.

Subang Statistics Agency. 2010. Subang in Figure [Subang dalam angka tahun 2020]. (accessed 2021 August 15). Available from https://subangkab.bps.go.id/publication/2010/12/09/1f95dbf714d659ea30.a873cc/kabupaten-subang-dalam-angka-2010.html. Indonesian.

Sulaiman A, Soehardi I. 2008. Introduction to coastal geomorphology quantitative. Jakarta: Agency for the Assessment and Application of Technology.

Susman R, Gütte AM, Weith T. 2021. Drivers of land use conflicts in infrastructural mega projects in coastal areas: a case study of Patimban Seaport, Indonesia. Land. 10(6):615. http://doi.org/10.3390/land10060615.

Syvitski JP. 2008. Deltas at risk sustainability. Sustain Sci. 3(1):23–32. http://doi.org/10.1007/s11625-008-0043-3.

Taofiqurohman A, Ismail M. 2012. Spatial analysis of shoreline changes in the coastal of Subang District, West Java. [Analisis Spasial Perubahan Garis Pantai di Pesisir Kabupaten Subang, Jawa Barat.] J Trop Mar Sci Technol. 4:81–87. http://doi.org/10.1007/s13398-014-0173-7. Indonesian.

Tarunamulia T, Mustafa A, Hasnawi H, Kamariah K. 2015. Silvofishery Pond Engineering Feasibility in Blanakan District, Subang Regency, West Java Province [Kelayakan Rekayasa Tambak Silvofishery di Kecamatan Blanakan Kabupaten Subang Provinsi Jawa Barat.] Jurnal Riset Akuakultur. 10(4):579–592. http://doi.org/10.15578/jra.10.4.2015.579-592. Indonesian.

Thieler ER, Hammar-Klose ES. 2000. National assessment of coastal vulnerability to sea-level rise; preliminary results for the US Pacific Coast; Technical Report. Woods Hole (MA): U.S. Geological Survey.

Thomas V, López R. 2015. Global Increase in Climate-Related Disasters. No. 466. ADB economics working paper series. Manila, Philippine: Asian Development Bank. p. 1–45.

Willemsen P, van der Lelij AC, van Wesenbeeck B. 2019. Risk assessment North Coast Java. Deltas, Report Project No. 1220476-002-ZKS-0007. p. 1–25. https://www.wetlands.org/download/18264/1220476-002-ZKS-0007_v0.1-Risk-Assessment-North-Coast-Java-final.pdf

Wyrtki K. 1961. Physical oceanography of the Southeast Asian waters. NAGA Report vol 2. The University of California. La Jolla, California.

Yoo G, Kim AR, Hadi S. 2014. A methodology to assess environmental vulnerability in a coastal city: application to Jakarta, Indonesia. Ocean Coast Manage. 102:169–177. http://doi.org/10.1016/j.ocecoaman.2014.09.018.

Yusrizal WES, Simbolon D, Solihin I. 2018. Estimation of the utilization rate of fish resources in the northern coast of Java, Indonesia. AACL Bioflux. 11:1807–1824.

Zikra M, Suntoyo L. 2015. Climate change impacts on Indonesian coastal areas. Procedia Earth Planetary Sci. 14(2015):57–63. http://doi.org/10.1016/j.proeps.2015.07.085.