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Coastal Vulnerability Analysis Using CVI (Coastal Vulnerability Index) Methode in Sunda Strait - Indonesia

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Abstract. The Sunda Strait in Indonesia is a vital Indonesian Archipelagic Sea Lane (ALKI) but is prone to natural disasters. To minimize future impacts and ensure societal well-being, coastline changes are analyzed using satellite image processing in Google Earth Engine (GEE). Landsat 8 TIRS images from 2013 and 2020, along with the Modified Normalized Difference Water Index (MNDWI) algorithm, map shoreline changes by considering green and shortwave infrared channels. Tidal correction involves assessing coastal slope and adjusting shoreline positions based on the discrepancy between image recording and Mean Sea Level (MSL). Digital Shoreline Analysis System (DSAS) in ArcGIS determines change rates by creating transects and measuring distances at intersection points with coastline vectors. Oceanographic data (e.g., geomorphology, tides, wave height, sea surface level change) are factored in, obtained from various sources. Coastal Vulnerability Index (CVI) is used for vulnerability analysis, incorporating multiple parameters to rank coastal areas. This analysis aids in planning disaster risk reduction and mitigation efforts in the Sunda Strait, particularly regarding sea level rise.

Keywords: *coastal vulnerability index; climate change; shoreline change; sunda strait.*

1 Introduction

The Sunda Strait has great potential and a strategic position as it is traversed by one of the Indonesian Archipelagic Sea Lanes (ALKI). This region is also designated as a national strategic area (KSN) based on Government Regulation No. 32/2019 in [1] concerning marine spatial planning. Besides its crucial role for the livelihood of the communities, the coastal areas of the Sunda Strait are vulnerable to the impacts of natural disasters. Generally, natural disasters are defined as events or a series of events that threaten and disrupt the lives and livelihoods of people, caused by natural factors and/or abnormal and human-induced factors, resulting in loss of life, environmental damage, property damage, and psychological impacts. Some of the natural disasters that frequently occur in coastal areas include flooding and shoreline changes, which can be caused by sea-level rise and human activities.

Three aspects need to be considered to achieve a balance in the coastal environment: utilization balance, ecological balance, and mitigation. As stated in the Guidelines for Natural Disaster Mitigation in Coastal and Small Island Areas, mitigation is defined as various preventive efforts to minimize the anticipated negative impacts of future disasters in a specific area, representing a long-term investment for the well-being of all layers of society. Pratikto in [2] explains that mitigation can be structural and non-structural. Structural mitigation involves technical measures, both natural and artificial, such as coastal structures. Non-structural mitigation refers to non-technical measures that are carried out in conjunction with structural mitigation efforts.

According to Widura and Mardiatno in [3] analyzing the level of coastal vulnerability and developing a Vulnerability Map can be utilized as an initial measure for planning disaster risk reduction and mitigation.The analysis of coastal vulnerability is conducted using the Coastal Vulnerability Index (CVI) method. According to Hastuti *et al*. in [4], the CVI method was introduced by Gornitz in [5] and is a very common and simple method for analyzing the vulnerability of coastlines to sea-level rise based on an index calculation that combines parameters representing several geographic data that influence coastal vulnerability. The main focus of the Coastal Vulnerability Index or CVI is to address geophysical vulnerability based on remote sensing data processed through GIS methodology.

The parameters used as input for analyzing coastal vulnerability in this study are the shoreline change rate processed using the Google Earth Engine platform and the Modified Normalized Difference Water Index (MNDWI) algorithm, calculated with the Digital Shoreline Analysis System (DSAS), geomorphology, sea-level change, coastal slope, tidal range, and significant wave height.

2 Study Area

The research location (Figure 1) is located in the Sunda Strait, more specifically along the coastlines of Lampung and Banten. The coastline of Lampung spans 494.7 km, while the coastline of Banten spans 269.6 km. The analysis was conducted by dividing the area into 18 grids, with 11 grids along the Lampung coastline and 7 grids along the Banten coastline, each measuring 30 x 30 km.

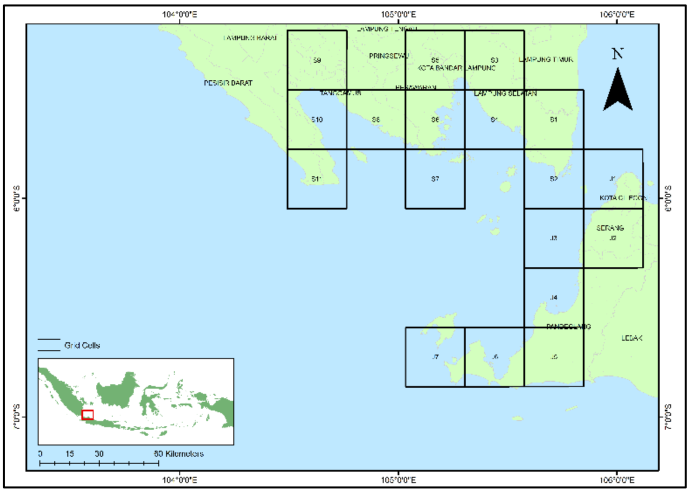

Figure 1 The study area with grid cells along the shoreline

3 Methodology

3.1 Image Processing

Satellite image processing is carried out using the Google Earth Engine (GEE) platform. GEE is a cloud-based platform that offers global-scale environmental data analysis. It provides information about the available image types, channel information, and desired image metadata. The data used in the image processing are Landsat 8 TIRS satellite images captured in 2013 and 2020. The spectral wavelength characteristics of Landsat imagery are shown in Table 1. Satellite images are used to map shoreline changes that occur in the coastal areas of the Sunda Strait. Both datasets are processed using the same algorithm, which is the Modified Normalized Difference Water Index (MNDWI).

Table 1 Spectral wavelength characteristics of Landsat 8 image channels

Channel	Length (μm)
Channel 1 Coastral/Aerosol	0.435 – 0.451
Channel 2 Blue	0.452 – 0.512
Channel 3 Green	0.533 – 0.590
Channel 4 Red	0.636 – 0.673
Channel 5 NIR	0.851 – 0.879
Channel 6 SWIR -1	1.566 – 1.651
Channel 7 SWIR-2	2.107 – 2.294
Channel 8 Panchromatic	0.503 – 0.676
Channel 9 Cirrus	1.363 – 1.384
Channel 10 TIRS-1	10.60 –11.19
Channel 11 TIRS-2	11.50 –12.51

3.1.1 MNDWI Algorithm

According to Singh *et al*. in [6] the MNDWI (Modified Normalized Water Index) algorithm is used because it is considered more sensitive to water features mixed with vegetation compared to the NDWI (Normalized Difference Water Index). Generally, the MNDWI algorithm is formulated as follows:

$$\text{MNDWI} = (\text{Green} - \text{MIR}) / (\text{Green} + \text{MIR}) \quad (1)$$

The algorithm described above applies when Landsat TM and ETM+ satellite imagery data is used, where green refers to the green channel and MIR refers to the infrared channel. However, since the data used in this study is Landsat 8 Surface Reflectance imagery processed from the Landsat-8 OLI/TIRS sensor, Ko *et al*. in [7] in Julianto *et al*. in [8] formulated the MNDWI algorithm (Modified Normalized Difference Water Index) as follows:

$$\text{MNDWI} = (\text{Green} - \text{SWIR}) / (\text{Green} + \text{SWIR}) \quad (2)$$

The channels used in the MNDWI algorithm (Modified Normalized Water Index) are channel 6 (SWIR1) with a wavelength of 1.566-1.651 µm and channel 3 (green) with a wavelength of 0.533-0.590 µm. Both channels have a spatial resolution of 30 meters. By using the MNDWI algorithm, accurate classification of land and water areas can be achieved.

Julianto *et al*. in [8] state that the MNDWI algorithm provides accurate extraction of open water features by suppressing or even eliminating built-up areas, soil, and vegetation due to their negative values. The algorithm classifies water through high brightness values ranging from 0 to 1, while non-water values are significantly low and range from -1 to 0. Hence, the algorithm demonstrates the capability to identify water bodies, rocky shores, and shorelines.

3.2 Analysis of the Rate of Change of the Coastline

3.2.1 Coastal Slope

The obtained shoreline is then corrected for tides through several stages, including calculating the slope of the coastline, determining the difference in sea level height between the image recording and Mean Sea Level (MSL), and calculating the distance of shoreline shift after correction. The data used as inputs for measuring the coastal slope and tidal correction are as follows:

Table 2 Input data for slope calculation and shoreline correction for tides

Data	Sumber
Garis pantai historis hasil export GEE	Google Earth Engine Processing
Data Batimetri	BATNAS (Batimetri Nasional)
Data Pasang Surut	BIG (Badan Informasi Geospasial)

The coastal slope (slope) is determined by knowing the depth value (d) obtained from bathymetric data and the horizontal distance (m) from the coastline to the specified depth during processing in ArcGIS software. According to Darmiati *et al*. in [9], the coastal slope is illustrated as follows:

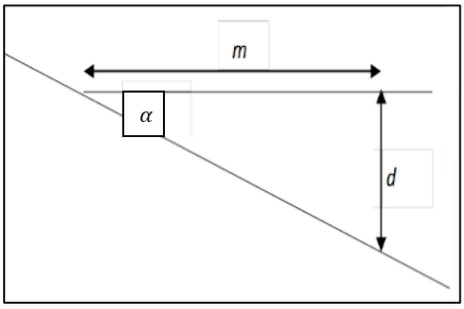

Figure 2 Illustration of slope calculation

Based on the figure 2, the equation for the coastal slope is obtained as:

$$\tan \alpha = d/m \tag{3}$$

Eq.3 allows us to calculate the slope of the coastline based on the known depth and horizontal distance values where d is water depth (meter) and m is horizontal distance from coastline to depth d.

3.2.2 DSAS (Digital Shoreline Analysis System)

The rate of change of the coastline is calculated and analyzed using the DSAS (Digital Shoreline Analysis System). DSAS is software that is integrated with ArcGIS. In this study, the rate of change of the coastline is analyzed using two stages: the NSM (Net Shoreline Movement) method followed by the EPR (End Point Rate) method.

The analysis of the coastline's rate of change with DSAS involves creating a series of transects at appropriate angles from the baseline defined. The points of intersection with all target lines are used to calculate the distances and rates of shoreline change. The inputs for the analysis of the coastline's rate of change are as follows:

1. Geodatabase

All DSAS input data must be managed within a personal geodatabase, which also serves as the storage location for the generated transect feature class and related statistical output tables. Previously existing data, such as shapefiles, can be imported as feature classes within the geodatabase in ArcCatalog.

DSAS provides a comprehensive framework for analyzing and quantifying shoreline changes over time, allowing for effective coastal management and decision-making processes.

2. Coastline Data

All coastline data should be in a single feature class within a personal geodatabase. In this study, the coastline data was obtained from satellite image extraction processed in Google Earth Engine (GEE). The data has been corrected for tides and collected as shapefiles, which were combined into a single file and then imported into the geodatabase within ArcCatalog.

Each coastline vector represents a specific position in time and should be assigned a date in the attribute table of the coastline feature class. The measurement transects created by DSAS from the baseline will intersect with the coastline vectors. The intersection points provide location and time information used to calculate the rate of change. Based on Thieler *et al*. in [10], as shown in (Figure 3), the distance from the baseline to each intersection point along the transect is used to compute selected statistics.

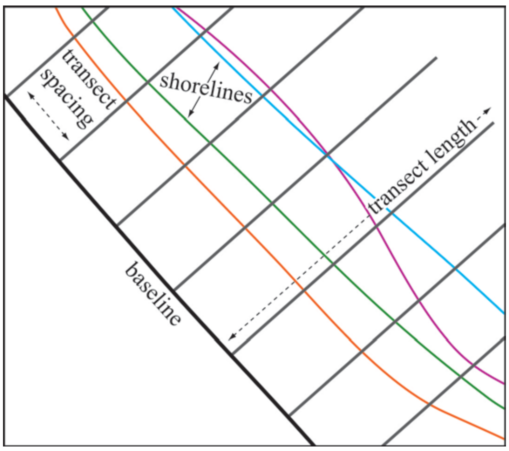

Figure 3 Description of baseline, transect distance and transect length

3. Baseline

DSAS utilizes the baseline measurement method as described by Leatherman and Clow, in [11] in Thieler in [10] to calculate the statistics of shoreline change rate. The baseline serves as the starting point for all transects generated by the DSAS application. Transects intersect each coastline at measurement points used to compute shoreline change rates. The following requirements should be considered when creating the baseline:

1. It should be a feature class within a personal geodatabase.
2. It must be in a projected coordinate system, preferably in meters (WGS 48).
3. It can consist of a single line or a collection of segments.
4. Each baseline segment should be entirely located on land or offshore from the coastline.

Once the necessary geodatabase and input features have been created or imported from shapefiles, and all required feature classes have been added and properly associated, the DSAS application can be used within ArcMap to define transect locations and calculate change statistics. In summary, the analysis of coastline change using DSAS, as described by Suhana *et al*. in [12], involves the following steps:

1. Set initial parameters for analyzing coastline change, including the positions of the processed satellite image coastlines.
2. Create transects by inputting the desired transect length.
3. Determine the spacing between each transect. In this study, a transect spacing of 500 meters is used to ensure that the transects cover the entire coastline without overlapping.
4. Modify transects by cutting them, ensuring that the non-overlapping sections of the transects do not interfere with the reference shoreline, thus avoiding calculation errors during the running process.
5. Calculate the rate of shoreline change using NSM (Net Shoreline Movement) (meters) and EPR (End Point Rate) (meters per year).

NSM represents the distance between the oldest and the most recent shoreline, measured in meters (m). While EPR is calculated by dividing the shoreline movement distance by the time elapsed between the oldest and the most recent shorelines (Figure 4). The advantage of EPR is its simplicity in calculation, requiring only two dates of the shoreline.

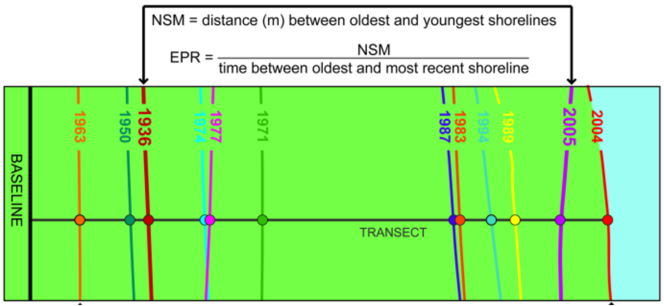

Figure 4 Illustration of Net Shoreline Movement and End Point Rate based on Himmelstoss *et al* in [13]

3.3 Oceanographic Data Processing

The oceanographic data used in this study are as follows:

1. Geomorphology

The coastal geomorphology index was obtained from the coastal geomorphology index map of Indonesia which was downloaded from the Ministry of Marine Affairs and Fisheries of Indonesia. The map has a scale of 1:7,500,000 and the data sources used include the Administrative Boundary Map (Bakosurtanal) from 2009, ETOPO1 Bathymetry Map, Indonesian Geological Map (Research and Development Center for Geological ESDM) from 1998, and Shuttle Radar Topography Mission (SRTM) Data from 1997.

2. Tides

Tidal data was obtained from the Indonesian Geospatial Information Agency for the month of March 2020 at the Panjang in South Lampung, and Cilegon tide stations. To obtain the MSL (Mean Sea Level) and tidal constituents for the period from January 2013 to December 2020, tidal prediction was performed using the ERGTIDES software. The elevation data for March 2020 was used as input in the ERGTIDES software to derive the harmonic constants of the tides. The obtained harmonic constants were then used as input in the ERGRAM program. After inputting the data into the ERGRAM program and specifying the observation period, the program automatically generates the forecasted tidal elevations for the specified period, in this case, from January 2013 to December 2022. The forecasted tidal elevation data is then used as input in the ERGLEV program to obtain the tidal constituents.

3. Significant Wave Height

Significant wave height data is obtained from ECMWF using the ERA5 model, which is a fifth-generation global weather reanalysis model with a spatial resolution of 0.5°. The downloaded significant wave height data is exported using the Ocean Data View (ODV) software to be compatible with Microsoft Excel for further analysis.

4. Sea Surface Level Change

Relative sea surface level change data is a historical record. The average sea surface height variation in the Sunda Strait over a 27-year period is derived from altimetry satellite measurements. Satellites provide an independent source of information about the sea surface, in addition to tide gauge measurements.

Monthly average sea surface height data from 1992 to 2019 for the Tanjung Lesung Station in the Sunda Strait is obtained from the Sea Level Explorer (https://ccar.colorado.edu/altimetry/index.html) in CSV format. This data is used to calculate the sea surface level change rate and assign vulnerability rankings.

3.4 Coastal Vulnerability Analysis

The coastal vulnerability analysis is conducted using the Coastal Vulnerability Index (CVI) method, which is based on the weights and scores of variables determined by the United States Geological Survey (USGS) and adjusted for the study area. The data required for the coastal vulnerability analysis are shown in the following table.

Table 3 Coastal Vulnerability Analysis Data

Parameter	Source	Resolution	Time Periode
Coastal Geomorphology Index	Ministry of Marine Affairs and Fisheries	Scale 1:75.000	2009
Sea Surface Level Change	Altimetri Satelite Data (https://ccar.colorado.edu/altimetry/index.html)	1/6th deg	1992 to 2019
Tidal Data	Geospatial Information Agency	-	2020
Significant Wave Height Data	Sentinel Copernicus	0,5 deg	January 2013 to December 2020
Coastline Change Data	Google Earth Engine Processing Result	30 m	2013 and 2020
Coastal Slope	BATNAS		

Table 3 shows the data used as inputs to determine the Coastal Vulnerability Index (CVI). The analysis of coastal vulnerability level is conducted using the CVI method, which is based on the weighting and scoring of variables established by the United States Geological Survey (USGS). The criteria, weights, and scores for determining the CVI refer to Pendleton *et al.* in [14] and Hastuti *et al.* in [4], as shown in Table 4

Table 4 Categories and weighting of CVI variable

	Category and Score				
	Very Low (1)	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
Geomorphology	Rocky cliffs	Moderate rocky cliffs, Rocky	Low rocky cliffs, Alluvial plains	Gravel beaches, Estuaries, Lagoons	Sandy beaches, Brackish marshes, Mangroves, Coral reefs, Deltas, Muddy areas, Seagrass beds
Shoreline Change Rate (m/year)	$\geq 2{,}1$ Accretion	1,0 – 2,0 Accretion	-1,0 – 1,0 Stable	-1,1 – (-2,0) Erosion	$\leq -2{,}0$ Erosion
Coastal slope (%)	>1,20	1,20 – 0,90	0,90 – 0,60	0,60 – 0,30	<0,30
Sea Surface Level Change (mm/year)	$\leq -1{,}1$	-1,0 - 0,99	1,0 – 2,0	2,1 – 4,0	$\geq 4{,}1$
Tidal Range (m)	$\leq 0{,}99$	1,0 - 1,9	2,0 - 4,0	4,1 - 6,0	$\geq 6{,}1$
Significant Wave Height (m)	<0,55	0,55 - 0,85	0,85 - 1,05	1,05 - 1,25	>1,25

Here is the translation of the CVI formulation for coastal vulnerability analysis as determined by the USGS in Koroglu *et al*, in [15]:

$$CVI = \sqrt{\frac{n_1 \cdot n_2 \cdot n_3 \cdot n_4 \cdot n_5 \cdot n_6}{6}} \tag{4}$$

Eq5 provides a method for calculating the Coastal Vulnerability Index (CVI) based on several variables. Where n_1= coastal geomorphology variables, n_2= risk rating assigned for shoreline change rate, n_3= risk rating for coastal slope variable, n_4= risk rating for sea surface level change, n_5= risk rating assigned for tidal range, and n_6= risk rating for significant wave height

4 Preliminary Result and Discussion

4.1 Geomorphology

Based on the results obtained from the Indonesian coastal geomorphology map, it can be seen that the coastline in the Sunda Strait in Lampung consists of four categories of geomorphology index, ranging from very low to high. Meanwhile, the coastline in Banten consists of two categories, namely very low and high. According to Table 4, the higher the category of a parameter, the more vulnerable the coastline is.

4.2 Tidal Range

Based on the predicted tidal range at two tidal stations, it is known that the tidal range at the Panjang tidal station is 1.45 meters, while at the Serang Cilegon station, it is 1.17 meters. Based on the obtained tidal range, the type of tidal range in the waters of the Sunda Strait is microtidal.

4.3 Sea Level Rise

Based on altimetry data from the Tanjung Lesung Station in the waters of the Sunda Strait, obtained from The Sea Explorer website (https://ccar.colorado.edu/altimetry/), it is known that the sea level rise trend in the Tanjung Lesung, Banten waters from 1994 to 2018 is 0.44 cm/year, which is higher than the global average.

4.4 Slope

The calculation and analysis of coastline slope were conducted along the coastlines of Lampung and Banten. The calculation of coastline slope was performed using bathymetric data provided by BIG (Badan Informasi Geospasial) with a calculation distance of 1000 meters from the coastline. Based on the calculations, it is known that the coastline slope in the Lampung area ranges from 0.02% to 5.36%, categorized as very low to very high according to the categories in Table 4. Meanwhile, in the Banten area, the coastline slope ranges from 0.52% to 5.65%, categorized as very low to high based on Table 4.

4.5 Significant Wave Height

The significant wave heights obtained from ECMWF data indicate that the average significant wave height in the waters of Lampung varies between 0.79 1.21 and 1.69 meters. Specifically, in the southern region of Lampung, it is 0.79 meters, while in the Tanggamus area, it is 1.69 meters. Along the coast of Banten, the significant wave heights range from 0.79 to 1.91 meters. The lowest value is observed in the Pandeglang area, while the highest values are found in Serang and Cilegon. Based on the data obtained, significant wave heights can be categorized in the Coastal Vulnerability Index (CVI) weighting as follows: low at 0.79 meters, high at 1.21 meters, and very high at 1.91 meters.

4.6 Shoreline Change Rate

Based on the analysis results, it was found that the coastline of the Sunda Strait in Lampung and Banten experienced both accretion and erosion during the period from 2013 to 2020. In the Lampung coastline, the highest accretion observed was 395.06 meters, while the highest erosion recorded was 403.9 meters. The average shoreline change in Lampung was estimated to be erosion at a rate of 0.5 meters per year. On the other hand, the highest accretion in the Banten coastline was 442.49 meters, and the highest erosion was 242.15 meters. The average total shoreline change in Banten was 0.3 meters per year, indicating overall accretion.

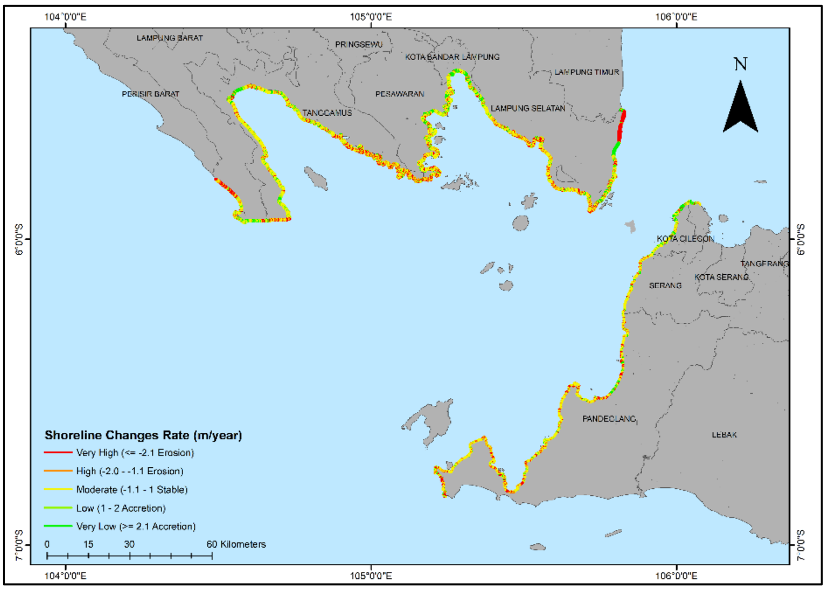

Figure 5 Shoreline change rate (m/year) in Sunda Strait

The shoreline changes in Lampung and Banten, based on the grid created, exhibited varying values. The Lampung coastline showed a range of -7.2 meters per year (erosion) to 1.94 meters per year (erosion). Meanwhile, the Banten coastline ranged from -1.01 meters per year (erosion) to 5.74 meters per year (accretion). The classification of shoreline change rates based on the Coastal Vulnerability Index (CVI) is presented in Figure 5.

4.7 Coastal Vulnerability Index

Ranking and evaluation were conducted along the 269.4 km of the Banten coastline and 494.7 km of the Lampung coastline. The ranking and classification of CVI values are divided into four colors: green for low vulnerability, yellow for moderate vulnerability, orange for high vulnerability, and red for very high vulnerability, as shown in Figure 6. The CVI classification, according to Hastuti et al. in [4], is based on quartile ranges and visual examination of the data. Based on the CVI calculations, vulnerability values range from 2.8 to 20. CVI values that are less than 4.73 are categorized as low vulnerability. Values within the range of 4.73 to 6.32 are categorized as moderate vulnerability. Values within the range of 6.32 to 10 are categorized as high vulnerability, and values greater than 10 are categorized as very high vulnerability.

From Figure 6, it can be observed that the vulnerability of the Lampung and Banten coastlines varies. Areas with very high vulnerability can be found along the eastern coastal areas of Lampung Selatan and small portions of Pandeglang and Serang in Banten. The very high vulnerability in the eastern coastal area of Lampung Selatan is primarily influenced by the steepness of the coastline, which is categorized as high with a slope of 0.48%, and the shoreline change rate of 7.2 m/year, indicating erosion.

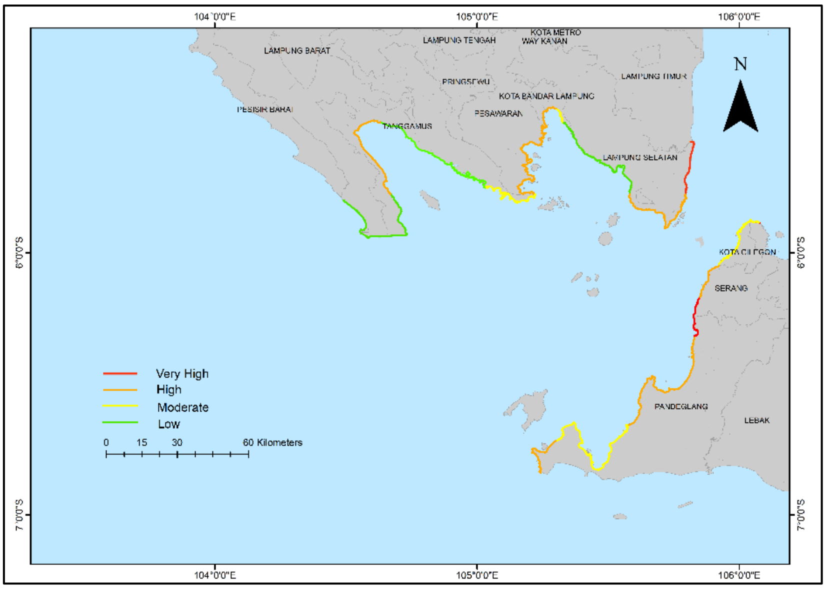

Figure 6 Coastal vulnerability index in Sunda Strait

5 Conclussion

Based on the results obtained, it can be concluded that the coastal vulnerability in the Sunda Strait will vary according to the location characteristics. Most vulnerable shore found in Banten and Lampung shore, to be exact in the Pandeglang Regency and eastern of South Lampung shore, and the area in Lampung is found to be less vulnerable. However, this study is based on secondary dataset with a coarse data resolution hence the accuracy could still be improved. It is recommended that similar study for CVI analysis to use a higher data resolution i.e., based on a numerical simulation or in-situ measurement.

6 Nomenclature

α = Coastal slope angle

β	= Difference in sea level between image recording and MSL (Mean Sea Level)
CVI	= Coastal Vulnerability Index
d	= water depth
m	= horizontal distance from the coastline to the depth d
n_1	= Coastal Geomorphology variable
n_2	= Rate of Coastal Line Change variable
n_3	= Coastline Slope variable
n_4	= Significant Wave Height variable
n_5	= Tidal Range variable
n_6	Coastal Erosion variable
r	= Tidal correction

Refference

[1] Republik Indonesia. 2019. Peraturan Pemerintah Nomor 32 Tahun 2019 tentang Rencana Tata Ruang Laut. Kementrian Kelautan dan Perikanan Indonesia. Jakarta

[2] Pratikto, W. A. (2004): Pedoman Mitigasi Bencana Alam di Wilayah Pesisi dan Pulau-Pulau Kecil. Direktorat Jenderal Pesisir dan Pulau-Pulau Kecil. Departemen Kelautan dan Perikanan. ISBN 979-3556-18-8

[3] Widura, Elsa & Mardiatno, Djati. (2022). Assessment of the Coastal Vulnerability Index (CVI) for disaster mitigation strategies in some coastal tourism areas in Gunungkidul, Yogyakarta-Indonesia. IOP Conference Series: Earth and Environmental Science. 989. 012014. 10.1088/1755-1315/989/1/012014.

[4] Hastuti, A. W., Masahiko, N., and Komang I. S. (2022): Coastal Vulnerability Assessment of Bali Province, Indonesia Using Remote Sensing and GIS Approaches. Remote Sensing 14, no. 17: 4409. https://doi.org/10.3390/rs14174409

[5] Gornitz, V. (1991). Global coastal hazards from future sea level rise. Palaeogeography, Palaeoclimatology, Palaeoecology, (89)(4), 379–398. https://doi.org/10.1016/0031-0182(91)90173-O

[6] Singh, K. V., Setia, R., Sahoo, S.,Prasad, A., dan Pateriya, B. (2015): Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. Geocarto International, 30(6), 650 661, doi: 10.1080/10106049.2014. 965757

[7] Ko, B. C., Kim, H. H., & Nam, J. Y. (2015). Classification of Potential Water Bodies Using Landsat 8 OLI and a Combination of Two Boosted Random Forest Classifiers. Sensors (Basel, Switzerland), 15(6), 13763–13777. https://doi.org/10.3390/s150613763

[8] Julianto, F. D., Cahya, R. F., Salsabila, D. R., dan Taufiq, I. (2021): Shoreline Changes After Sunda Strait Tsunami on The Coast of Pandeglang Regency Banten. International Journal of Remote Sensing and Earth Sciences Vol (17)(2)

[9] Darmiati, Nurjaya. W., dan Atmadipoera. S. (2020): Analysis of Shoreline Change in West Coast Area of Tanah Laut District South Kalimantan. Jurnal Ilmu dan Teknologi Kelautan Tropis 12(1), 211-222 https://doi.org/10.29244/jitkt.v12i1.22815

[10] Thieler, E. R., Himmelstoss, E. A., Zichichi, J. L., Ergul, A. (2009). The Digital Shoreline Analysis System (DSAS) Version 4.0 - An ArcGIS extension for calculating shoreline change. In. https://doi.org/10.3133/ofr20081278

[11] Leatherman, S. P., Clow, B. (1983). UMD Shoreline Mapping Project.IEEE Geoscience and Remote Sensing Society Newsletter, XXII(3). https://www.researchgate.net/publication/346570859

[12] Suhana, M. P., I Wayan, N., dan Nyoman, M. (2016): Analisis Kerentanan Pantai Timur Pulau Bintan Menggunakan Digital Shoreline Analysis dan Coastal Vulnerability Index. Jurnal Teknologi Kelautan Perikanan dan Kelautan Vol (7)(1). ISSN 2087-4871

[13] Himmelstoss, E.A., Henderson, R.E., Kratzmann, M.G., dan Farris, A.S., (2018): Digital Shoreline Analysis System (DSAS) version 5.0 user guide: U.S. Geological Survey Open-File Report 2018–1179, 110 p., https://doi.org/10.3133/ ofr20181179.

[14] Pendleton, E., Klose, E., Thieler, E., Williams, S. J. (2004). Coastal Vulnerability Assessment of Gulf Islands National Seashore (GUIS) to Sea-Level Rise. Open-File Report 03-108. USGS: Reston, VA, USA. Volume 3

[15] Koroglu, A., Roshanka, R., José A. J., dan Ali, D. (2019): Comparison of Coastal Vulnerability Index applications for Barcelona Province. Ocean & Coastal Management. Volume 178 (104799). ISSN 0964-5691.