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# ASSESSMENT OF COASTAL VULNERABILITY INDEX (CVI) AND ITS APPLICATION ALONG THE SRAGI COAST, SOUTH LAMPUNG, INDONESIA

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**ABSTRACT:** One of the simplest and most widely used methods for evaluating coastal susceptibility to geomorphological and physical parameters is the Coastal susceptibility Index (CVI). This approach can thus be utilized as a resource for the local government to evaluate to measure vulnerability and determine the degree of risk that a coast faces. To execute successful risk reduction measures, this measurement is a fundamental first step. Thus, the purpose of this study is to evaluate the vulnerability of the coastal areas in Sragi, South Lampung, Indonesia, using the Coastal Vulnerability Index (CVI) approach, which calculates physical and geomorphological parameters. The six factors that make up the assessment of coastal vulnerability are as follows: tidal range, significant wave height, coastal elevation, sea-level change rate, shoreline change rate, and geomorphology. The 6 km long Sragi coastal areas are split into 12 sections. With a covering area of 500 meters, each segment accurately reflects the size of the region under assessment. The result shows that the total of 83.33% of the Sragi coastal area is classified as having a very high vulnerability index, influenced by the values of shoreline change predominantly experiencing a change of < -2.0 m/year along a 5 km stretch of the coastline and the number of coastal slopes. This condition indicates that along the 5 km coastline of Sragi, there is a more predominant occurrence of erosion or shoreline retreat.

*Keywords: Vulnerability assessment, Coastal area, Coastal vulnerability index, Coastal zone*

## 1. INTRODUCTION

The coastal region is a very complex and dynamic area because it is a meeting place between land and ocean. This condition causes coastal areas to have a high degree of susceptibility to environmental change. This makes the coastal environment potentially highly vulnerable and environmentally unstable in settlement areas along the coastal, tourist, and fishing sectors so that they cannot be exploited properly and sustainably over a long period of time. Kaiser [1] shows that the vulnerability of coastal areas is a description of conditions that are easily influenced by natural factors and human activity factors. Sragi coastal areas located in South Lampung, Indonesia have the potential of coastal areas to be developed from the mining, catch fishing, and tourism sectors. The potential exploitation can be sustainable if supported by the balance and sustainability of coastal regions by identifying the level of vulnerability in coastal areas by mapping the area vulnerability using the Coastal Vulnerability Index (CVI) method.

The region along the coast is identified as the most susceptible area impacted by the effects of climate change [2,3,4,5]. The likelihood of coastal erosion and flooding in numerous coastal areas is anticipated to substantially rise due to climate change, including elevated sea levels and potential amplification in the frequency and/or strength of storms, along with alterations in wave patterns [6,7,8,9,10,11,12,13,14]. Since the early 1990s, high-precision altimeter satellites have routinely been used to measure sea level, showing that the global mean sea level is rising by 3.4 mm/year [15], and has seen a significant rise by 21–24 cm since 1880 [16].

In this context, it is essential to pinpoint the susceptibility of diverse coastal sectors to the effects of increasing sea levels as a fundamental aspect of coastal zone management. Numerous techniques have emerged in the last twenty years to ascertain coastal vulnerability. The most widely used and straightforward approach to evaluate vulnerability to rising sea levels involves calculating an index that combines a set of parameters representing various spatial entities (geographic data) influencing coastal vulnerability.

Gornitz [17] first presents the Coastal Vulnerability Index (CVI). The model developed is composed of seven variables to determine physical vulnerability in the USA to SLR impacts, consisting of relief (elevation), rock type (geology), landform (geomorphology), vertical movement (relative sea-level change), shoreline displacement, tidal range, and wave height [17]. The CVI approach has been applied and/or adopted by numerous researchers to assess coastal vulnerability around the world coastlines [18,19,20]. In this study, CVI is based on the previous studies [19] because of their efficiency and wide and large spatial scale use. They use similar physical variables and permit to assessment of vulnerability just associated to the physical impacts of erosion and inundation.

Beaches serve a crucial role as a natural defense system against coastal erosion, playing a significant part in minimizing the risks associated with such events. Therefore, the increased vulnerability of beaches to hazard events is heightened with their retreat and potential disappearance. Therefore, this study aims to quantitatively calculate the susceptibility of the coastal areas in Sragi coastal areas, South Lampung Indonesia. This assessment considers the geological and physical attributes related to coastal processes.

## 2. RESEARCH SIGNIFICANCE

First and foremost, these investigations offer a thorough comprehension of the degrees of susceptibility in coastal regions. This comprehension aids in recognizing the regions that are very susceptible and necessitates prompt action to alleviate the potential consequences of natural disasters.

Furthermore, studies on coastal vulnerability play a significant role in the advancement of future planning and decision-making procedures. Policymakers can make well-informed decisions about land-use planning, infrastructure development, and disaster preparedness by identifying the elements that contribute to coastal vulnerability and comprehending their implications.

## 3. METHODOLOGY

The location of study area is Sragi coastal areas, South Lampung, Indonesia is provided in Fig. 1.

Fig. 1 Research study location

This study evaluated coastal vulnerability by utilizing data, which encompassed various indicators such as geomorphology and geology, the coastal slope of the region, sea level fluctuations, shoreline alterations, significant wave height, and tidal range. The necessary data for this assessment were organized and processed using a geographic information system, as detailed in Table 1.

Table 1 Data sources used in CVI calculations in this study

| Variables | Source of Data |
|---|---|
| Geomorphology | Field visits, field photos and geomorphological observations |
| Coastal slope | (1) beach profiling survey; (2) digital elevation model (dem) data from tanahair.indonesia.go.id |
| Sea level change | Mean sea level anomaly global ocean |
| Shoreline change | Landsat satellites imagery |
| Significant wave height | Wave hindcasting |
| Tidal range | (1) Mike tide prediction; (2) Field measurement |

### 3.1 The CVI and Its Components

Studies on Coastal Vulnerability Index (CVI) that focus on geophysical vulnerabilities often draw inspiration from Gornitz [17]. The fundamental physical-geological parameters considered in these studies are geomorphology, coastal slope, sea level rise (SLR), regional elevation, shoreline dynamics, significant wave height, and tidal range. Geomorphological landforms serve as indicators of resistance to erosion, with erosion rates reflecting sensitivity to coastal processes. Wave energy is associated with the capacity for erosion, with relief and vertical land movements serving as indicators of inundation risk. The methods employed in these studies, along with their corresponding rankings, are outlined in Table 2.

### *3.1.1 Geomorphology*

Coastal geomorphology relates to the sighting of coastal areas [21]. The geomorphological data was collected with field observations of the coast which were conducted directly at the 12 segments of the research location to determine the geomorphological conditions at the Sragi coastal areas.

### *3.1.2 Coastal slope and regional elevation*

The coastal slope serves as an indicator not only for assessing the relative risk of inundation but also for estimating the potential speed of shoreline retreat. The coastal slope data collected with beach profiling survey for all the coastal areas. Despite that, the coastal slope data also uses secondary data namely Digital Elevation Model Nasional (DEMNAS) from the official INA-Geoportal.

The elevation data is grouped using a reclassify tool, then a buffer is carried out at the point of the research station (land) to create a new point (sea) with varying distances so that the reduction between the elevation on land and at sea obtains a difference in elevation at the station point.

Field measurement data is needed for the validation of secondary data. The topographic measurement using the GNSS-RTK (Real-Time Kinematic) method on the beach's edge is aimed at obtaining beach slope data. This measurement is conducted along a 5.4 km stretch with a measurement interval of 50 meters at each detailed point. The measurement yields detailed data on the coastal slope area situation, which is used to determine the slope gradient level at the observation area. The points used as bases in the detailed situation measurement are the results of static measurements in the form of BM KL01, BM KL02, and BM KL03.

### *3.1.3 Sea level change*

The data used to analyze Sea Level Rise is the mean sea level anomaly of the global ocean taken in the time from 1992 to 2022.

The data was taken from NOAA Sea Level Rise (http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/) and Radar Altimeter Database System (http://www.deos.tudelft.nl/altim/rads/).

The prediction of the future sea level rise is also uncertain [27]. If the worldwide greenhouse gas emission is controlled significantly, the rate of sea level rise may reduce to within 0.3 m by 2100. In many countries around the world, due to coastal zone regulations, some width of the coastal land from high water line (set back distance) is not allowed for any construction activity and is the buffer for the sea to advance into the beach due to sea level increase.

### *3.1.4 Shoreline change*

Digital Shoreline Analysis System (DSAS) is an Arc Map extension, developed by US Geological Survey (USGS), publicly available. Shoreline data can be obtained by importing shape files from digitation output or from other techniques such as aerial imagery which is LANDSAT satellite imagery.

Satellite imagery used in this study was first geometrically corrected to align the image position with its geographic position, as well as to avoid any mistake in analyzing shoreline change. Image was also re-sampled to align spatial resolution. After being geometrically corrected according to its geographic location, the image was then cropped according to the correct location of Sragi coastal areas. Shoreline data from geometrically corrected images were obtained through digitation method, namely digitation screen, on monitor using ArcGIS software. The outcome of the digitized multi-temporal satellite imagery (Landsat) from 2002-2022.

Observations of changing coastlines were conducted using remote sensing methods and Geographic Information Systems (GIS). The analysis of coastline changes from multi-temporal satellite imagery (Landsat) from 2002-2022 was carried out using Net Shoreline Movement (NSM) with Digital Shoreline Analysis System (DSAS) add-ins in the ArcGIS software. The coastline data for 20 years is then corrected using tidal data to observe the position of the coastline defined during the lowest tide conditions. Calculating the correction of the coastline due to tidal changes involves using tide data (elevation during image data acquisition) and average slope data of the coastline.

### *3.1.5 Significant wave height*

ECMWF ERA-Interim wind field was used to force the wave forecasting model using SPM 1984 (Shore Protection Manual) method aimed at obtaining significant wave height values. Wind data came from 1 January 2013 to 31 December 2022 from the official website of the European Centre for Medium Range-Weather Forecast (ECMWF). The wind data was used for the Hindcasting Wave with the SPM 1984 (Shore Protection Manual) method aimed at obtaining significant wave height values.

In the hindcast of wave parameters, the required variables can be determined as wind speed, fetch length, and wind duration. The daily wind data records taken from ECMWF do not coincide with the standard 10 m reference level. It must be converted to the 10 m reference level to predict the waves.

Wind fetch length was defined as the unobstructed distance that wind can travel over water in constant direction. The concept of effective fetch assumes that: waves are generated over 450 range either side of the wind direction and energy transfer from wind to wave is proportional to the cosine of the angle between the wind and wave directions, and wave growth is proportional to fetch length and the formula refer to Eq. (1):

$$F_{eff} = \frac{\sum F_i cos^2 \propto_i}{\sum cos \propto_i} \quad (1)$$

where $Feff$ is the effective fetch and is the length to be used.

Significant wave height (Hs) refers to Eq. (2) and peak period (Tp) which is the period at the peak of the wave energy density spectrum are associated with the wind speed, duration, and fetch length refer to Eq. (3).

$$T_s = 8.61 \frac{U_{10}}{9} \left[ 1 - \left[ 1 + 0.008 \left( \frac{gF}{U_{10}^2} \right)^{\frac{1}{3}} \right]^5 \right] \quad (2)$$

$$H_s = 0.30\ \frac{{U_{10}}^2}{9}\left[1-\left[1+0.004\left(\frac{gF}{U_{10}^2}\right)^{\frac{1}{2}}\right]^2\right] \qquad (3)$$

### *3.1.6 Tidal range*

Two different sources of tidal data were used: first, MIKE Tide Prediction provided tidal model prediction data for the period of January 2023 to December 2023. MIKE 21 is a software module used for evaluating and predicting tidal patterns. The analysis created by [26] served as the foundation for this application. In the meanwhile, the Valeport Tide Master device is used to collect tidal measurement data directly in the field. where a 15-day field measurement data collection period from June 22, 2023, to July 7, 2023, is scheduled. Field measurement data will next be used to validate the tidal forecast data.

## 3.2 CVI Calculations

The present study adopts an index-based methodology applying the CVI. CVI represents a combined result of the parameters influencing coastal vulnerability in the coastal area. The data were compiled from various sources to initially build a database of the parameters. The database is based on that used by Thieler and Hammar-Klose [19]. The parameters data values were allocated vulnerability rankings determined by their value ranges, which contribute to coastal vulnerability. The non-numerical geomorphology parameter was qualitatively ranked based on the landform's relative resistance to erosion. Each parameter input was assigned a corresponding risk level (refer to Table 2), considering its potential to cause damage categorized as very low, low, moderate, high, or very high for a specific coastal area.

Table 2 Risk rating assigned for different parameters [19]

| Variables | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Geomorphology | Rocky, Hard Cliffs | Medium Cliffs | Low cliffs | Cobble beaches | Barrier beaches |
| Coastal Slope (%) | > 1.9 | 1.3-1.9 | 0.9-1.3 | 0.6-0.9 | < 0.6 |
| Sea Level Rise (mm/yr) | <-1.21 | -1.21 – 0.1 | 0.1 – 1.24 | 1.24-1.36 | > 1.36 |
| Shoreline Change (m/yr) | > 2.0 | 1.0-2.0 | -1.0-+1.0 | -1.1 – -2.0 | < -2.0 |
| Significant Wave Height (m) | < 1.1 | 1.1-2.0 | 2.0-2.25 | 2.25-2.60 | >2.60 |
| Tidal Range (m) | > 6.0 | 4.1-6.0 | 2.0-4.0 | 4.0-6.0 | >6.0 |

**Very Low (1); Low (2); Moderate (3); High (4); and Very High (5)*

An early approach to assess potential vulnerability [17], involved the examination of the U.S. coastline on a national scale. The calculation was focused on six variables that significantly influenced coastal evolution. The comprehensive Coastal Vulnerability Index (CVI) is defined as the square root of the product of these variables divided by the number of variables (n) and the formula of CVI refers to Eq. (4).

$$\boldsymbol{CVI} = \sqrt{\frac{\boldsymbol{a_1 x a_2 x a_3 x a_4 x a_5 x a_6}}{\boldsymbol{n}}} \qquad (4)$$

$a_1$ = geomorphology
$a_2$ = coastal slope/relief
$a_3$ = relative sea level rate
$a_4$ = shoreline change rates
$a_5$ = significant wave height
$a_6$ = tidal range
n = the number of CVI parameters

In this study, quantile classification was used to classify the CVI range into four risk level. It divides an equal-sized group of CVI range values into quarters. Therefore, the CVI scores in the lowest range were assigned low vulnerability, followed by moderate vulnerability, high vulnerability, and very high vulnerability for the highest range of CVI values. The vulnerability classes of cells are analyzed using statistical analysis techniques such as skewness and mean values. This analysis aims to understand the causes behind the discrepancies in vulnerability classes and to identify the most appropriate method for future planning.

Within this context, we provide further details about the distribution of numbers among the vulnerability groups by examining skewness, mean, and maximum values (Table 2). This fundamental statistical concept elucidates the distribution of cells around the sample mean, also known as skewness, specifically among the low and extremely high vulnerability classes.

## 4. RESULT AND DISCUSSION

As a result of the CVI determination, it is possible to classify the geological and physical vulnerability of the Sragi coastal areas based on six parameters. In this context, a further characterization of the number cell distribution among the vulnerability classes is explained using skewness, mean and maximum values (Table 2). This basic statistical terminology explains how the cells are distributed around sample mean (skewness) or in other words among the low and very high vulnerability classes.

### 4.1 Geomorphology

The geomorphology of Sragi Coastal areas, South Lampung Indonesia is classified mud flats. The level of vulnerability of the Sragi coastal region, as determined by vulnerability parameters, is depicted in Fig. 2. Based on the coast's geomorphological conditions, the mapping outcomes indicate that the Sragi Coastal areas have a high vulnerability value**.**

Coastal vegetated wetlands and mangrove communities, being closely tied to sea level, exhibit sensitivity to climate change and prolonged sea-level alterations. Due to their location and relatively low resistance, these areas are exceptionally susceptible to the impacts of erosion and rising sea levels [22].

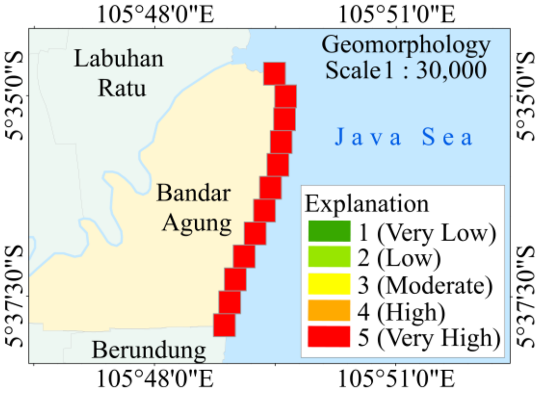

Fig. 2 Vulnerability result of geomorphology parameter

### 4.2 Coastal Slope

Coastal elevation vulnerability rank based on the spatial distribution of coastal elevation is shown in Fig. 3, which shows the elevation along the coastal area had a variation number of classifications. Segments 1, 4, and 8 were classified as a low index. Segments 2, 3, 5. 6 were classified as a very low index. Segments 7, 11, and 12 were classified as a moderate index and the very high index was classified for segments 9 and 10.

Using geomorphology and elevation as indicators of sea level vulnerability, the impacts of shoreline change, and flood hazards are likely to have a great effect [23]. The hazard decreases progressively with higher average elevation [17].

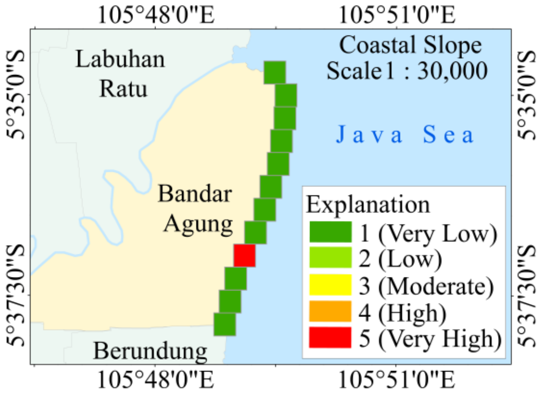

Fig. 3 Vulnerability result of the coastal slope parameter

### 4.3 Sea Level Rise

Considering the sea-level change rate range in Sragi coastal areas and utilizing a scoring, the coastline of Sragi is experiencing notably high relative sea-level rise rates, marking it as a highly vulnerable area due to the potential inundation of coastal land (Fig. 4).

Over the period 1992–2022, the mean sea-level variation's range value is measured at 3.07 mm/year. Furthermore, the average temperature of the atmosphere is on the rise, and the rate of disintegration of polar ice sheets is accelerating, all of which contribute to the rising sea level. Coastal areas are anticipated to be submerged at an accelerated rate in the future consequently. Additionally, an increase in the rate of coastal erosion and more intense wave action along the coast may result from the sea level rise.

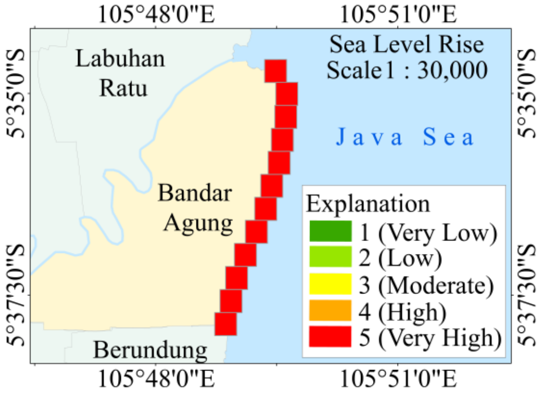

Fig. 4 Vulnerability result of sea level rise parameter

Sea-level rise represents a relatively subtle signal, with changes occurring in the range of millimeters to centimeters over decades. Consequently, the stability of the tide gauge datum is a critical factor in observations. It's important to note that the rate of sea-level rise varies at different locations, with contributions from both global phenomena and regional factors related to land and ocean processes, as outlined by [24].

### 4.4 Shoreline Change

According to the results of this analysis, each regency has experienced both erosion and accretion (Fig. 5). Over 6 km of coastline was evaluated the average rate of shoreline change is < -2.0 m/year, with 5 km classified as a very high index, and 1 km classified as a very low index.

Shoreline changes are greatly influenced by processes occurring in the surrounding beach area (nearshore processes), where the beach always adapts to various conditions that occur [25]. This complex process is influenced by three factors, namely the combination of waves and currents, sediment transport, and beach configuration, which mutually affect each other. The changes in these factors vary spatially and temporally, lasting a long time.

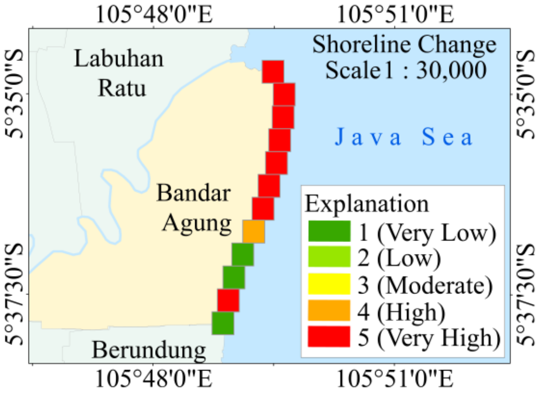

Fig. 5 Vulnerability result of shoreline change parameter

### 4.5 Significant Wave Height

The wave-high significant conditions at Sragi coastal areas is very low vulnerability rank (Fig. 6).

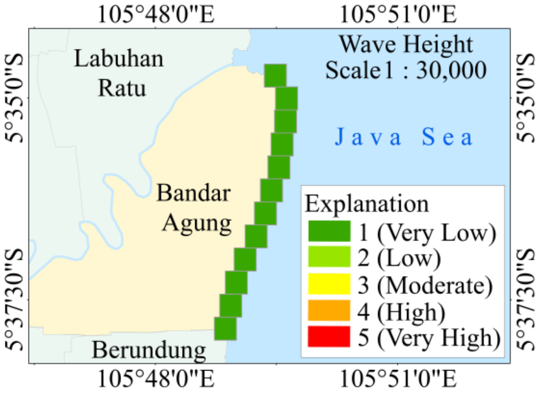

Fig. 6 Vulnerability result of significant wave height

The number of significant wave heights ($H_s$) is 0.49 m with a peak period ($T_p$) is 3.2 s. Waves are predominantly generated by the wind as it moves across the sea surface, transferring energy from the air to the water and giving rise to wave formation. The height of waves is contingent on the specific attributes of the wind responsible for their generation.

### 4.6 Tidal Range

Based on the tide data obtained from the four permanent tide stations, the mean tidal range in Sragi's zone is 125.48 cm. The elevation number of HHWL is 111.01 cm and the number of LLWL is -14.47 cm.

Remarkably, it is claimed that vulnerability evaluations for the tidal range rank at a high vulnerability level, which is indicated with orange color (Fig. 7). The tidal range, which is incorporated in the CVI as an indicator of the zone impact, with microtidal coastlines ranked as less vulnerable than macrotidal coastlines.

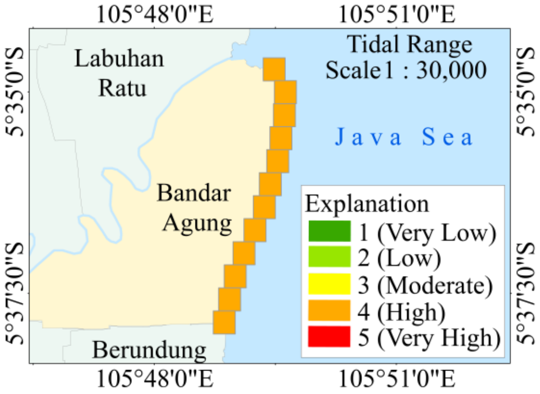

Fig. 7 Vulnerability result of tidal range parameter

### 4.7 Coastal Vulnerability Index of Sragi

Over 6 km of shoreline is evaluated and ranked along the Sragi coastal areas, South Lampung Indonesia. The classes of CVI values are divided into "low vulnerability" (green), "moderate vulnerability" (yellow), "high vulnerability" (orange), and "very high vulnerability" (red) categories, based on the quartile ranges and visual inspection of the data. The calculated CVI values range from 4.08 to 9.13.

Fig. 8. shows the overall ranking category distribution for the classes' CVI values, and also the CVI map of Sragi coastal areas. Based on the CVI ranking classification, it is known that along the 6 km stretch of the Sragi coastal line, there is a 5 km area classified as having very high vulnerability, while the remaining 1 km is classified as having moderate vulnerability.

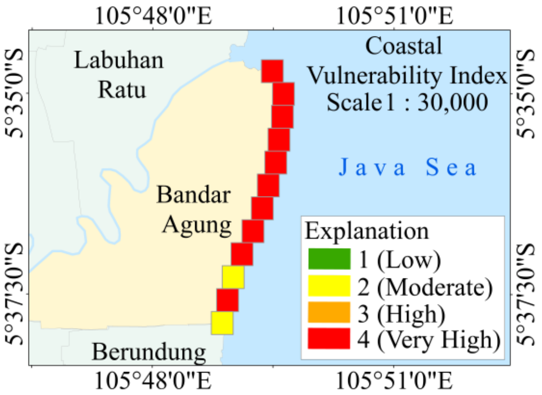

Fig. 8 The Coastal Vulnerability Index (CVI) map

A total of 83.33% of the Sragi area is classified as having a very high vulnerability index, influenced by the values of shoreline change predominantly experiencing a change of < -2.0 m/year along a 5 km stretch of the coastline and the number of coastal slopes. This condition indicates that along the 5 km coastline of Sragi, there is a more predominant occurrence of erosion or shoreline retreat.

Regarding the contribution of tides, CVI's reflect very different vulnerability conditions because they consider the role played by this variable in a very different way. In the research area, CVIs identified the whole coast as either very vulnerable or minimally vulnerable, without any small-scale variations. To determine how to account for the role of

When evaluating the projected impact, it is important to carefully analyze the contribution of tides in CVI. While there are varying perspectives, it is important to note that micro-tidal coastlines are highly susceptible to sea level rise (SLR) and their coastal ecosystems, such as wetlands, are not very resilient to changes in water levels.

## 5. CONCLUSION

This research revealed that coastal vulnerability is primarily influenced by geomorphology, shoreline change rate, coastal elevation, and significant wave height. Sea level change rate and tidal range were assigned equivalent risk levels along the coast. Enhancements in determining the most influential parameter could be achieved through weighted considerations.

Moreover, the suggested index demonstrates its applicability for assessing coastal vulnerability in other coastal regions confronting climate change. The Coastal Vulnerability Index (CVI) map developed for South Lampung, as presented in this study, offers a valuable tool for decision-makers and stakeholders involved in disaster mitigation and management, aiding efforts to alleviate the impacts of climate change.

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