# Mapping of Coastal Vulnerability using The Coastal Vulnerability Index and Geographic Information System

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# MAPPING OF COASTAL VULNERABILITY USING THE COASTAL VULNERABILITY INDEX AND GEOGRAPHIC INFORMATION SYSTEM

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## ABSTRACT

The mapping of coastal vulnerability using the Coastal Vulnerability Index (CVI) and the Geographic Information System (GIS) at Doreri Bay, Manokwari Regency, West Papua Province was carried out from September 2013 to March 2014. The aims of this study are to analyze and map the coastal vulnerability of Doreri Bay. The study was conducted using a combination of the CVI and GIS methods to assess the geological and physical parameters of the coastal region. The geological parameters consisted of geomorphology, coastline changes (accretion/erosion), the coastline slope, and physical processes. The physical parameters consisted of the relative changes in the sea surface height, the average wave height, and the average tidal height. The results of this research show that the CVI values were within the range of 6.7–43.3, and there were five class categories of coastal vulnerability: (1) very low vulnerability with an area of 6,635.4 Ha or 47.8%, (2) low vulnerability with an area of 2,654.1 Ha or 19.1%, (3) medium vulnerability with an area of 1,692.8 Ha or 12.2%, (4) high vulnerability with an area of 992.7 Ha or 7.2%, and (5) very high vulnerability with an area of 1,904.2 Ha or 13.7%.

*Keywords:* Class ranks; Coastal vulnerability index; Doreri Bay; Geographic information systems; Spatial analysis

## 1. INTRODUCTION

Indonesia is an archipelagic country consisting of groups of islands with a high potential for natural disasters of various levels and intensities due to its geological and geographical conditions. This is represented by coastal regions that are susceptible to environmental changes and disasters such as climate changes, earthquakes, tsunamis, rising sea level, and flooding (BNPB, 2008; Hartoko, 2008; Hartoko, 2013). One of the vulnerabilities in Indonesia's coastal regions requiring attention and anticipation for coastal development is the changes in the sea surface height (Gornitz, 1991). The sea surface height is increasing gradually and will cover lowlands of the coastal regions and small islands, increasing the frequency of flooding, abrasion/erosion, seawater intrusion, and ecological changes in the coastal regions. These changes will also affect socio-economic aspects of Indonesia's coastal communities, causing infrastructure damages, economic and social disturbances, changes in dwelling regions, and population growth in the coastal regions.In that regard, the coastal region of Doreri Bay is also vulnerable to an increase in the sea surface height (Manaf, 2008). Therefore, this condition must

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be anticipated by the local government because (1) coastal regions have natural resources and fishery potential; (2) population increases and most activities are concentrated in coastal regions; (3) the Manokwari Regency development is concentrated in a coastal region. The Coastal Vulnerability Index (CVI) is an approach used to assess coastal vulnerabilities based on geological variables and physical process variables (USGS, 2013). The CVI uses physical and geological variables that are related quantitatively and characterize the relative vulnerability of coasts to physical changes due to sea surface height in the future (Reyes & Blanco, 2012). Geological parameters include geomorphology, coastline changes (accretion), and the coastline slope; physical parameters include sea surface changes, the average wave height, and the average tide height.

The CVI method is commonly used for assessing the effects of sea surface increases on the coastline. Several countries have developed and used this method to assess coastal vulnerability, e.g., Canada (Shaw et al., 1998), Australia (Abuodha & Woodroffe, 2006), Spain (Ojeda-Zújaret al., 2008), Greece (Alexandrakis et al., 2009), Turkey (Özyurt & Ergin, 2010), and India (Kumar et al., 2010), as well as several researchers in Indonesia (Disaptono, 2008; Ali et al., 2008; Wahyudi et al., 2009; Rositasari et al., 2011; Kasim, 2011). The application of CVI has several advantages and disadvantages. The CVI method is simple, as it uses a ranking system; therefore, it is easy to identify regions with high vulnerability. It is easy for policy and decision makers to make decisions on proper management programs for coastal regions with high vulnerability to prevent the effects of sea surface increases (Gornitz et al., 1997; Gutierrez et al., 2009; Kasim & Siregar, 2012). However, the CVI method has several disadvantages as well; for one, it is only based on physical parameters. It does not consider the effects of social/human activities on ecological and physical changes, and a limited number of parameters are used as input to assess vulnerability (Kasim, 2011). Coastal vulnerability studies can be conducted using the geographic information system (GIS) through spatial analysis of the related parameters. The application of GIS technology in the management of coastal regions can help in planning and decision making (Kasim, 2011).

Considering the threat of the rising sea level in coastal regions and on small islands including Doreri Bay, it is necessary to study coastal vulnerability in coastal regions using a combination of CVI and GIS approaches. The aims of this study are to map and analyze the coastal vulnerability levels of Doreri Bay based on geomorphology, coastline changes, the coastline slope, sea level increases, and wave and tidal heights.

## 2. METHODOLOGY

The study was conducted from September 2013 to March 2014 in the coastal region of Doreri Bay, Manokwari Regency, West Papua Province, which is located at 0.855$^{o}$–1.356$^{o}$ South Latitude and 134.009$^{o}$–134.279$^{o}$ East Longitude.

The research method used was the spatial analysis of vulnerability variables. Data on geomorphology variables were obtained from the satellite image Aster DEM 30m and RBI map sheet 3015 scale 1:25.000, coastline changes from the satellite image of Landsat TM 1989 and ETM+ 2013, the coastline slope from the satellite image of Aster DEM 30m, the sea level trend from the satellite image of Altimeter TOPEX/POSEIDON. JASON 1 and JASON 2, the average wave height from the European Centre for Medium-Range Weather Forecasts (ECMRWF), and the average tidal heights from the literature review and the Hydro-Oceanography Service of the National Army Navy (Dishidros TNI AL) (Surinati, 2013). Data were analyzed using the GIS technique, including the following: downloading, importing, cropping, geometric correction, interpolation, grid conversion, classification (made for each vulnerability variable), digitation, and inputting and exporting files. Data for each variable were classified using a vulnerability matrix (Table 1), which was developed based on the literature review and spatial analysis through scoring and weighting. Scoring values ranged from 1 to 5, and weighting values ranged from 10 to 100 (Forman & Selly, 2012).

Table 1 Research results on the matrix scores and weightings of coastal vulnerability at Doreri Bay

| Variable/ Parameter | Range Core/Category[1)] | Vulnerability Scores (A) | Weighting (B)[2)] | Class (A×B) |
|---|---|---|---|---|
| a. Geomorphology | Land height ≥30m | 1 | 2 | 2 |
| | Land height 20–<30m | 2 | | 4 |
| | Land height 10–<20 m and alluvial plains | 3 | | 6 |
| | elevation 5–<10 m, buildings, estuaries, lagunas | 4 | | 8 |
| | Elevation <5 m, coastal structures, sandy beaches, brackish water swamps, mudflats, deltas, mangrove | 5 | | 10 |
| b. Coastline changes (m/year) | > 2 | 1 | 0.5 | 0.5 |
| | >1–2 | 2 | | 1 |
| | >-1–1 | 3 | | 1.5 |
| | >-2– -1 | 4 | | 2 |
| | ≤-2 | 5 | | 2.5 |
| c. Coastline slope (%) | >15 | 1 | 3 | 3 |
| | 10–15 | 2 | | 6 |
| | 5–<10 | 3 | | 9 |
| | 2–<5 | 4 | | 12 |
| | <2 | 5 | | 15 |
| d. Trend relative sea surface increase (mm/year) | <1.8 | 1 | 0.5 | 0.5 |
| | 1.8–2.5 | 2 | | 1 |
| | >2.5–3 | 3 | | 1.5 |
| | >3–3.4 | 4 | | 2 |
| | >3.4 | 5 | | 2.5 |
| e. Average wave height (m) | <0.5 | 1 | 3 | 3 |
| | 0.5–1 | 2 | | 6 |
| | >1–1.5 | 3 | | 9 |
| | >1.5–2 | 4 | | 12 |
| | >2 | 5 | | 15 |
| f. Average tidal range (m) | <0.5 | 1 | 1 | 1 |
| | 0.5–1 | 2 | | 2 |
| | >1–2 | 3 | | 3 |
| | >2–4 | 4 | | 4 |
| | >4 | 5 | | 5 |
| Total | | | 10 | |

Description:
1) Source: BNPB (2008); Gornitz (1991); Hartoko (2008); Wahyudi (2009); Kasin (2011); USGS (2013) with modifications
2) Weight based on the consideration of influential/dominant variables

After class scores were obtained, then CVI scores were calculated using the following formula (USGS, 2013):

$$CVI = \sqrt{\frac{(a*b*c*d* \ *f)}{6}} \quad (1)$$

where CVI is the coastal vulnerability index, *a* is geomorphology, *b* is coastline changes due to accretion and erosion (m/year), *c* is coastline slope (%), *d* is sea surface increase (mm/year), *e* is average wave height (m), *f* is average tidal range (m).

This matrix was divided into five ranks: very low (1), low (2), moderate (3), high (4), and very high (5). Percentiles are used to determine the limits of scores in ranking as follows: percentile 1=20%, percentile 2=40%, percentile 3=60%, percentile 4=80%.

After this categorization, ground truth was conducted to assess the truth of these results using the purposive sampling method. Sampling sites were determined based on plots of the locations that represent the five levels of coastal vulnerability and located at accessible places (Wahyudi, 2009). Plots of the locations were noted using the Global Positioning System (GPS) as coordinate points in latitude and longitude. The mapping of coastal vulnerability is based on the data ranks and tabulations of each vulnerability variables, the analysis of a modified CVI method, and the ground truth assessment.

## 3. RESULTS AND DISCUSSION

### 3.1. Coastal Vulnerability of Doreri Bay

The results obtained show that, in general, three variables—the trend of the relative sea surface level increase, the average wave height, and the average tidal range—are constant factors determining the coastal vulnerability of Doreri Bay. The other three variables— the coastline slope, coastline changes, and geomorphology—are variability factors. The CVI values ranged from 6.7 to 43.3 with the following five categories of coastal vulnerability at Doreri Bay: very low (class 1), low (class 2), medium (class 3), high (class 4), and very high (class 5). These classes of vulnerability are unevenly distributed along the coastal region of Doreri Bay, as presented in Figure 1 below. Table 2 shows the research results on the ranks and classes of CVI at Doreri Bay, and Figure 1 shows a map of the CVI at Doreri Bay.

When the results are spatially converted into areas (Ha) and percentages (%), it is clear that the very low vulnerability class applies to the greatest area along the coastal region of Doreri Bay (6,635.4 Ha or 47.8%), followed by low vulnerability (2,654.1 Ha or 19.1%), very high vulnerability (1,904.2 Ha or 13.7%), medium vulnerability (1,692.8 or 12.2%), and the smallest area is the high vulnerability class (992.7 Ha or 7.2%). This indicates that the coastal vulnerability at Doreri Bay is mainly at very low and low levels (66.9%).

Table 2 Results on the class rank of the CVI and the area along the coastal region of Doreri Bay

| Class Ranks of CVI | Ha | % |
|---|---|---|
| 1 (very low) | 6,635.4 | 47.8 |
| 2 (low) | 2,654.1 | 19.1 |
| 3 (medium) | 1,692.8 | 12.2 |
| 4 (high) | 992.7 | 7.2 |
| 5 (very high) | 1,904.2 | 13.7 |
| Total | 13,879.2 | 100 |

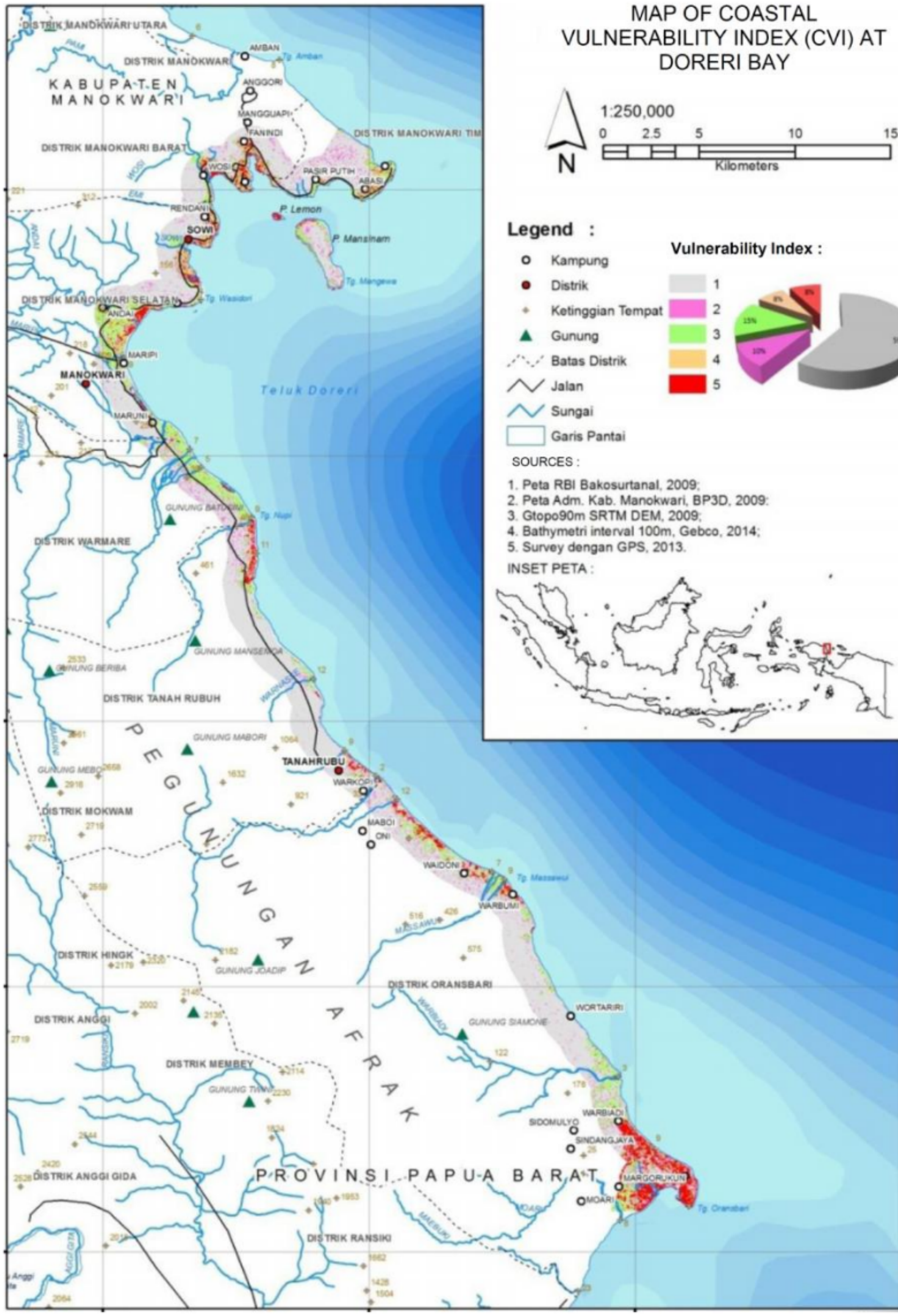


Figure 1 Map of the coastal vulnerability at Doreri Bay

### *3.1.1. Very low vulnerability*

Regions with very low vulnerability are formed from variations in geomorphological variables with a height range of 5–≥30 m. A height ≥30 m is the most determinant factor accounting for 73.8% of all geomorphological factors. The remaining 26.2% is composed of various variables of geomorphology with heights ranging from 5–30 m where the land is mainly used for buildings and alluvial plains. Generally, the topography of Manokwari Regency consists of hills and high lands; more than 60% are mountains and plateaus. Several mountains in the coastal regions of Manokwari include Itsiwei (2,117 m), Togwomeri (2,680 m), Borai (2,340 m), and Twini (2,175 m).

The rate of coastline change between accretion and erosion is in the range of -1 to 1 m/year and is the greatest determinant factor (98.1%) of total coastline changes, while the remaining 0.3% and 1.6% constitute various rates of coastline change due to accretion and erosion. Coastline slope of 10–>15 % is the determinant factor of total factor of coastline slope 100%. Regions with very low vulnerability spread and dominate along the coastal regions of Doreri Bay and are considered safe regions for future developments.

### *3.1.2. Low vulnerability*

Regions with low vulnerability were formed from geomorphological variables variation with a height range of 5–≥30 m. A height ≥30 m is the greatest determinant factor, accounting for 41.3% of all geomorphological factors, followed by heights of 20–30 m and 10–20 m with land used for buildings and alluvial plains (26.2% and 23.2%, respectively). The remaining 9.3% is composed of a combination of various geomorphological variables with heights ranging from <5–<10 m, land used for coastal buildings, sandy beaches, brackish water swamps, deltas, and mangroves.

The rate of coastline change due to balanced condition of accretion and erosion is in the range of -1 to 1 m/year and is the greatest determinant factor, accounting for 94.9% of total coastline change, while the remaining condition constitutes various rates of coastline change due to accretion (5%) and erosion (4.6%). The coastline slope varies from <5–>15%. A coastline slope >15% is the greatest determinant factor of the total coastline slope (32.7%), followed by a coastline slope of 5–<10 % (28%), 10–15% (25%), and 2–<5 % (12.8%). Regions with low vulnerability overlap with regions with very low vulnerability along the coasts of Doreri Bay and are categorized as safe regions.

### *3.1.3. Medium vulnerability*

Regions with medium vulnerability were formed from variations in the geomorphological variables with heights ranging from 5–≥30 m. A height of 10–20 m and alluvial plains are the greatest determinant factor, accounting for 30.4% of all geomorphological factors, followed by a height of 20–30 m (28.8%). A height ≥30 m only accounts for 3.2%.

The rate of coastline change due to balanced condition of accretion and erosion is in the range of 1 to –1 m/year) and is the greatest determinant factor, accounting for 86.3% of all coastline changes, while the remaining 1.2% and 10.5% account for the various rates of coastline change due to accretion and erosion. The coastline slope varies from <2%–>15 %. A coastline slope of 10–15% is the greatest determinant factor of the total slope (44.9%), followed by a coastline slope >15 % and 5–<10 m (23.2% and 19.7%, respectively). A coastline slope 0–<5 % accounts for only 12.1%. Regions with medium vulnerability are located at Mansinam, Abasi and Pasir Putih islands (East DistrictofManokwari), Wosi island (West District Manokwari), Sowi, Andai, and Maripi dan Maruni islands (South Manokwari), the coastal area of the Warmare District, and small parts of Tanah Rubu and Oransbari Districts. Medium vulnerability can also be categorized as safe regions; however, if those regions are not managed appropriately, they can become high or very high vulnerability regions.

### *3.1.4. High vulnerability*

Regions with high vulnerability were formed from variations in geomorphological variables, and heights ranging from 10–20 m and alluvial plains are the greatest determinant factors, accounting for 57.7% of all geomorphological factors. This is followed by heights < 5 m (39.5%), with land used for coastal buildings, sandy beaches, brackish water swamps, deltas, and mangroves. Heights of 5–< 10m and 20–30 m account for 3.1% and 4.7% of all geomorphological factors, respectively.

The rate of coastline change due to balanced condition of accretion and erosion is in the range of 1 to –1 m/year and is the greatest determinant factor, accounting for 93.4% of all coastline changes, while the remaining 1.3% and 5.3% account for various rates of coastline change due to accretion and erosion. The coastline slope ranges from <2–>15%. A coastline slope of 5–< 10% is the greatest determinant factor (52.2%), followed by a coastline slope of 10–15% (43.2%). A coastline slope of <2–<5% accounts for 4.8% of the total coastline slope. Regions with high vulnerability are scattered throughout medium vulnerability regions and are present in the Abasi region to Andai region (South Manokwari District), and Margorukun (District of Oransbari). Regions with high vulnerability require more attention to protect them from potential damages or the degradation of coastal lands.

### *3.1.5. Very high vulnerability*

Regions with very high vulnerability were formed from variations in geomorphological variables with heights <5 m, with land used for coastal buildings, sandy beaches, brackish water swamps, deltas, and mangroves, which are the greatest determinant factors, accounting for 46.1% of all geomorphological factors. This is followed by heights of 5–< 10 m and alluvial plains and heights of 10–20 m (29.3% and 24.5%, respectively). Heights of 20–30 m cover only a small part of the region and account for 0.1% of all geomorphological factors.

The rate of coastline change with balanced accretion and erosion is in the range of 1 to -1 m/year, and is the greatest determinant factor, accounting for 80.3% of all coastline changes. The rate of coastline change due to erosion accounts for 19.3%, while the rate of coastline change due to accretion accounts for only 0.4% of all coastline changes.

The coastline slope varies from <2–>15%. A coastline slope of 5–< 10 m is the greatest determinant factor of the total coastline slope (40.2%). This is followed by coastline slopes of 2–< 5% and <2% (38.7% and 15.9%, respectively). A coastline slope of 10–15% accounts for only 5.1% of the total coastline slope. Regions with very high vulnerability are found at Lemon, Mansinam, and Abasi dan Pasir Putih islands (District of East Manokwari); Fanindi and Sanggeng dan Wosi islands (District of West Manokwari); Rendani and SowidanAndai islands (South Manokwari); around Tanjung Nupi and Warkapi (District of Tanah Rubu); and Maboi, Waidoni, Warbumi, Warbiadi, and Margorukun islands (District of Oransbari). Regions with very high vulnerability require attention to protect them from land damage/degradation in the coastal region of Doreri Bay.

## 4. CONCLUSION

Based on the results of this research, the levels of coastal vulnerability at Doreri Bay primarily appear to be very low and low, accounting for 66.9% of the total area of the region. The remaining areas have medium vulnerability (12.2%), high vulnerability (7.2%), and very high vulnerability (13.7%). These findings are very important for the local government of Doreri Districts, as they provide a basis for consideration in future development and management, particularly spatial planning in the coastal region of Doreri Bay, Manokwari Regency.

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