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Study of the Coastal Vulnerability in Indramayu Regency, Indonesia

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ABSTRACT

Coastal vulnerability is a condition of a coastal community or society that leads to or causes an inability to face the threat of danger. The level of vulnerability can be viewed from the physical (infrastructure), social, demographic, and economic vulnerabilities. Physical vulnerability (infrastructure) describes a physical condition (infrastructure) that is prone to certain hazard factors. The coastal vulnerability areas can also be interpreted as a condition where there is an increase in the process of damage in the coastal area which is caused by various factors such as human activities and factors from the nature. This research aims to determine the level of coastal vulnerability in Indramayu coastal Regency with a Coastal Vulnerability Assessment (CVA) analysis approach and a Geographic Information System (GIS). Mapping the status of the vulnerability level of the Indramayu coastal area using the CVA method where the index range generated from the calculation of the four physical parameters mentioned above is between 2.887-3.651 or are in moderate vulnerability. A higher vulnerability value is found in several locations such as Juntikedokan and Benda villages. It is necessary to develop coastal protection in this area to prevent damage to the coastal area.

1. Introduction

The definition of coastal areas is very diverse, so there is no single definition of coastal areas either in law or in specific coastal management mechanisms. The boundary of the coastal area will depend on the extent of the direct influence of the sea and associated coastal activities, where some in some places the coastal area may be relatively narrow, such as a cliffed coast. However, there is also a flat area and a large tidal influence. The coastal area boundary will be wider^[1]. The definition of coastal areas based on Law Number 27 of 2007 concerning Management of Coastal Areas and Small Islands in Article 1 Para-

graph (2) states that coastal areas are transitional areas between terrestrial and marine ecosystems that are affected by changes in land and sea. Furthermore, in Article 2 it is stated that the scope of regulation of coastal areas and small islands includes transitional areas between terrestrial and marine ecosystems which are affected by changes in land and sea, landward includes the administrative area of sub-districts and seaward as far as 12 nautical miles measured coastline^[2].

Coastal areas are very dynamic and rich in biological and non-biological resources. The coastal area is the meeting area between land and sea, with a boundary towards the land covering parts of the land, both dry and submerged in

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water, which is still influenced by sea characteristics such as sea breezes, tides, seawater seepage (intrusion) which is characterized by its vegetation typical, while the coastal area boundary towards the sea includes the outer part or boundary of the continental shelf, where the characteristics of these waters are still influenced by natural processes that occur on land such as sedimentation and freshwater flow, as well as processes caused by human activities on land such as deforestation and pollution ^[3].

Coastal areas have a very strategic role and are vulnerable to environmental changes and human activities, so the utilization of coastal areas needs to find the optimum balance between its use, management, and preservation. The high intensity of utilization and the lack of awareness in conservation will hurt the physical and social conditions of this area, thereby affecting its vulnerability. In general, efforts to protect, conserve and utilize coastal areas in Indonesia are following the provisions contained in Article 28 of Law Number 27 of 2007 (Government of the Republic of Indonesia, 2007) and in Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 23 of 2016 concerning Planning for the Management of Coastal Areas and Small Islands ^[4].

Vulnerability is a condition of a community or society that leads to or causes an inability to face threats of danger. The level of vulnerability can be viewed from the physical (infrastructure), social, demographic, and economic vulnerabilities ^[5]. The vulnerability of coastal areas is a condition in which there is an increase in the process of damage in coastal areas caused by various factors such as human activities and factors from nature ^[6]. Damage to coastal areas that can occur is flood disasters, floods occur almost throughout the year in areas located along the northern coast of Java. The cause of this flood is continuous rain so that the channel cannot accommodate water. Flooding is caused by tides of seawater entering the land area, or tidal flooding ^[7]. As a result of the damage in the coastal area which affects vulnerability, a general definition of vulnerability is the level of a system that is easily affected or unable to cope with disasters. The level of vulnerability can be viewed from the physical, social, demographic, and economic aspects. Physical vulnerability describes a physical condition that is prone to certain hazard factors ^[8].

Indramayu Regency is one of the regencies in West Java which is directly adjacent to the Java Sea in the north and east. Other parts are limited by districts in West Java, including Cirebon Regency, Sumedang Regency, and Subang Regency. Given the coastal area of Indramayu is a densely populated area where most of the activities of the population are centered on the coast and cause changes to

the beach. The existence of changes on the coast is very interesting to study, especially regarding the effect on the level of coastal vulnerability.

Efforts to prevent the impact caused by disasters in coastal areas can be done by mapping the vulnerability of the area. Determination of the vulnerability of coastal areas can be done by assessing the physical conditions of the coastal areas. One method that can be used is Coastal Vulnerability Assessment (CVA). CVA is a relative ranking method based on an index scale of physical parameters such as changes in coastline, elevation, tides, sea-level rise, and wave height. Therefore, a study on the level of vulnerability mapping of coastal areas in Indramayu is needed as a consideration for the management of coastal areas to reduce the impacts caused by dynamic conditions of the coastal environment. The scope of this research includes periodic shoreline changes that will affect the vulnerability of the coastal area in the Indramayu Regency.

2. Methodology

2.1 Location

This research was conducted in October - December 2020 at the Bungus Coastal Resources and Vulnerability Research Workshop (LRSDKP), Padang City, West Sumatra Province, Indonesia. While the research data used secondary data from sampling on the coast of Indramayu Regency, West Java Province, Indonesia in 2019.

The research location is coastal Indramayu Regency which covers the coastline of 12 villages in Indramayu and Subang districts, Province of Java. The research area (Area of Interest) is geographically located at position 107° 48' 0.572" - 108°15' 0.576" East Longitude and 6° 7' 29.766" - 6° 22' 29.766" South Latitude. Its territory is located in the northern part of West Java province which is directly adjacent to the Java Sea. Indramayu Regency is about 52 Km northwest of Cirebon City, 144 Km from Bandung City via Sumedang, and 205 Km from Jakarta to the east. The research location is shown in Figure 1.

The coastal area of Indramayu and its surroundings has long been recognized as one of the potential areas in the marine sector, particularly in fisheries and shrimp farming. The economic improvement, especially in the fisheries and shrimp ponds sector, collided indirectly with the problem of coastal abrasion which is thought to have been going on for a long time. On the other hand, on the coast in another part of the abrasion zone, there is sedimentation that tends to cover the river mouths in the study area. This condition is due to the clearing of mangrove forests for fish and shrimp aquaculture, which has triggered erosion and sedimentation along the coast. The balance between

the erosion and sedimentation processes along the West coast of Indramayu is the effect of currents and waves in the West Season which causes the coastal area to retreat and the coastal area to advance.

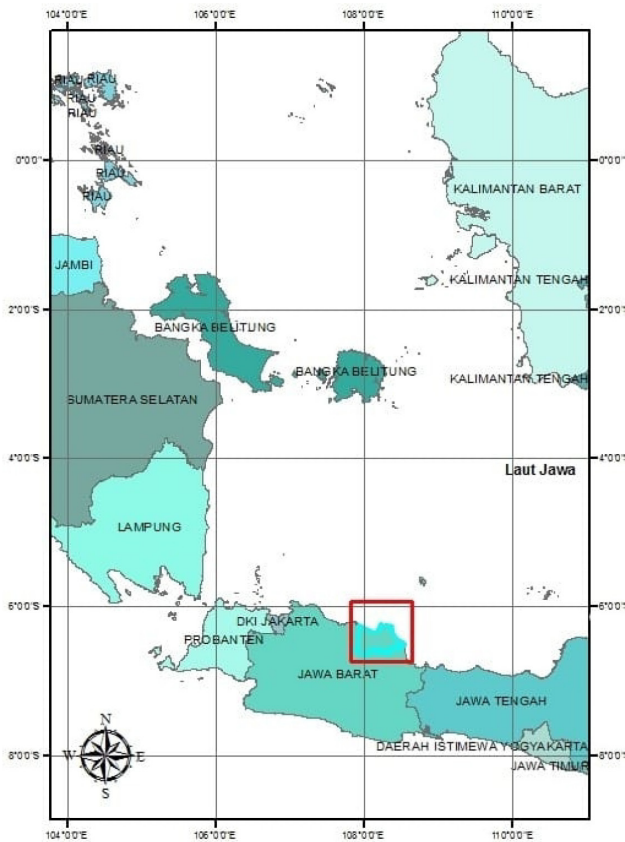


Figure 1. The research location

2.2 Data Analysis

2.2.1 Shoreline Changes

The coastline is obtained from the results of the 2018 and 2020 Landsat image extraction, which are then compiled overlapping on the 2018 Landsat image as the oldest image so that a picture of changes from year to year is obtained. Furthermore, to obtain numerical changes, further processing is required using the DSAS (Digital Shoreline Analysis System) application which is an extension in the ArcGIS software. The input required in processing consists of two main data, namely the coastline (at least from 2 different years), and the baseline. Both the shoreline and baseline can be digitized manually over the corresponding image, where the baseline digitization must follow the shoreline that will be used as the measurement basis.

Meanwhile, the length and distance of the transect line must be determined in advance, where the length of the line must pass through all coastlines for which changes

are calculated. The starting point of the transect line will be raised from the baseline which then goes to the shorelines. After all the required data are available and all processing procedures have been carried out, transect lines will be generated along the baseline. The amount of distance between the two coastlines that have been generated and stored in the transect line database will be the input for calculating the rate of change in the coastline using the End Point Rate (EPR) statistical method [9], with the following formulation :

$$EPR = \frac{\text{distance between two coastlines (m)}}{\text{the span of years two coastlines (km)}}$$

The results of shoreline processing are changes with positive and negative values. Where a positive value indicates the addition of sediment in the coastal area which causes the coastline to advance toward the sea. Meanwhile, negative changes indicate a decrease in the land, which causes the coastline to retreat towards the mainland. The data needed in designing the model are a base map of the location of the research area. The digitization process is carried out to determine the land boundary area, sea boundary, and other objects in the waters. The next process is making a mesh/grid, where each element has different parameters for hydrodynamic calculations then carried out computationally based on the continuity equation and the common equation. It is better if the mesh forms a minimum angle so that the coefficient of friction is not too large so that the running process is easier.

2.2.2 Tidal Type

Analysis of tidal types by knowing the harmonic components of the tide, then to determine the type of tide, the Formzahl number (F) is calculated using the Admiralty method approach, namely the following formula ^[10, 11]:

$$F = \frac{(O_1 + K_1)}{(M_2 + S_2)}$$

F: Formzahl numbers

O_1 : Amplitude of the main single tidal components caused by the pull of the moon

K_1 : Amplitude of the main single tidal components caused by the pull forces of the moon and the sun

M_2 : Amplitude of the main double tidal component caused by the pull of the moon

S_2 : Amplitude of the main double tidal component caused by the tensile force of the sun

Criteria for Formzahl numbers:

0.00 < F = 0.25: half-daily (semidiurnal / double)

0.25 < F = 1.50: mixed tide with double type

1.50 < F = 3.00: mixed tide with a single type

F > 3.00: single daily tides

- d. Low accretion (2): accretion is quite low, namely 1.3 - 1.6 m/year, and
- e. Very high accretion (1): experiencing accretion is 2.4 - 22.3 m/year.

The map of shoreline changes in Indramayu (Figure 2) shows that most of the shoreline changes with a very high level of abrasion susceptibility to abrasion of more than 2 m/year are almost evenly distributed across the coast in Indramayu. On the map of changes to the coastline of Indramayu, the villages that experienced very high abrasion were Singaraja, Juntinyuat, Dadap, and Benda.

Based on other research on coastal vulnerability in the same location, it shows that changes in the Indramayu coastline are quite variable. The results of the extraction of the value of the change in the shoreline value of the Indramayu coastal area for 12 years were 1.80-12.78 m / year (erosion) and 0.23-44.88 m / year (accretion), respectively. The results of the extraction of geomorphological aspects and coastal slopes show that in general, the coastal areas of Indramayu consist of sandy beaches, ponds, and mangroves in the West and East, and are alluvial fan areas with very low coastal slopes. Thus it is also known that the process of the evolutionary rate that dominates is accretion versus erosion with the respective percentages of 49.02% (erosion) and 50.98% (accretion) ^[13].

The results of the shoreline change analysis using Landsat TM images for the 2000 and 2011 recording years show that most of the Indramayu coast is experiencing erosion. Coastal erosion ranges from 0.23 - 99.76 meters with an erosion speed of -0.02 - -9.41 m / year. The results of shoreline change analysis based on Landsat image processing in 2000 and 2011 show that the Indramayu coastal area covering an area of $\pm 47.52 \text{ km}^2$ ($\pm 31.34\%$) is experiencing erosion at a speed of more than -2.0 m / year which is classified as very vulnerable. Coastal areas with erosion speeds between -1.1 to -2.0 m / year are classified as a vulnerable class with an area of $\pm 74.03 \text{ km}^2$ ($\pm 48.82\%$), while an area of $\pm 28.33 \text{ km}^2$ ($\pm 18, 68\%$) are included in the medium class because they experience the addition and reduction of the coastline with a speed between -1.1 to 1.0 m / year, including in the medium class ^[14].

3.2 The Coastal Slope

A coastal slope is a measure of the slope of the land relative to the plane, which is generally expressed in percent or degrees. Slope steepness, slope length, and slope shape will all affect the amount of erosion and runoff. On the coastal slope in Indramayu, it is more dominant to very low criteria, namely the range of $10\text{-}36^\circ$, while the moderate status ranges from $4\text{-}5^\circ$ and high status is $2\text{-}3^\circ$. Coastal slope map in Indramayu is shown in Figure 3.

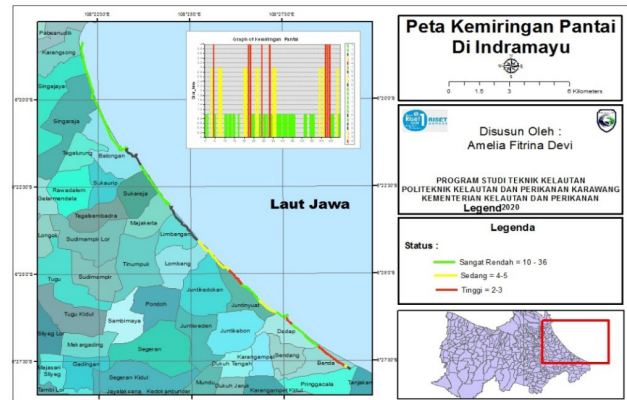


Figure 3. Coastal slope map in Indramayu

3.3 Tidal Type

Tide analysis in the Indramayu district is intended to determine the type of tide and determine the sea level and the average tide level. The data analyzed was tidal data for 15 days, from August 20 to September 5, 2020, the tide data was obtained from the Geospatial Information Agency (GIA) then processed with MS Excel and calculated using the Admiralty method. Tidal type in coastal Indramayu is shown in Figure 4 and Table 1.

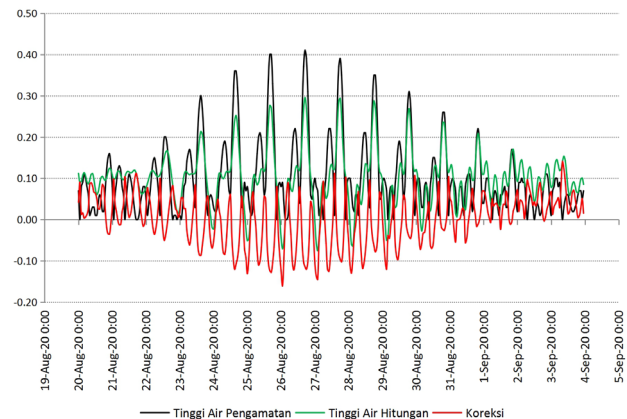


Figure 4. Tidal type in coastal Indramayu

The value of the tidal Fomzahl (F) number in Indramayu for 15 days is 1.47 So that it can be determined that the type of tide in Indramayu is a mixture with a more prominent/double inclined double type. After knowing the formzahl value and to produce the Mean Sea Level (MSL) value or the average height of the sea level, that is, we calculate the Mean High Water Level (MHWL) and Mean Low Water Level (MLWL) values and then obtain the average tidal riding value. retroactively using the least square method, this value can then be determined by the class of vulnerability assessment. Based on the MHWL

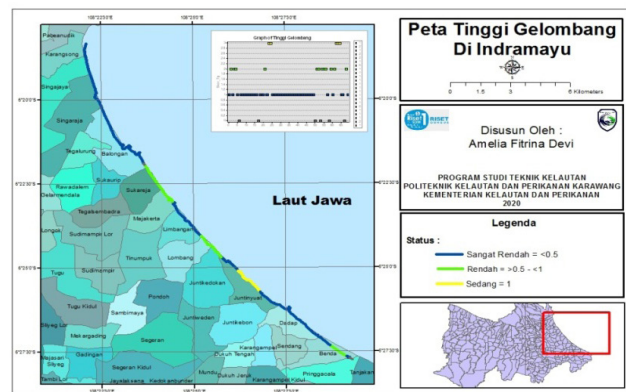
Table 1. The value of the tidal components of the Indramayu coastal

No	Symbol	Parameter Z0	A	B	Aplitudo (m)	Phase (deg/hour)	Phase (rad/hour)
0	Z0	0.1030			0.1030		
1	M2		0.0215	0.0013	0.0215	3.3933	0.0592
2	S2		-0.0073	0.1004	0.1006	94.1429	1.6431
3	N2		0.0245	0.0039	0.0248	8.9495	0.1562
4	K2		-0.0348	-0.0772	0.0846	245.7044	4.2884
5	K1		-0.0513	0.1025	0.1146	116.5565	2.0343
6	O1		0.0289	-0.0586	0.0654	296.2468	5.1705
7	P1		0.0583	-0.0404	0.0709	325.2672	5.6770
8	M4		0.0215	0.0043	0.0219	11.4340	0.1996
9	MS4		-0.0155	0.0158	0.0222	134.4635	2.3468

and MLWL calculations, it shows that the average tidal riding value (m) is 0.39672, while the value of its vulnerability into the class is very low to the tidal influence.

3.4 Sea Wave Height

The tidal data from field measurements appear to be more fluctuating because of the formation of tides that coincide with the waves so that the movement of these ocean waves affects the tide and ebb levels in sea waters. Based analysis show that the height of the breaking waves in Indramayu waters ranges from $<0.5 - 1$ meter, the breaking wave is a measurement of the wave height in the surf zone area, so it looks more random. After exiting the generated regions the waves start moving away (swell waves). The swell waves have already left the area of influence of the wind so that conditions are more stable and release their energy to the beach in the form of crashing waves, swell waves have good consistency with significant wave heights so that the wave characteristics are relatively more stable^[15]. So the maximum wave height (m) is obtained from the recording of tools in the field, which ranges from $<0.5 - 1$ meter so that the maximum effect of wave height is very low on coastal vulnerability. Meanwhile, the low status ranges from 0.5 to 1 meter and the medium one is 1 meter. The sea wave height in coastal Indramayu is shown in Figure 5.

**Figure 5.** The sea wave height in coastal Indramayu

3.5 Coastal Vulnerability Level

After classifying each parameter at the research location, a group of each physical parameter was obtained according to the criteria for coastal vulnerability. After the parameter data are scored, the next step is to classify the vulnerabilities calculated with the CVA (Coastal Vulnerability Assessment) formula, where the index range is generated from the calculation of the four physical parameters used. The resulting CVA is then classified into 4 levels of vulnerability: 1) low, 2) moderate, 3) high, and 4) very high. The vulnerability map prepared based on index grouping includes coastal areas in Indramayu, along with a coastal vulnerability map image in Indramayu using the

CVA method that has been laid out in ArcGIS.

Based on the analysis, it shows that the vulnerability index along the Indramayu coast is more dominant in the medium category or is 2.887 - 3.65. The coastal vulnerability mapping shows that villages in Indramayu are grouped into moderate to high categories. The low vulnerability status ranged from 0.54 to 1.93, while the high was 3.17 - 3.81. Limbangan village is a village that is categorized as low. Karangsong and Singaraja Villages are categorized as medium villages. Meanwhile, Juntikedokan and Benda villages are in the high category. The level of coastal vulnerability using the CVA method can then be used to analyze areas that have a vulnerability to the Indramayu coastal.

Coastal vulnerability analysis shows that most of the Indramayu coast is dominated by vulnerable classes of $\pm 60.69 \text{ km}^2$, followed by highly vulnerable classes of $\pm 49.94 \text{ km}^2$, moderate $\pm 23.45 \text{ km}^2$, non-vulnerable covering an area of $\pm 7.85 \text{ km}^2$ and very vulnerable area of $\pm 1.28 \text{ km}^2$. Three sub-districts are dominated by highly vulnerable vulnerability classes, namely, Pasekan ($\pm 22.47 \text{ km}^2$), Cantigi ($\pm 6.27 \text{ km}^2$), and Kandanghaur ($\pm 2.09 \text{ km}^2$) districts ^[14].

The results of the analysis of all coastal vulnerability parameters in all coastal districts of Indramayu obtained six sub-districts that have areas with very vulnerable classes of vulnerability. These sub-districts are Losarang district with an area of $\pm 1.03 \text{ km}^2$, Krangkeng with an area of $\pm 0.14 \text{ km}^2$, Balongan with an area of $\pm 0.07 \text{ km}^2$, Kandanghaur with an area of $\pm 0.03 \text{ km}^2$, Cantigi with an area of $\pm 0.02 \text{ km}^2$ and Indramayu with an area of $\pm 0.01 \text{ km}^2$ ^[14]. The coastal vulnerability map in Indramayu is shown in Figure 6.

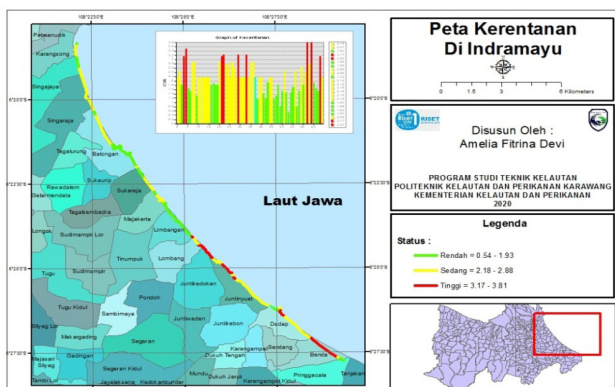


Figure 6. The coastal vulnerability map in Indramayu Coastal

4. Conclusions and Suggestions

Mapping the status of the vulnerability level of the In-

dramayu coastal area using the CVA method where the index range generated from the calculation of the four physical parameters mentioned above is between 2.887-3.651 or are in moderate vulnerability. A higher vulnerability value is found in several locations such as Juntikedokan and Benda villages. It is necessary to develop coastal protection in this area to prevent damage to the coastal area.

After conducting a study of the mapping, efforts that can be done include managing coastal areas, controlling the construction of new houses/buildings in coastal areas, and making infrastructure or coastal building design models to prevent abrasion on the coast such as groins and breakwaters as well as coastal forests (mangroves), namely as the first defense from coastal disasters to minimize the risk of coastal vulnerability.

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