Vulnerability Assessment of Mangroves using the Coastal Vulnerability Index in Timbulsloko Village, Sayung, Demak

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Abstract

The ongoing global warming is causing climate change in several regions of Indonesia, resulting in various impacts. One of these impacts affects coastal areas, namely, the rise in sea levels. The mangrove ecosystem is one of the coastal ecosystems with a crucial role in both ecological and economic aspects of life. This ecosystem is more susceptible to damage due to climate change and human activities. The purpose of this research is to determine the vulnerability level of the mangrove ecosystem, thereby serving as a reference for the rehabilitation of the mangrove ecosystem in Timbulsloko Village. The method used is descriptive exploratory, involving direct field measurements of oceanographic variables, such as salinity, substrate, and tidal data. The analysis employed was the Coastal Vulnerability Index (CVI) with scores divided into three categories: low, moderate, and high, with respective scores ranging between 0.45-2.31, 2.32-4.62, and 4.63-6.93. An analysis of the mangrove substrate was also conducted to determine the existing substrate types in Timbulsloko Village. The obtained results indicate that the salinity around the mangrove ranges from 29-30 ppt, the substrate type is characterized as mud, and the average tidal height is 1.5 m with a mixed leaning towards diurnal single tide. As a result, the vulnerability index value of the mangrove ecosystem in Timbulsloko Village is considered moderate, with a score of 3. The level of mangrove vulnerability is moderate, but sustainable management of the mangrove ecosystem is still required for the future.

Keywords: *Coastal Vulnerability Index, Mangrove Ecosystem, Oceanographic Variables, Sea Level Rise*

INTRODUCTION

The coast is the region that lies at the interface between land and sea. Coastal areas are more vulnerable to issues related to global warming, which leads to increased atmospheric temperatures and rising sea levels. The occurrence of tidal flooding ('rob') and erosion in coastal settlements contributes to a highly complex problem that necessitates serious attention and management (Mehvar *et al*., 2018). The Sayung coastal area, located in Demak Regency, is a region that frequently experiences tidal flooding (rob) and has the highest coastal erosion rate in Central Java. The sea-level rise in the Sayung coastal area is approximately 0.6-1.15 meters per year, which falls into the high-risk category (Rudiarto *et al.*, 2019).

Timbulsloko Village features a gentle and flat topography, with elevation ranging from 0 to 10 meters above sea level (Utomo *et al*., 2022). The coastal area of Timbulsloko Village is categorized as being susceptible to environmental degradation. In the 1980s, extensive land conversion was undertaken to establish aquaculture ponds, resulting in erosion within Timbulsloko Village. Erosion is a natural factor leading to a decrease in the extent of mangrove ecosystems (Suyono *et al*., 2015). Over the past 20 years, significant erosion impacts have been observed. However, from 2000 to 2005, there was a lesser decline in mangrove coverage compared to the 1990s, indicating an increased awareness of the value of mangrove ecosystems (Perdana *et al*., 2018). In addition to erosion, tidal inundation is also a concern in Timbulsloko Village. Erosion that occurred from 2015 to 2017 in Timbulsloko amounted to 0.9502 hectares (Purba *et al*., 2019). Nonetheless, the coastal area of Timbulsloko Village features a mangrove ecosystem, which plays a significant role along the coast. Mangrove ecosystems can mitigate vulnerability in coastal areas, although high erosion intensity can render mangroves susceptible (Ahmad *et al*., 2018).

Mangrove ecosystems play a crucial role in coastal and marine areas. The most vital functions of mangrove ecosystems along coastlines include bridging the gap between land and sea, carbon sequestration, mitigating natural phenomena caused by water bodies, such as erosion, waves, storms, and providing support for other biota that serve as livelihood resources for

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the surrounding communities (Mappanganro *et al*., 2018). Some of the ecosystem services provided by mangroves include supporting services (nutrient cycling, primary productivity, and land formation), provisioning services (such as food and fuel supply), and regulating services (for instance, climate change protection, storm defense, and water purification) (Hanggara *et al*., 2021). Ecosystem services from mangroves are highly significant and essential for human well-being, especially in coastal areas (Fauziyah *et al*., 2023).

The Coastal Vulnerability Index (CVI) is a method developed to assess the vulnerability of coastal regions to climate change, erosion, and sea-level rise. Vulnerability assessment is a way to understand the susceptibility of coastal areas. If an area is highly vulnerable, measures are needed to prevent or reduce its vulnerability. Coastal vulnerability in mangrove ecosystems can be assessed through various oceanographic aspects such as temperature, salinity, and tides (Ahmad *et al*., 2018). Analyzing mangrove vulnerability is of utmost importance to mitigate the impacts of various threats and protect coastal resources (Mondal *et al*., 2022). This research aims to assess the vulnerability of the Timbulsloko mangrove ecosystem, providing guidance for future mangrove rehabilitation and management efforts.

MATERIALS AND METHODS

This research focuses on the mangrove ecosystem as the object of research to assess its vulnerability using oceanographic variables measured directly in Timbulsloko Village. Field data collection was conducted on December 3-4, 2022, in Timbulsloko Village, Sayung District, Demak Regency. The research procedure involved determining the location and the collection of oceanographic variables. The selection of sampling points consisted of 27 locations, chosen to represent the distribution of dense, moderate, and sparse mangrove stands in the Timbulsloko mangrove ecosystem (Figure 1).

The sampling of variables used to assess mangrove vulnerability includes four variables, consisting of primary data collected directly in the field. This primary data includes salinity data measured using a refractometer and substrate data collected using a sediment trap device made of pipes. Additionally, tidal data from www.pasanglaut.com was obtained for a one-year period, which was later analyzed to determine the duration of tidal inundation (tidal type) using the admiralty method and the maximum tidal inundation height. Salinity measurements were taken with three repetitions at each sampling point, and the average salinity value was determined. The collected substrates were processed in the Civil Engineering Laboratory at Diponegoro University, and their substrate types were analyzed using the hydrometer method.

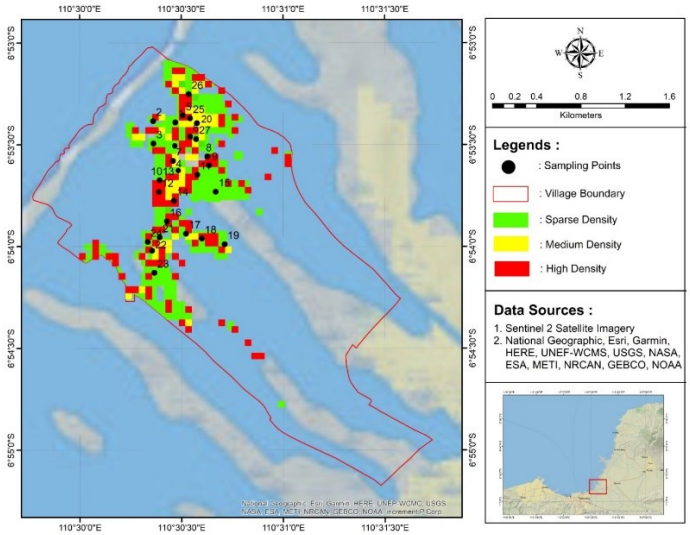

Figure 1. Research Location Map and Distribution of Mangroves in Timbulsloko Village, Sayung Subdistrict, Demak Regency

***Coastal Vulnerability Index* (CVI)**

$$CVI = \sqrt{\frac{a \times b \times c \times d}{4}}$$

Note: CVI = value (score) of Mangrove Habitat Vulnerability Index; a = value of salinity variable; b = value of substrate type variable; c = value of frequency duration of tidal inundation variable; d = value of maximum tidal inundation height variable (Ahmad *et al*., 2018).

RESULTS AND DISCUSSION

The coastal vulnerability index, measured in various aspects such as tidal height, duration of inundation/tidal type, temperature, and substrate, holds distinct values. Tidal data was obtained from *www.pasanglaut.com* for the Timbulsloko waters, with the highest tidal height recorded at 1.6 m in the months of January, May, June, July, November, and December. The lowest tide measured was 1.3 m in September. The average tidal height result is 1.5 (categorized as high). The data for tidal heights can be seen in Table 2.

The variable that most influences coastal vulnerability is the tidal cycle of seawater, with tidal fluctuations occurring in the Timbulsloko waters nearly every day. The variable that has the most significant influence on coastal vulnerability is the tidal inundation of seawater. Tidal inundation occurs daily in the waters of Timbulsloko. The optimal condition for a mangrove ecosystem typically involves tidal inundation for about 10-19 days in a month. According to Perdana *et al*. (2018), high tidal inundation intensity leads to coastal erosion in the area. The height of the tidal inundation causes land erosion, accelerating the erosion process (Sugianto *et al*., 2022).

The results of tidal data processing by determining the Formzhal value can be seen in Table 2. Tidal inundation in the waters of Timbulsloko Village occurs once for both high tide and low tide each day, typically with high tide starting in the morning and ebbing tide beginning in the evening. The tidal pattern in the waters of Timbulsloko Village is categorized as amixed tide prevailing diurnal. This aligns with Kusuma's outcomes (2013), indicating that the waters of Demak Regency and its vicinity exhibit a tidal pattern of predominantly diurnal single tide with mixed characteristics. The duration and extent of inundation significantly influence mangrove root systems as they become completely submerged, thereby reducing the supply of brackish water. Additionally, during inundation, young mangrove seedlings face challenges in acquiring oxygen and nutrient transfer within the mangrove habitat (Ahmad *et al*., 2018). Consequently, Timbulsloko Village is situated in an area characterized by high erosion susceptibility (Kharimah *et al*., 2021). Mangrove ecosystems can prevent erosion on the Timbulsloko coast.

Table 1. Modification of Coastal Vulnerability Index (Ahmad *et al*., 2018)

Variable	Weight		
	Low = 1	Medium = 2	High = 3
Salinity	15-30 $^{0}/_{00}$	10-15$^{0}/_{00}$; 30-33$^{0}/_{00}$	< 10 $^{0}/_{00}$; > 33 $^{0}/_{00}$
Substrate	Mud and clay	Sand	Stone and Pebbles
Duration of Tidal Inundation (Months)	10 – 19	20	< 10 or > 20
Maximum Tidal Inundation Height (m)	< 0,5	0,5 – 1	> 1
Coastal Vulnerability Index (CVI)	0,45-2,31	2,32-4,62	4,63-6,93

Table 2. Tides in the Waters of Timbulsloko Village

Months	Tidal Height (m)	Formzhal Value	Type of Tidal Inundation	Value
Januari-December	1.5	1.77	Mixed tide prevailing diurnal	3

Table 3. Oceanographic Variables

Variable	Result	Value
Salinity	30 ppt	1
Substrat type	silt	1

The salinity measurements taken at 27 points in the Timbulsloko mangrove ecosystem range from 29 to 30 ppt, with an average salinity of 30 ppt. These salinity results are assigned a value of 1 (low). The salinity levels are still considered optimal for mangrove growth, in line with Wantasen's (2013) outcomes that mangrove plants thrive in salinity ranges of 10-30 ppt. Based on field observations, the growth of mangroves in Timbulsloko is in good condition. Salinity is a key factor influencing mangrove growth (Efriyeldi *et al*., 2023). Other factors that influence salinity levels include land openness, area size, tidal activity, and the influence of seawater intrusion in the region (Wahyudi *et al*., 2014). *Rhizophora mucronata* and *Rhizophora apiculata* are species that grow closest to the sea and can survive in conditions with prolonged inundation of substrates (Irawan *et al*., 2021). In accordance with the mangrove ecosystem in Timbulsloko, besides *Avicennia marina*, species such as *Rhizophora mucronata* and *Rhizophora apiculata* are also found. Therefore, these species can be planted along the Timbulsloko coast to protect the coastal area.

The substrate type present in the Timbulsloko mangrove ecosystem, based on sediment particle analysis, falls into the silt substrate type category, hence assigned a value of 1 (low). According to the research conducted by Muskananfola *et al*. (2020), the substrate present in Demak is predominantly silt. This silt substrate can be utilized for the growth and development of mangroves. Silt substrate possesses fine and small grain sizes, facilitating efficient and facile nutrient absorption by the roots (Wahyudi *et al*., 2014). The waters of Timbulsloko exhibit weak currents, and their sediment composition comprises silt and clay. Silt sediment, in particular, experiences challenges in distribution due to currents (Rahmadi *et al*., 2021). A considerable number of *Avicennia marina* species were found in Timbulsloko Village. The Avicennia species of mangroves can thrive in sediment that is predominantly composed of mud or a mixture of clay and fine sand (Efriyeldi *et al*., 2023). Mangrove roots capture soil particles, which then accumulate as sediment, thereby mitigating the erosion along the coastline (Irsadi *et al*., 2019).

The CVI value obtained from the calculation of salinity, substrate type, and tidal variables is 3. Oceanographic variables can indeed influence the mangrove ecosystem. A value of 3 is assigned to the tidal variable, comprising the frequency and height of inundation, due to their relatively high values. Conversely, a value of 1 is assigned to salinity and substrate, as salinity falls within optimal levels and the substrate type is mud, categorizing both variables as low. The obtained CVI value for the mangrove ecosystem falls within the moderate vulnerability range. Robust mangrove growth plays a crucial role in safeguarding the Timbulsloko coast against erosion. In order to effectively reduce vulnerability, it is necessary to implement mangrove management that is overseen by both the government and the local community, utilizing various approaches (Soanes *et al*., 2021). Optimal management strategies have the potential to ensure the sustainability of the mangrove ecosystem and its ecosystem services, particularly in terms of coastal protection (Handayani *et al*., 2021).

Table 4. CVI value in the mangrove ecosystem of Timbulsloko Village

Variable				CVI value
a (Salinity)	b (Substrate type)	c (Long-term tidal frequency)	d (Tidal inundation height)	
1	1	3	3	3

CONCLUSION

Based on the research outcomes, it is possible to draw a conclusion that the vulnerability of the mangrove ecosystem in Timbulsloko Village, Sayung Subdistrict, Demak Regency, belongs to the moderate as indicated by a CVI value of 3. Nevertheless, the implementation of sustainable management practices for the mangrove ecosystem is essential in order to protect the coastal area.

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