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Mangrove for Climate Resilience based on Coastal Vulnerability Index, Application for Mempawah, West Kalimantan

Mangrove untuk Ketahanan Iklim berdasarkan Indeks Kerentanan Pesisir, Penerapan di Mempawah, Kalimantan Barat

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ABSTRACT
Coastal areas are particularly vulnerable to climate change. The primary objective of this study is to use the Geographic Information System (GIS) approach to assess the level of vulnerability in the coastal area of Mempawah Regency, West Kalimantan, Indonesia, by utilizing the Coastal Vulnerability Index (CVI) and analyzing the role of mangrove land cover in explaining the coastal vulnerability based on land cover characteristics. From 41 surveyed grids, a substantial 65.83% are classified under the category of very low vulnerability, while 34.14% fall within the range of low vulnerability, in Mempawah. The validation of the mangroves' role as a defense mechanism in mitigating climate phenomena within coastal areas was validated through various approaches such as Normalized Difference Vegetation Index (NDVI) and land cover
Keyword: CVI, Climate change, GIS, Vegetation, Vulnerability

ABSTRAK
Kawasan pesisir sangat rentan terhadap dampak perubahan iklim. Tujuan utama dari penelitian ini adalah menggunakan pendekatan Sistem Informasi Geografis (SIG) untuk menilai tingkat kerentanan di kawasan pesisir Kabupaten Mempawah, Kalimantan Barat, Indonesia, dengan memanfaatkan Coastal Vulnerability Index (CVI) serta melakukan analisis peran tutupan lahan mangrove dalam menjelaskan kerentanan pesisir berdasarkan karakteristik tutupan lahan. Berdasarkan 41 grid area kajian, sebanyak 65.83% diklasifikasikan sebagai kategori kerentanan sangat rendah, sementara 34.14% berada dalam kisaran kerentanan rendah, di kawasan Mempawah. Validasi peran mangrove sebagai mekanisme pertahanan dalam mengurangi fenomena iklim di kawasan pesisir telah terverifikasi melalui berbagai pendekatan Normalized Difference Vegetation Index (NDVI) dan tutupan lahan.
Kata kunci: CVI, GIS, Kerentanan, Perubahan iklim, Vegetasi

1. Introduction

West Kalimantan is one of the provinces in Indonesia boasting a coastline that stretches for a remarkable 1940 kilometers (Fitria et al., 2020). Coastal areas represent a critical ecosystem setting vulnerable to the effects of climate change. Climate change affected the sea level rise with a projected increase 1,6 m per century (Hapsari et al., 2022). Naturally, these impacts are set to significantly affect the decline in fisheries production. Increased sea level damages fish habitats and disrupts fishing operations and communities (Monnereau and Oxenford, 2017). The biogeophysical conditions of the coastal region in West Kalimantan are profoundly influenced by the interaction between the South China Sea and the tropical monsoon climate. In addition, human activities also play a role in shaping the coastal landscape (Susiati et al., 2022).

The mangrove ecosystem is one of the coastal ecosystems that plays a crucial role in maintaining the sustainability of both marine and terrestrial environments. In Indonesia, the province of West Kalimantan boasts the largest expanse of mangrove forests, covering a substantial 119,327 hectares, and hosting a remarkable 75% of the nation's mangrove species. The mangrove forest zones within West Kalimantan are distributed across multiple districts, encompassing Mempawah, Ketapang, North Kayong, Kubu Raya, Singkawang, and Sambas (SAMPAN Kalimantan, 2015). The mangrove community encompasses a diverse array of species including Avicennia spp., Sonneratia spp., Rhizophora spp., Bruguiera spp., Xylocarpus spp., Nypa sp., and many others. Various types of terrestrial animals and rare and endemic aquatic biota such as porpoises (Orcaella brevirostris), reptiles, such as estuarine crocodiles, snakes, and monitor lizards, various types of fish, crustaceans, molluscs, proboscis monkeys, macaques, Bornean ladam bats, fireflies, birds and various other types of biota also live in the Mangrove area. The biota within the mangrove ecosystem can be utilized by coastal communities. The Mangrove ecosystem also plays a role in enhancing the economic status of coastal communities through the presence of mangrove ecotourism. Ecotourism can serve as a conservation measure by bringing forth positive impacts such as economic enhancement, conservation efforts, environmental preservation, and empowerment of the local community (Nugroho et al., 2018).

The empirical establishment of a connection between the vulnerability of coastal areas and the climate-induced phenomenon of sea-level rise emphasizes a significant influence on these geographic regions. The progressive elevation of sea levels serves as a primary catalyst for transformative shifts within coastal territories. Without a doubt, the level of risk faced by human settlements and coastal domains becomes considerably more pronounced as the global climate change trajectory advances. Moreover, historical data reveals that in the 20th century, the average global sea-level rise was 1,7 mm/yr, whereas the current rate has escalated to 3,1 mm/yr—a 50% increase over the last two decades. This underscores the necessity for a concerted focus on the comprehensive management of coastal ecosystems (Williams, 2013).

The assessment of coastal vulnerability regions can be conducted using a range of methodologies, among which the Coastal Vulnerability Index (CVI) emerges as a comprehensive framework incorporating climate change variables, including sea level rise and coastal morphological conditions. Notably, a study by (Joesidawati, 2016) highlights the advantageous utility of the CVI approach for decision-makers in effectively managing coastal areas highly susceptible to climate change impacts. Moreover, other investigations applying the CVI to evaluate vulnerability, such as in Greece's coastal zones, have evidenced the efficacy of CVI in quantifying vulnerability arising from climate change, encompassing factors like the greenhouse effect (Doukakis, 2005). The CVI functions as a pivotal metric in appraising vulnerability within the context of coast-to-climate change interactions along the Australian coastline and similarly in the Himalayan regions of India (Abuodha & Woodroffe, 2006). The utilization of the CVI approach emerges as an invaluable mechanism for both the assessment and ongoing monitoring of coastal regions vulnerability, as exemplified through research by (Pandey & Jha, 2012). Therefore, the primary objective of this paper is to use the Geographic Information System (GIS) approach to assess the level of vulnerability in the coastal area of Mempawah Regency, West Kalimantan by utilizing the Coastal Vulnerability Index (CVI) and analyzing the role of mangrove land cover in explaining the coastal vulnerability based on land cover and vegetation density indices.

2. Methods

The research methodology employed encompasses an analysis of both secondary and primary mangrove distributions, utilizing data from the Ministry of Environment and Forestry for the year 2018 in Indonesia. Subsequently, the research locations were determined based on mangrove distribution, facilitating the analysis of coastal vulnerability levels through the Geographic Information System (GIS) methodology and the application of the Coastal Vulnerability Index (CVI). This endeavor aimed to validate the role of mangroves in climate change mitigation, achieved through a comprehensive examination of satellite data and climate model datasets.

2.1. Time and Location of the Research

The processing and interpretation of assembling of this research commenced from July through August 2023. The research focuses on the Pontianak District West Kalimantan Province, with geographical coordinates ranging from 108°24'00" to 109° 21' 00" East Longitude and from 0° 44 '00 " North Latitude to 0° 0' 4" South Latitude. According to the 2022 data from the Central Statistics Agency (BPS), the area dimensions for each analyzed region, based on mangrove distribution, are 120.92 km²/sq.km for East Mempawah Subdistrict and 121.12 km²/sq.km for Sungai Pinyuh Subdistrict. The specific conditions of the study area can be observed in the figure below.

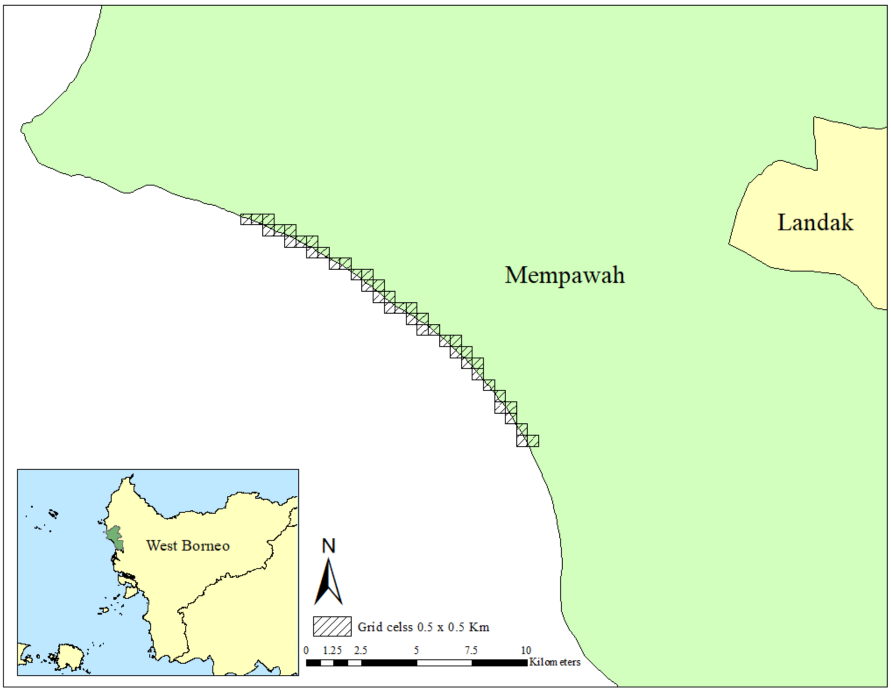

Figure 1. Map of Study Area

2.2. Tools and Data of the Research

Tools and materials employed for the analysis of coastal vulnerability levels in Mempawah Regency using the Coastal Vulnerability Index (CVI), involving coastal geomorphology parameters, coastal slope, shoreline changes (erosion or abrasion), sea level rise, significant wave height, and tidal, are presented in the table 1.

2.3. Data Procedures

The data collection procedures in this scientific research paper encompass the utilization of primary observational data, including satellite imagery data and port station data for the West Kalimantan region. Additionally, secondary data from the ECMWF climate model and forecasting, comprising oceanic information such as sea level rise and significant height wave, are incorporated. Furthermore, the paper conducts an analysis to validate the relationship between vulnerability levels and the distribution of mangrove land cover as a measure of climate resilience. This analysis involves assessing vegetation density and validating the distribution of land cover.

2.4. Data Analysis

2.4.1.Vulnerability coastal area analysis

The assessment of coastal area vulnerability in this study was conducted through the utilization of the Coastal Vulnerability Index (CVI) method, where The CVI technique, employing a ranking system, is straightforward, facilitating the identification of highly vulnerable regions especially for coastal areas. This methode simplicity enables policymakers to efficiently implement management strategies for coastal areas facing elevated sea levels, mitigating their adverse impacts.

Table 1. Tools and Datas as well as Output of Parameters for Analysis

Tools	Data	Source	Output parameters
ArcGIS 10.8	*Shuttle Radar Topographic Mission* (SRTM) 30 m	earthexplorer.usgs.gov	Topography and Slope
	Landsat collection 2 level 1, landsat 8-9 OLI/TIRS C2 L1	earthexplorer.usgs.gov	Normalized Difference Vegetation Index (NDVI)
	Sea Level Rise (SLR)	European Centre for Medium-range Weather Forecast (ECMWF)	Sea Level Rise
	Significant height of combined wind wave and swell	European Centre for Medium-range Weather Forecast (ECMWF)	Wave Height
	Land cover	Ministry of Forest and Environment	Mangrove and non mangrove land cover
	Indonesian geomorphology map	geologi.esdm.go.id	Geomorphology
MIKE 21	Tides	Port station Lon : 1.1798 N Lat : 108.968 W	Tides
Google Earth Pro	Google Earth Pro satellite	Google Earth Pro	Basemap and digitization of shoreline for shoreline change

The CVI approach, initially developed by Gornitz in 1991, has been adapted and extended to include a range of physical and geological variables. These variables encompass geomorphology, sea level rise, coastal slope and regional elevation, shoreline change, significant wave height, and tidal patterns (Koroglu et al., 2019). The calculation of coastal area vulnerability is based on a set of categorized parameters as table 2.

Each constituent within the vulnerability index calculation contributes to the extent of vulnerability exhibited by the coastal region. Risk variables are classified and ranked based on assessment weights employing a scale ranging from 1 to 5, signifying minimal vulnerability (scale 1) to elevated vulnerability (scale 5). The methodology for analyzing coastal vulnerability in this study employs the gridding technique within the ArcGIS software. These grid cells are distributed across the Mempawah Regency coastline, corresponding with the scattered mangrove distribution. The assumption underlying this approach is that each grid represents the specific area's condition, taking into account diverse CVI values attributable to distinct parameter influences. The computation of CVI values employs the subsequent equation (Koroglu et al., 2019).

$$CVI = \sqrt{\frac{a1 * a2 * a3 * a4 * a5 * a6 * a7}{n}}$$

Where :

CVI = Coastal Vulnerability Index

a1 = Geomorphology

a2 = Shoreline change
a3 = Slope
a4 = Topography
a5 = Sea level rise
a6 = Significant wave height
a7 = Tides
n = Total of variable

Table 2. Assessment of vulnerability magnitude in CVI computation (López Royo et al., 2016)

No	Variable	Score					
		Very low (1)	**Low (2)**	**Moderate (3)**	**High (4)**	**Very high (5)**	**Unit**
1	Geomorphology	Rugged and rocky coastline	Medium cliff beach, rocky beach	Rocky low-lying beaches, and alluvial plains	Pebble beach, estuary, lagoon	Sandy beach, brackish swamp, mangrove, coral reef, delta, muddy, seagrass	-
2	Shoreline change, Abrasion (-) / Accretion(+)	>2,00	1,00 - 2,00	-1,00 - 1, 00	-2,00 - 1,00	< - 2,00	m/year
3	Slope	>1,90	>1,30 - 1,90	>0,90 - 1,30	0,60 - 0,90	<0,60	%
4	Topography	>30,00	>20,00 - 30,00	>10,00 - 20,00	>5,00 - 10,00	0,00-5,00	m
5	Sea level rise	<-1,00	-1,00 - 0,90	>0,90 - 2,00	>2,00 - 4,00	>4,00	mm/ year
6	Significant wave height	<1,10	1,10 - 2,00	>2,00 - 2,25	>2,25 - 2,60	>2,60	m
7	tides	<0,50	0,50 - 1,90	>1,90 - 4,00	>4,00 - 6,00	>6,00	m

The magnitude of the vulnerability value, represented by the CVI in this context, is categorized according to the range of values computed for each grid along the coastline, and is classified as follows (Table 3).

Table 3. CVI Classification (López Royo et al., 2016)

Vulnerability categorized				
Very Low	Low	Moderate	High	Very high
2,263≤n≤6,928	6,928< n≤10,206	10,206< n≤13,693	13,693< n≤20	20< n≤45,644

Note: n meanings value of vulnerability

2.4.2 Analysis of Vegetation Density

The distribution of vegetation density in the Mempawah area, specifically within coastal regions, was assessed using the Normalized Difference Vegetation Index (NDVI) methodology. The evaluation of greenness levels, indicated by NDVI values, serves as an indicator of vegetation photosynthetic activity. This is achieved through the analysis of distinct surfaces under various wavelengths of light using satellite imagery. NDVI, a form of spectral sharpening image transformation, is recognized for its utility in vegetation-related investigations (Andini et al., 2018). The computation of NDVI values is conducted mathematically using the following equation. Meanwhile, the level of vegetation density can be categorized in Table 4.

$$NDVI = ((NIR-RED))/((NIR+RED))$$

Where :
NDVI = Normalized Difference Vegetation Index
NIR = Citra band 5 pada satelit landsat 8
RED = Citra band 4 pada satelit landsat 8

Table 4. Categorized of NDVI (Sunaryo & Iqmi, 2015)

Dense of vegetation classification	**NDVI**
Cloud and Water	$-2{,}00 < n \leq 0{,}00$
Non-vegetation	$0{,}00 < n \leq 0{,}21$
Not dense vegetation	$0{,}21 < n \leq 0{,}42$
Moderate dense vegetation	$0{,}42 < n \leq 0{,}63$
Dense vegetation	$0{,}63 < n \leq 0{,}85$

Note: n meanings value of NDVI

2.4.3. Land Cover Distribution Validation

The validation of mangroves as a defense mechanism in mitigating climate phenomena within coastal areas is established through the examination of scattered mangrove and non-mangrove land cover data across the Mempawah Regency region. Land cover data is classified into clusters based on the presence or absence of mangrove vegetation. This comprehensive validation, utilizing a combination of primary data sources, aims to elucidate the theoretical and detailed understanding of how mangroves significantly contribute to the preservation of coastal area conditions.

3. Results and Discussion

3.1. CVI and Its Components

Geomorphological conditions establish the foundational characteristics of the coastal environment. Coastal geomorphology further influences the resilience of diverse landforms against erosion, thus bearing significant implications for coastal vulnerability (Noor & Abdul Maulud, 2022). Through an analysis of vulnerability predicated upon geomorphology, utilizing the Indonesian geomorphology map, Mempawah Regency's coastal condition in 2010 was characterized as a mangrove-covered beach/swamp. (Kumar et al., 2010) expound that geomorphic regions categorized as high vulnerability areas include sandy beaches, mangroves, and spits. Consequently, coastal zones displaying heightened vulnerability necessitate robust adaptive strategies to contend with climate change-induced challenges such as sea level rise. Alterations in coastal geomorphological attributes exhibit a correlation with shoreline change (Maiti & Bhattacharya, 2009). Observing the Mempawah Regency, it becomes evident that the shoreline change is predominantly positioned within the low to moderate vulnerability, with values ranging from 0.2 to 10.3 meters.

Additional parameters serving as benchmarks for assessing the vulnerability of coastal areas include the slope and topography characteristics of the region. Regarding the coastal slope, Mempawah Regency demonstrates various slope percentages, as illustrated in the figure 2, with a maximum slope value of 12.24% and a minimum slope of 2.79%. These slope conditions fall within the classification of very low to low vulnerability levels. Conversely, in terms of topographic features, Mempawah Regency exhibits areas along the coastline characterized by high to very high vulnerability. Notably, a higher elevation of the coastal terrain corresponds to a reduced vulnerability level. For instance, Mempawah beach rests at an elevation ranging from 0.35 to 11.29 meters.

The vulnerability of coastal areas, as assessed through parameters such as sea level rise, significance wave height, and tides patterns, can significantly describe the vulnerability of these areas, particularly in the context of climate change events. Within the vulnerability classification, the sea level rise rate along the coast of West Kalimantan, measured at 0.319 mm/year, falls within the moderate category. Consequently, it becomes imperative to implement suitable mitigation and adaptation strategies to reduce risks to coastal communities.On the other hand, when considering the wave height parameter, which registers at 0.01 meters, and the tides values derived from port data, amounting to 0.72 meters, these conditions exert a positive influence on vulnerability. In essence, the region is characterized b

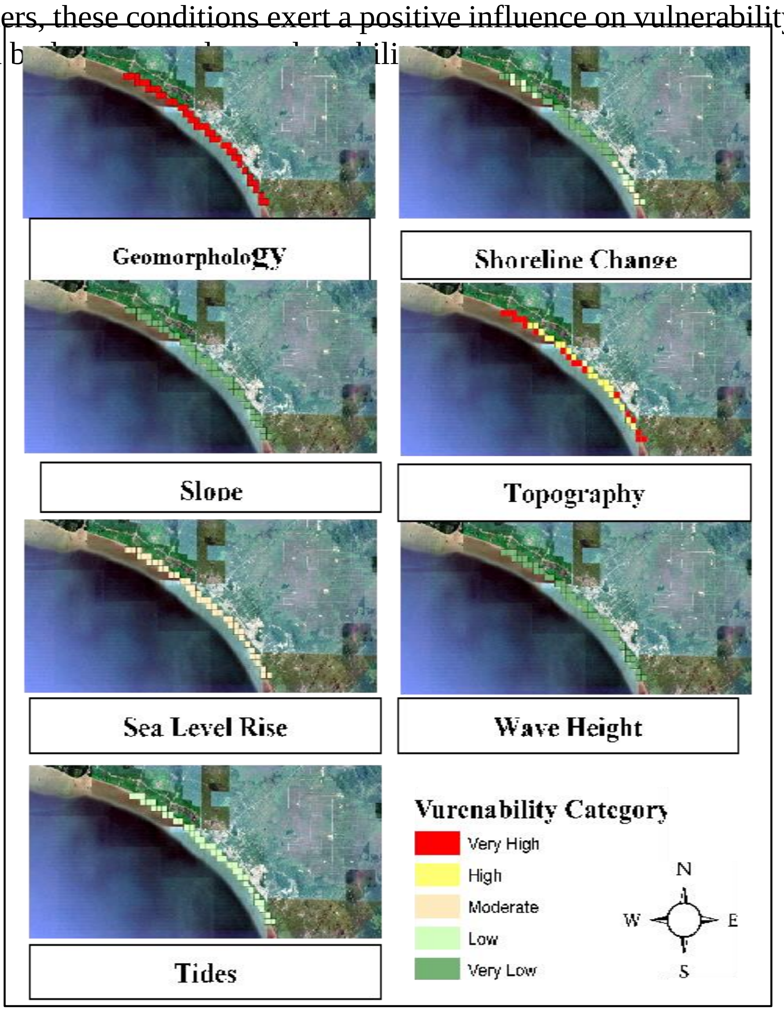

Figure 2. Vulnerability of Coastal Area Map, Mempawah Regency, based on CVI Calculation of Parameters

Regions characterized by a substantial distribution of mangroves, as depicted in Figure 3, underscore the important role of mangrove ecosystems in preserving coastal area conditions with regard to vulnerability. Notably, along the shoreline area, segments showing a state of very low vulnerability are mainly characterized by dense mangrove coverage, although certain CVI category values also correspond to low vulnerability levels. Remarkably, the scope of the very low vulnerability zone is up to 8.8 kilometers along the coastline. Furthermore, Table 5 emphasizes that among the 41 surveyed grids, a significant proportion of 65.83% is classified under the category of very low vulnerability, while 34.14% fall within the low vulnerability range. These findings suggest that utilizing mangrove ecosystems can emerge as a viable strategy to address the challenges posed by global climate change, particularly in coastal areas.

Coastal regions are particularly vulnerable to climate change impacts from an oceanographic standpoint (Rositasari et al., 2011). These impacts incorporate factors such as sea level rise, coastal erosion, and shifts in ecosystems. The assessment of coastal vulnerability plays an important role in understanding various elements that can influence the coastal condition during natural disaster scenarios, notably the global phenomenon of climate change (Zhu et al., 2019). The Coastal Vulnerability Index (CVI) stands as a significant tool for evaluating the degree of coastal vulnerability, especially in relation to erosion and wave effects. Several studies, exemplified by Friess et al. (2019), underscore the multifaceted benefits of mangroves in mitigating coastal hazards such as shoreline stabilization and erosion reduction. These works highlight the necessity of integrating mangrove resilience and adaptation into Coastal Vulnerability Index (CVI) analyses, thereby enhancing the understanding of coastal vulnerability. The Intergovernmental Panel on Climate Change (IPCC) outlines that CVI is determined by three key criteria components: exposure, sensitivity, and the adaptive capacity of the coastline in response to climate change events (Nguyen et al., 2021).

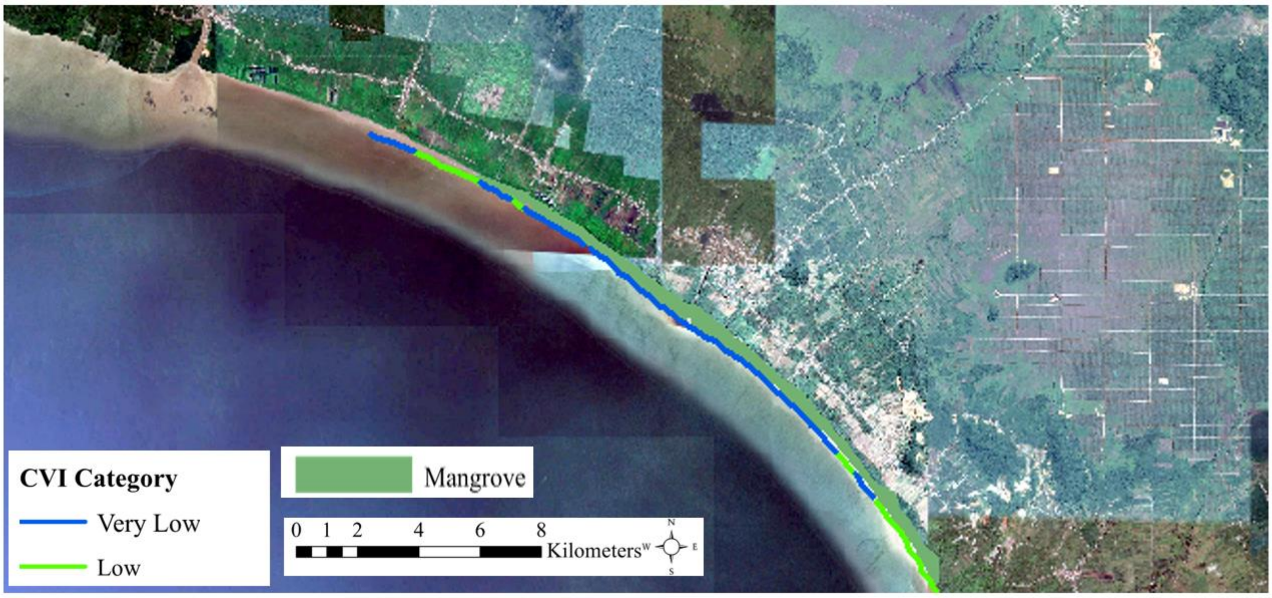

Figure 3. Distribution of vulnerability category base on CVI value in shoreline area Mempawah Regency

Coastal Vulnerability using the Coastal Vulnerability Index (CVI) for this research focuses on determining the magnitude of coastal vulnerability within the Mempawah Regency. The vulnerability analysis was conducted by partitioning the coastline into 41 grids, each with dimensions of 0.5 x 0.5 km. The assessment of vulnerability levels, based on the CVI values, encompassed various parameters such as coastal geomorphology, shoreline change, coastal slope, regional topography, sea level rise, significant wave height, and tidal range. The coastal geomorphology of Mempawah Regency exhibited a significant characteristic, with the entire coastal area falling within the very high vulnerability class. In terms of coastline changes and coastal slope, the Mempawah coastal area generally exhibited a very low to low vulnerability class. This can be attributed to the protective influence of the mangrove ecosystem, which helps maintain the stability of the coastline and reduces susceptibility to sedimentation and abrasion. Additionally, the steep nature of the coastal slopes contributes to the region's low vulnerability level. Unlike sloping coasts, steep coastlines are less prone to the significant consequences of sea level rise (Rao et al., 2009), which is in contrast to the potential flooding risks faced by mildly sloping coastal areas.

The topographic parameter, specifically area elevation, illustrates a gradient of vulnerability across various coastline grids, ranging from high to very high levels. Lower coastal elevations correlate with increased vulnerability potential and conversely, higher elevations exhibit reduced vulnerability. Notably, the distribution reveals that 51% of the topographic vulnerability level falls within the high category, while 46.34% resides in the very high category. Sea level rise, wave height, and tidal patterns are additional factors impacting the distribution of Coastal Vulnerability Index (CVI) values. Each parameter is classified into moderate, very low, and low categories. The application of CVI to oceanic conditions serves as an indicator for flood vulnerability, exemplified by a sea level rise of 0.31 meters, which elevates the risk of intensified and recurrent flooding. Moreover, wave height's magnitude assumes significance as an indicator of wave energy, influencing coastal sediment budgets (Koroglu et al., 2019). In conjunction, coastal tides play a role, particularly in instances of elevated tidal events that increase flood risk.

Table 5. Classification of CVI Value by the parameters in Mempawah Regency

Grid	Score							CVI	Category
	Geomor-fology	Shoreline change	Slope	Topo-graphy	Sea Level Rise	Significant Wave Height	Tides		
A1	5	1	1	5	3	1	2	5,477	Very Low
A2	5	1	1	5	3	1	2	5,000	Very Low
A3	5	2	1	5	3	1	2	7,071	Low
A4	5	3	1	5	3	1	2	8,660	Low
A5	5	1	1	5	3	1	2	5,000	Low
A6	5	3	1	5	3	1	2	8,660	Low
A7	5	2	1	5	3	1	2	7,071	Low
A8	5	1	1	4	3	1	2	4,472	Very Low
A9	5	1	1	4	3	1	2	4,472	Very Low
A10	5	2	1	5	3	1	2	7,071	Low
A11	5	1	1	4	3	1	2	4,472	Very Low
A12	5	1	1	4	3	1	2	4,472	Very Low
A13	5	1	1	4	3	1	2	4,472	Very Low
A14	5	1	1	4	3	1	2	4,472	Very Low
A15	5	1	1	4	3	1	2	4,472	Very Low
A16	5	1	1	5	3	1	2	5,000	Very Low
A17	5	1	1	4	3	1	2	4,472	Very Low
A18	5	1	1	5	3	1	2	5,000	Very Low
A19	5	1	1	4	3	1	2	4,472	Very Low
A20	5	1	1	5	3	1	2	5,000	Very Low
A21	5	1	1	5	3	1	2	5,000	Very Low
A22	5	1	1	3	3	1	2	3,873	Very Low
A23	5	1	1	5	3	1	2	5,000	Very Low
A24	5	1	1	4	3	1	2	4,472	Very Low
A25	5	1	1	4	3	1	2	4,472	Very Low
A26	5	1	1	4	3	1	2	4,472	Very Low
A27	5	1	1	4	3	1	2	4,472	Very Low
A28	5	1	1	4	3	1	2	4,472	Very Low
A29	5	1	1	4	3	1	2	4,472	Very Low
A30	5	1	1	4	3	1	2	4,472	Very Low
A31	5	1	1	4	3	1	2	4,472	Very Low
A32	5	1	1	5	3	1	2	5,000	Very Low
A33	5	3	1	4	3	1	2	7,746	Very Low
A34	5	2	1	4	3	1	2	6,325	Very Low
A35	5	2	1	5	3	1	2	7,071	Low
A36	5	3	1	4	3	1	2	7,746	Low
A37	5	2	1	5	3	1	2	7,071	Low
A38	5	3	1	4	3	1	2	7,746	Low
A39	5	3	1	5	3	1	2	8,660	Low

A40	5	3	1	5	3	1	2	8,660	Low
A41	5	2	1	5	3	1	2	7,071	Low

The evaluation of each Coastal Vulnerability Index (CVI) parameter indicates that coastal vulnerability in the Mempawah area principally falls within the very low and low vulnerability categories. This conclusion is reinforced by the classification of 5 out of 7 CVI variables into the low vulnerability class. Notably, marine-related variables (sea level rise, wave height, and tides), as well as coastal conditions like coastal slope and shoreline changes, exhibit relatively minor fluctuations in this region. Effective coastal geophysical management prioritization, particularly concerning geomorphological and topographic considerations that trend towards lower vulnerability. Addressing these aspects is essential to mitigate potential threats to coastal vulnerability. As a result, informed decisions and robust resilience management strategies can be developed to proactively combat future climate change impacts.

3.2. NDVI and Land Cover

The distribution of vegetation density in the Mempawah Regency is captured through the employment of NDVI, resulting in values spanning from -0.28 to 0.64. Spatially depicted in Figure 4 (a), the coastal vicinity of Mempawah Regency predominantly exhibits substantial vegetation density. This observation is further reinforced by the focal study area showcased in Figure 5(b), underscoring the prevalence of mangrove vegetation among the distributed vegetation within the Mempawah region.

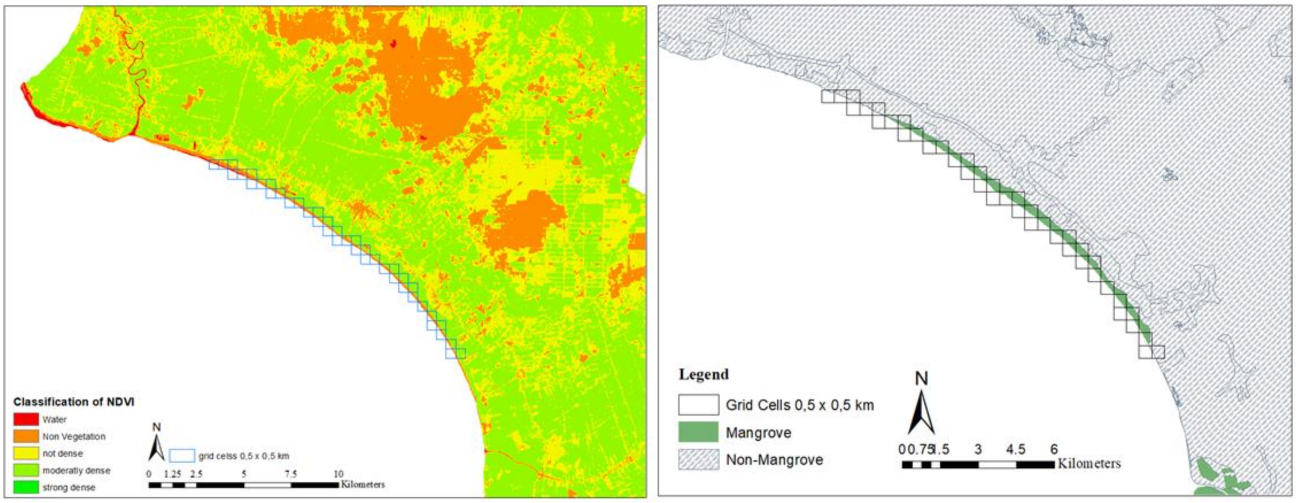

Figure 4. (a) Vegetation Density Map Using NDVI (b) Mangrove and Non-Mangrove Land Cover Map

A wide range of critical characteristics and functions that are inherent to vegetation are represented by the simple Normalized Difference Vegetation Index (NDVI) formula and its direct connection to the photosynthetic capacity of vegetation. These cover a wide range of topics with several applications in areas including agriculture, forestry, ecology, biodiversity, and many other areas, such as the percentage of photosynthetic radiation assimilated by the canopy, leaf area, canopy "greenness," and gross primary productivity (Robinson et al., 2017). Based on the NDVI value classification table 4, the study area in Figure 4(a) shows that 80% of the grid is in a dense vegetation area and the other 20% is in an area with little and no vegetation. The NDVI value is in accordance with the figure 4(b) with KLHK land cover map which shows the distribution of mangroves in 80% of the study area grid. CVI values in the 80% densely vegetated grid show very low values and in the 20% grid show low values. Categories of high geomorphological vulnerability values categorize Sandy beach, brackish swamp, mangrove, coral reef, delta, muddy, seagrass into one. Mangroves can play a role in reducing CVI values with coastal geomorphology area conditions such as Sandy beach, brackish swamp, or delta. Climate resilience of coastal areas can be pursued by maintaining mangrove ecosystem habitats. By conducting studies on vulnerability in coastal areas based on physical parameters using CVI index calculations, valuable guidance can be provided for mitigation and adaptation efforts to climate change in coastal regions, particularly in preserving mangrove ecosystems. This research has demonstrated the critical role of mangroves in determining coastal area vulnerability. Suggestions for future research include integrating social factors to elucidate the correlation between the societal role of coastal communities in confronting climate change, including aspects of social vulnerability.

4. Conclusion

The vulnerability assessment of the Mempawah coastal area utilized seven variables (geomorphology, shoreline change, coastal slope, topography, sea level rise, significant wave height, and tides) to calculate Coastal Vulnerability Index (CVI) values. This categorization positioned the Mempawah coastal region within a state of very low vulnerability (>50% on the sampled shoreline grid). The effectiveness of mangrove vegetation in sustaining vulnerability levels was validated through various approaches. Notably, the analysis of vegetation density distribution using NDVI demonstrated high values (up to 0.64 NDVI) within the region. Additionally, Ministry of Forestry and Environment data from 2019 indicated the prevalence of mangrove domination across the average coastal expanse.Consequently, mangroves play a vital role in safeguarding coastal areas against the ongoing challenges posed by climate change. The quantitative nature of this CVI analysis enhances the realism of vulnerability assessment for the Mempawah coast. As a result, CVI emerges as a pivotal tool to aid future decision-making processes in coastal management. This study underscores the significance of minimizing reliance on qualitative, subjective theories when analyzing vulnerability, emphasizing the need for more objective approaches.

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