SPATIAL DISTRIBUTION OF VULNERABILITY LEVELS DUE TO SEA LEVEL RISE AND TIDAL WAVES IN THE COASTAL AREA OF NORTH BALI

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Abstract: Vulnerability is a condition or situation that can reduce a community's ability to prepare themselves for danger. Amidst various disaster threats to coastal areas, including rising sea levels and tidal waves, data and information on regional vulnerability as a basis for policymaking are urgently needed. This study analysed the spatial distribution of the regional vulnerability index on the coast of northern Bali. The work process in this study was carried out through spatial analysis of regional vulnerability indicators facilitated by Geographic Information Systems (GIS) software. The results of this study found variations in the vulnerability index of the coastal areas of northern Bali, which were generally in the high category, except for Celukan Bawang Village and Purwakerthi Village. These variations are caused by variations in social, physical, economic, and environmental indicators in coastal areas that are potentially affected by disasters.

Keywords: Vulnerability, coastal areas, social, physical, economic, environmental.

Introduction

One of the impacts of climate change that continues to be discussed by the international community is rising sea levels. Rising sea levels will have negative impacts on coastal areas such as coastline erosion, inundation of coastal areas, increased risk of flooding, coastal erosion, tsunamis, tropical storms, and seawater intrusion (Nicholls, 2003; Hopkinson *et al.*, 2008; Marfai *et al.*, 2011; McEvoy *et al.*, 2021). Recent studies by several researchers have made similar findings of rising sea levels impacting coastal areas such as tidal flooding and disruption to coastal ecosystems and biodiversity (Zainuri *et al.*, 2022; Jasour *et al.*, 2022; De Bosschere, 2023). Other studies found rising sea levels resulted in changes in water quality (De Bosschere, 2023) and coastal morphology (Anwar *et al.*, 2022), as well as increased incidences of tidal waves (Bachtiar, 2012; Ulfah *et al.*, 2023).

Rising sea levels can threaten the existence of archipelagic countries and the maritime interests of nations. The increase in sea levels is felt in almost all areas directly adjacent to the sea, especially Indonesia, an archipelagic country with many small islands that are vulnerable to rising sea levels (Ministry of National Development and Planning, 2014).

The Intergovernmental Panel on Climate Change (IPCC) has carried out simulations on the impact of rising sea levels worldwide reaching 110 cm by 2100 while the Asian Development Bank (2007) estimates that sea levels, especially in Indonesia could rise as much as 15 cm to 90 cm by 2100. This increase in sea level is expected to affect the coastal areas of Indonesia, at least by increasing the area of inundation in coastal areas, thereby causing coastline erosion and increasing the area of areas experiencing saltwater intrusion. This condition will impact the environment in coastal areas because it has the potential to sink and lose coastal ecosystems (IPCC, 2022). In light of the numerous adverse effects of sea level rise on coastal regions, it is essential to

assess the vulnerability of these areas to rising sea levels. This vulnerability level data will be used as a reference for disaster management in coastal areas. It is expected to protect, conserve, rehabilitate, utilise, and enrich coastal resources sustainably (Law of the Republic of Indonesia Number 27, 2007). The focus of this study is the coastal area of North Bali. According to results of the BNPB data analysis released via inaris. bnpb.go.id, North Bali could be impacted by rising sea levels, especially tidal waves.

Methods

This research was conducted along the coastal area of northern Bali, focusing on the western, central, and eastern regions, as presented in Figure 1.

Referring to Figure 1, the vulnerability analysis in this study was conducted spatially by combining all components of vulnerability obtained by combining several constituent parameters as shown in Figure 2. The constituent components and vulnerability parameters consist of social, physical, economic, and environmental vulnerability.

The data sources used to analyse, as shown in Figure 2 are presented in Table 1.

Based on the guidelines in Table 1, an overlay analysis is then carried out to obtain the coastal area vulnerability index, which is facilitated using Geographic Information Systems (GIS) software. Each score of each indicator greatly affects the coastal area vulnerability index. The determination of the coastal area vulnerability index after the overlay process is shown in Table 2.

Results and Discussion

Vulnerability is the inability of a region, including the elements within it to face the threat of disaster (Cannon & Muler, 2010). Vulnerability consists of physical, social, economic, and environmental vulnerabilities. Based on the results of data analysis referring to the guidelines in Tables 1 and 2, the results are obtained as presented in the Table 3.

Based on Table 3, each village has a quite varied spatial distribution of vulnerability indices, which is greatly influenced by the index of each vulnerability indicator. Although

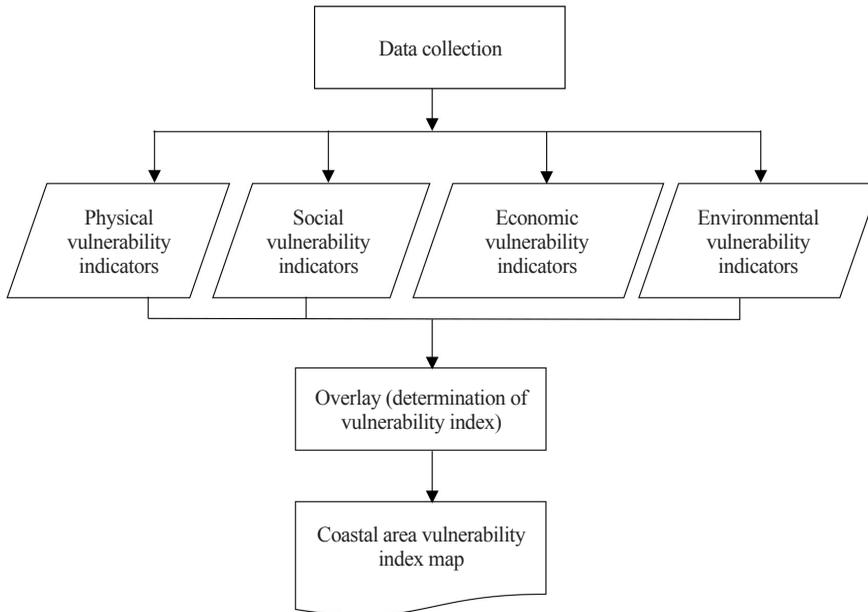Figure 1: Research location on the North Bali Coast

Figure 2: Vulnerability components and parameters of each vulnerability component

the index of one indicator is low because the other indicator is at high vulnerability, the area generally has a high category vulnerability index. In general, the spatial distribution of the vulnerability level of northern Bali's coastal area and the data analysis results are presented in Figure 3.

Based on Figure 3 and Table 3, it is known that the spatial distribution of the coastal area vulnerability index due to the increase in sea level and extreme waves on the coast of North Bali is in the medium and high categories. Villages with a dominant high vulnerability index are found in all coastal villages except Pacung Village and Purwakerthi Village. The variation in the coastal area vulnerability index is mainly because in these areas, the physical vulnerability index at several points is in the low category. The low physical vulnerability index in the two villages is because some of the coasts comprise high cliffs, so they can be a safeguard against increasing sea levels and tidal waves. Further analysis of Table 3 was carried out in one of the villages that has been developed into a tourist destination, namely Baktiseraga Village. The results of the overlay of social, physical,

economic, and environmental vulnerability indicators obtained the following results.

Based on Figure 4, the coastal area vulnerability index of Baktiseraga Village is in the high category. There is a location in Baktiseraga Village whose economic vulnerability index is in the very high category because the area has a cultural heritage in the form of the Segara Penimbangan Temple. There is also a location in Baktiseraga Village whose physical vulnerability index is in the high category because in the area, there are residential houses, which is also in line with the research results of Marfai (2011) and Roukounis and Tsihrintzis (2022). After overlaying all these vulnerabilities, the coastal area vulnerability index is in the high category. However, in terms of social vulnerability, it is in the medium category because in the area, there are population activities that result in physical development, as shown in Figure 5, which will cause a high level of vulnerability. Physical factors are closely related to the condition of the area both naturally and after human intervention through physical development in coastal areas.

Table 1: Vulnerability indicators

No.	Indicators	Unit	Criteria				
			S. R.	R	M	T	S. T.
			Score 1	Score 2	Score 3	Score 4	Score 5
			Social vulnerability				
1	a. Population density	Soul/ha	< 5	5-7.5	7.5-10	10-12.5	> 12.5
	b. Sex ratio	%	> 40	40-30	30-20	20-10	< 10
	c. Poor population ratio	%	< 10	10-20	20-30	30-40	> 40
	d. Disabled ratio	%	< 10	10-20	20-30	30-40	> 40
	e. Age group ratio	%	< 10	10-20	20-30	30-40	> 40
	f. Education	-	High school and above	High school	Junior high school	Elementary school	No school
	g. Population awareness	-	Nothing	-	-	-	Available
			Economic vulnerability				
2	a. Coastal income	-	Nothing	-	-	-	Available
	b. Coastal jobs/livelihoods	-	Nothing	-	-	-	Available
	c. Cultural heritage	-	Nothing	-	-	-	Available
	d. GRDP	Rp1,000	449,500	449,500-36,250	362,500-246,500	246,500-130,500	< 130,500
	e. Productive land (cultivated areas)	-	Nothing	-	-	-	Available
			Physical vulnerability				
3	a. House	-	Nothing	-	-	-	Available
	b. House type	-	Permanent	-	-	-	Not permanent
	c. Coastal typology	-	Mountain relief	Mountain relief	Hill relief	Wavy relief	Flat relief
	d. Geomorphological forms	-	High cliff	Medium cliffs, indented coasts	Low cliffs, coral reefs, mangroves	Rocky sand, lagoon alluvial plains	Beach with buildings, sand, muddy delta
	e. Elevation	m	> 30	20-30	10-20	5-10	< 5

f. Rate of coastline change	% per region	Less than 20% of the coastline is eroded	-	Between 20% to 60% of the coastline is eroded	-	Over 60% of the coastline is eroded
g. Coastal slope	%	>1/10	1/10-1/20	1/20-1/30	1/30-1/50	1/50-1/100
h. Extreme wave events	m	<1	1-1.6	1.6-2.2	2.2-2.8	>2.8
i. Tide	m	<1	1-2	2-4	4-6	>6
j. Distance from the beach	m	>4,500	4,500-2,100	2,099-900	899-300	<300
k. Geological type	-	Volcanic	Conglomerate	Sediment	Consolidated sediments, clay, silt	Consolidated sediment, gravel, sand
l. Surface roughness	-	Forest	Mountain relief	Land without cover	Rural settlements	Urban settlements
m. Structural security	-	Available	-	-	-	Nothing
n. Infrastructure	-	Nothing	-	-	-	Available
o. Estuary	-	Nothing	-	-	-	Available
Environmental vulnerability						
a. Protected forests	-	Available	-	-	-	Nothing
b. Natural forests	-	Available	-	-	-	Nothing
c. Mangrove forests	-	Available	-	-	-	Nothing
d. Shrubs	-	Available	-	-	-	Nothing

(Section label: 4)

Source: Gornitz et al. (1991), Marfai (2011), Handayani et al. (2017), BNPB Disaster Risk Assessment Technical Module (2019), Thieler and Hammar-Klose (2000), Furlan et al. (2021), and Roukounis and Tsihrintzis (2022).

Table 2: Coastal area vulnerability index criteria

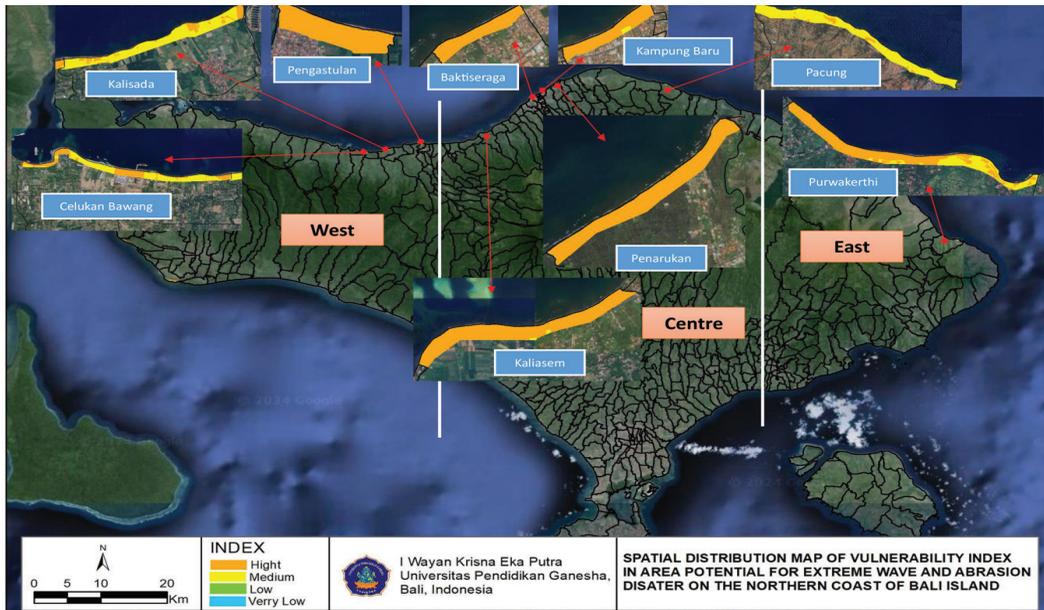| Coastal Area Vulnerability Index	Calculation Criteria	Information
Very low (S. R.)	≤ 55.8	
Low (R)	$55.8 \leq 80.6$	The score range is adjusted
Medium (M)	$80.6 \leq 105.4$	according to the number of
High (T)	$105.4 \leq 130.2$	indicators used
Very high (S. T.)	> 130.2	

Figure 3: Spatial distribution of vulnerability index for potentially impacted by sea level rise and extreme wave disasters on the North Bali Coast
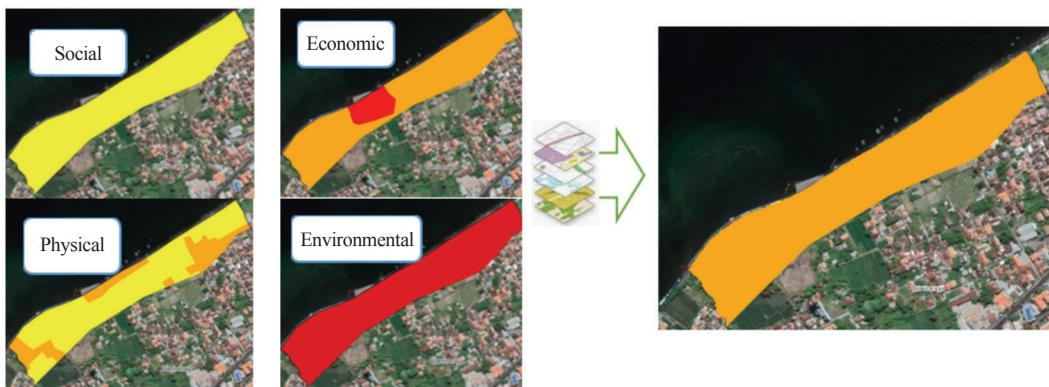

Figure 4: Overlay process for determining coastal area vulnerability

Table 3: Results of the analysis of the vulnerability index of the North Bali coastal area

Villages	Social	Index	Physical	Index	Economic	Index	Environmental	Index	Total Vulnerability	Index
Baktiseraga	20	Medium	49	Medium	21	High	20	Very high	110	High
	20	Medium	47	Medium	25	Very high	20	Very high	112	High
	20	Medium	54	High	21	High	20	Very high	115	High
	20	Medium	54	High	25	Very high	20	Very high	119	High
Celukan Bawang	20	Medium	47	Medium	21	High	20	Very high	108	High
	20	Medium	56	High	21	High	16	High	113	High
	20	Medium	54	High	21	High	20	Very high	115	High
	19	Medium	47	Medium	21	High	16	High	103	Medium
	19	Medium	48	Medium	21	High	20	Very high	108	High
Kaliasem	19	Medium	54	High	21	High	16	High	110	High
	19	Medium	54	High	21	High	20	Very high	114	High
	19	Medium	40	Medium	21	High	16	High	96	Medium
	20	Medium	47	Medium	21	High	16	High	104	Medium
Kampung Baru	20	Medium	49	Medium	21	High	20	Very high	110	High
	20	Medium	54	High	21	High	16	High	111	High
	20	Medium	56	High	21	High	20	Very high	117	Medium

	17	Low	36	Medium	25	Very high	16	High	94	Medium
	17	Low	45,3	Medium	21	High	16	High	99,3	Medium
Pacung	17	Low	43,5	Medium	21	High	20	Very high	101,5	Medium
	17	Low	52	High	21	High	16	High	106	High
	17	Low	52	High	21	High	20	Very high	110	High
	20	Medium	47	Medium	21	High	20	Very high	108	High
Penarukan	20	Medium	50	Medium	21	High	20	Very high	111	High
	20	Medium	55	High	21	High	20	Very high	116	High
Pengastulan	20	Medium	49	Medium	21	High	16	High	106	High
	20	Medium	56	High	21	High	16	High	113	High
	19	Medium	36,5	Low	21	High	16	High	92,5	Medium
	19	Medium	49	Medium	21	High	16	High	105	Medium
Purwakerthi	19	Medium	47	Medium	21	High	20	Very high	107	Medium
	19	Medium	54	High	21	High	16	High	110	High
	19	Medium	54	High	21	High	20	Very high	114	High

Source: Research results (2023)

The year 2004   The year 2004

Figure 5: Development of settlement on coastal borders in coastal areas

Developing coastal areas with various physical facilities will affect social indicators, especially the high number of people living in coastal areas (Roukounis & Tsihrintzis, 2022). The impact of various activities of residents living in coastal areas is the tendency of people to depend on their income from coastal areas, especially for fishermen. Likewise, from an environmental perspective because coastal areas have been subject to various community interventions, changes in the type of land use will affect environmental vulnerability (Furlan *et al*., 2021). Generally, coastal areas filled with protected forests, nature, or mangroves will have lower vulnerability because these natural features can mitigate damage to coastal areas.

However, because there have been various physical buildings in coastal areas, this condition increases the vulnerability of coastal areas. The existence of physical, social, economic activities, and changes in terms of environmental conditions are in line with research conducted by Siagian *et al.* (2014), Hamuna *et al.* (2018), Kim and Gim (2020), and other researchers who focus on coastal area vulnerability. In addition to being influenced by natural physical conditions, aspects of population activity, local wisdom, and suboptimal law enforcement are also contributing factors to the high vulnerability index of the area on the coast of North Bali. In terms of physical condition, the dominant factors influencing the high vulnerability index are typology, geomorphology, elevation and slope of the area, and the presence of physical facilities. The natural physical conditions at

the research location have turned out to be the dominant factor causing the high vulnerability.

Moreover, the situation is exacerbated by the physical conditions of the area as a result of community intervention, for example, the construction of houses. That is in line with research conducted by Roukounis and Tsihrintzis (2022), which found that the physical presence of buildings in coastal areas contributes to the increasing vulnerability of coastal areas. In terms of aspects of human activity that impact social vulnerability, it is known that coastal areas are where residents live, especially fishermen, including activities related to tourism activities. Bali's coastal area is almost entirely used as a tourist destination. People in coastal areas carry out various activities as a source of livelihood, either as fishermen, farmers, or tourism actors. These activities will also cause high population density and increase the built-up area in coastal areas. That is the cause of high vulnerability, as also expressed by Moftakhari *et al*. (2017), Martyr-Koller *et al*. (2021), and van den Hurk *et al*. (2022).

Conclusions

Based on the results of the analysis that has been carried out, it was found that the coastal area of North Bali has a vulnerability index that is generally in the high category against the threat of rising sea levels and tidal waves. Development of the coastal area brings a multiplier effect on other activities that increase the vulnerability index of the coastal area. It is

also strengthened by the increasing optimisation of the coastal border area not only for residential development but also for economic activities, increasing the density of occupational activities in the coastal area.

Acknowledgements

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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