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ANALYSIS AND DEVELOPMENT OF VULNERABILITY INDICATORS DUE TO CLIMATE CHANGE IN THE COASTAL AREAS OF THE ISLAND OF BALI

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Abstract: Vulnerability is a situation or condition that can reduce a community's ability to prepare itself to face danger. The increasing development of vulnerability indicators has the impact of not being fully accommodated in disaster mitigation efforts, so, this research is aimed at analysing and developing vulnerability indicators for coastal areas affected by the threat of disasters, especially the impact of climate change in the coastal areas of Bali Island. The results of this research define that existing disaster risk reduction efforts still need to align with the concept of disaster risk reduction, which provides the most significant opportunity to reduce vulnerability because existing vulnerability indicators have not been fully used as a basis for disaster risk reduction. For this reason, when assessing regional vulnerability, we must pay attention to the elements of exposure, impact, capacity, sensitivity, and law enforcement. This research also found that massive development in coastal border areas multiplies other activities, increasing the regional vulnerability index.

Keywords: Vulnerability, coastal areas, climate change, disaster risk reduction.

Introduction

Climate change is a global issue that requires seriousness from all parties through cooperation, including international involvement in handling it (Rosyada *et al*., 2021). The impact of climate change on the socio-economic conditions of communities in coastal areas is severe. Recent research conducted by several researchers states the same thing that rising sea levels in coastal areas cause various impacts such as tidal floods, which will inundate coastal areas and disrupt the ecosystem and biodiversity on the coast (Zainuri *et al*., 2022; Jasour *et al*., 2022; De Bosschere, 2023) including impacts on changes in water quality (Achiari *et al*., 2022; De Bosschere, 2023) and changes in beach morphology (Anwar *et al*., 2022). Apart from that, it also has an impact on environmental and socio-economic damage to communities in coastal areas and is detrimental to marine ecosystems, including local assets in coastal areas (Moftakhari *et al*., 2017; Martyr-Koller *et al*., 2021; van den Hurk *et al*., 2022).

Based on the analysis of these impacts, the focus of handling is mitigation, which must be right on target according to the vulnerability of the affected area. The results of the literature studies, which focus on research on physical vulnerability indicators in various regions from 1991 to 2022 and social vulnerability indicators from 2002 to 2021, show that various types of vulnerability indicators have been analysed in various regions. The results show that the characteristics of a region influence regional vulnerability indicators (Nguyen *et al*., 2016; Furlan *et al*., 2021; Roukounis & Tsihrintzis, 2022). That is in line with the concept of spatial association analysis expressed by Ynus (2010), which states that geosphere phenomena are related to each other in space, including the relationship between regional characteristics and indicators of a region's vulnerability. Likewise, research conducted by Oloyede *et al*. (2022), which modified the results of the ETC-ACC study, stated that the main vulnerability

to climate change carried out in several regions in Europe has different vulnerability indicators, this is also will occur if it is carried out in other regions according to regional characteristics on a global, regional, and local scale such as the study conducted by Nguyen *et al*. (2016). For this reason, according to Oloyede *et al*. (2022), it is necessary to implement adequate adaptation strategies starting from assessing the region's vulnerability level.

Vulnerability is a situation or condition that can reduce a community's ability to prepare itself to face danger. In various disaster threats that threaten coastal areas, the problems and challenges of vulnerability indicators are increasingly varied, so, they have yet to be fully accommodated in disaster mitigation efforts. Oloyede *et al*. (2022) revealed that some vulnerability analysis efforts still need to be top-down and cannot accommodate what recipients feel directly about the impact of disaster threats. The bottom-up method is suitable for exploring indicators of vulnerability felt by the affected recipients so that treatment will focus more on the conditions in the field. For this reason, this research will answer this gap so that through comprehensive data on vulnerability, it will be possible to produce policies appropriate to vulnerability conditions to carry out more targeted disaster risk reduction efforts.

Materials and Methods

This research utilises the Participatory Rural Appraisal (PRA) research method to analyse and develop indicators of the vulnerability of coastal areas to climate change. To validate the results of indicator development, we conducted an analysis using the Triangulation method combined with the Gregory test (Budiastuti & Agustinus, 2018). The research was conducted in two main areas of Bali Island, namely the northern part and the southern part, which includes the western, central, and eastern parts. The geographical distribution of the research areas is illustrated in Figure 1.

The method used to determine detailed locations, including the sample for this research is cluster random sampling at a distance of 100 metres from the coastline in accordance with the mandate of Presidential Decree Number 51 of 2016. Details of the criteria for determining sample locations for each activity characteristic in coastal areas are shown in Table 1.

In accordance with the number of respondents targeted, this study used a purposive sampling technique combined with a snowball sampling technique. The data processing and analysis stages in this research are presented in Figure 2.

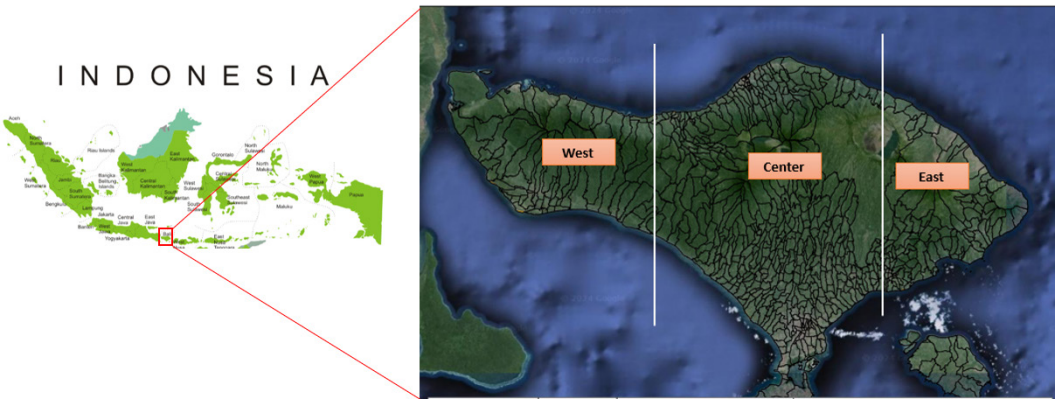


Figure 1: Research location (research area)

Table 1: Criteria for determining research sample locations and number of samples according to regional characteristics

Regional Characteristics	Criteria	Number of Respondents	
		North Bali	South Bali
Farm location	Farmers who own land in coastal areas, whether in the range of 100 m or more, but know the dynamics of coastal areas for at least 15 years	10 people	10 people
Settlement location	Residents whose homes are within 100 m of the coastline/in the coastal border area who have lived at least 15 years in that location	8 people	8 people
Tourism locations	Tourism actors who carry out tourism activities within a range of 100 m from the coastline/in the coastal border area who have lived at least 15 years in that location	5 people	5 people
Industrial locations	Industrial players who carry out tourism activities within a range of 100 m from the coastline/in the coastal border area who have lived/carried out activities for at least 15 years in that location	5 people	5 people
Temple location	The temple administrator/employer has carried out activities for a minimum of 15 years at that location	2 persons	2 persons

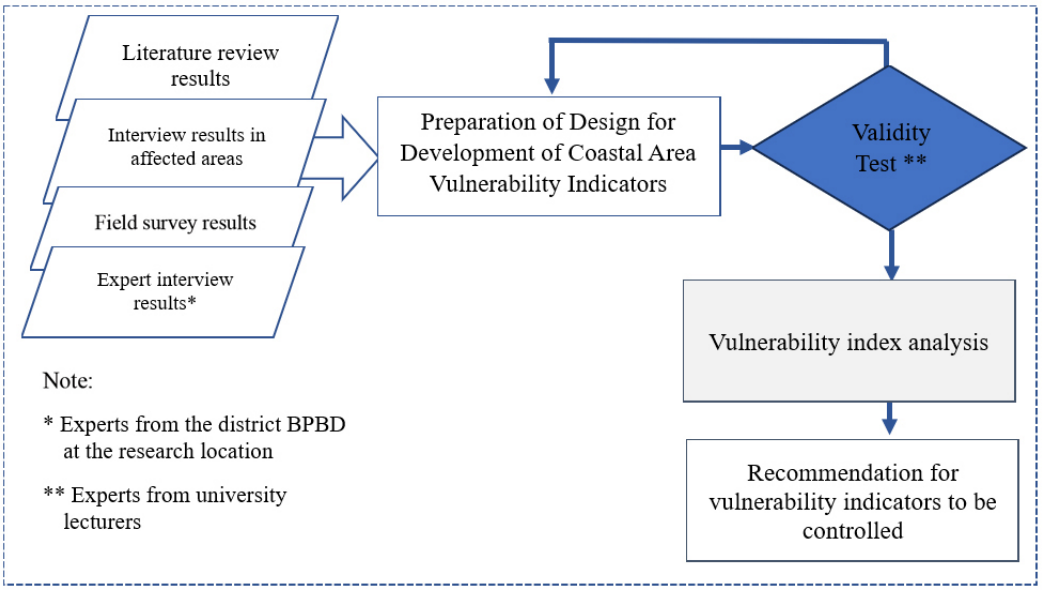


Figure 2: Stages of processing and analysis of coastal area vulnerability indicators

Results and Discussion

During the research process in the evaluation and design stage of developing vulnerability indicators, all vulnerability indicators that have the potential to occur in coastal areas, the results of studies from various researchers, including related regulations were confirmed with the respondents who were the subjects of this research. The following results (Table 2) were obtained based on the confirmation carried out.

Table 2: Results of confirmation and design for development of coastal area vulnerability indicators

Vulnerability Indicators	Confirmation Results (%)			
	North Bali South Bali		North Bali South Bali	
	In Accordance (%)	It is Not in Accordance With (%)	In Accordance (%)	It is Not in Accordance With (%)
The existence of the house	100	-	100	-
House type	100	-	100	-
Beach typology	-	100	-	100
Geomorphological form	31.6	68.4	62.2	37.8
Elevation of coastal areas	100	-	100	-
The rate of change in coastlines	84.2	15.8	100	-
Beach slope	100	-	100	-
Wave	100	-	100	-
Tide	100	-	100	-
Distance from the beach	100	-	100	-
Geological type	47.4	52.6	37.8	62.2
Surface roughness	86.8	13.2	100	-
Structural safety	100	-	100	-
estuary	89.5	10.5	94.5	5.5
Tourism spot	100	-	100	-
Population density	100	-	100	-
Sex ratio	100	-	100	-
Poor population ratio	100	-	100	-
Ratio of disabled people	100	-	100	-
Age group ratio	100	-	100	-
Education	73.7	26.3	75.7	24.3
Income	100	-	100	-
Work	100	-	100	-

Total population	100	-	100	-
Cultural heritage	100	-	100	-
Infrastructure	100	-	100	-
GRDP	100	-	100	-
Productive land	100	-	100	-
Access resources	100	-	100	-
Protected forest	5.2	94.8	8.1	91.9
Natural forest	5.2	94.8	8.1	91.9
Mangrove forest	5.2	94.8	8.1	91.9
Shrubs	5.2	94.8	8.1	91.9

Based on the research results, 33 vulnerability indicators have been confirmed with the affected communities at the research location. In general, the public agrees that the indicators in question influence the vulnerability of coastal areas. All 75 respondents, located on the south and north coasts of Bali Province, stated that they agreed that all indicators of coastal area vulnerability occurred at the research location. The public's lack of understanding of beach typology means that the public needs to explain these indicators.

Based on the evaluation that has been carried out and continued with the design of developing vulnerability indicators, validation is then carried out using triangulation between theories and triangulation between researchers combined with the Gregory test. Validation using theoretical triangulation in this research references previous research results as a basis for confirming the development of indicators in this research; the results are presented in Table 3.

Table 3: Validation of results of the development of coastal area vulnerability indicators using triangulation theory

No.	Indicator Development Results		Validation Using Theory/Research Results
A	**Physical Indicators**		
	1.	The existence of the house	Roukounis and Tsihrintzis (2022)
	2.	House type	
	3.	Beach typology	Marfai (2011)
	4.	Geomorphological form	Rachman and Arifki (2022)
	5.	Elevation	
	6.	Rate of change in coastline	
	7.	Beach slope	
	8.	Wave	
	9.	Tide	
	10.	Distance from the beach	Furlan *et al*. (2021)
	11.	Geological types	
	12.	Surface roughness	
	13.	Structure safety	
	14.	River mouth	

B	**Social Indicators**		
	1.	Population density	Roukounis and Tsihrintzis (2022)
	2.	Sex ratio	
	3.	Poor population ratio	
	4.	Ratio of disabled people	
	5.	Age group ratio	
	6.	Education	Choirunnisa and Giyarsih (2018)
C	**Economic Indicators**		
	1.	Income	Roukounis and Tsihrintzis (2022)
	2.	Employment	
	3.	Population	
	4.	Cultural heritage	
	5.	Infrastructure	
	6.	GRDP	Furlan *et al.* (2021)
	7.	Productive land	
D	**Environmental Indicators**		
	1.	Access resources	Roukounis and Tsihrintzis (2022)
	2.	Protected forest	BNPB Disaster Risk Assessment Technical Module (2019)
	3.	Natural forest	
	4.	Mangrove forests	
	5.	Undergrowth	
	6.	Environmental conservation	Furlan *et al.* (2021)

Apart from validation using theoretical triangulation, the results of indicator development in this research were also validated using triangulation between researchers, which was then analysed using cross-tabulation, according to Gregory.

$$Validy\ of\ Results = \frac{31}{2+0+0+31} = 0.94$$

Based on the validity test of the development results, a validity value of 0.94 was obtained, which means that the development of vulnerability indicators in this research has very high validity. The various indicators analysed in this research are in line with the results of previous research, including Roukounis and Tsihrintzis (2022), which emphasise indicators of house type, access to resources, employment, and cultural heritage; Marfai (2011) who emphasises beach typology; Permatasari (2021); Rachman and Arifki (2022) who emphasise geomorphology, elevation, rate of change in the coastline, slope, significant waves, and tides; Furlan *et al*. (2021), which emphasises coastal distance, geological type, surface roughness, structural safety, infrastructure, river estuaries, and environmental conservation; and Choirunnisa and Giyarsih (2018) emphasise education indicators. Meanwhile, other indicators continue to adopt technical guidelines used as guidance by the government.

As dynamic as indicators of coastal area vulnerability are, there is a tendency for regional vulnerability not to be less maximally involved in disaster management efforts in coastal areas. That is in line with research conducted by Wahyono *et al*. (2016), Furlan *et al*. (2021), Oloyede *et al*. (2022), and Roukounis and Tsihrintzis (2022) that the assessment of vulnerability, especially social vulnerability,

cannot be accommodated comprehensively because vulnerability can change at any time, both in the short and long term, depending on how big the affected area is (exposure to the threats), the potential impact, sensitivity, and capacity in facing disasters (capacity) (Nguyen, 2016). This relationship can be analogous to a function that:

Vulnerability = f (Exposure, Impact, Capacity, Sensitivity}

Then, this research was developed by adding elements of law enforcement so that it can be modelled as shown in Figure 3.

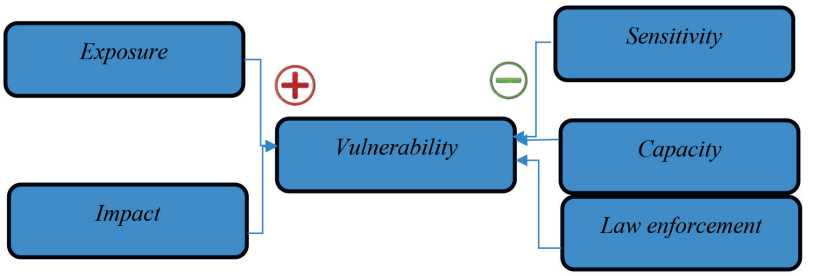
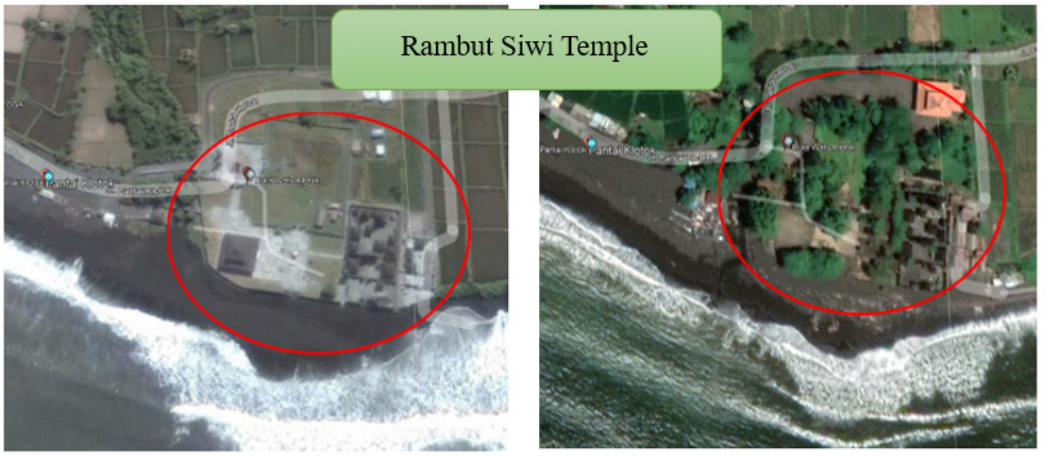


Figure 3: Relationship between exposure, potential impact, sensitivity, capacity, and law enforcement as a function of regional vulnerability

Based on this figure, regional vulnerability can be offset or reduced by increasing sensitivity, capacity, law enforcement, and vice versa. Based on the vulnerability indicators examined in this study, several indicators are highlighted for further discussion due to their significant impact on the regional vulnerability index. These indicators include physical development in coastal regions, mainly coastal border areas. One of the physical developments in the coastal area of Bali Island is the temple building used by the Hindu community in Bali as a place of prayer. The very close distance of the temple to the sea is an indicator of vulnerability, but this is a choice because the temple's existence cannot be separated from noetic elements, so sometimes there is no choice to place the temple, except at the current location. There are examples of conditions in the field in terms of the characteristics of the use of temples in coastal areas whose development is still stable despite the threat of tidal waves, as presented in Figure 4.



North Bali Coast, October 2009 North Bali Coast, July 2022



South Bali Coast, May 2022 South Bali Coast, October 2022

Figure 4: The existence of temples in coastal areas
Source: Google Earth Pro data

Another vulnerability that also increases the vulnerability index, which is included in the physical development category is related to granting permits to use coastal borders. However, in the Regulation of the Minister of Agrarian Affairs and Spatial Planning/Head of the National Land Agency Number 17 of 2016 concerning Land Arrangement in Coastal Areas and Small Islands, which is also confirmed in Article 16 of the Agrarian Law that the use of coastal border areas can be in the form of property rights, business use rights, building use rights, and use rights. Figure 5 shows the existing condition of using the coastal border, which has received the right to use it for residential use.

However, the government must take this condition seriously, especially those given the authority to control coastal border areas. The community has exploited this condition to carry out physical development without obtaining permission from the relevant parties, as shown in Figure 6.

Based on the data analysis results, development in coastal border areas is the most dominant indicator influencing the

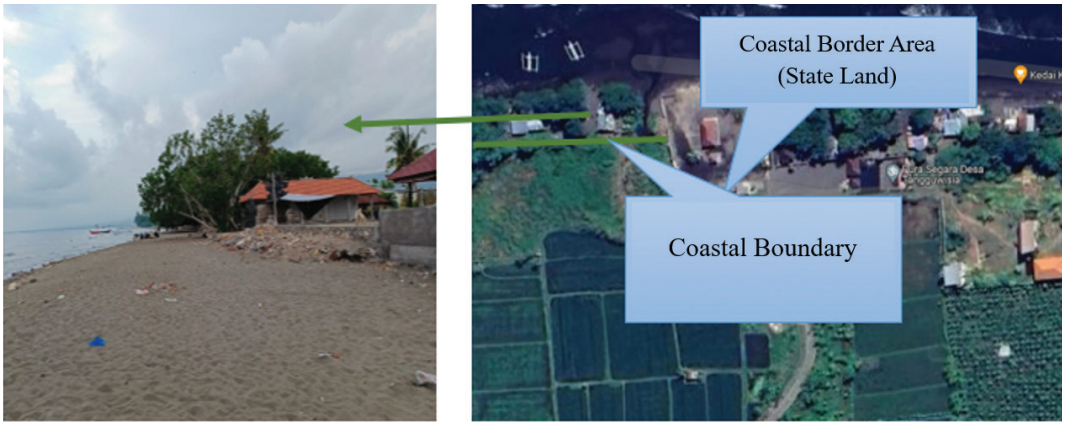


Figure 5: Example of coastal border use through use rights



Figure 6: The use of coastal borders does not comply with regulations

high vulnerability index of coastal areas. Development in coastal border areas will have a multiplayer effect on other activities, increasing the regional vulnerability index. That is also confirmed by the increasingly developing optimisation of coastal border areas for places to live and activities affiliated with economic interests.

Considering the complexity and interconnectedness of each regional vulnerability indicator, it can be concluded that regional vulnerability indicators are a condition that continues to develop. Previously, people's houses in coastal areas were not an indicator of vulnerability, but due to the area's physical development and the decreasing number of coastal areas, this condition will make existing houses vulnerable areas. Figure 7 illustrates this.

Paying attention to this picture, initially, people in coastal areas because they were not affected by abrasion or tidal waves, should have paid more attention to their vulnerability of the area. However, with changes in the coastline, settlements previously unaffected by the impact radius have finally become vulnerable areas. That is what causes many coastal areas to have high vulnerability.

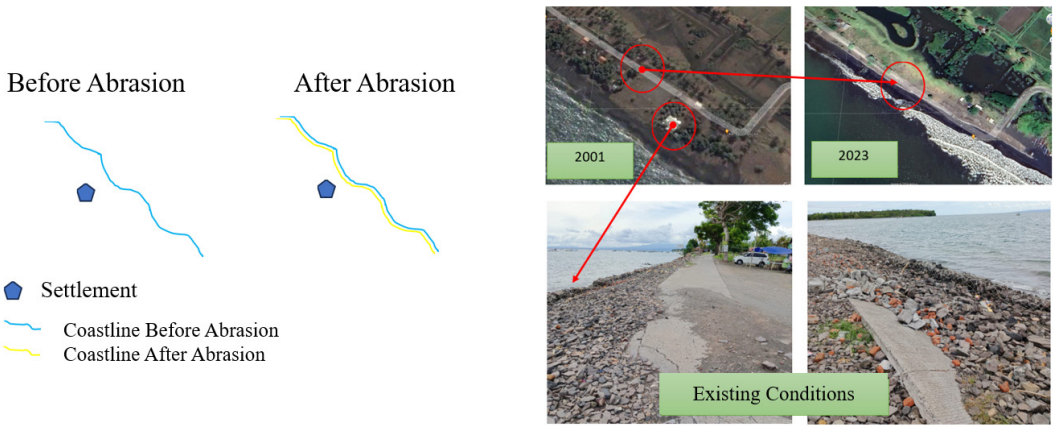


Figure 7: Changes in coastlines increase the vulnerability of coastal areas

Conclusions

The analysis and development of indicators in this research show several indicators of vulnerability felt by the affected communities but have yet to be fully used by the government to manage disasters. The vulnerability indicators in question are the type of house, access to resources, employment, cultural heritage, beach typology, geomorphological form, elevation, rate of change of coastline, slope, significant waves, tides, distance from the coast, geological type, surface roughness, safety of structures, infrastructure, river estuaries, environmental conservation, and education. All of these indicators are very dynamic and have the potential to increase because they are very dependent on exposure, potential impact, sensitivity, capacity, and law enforcement.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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