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Assessment Vulnerability Index of West Coast of South Sulawesi, Indonesia: A Case Study in Segeri Beach, Pangkajene and Islands Regency

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Authors' contributions

This work was carried out in collaboration between both authors. Author Paharuddin designed, analyzed, interpreted, and prepared the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The coastal area of Segeri Sub-district, Pangkajene and Island Regency, as one of the areas along the West Coast of South Sulawesi, is a zone prone to the natural phenomenon of sea level rise. The impact of this phenomenon needs to be studied to identify the level of coastal vulnerability and project changes in coastal vulnerability in the future. The research aims to calculate the coastal vulnerability index and project changes in vulnerability in the future due to changes in factors that

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affect coastal vulnerability. This research was conducted for five months at Bone-Village Beach of area Bawasalo and Bontomatene Segeri Sub-district, Pangkajene and Islands Regency, South Sulawesi, Indonesia. The method of data analysis carried out is the Analysis of coastal ecosystems and resources, analysis of physical and social characteristics of the community, and analysis of coastal environmental vulnerability with the Vulnerability Scoping Diagram (VSD) model that places exposure, sensitivity, and adaptive capacity as dimensions of Vulnerability Index. The components of the exposure dimension consist of coastal dynamics, natural disturbances, and population. Components of the sensitivity dimension are coastal characteristics, land use, and human settlements. The adaptive capacity dimension includes coastal habitat and marine conservation areas. Based on the score of each parameter in the three dimensions, the Coastal Vulnerability Index (CVI) of all observed locations is in the range of CVI values 7.96 - 9.59, which means the category of *Moderate Vulnerability*. Factors that strongly influence the CVI are the sensitivity dimensions, including Erosion, waves, and tides caused by oceanographic factors so; that if The Segeri Coastal Area does not make adaptation and mitigation efforts, then the possibility of the next 5 - 10 years, the level of Coastal vulnerability Index can be a high or very high Vulnerability. Adaptation efforts that can be made are strengthening the coastal boundary area, planting and expanding mangrove trees in the Segeri coastal area.

Keywords: Coastal; vulnerability-index; ecosystem; tides.

1. INTRODUCTION

Coastal areas are vulnerable to environmental factors such as climate variability, climate change, sea level rise, risk of earthquakes, tsunamis, volcanic events, and fragile ecosystems [1]. The coast is a dynamic zone because it is a zone of intersection and interaction between three very complicated phases: ocean, land, and air. The coastal zone always has a continuous adjustment process towards a natural balance against the impact of external and internal influences, both natural and non-natural. Natural factors include waves, currents, wind action, river inputs, coastal vegetation, and tectonic and volcanic activity. Non-natural factors, such as human/artificial intervention activities in this case, are the use of coastal areas as an area such as fisheries, industry, ports, tourism, agriculture/forestry, mining, and settlements. Coastal areas are in the land-sea transition zone (Coastal Transition Zone, CTZ). Their evolution and reactions to impacts depend on a complex interplay between humans and naturally occurring generated stresses [2].

Coastal vulnerability is the coast's propensity to react badly to dangers. The knowledge that an occurrence or hazard connected to one or more coastal risks is more likely to affect or harm a specific coastal community. The ecological and societal structures of the environment and communities can be disrupted or destroyed by hazards. According to [3], coastal hazards are occurrences that put the coastal zone in danger of harm or other negative effects. On the other hand, the environment is supported by structures like socioeconomic factors and ecosystems. As a result, vulnerability can be broken down into the level of environmental hazard exposure combined with the system's intrinsic sensitivity, balanced with the system's capability for responsiveness and adaptation.

Coastal areas are multipurpose spaces that can serve as administrative, habitational, industrial, port, fish farming, agricultural, and tourism hubs. Since coastal locations are so vulnerable to natural occurrences and environmental factors like climate change and sea level rise, this multifunctionality of coastal areas increases the need for land and other infrastructure, which creates new issues. The effects of this phenomenon can be explored by spatially determining the degree of vulnerability of coastal areas and predicting future changes in vulnerability. The geomorphological shape and elevation of the land play a significant role in determining how vulnerable coastal areas are to sea tide levels [4].

The west coast of Sulawesi Island in the south stretches from Bukukumba district to Pinrang district, where Pangkajene district and islands are in the middle area, one of which is the coast of Segeri sub-district which stretches from north to south along 5 km. Problems in coastal areas are susceptible and vulnerable to the natural phenomena of climate change and global warming. The impact received in coastal areas due to this phenomenon needs to be studied to identify the level of coastal vulnerability and project changes in coastal vulnerability in the future spatially due to changes in factors that affect coastal vulnerability.

The study aims to calculate the coastal vulnerability index and project future changes in vulnerability due to changes in factors that affect coastal vulnerability. Based on this, it is hoped that the information obtained can be used as input for the government in policy planning to develop coastal disaster adaptation and mitigation strategies on the west coast of South Sulawesi, especially in the Pangkajene and Islands Regency.

2. MATERIALS AND METHODS

This research was conducted at three villages in Segeri District, Pangkajene, and Islands Regency, (-4.62382281893449,119.56345155036256) Fig. 1.

The data used are Google Earth satellite image data of Segeri Beach in 2022, Earth Shape Map 2021 on Scale 1: 50,000, and data related to the components of coastal vulnerability dimensions, including coastal characteristics and coastal dynamics (typology, relative sea level rise, tidal ridge, wave height, elevation, slope, rock type, and shoreline changes). The equipment used was Global Positioning System (GPS), PC, MS Office, and Google Office software, water pass, and digital camera. Analysis was conducted on coastal ecosystems and resources, the community's physical and social characteristics, and the coastal environment's vulnerability. So that information related to the dynamics of coastal environmental vulnerability is obtained.

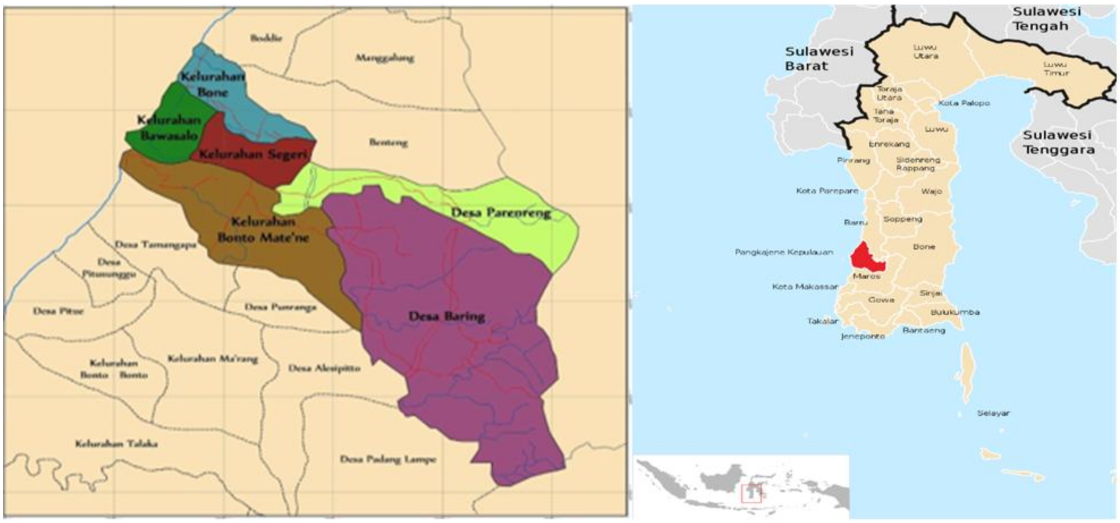

Fig. 1. Research Location, Segeri, South Sulawesi Province – Indonesia

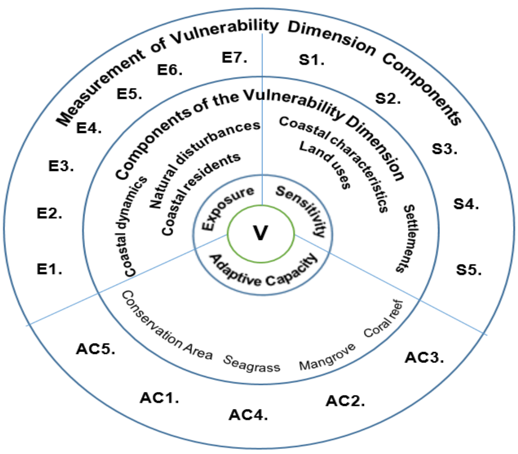

Fig. 2. Vulnerability scoping diagram [6]

List 1. Dynamics of coastal environmental vulnerability

E1. Rate Of Sea-Level Rise E2. Erosion Rate E3. Tsunami E4. Average Tidal Height E5. Average Wave Height E6. Population Growth E7. Population Density	S1. Slope S2. Elevation S3. Coastal Typologies S4. Land Use S5. Type and location of settlements	AC1. Proportion of coastal habitat AC2. Seagrass area and cover AC3. Mangrove area and density AC4. Coral reef area and cover AC5. Coastal conservation

The vulnerability analysis of the coastal environment refers to the concept developed by [5], where vulnerability is a function of a coastal system's exposure, sensitivity, and adaptive capacity. To identify the components of vulnerability, [6] developed the Vulnerability Scoping Diagram model. This VSD model places exposure, sensitivity, and adaptive capacity as dimensions of vulnerability. It then determines the components of the vulnerability dimension and measures the components of the vulnerability dimension. Exposure dimension components consist of coastal dynamics, natural disturbances, and population. Sensitivity dimension components are coastal characteristics, land use, and human settlements. The adaptability dimension includes coastal habitats and marine protected areas. The vulnerability scoping diagram is shown in Fig. 2.

The exposure dimension consists of three components with parameters including (a) coastal dynamics; sea level rise (SR), Erosion (ER), tides (T), Waves (W), (b) natural disturbances; tsunami events (TS) over the last 100 years, and (c) population; growth (PG) and population density (PD). The scaling system and parameter assessment scores are presented in Table 1.

The sensitivity dimension consists of three components, namely: (a) coastal characteristics, consisting of elevation (EL), slope (SL), and typology (TP); (b) land use (LU); and (c) human settlement (PP). The scaling system and parameter assessment scores are presented in Table 2.

Table 1. Scaling and scoring system of vulnerability parameters of the exposure dimension

Score Exposure	1	2	3	4	5	Source
Sea Level Rise mm/year	$\leq$ 4,99	5 – 9,99	10 – 14,99	15 – 25	>25	[7]
ER m/year	>2,0	1,0 – 2,0	-1,0 – 1,0	1,0 – (-2,0)	<-2,0	[7]
TH m	<0,50	0,51 – 1,0	1,1 – 2,0	2,1 – 4,0	>4	[7]
WH m	<0,50	0,51 - 1	1,1 - 1,5	1,51 – 2	>2	[7]
TS	0	1	2 – 3	4 – 10	>10	[8]
PG % /year	$\leq$0,5	0,51 – 1,0	1,1 – 1,5	1,51 – 2,0	$\geq$ 2,1	[8]
PD inh/ha	<75	76 – 150	151 – 200	201 – 400	>400	[9]

Notes: ER=Erotion, TH=Tidal Height, WH=Wave Height, PG=Population Growth, PD=Population Density

Table 2. Scaling system and scoring of sensitivity dimension vulnerability parameters

Sensity	1	2	3	4	5	Source
EL m	>5	3,1 – 5	2,1 – 3	1,1 – 2	0 – 1	[10]
SL %	>40	25,1 – 40	15,1 – 25	9 – 15	0 – 8	[10]
CT	Vegetated	Stony	Gravelly	Sandy Beach	Beach Deposited Products	[7]
LU	Open/unutilized lan	Marin cultivation	Agricultural	Livestock	Settlement	[7]
TS	In locations > 5 m high	At an elevation of 2-5 m	Behind the coastal boundary	Around the beach	Above The Waters	[10]

Notes: EL=Elevation, SL=Slope, CT=Coastal Typology, LU=Land Use, TS=Type & loc Settlements

Table 3. Scaling system and scoring of vulnerability parameters of the adaptive capacity dimension

Adaptive Cap.	1	2	3	4	5	Source
PH (Intensity)	≤ Mainland Beach	2 x > Mainland Beach	3 x > Mainland Beach	4 x > Mainland Beach	> 5 kali Mainland Beach	[10]
MR (tree/ Ha)	0 – 500	501– 1.000	1.001-1.250	1.251-1.500	>1.500	[11]
CR (%)	0 – 20	21– 40	41-60	61– 80	81 – 100	[11]
SG (%)	<10	10 – 29,9	30 – 59,9	60 – 79,9	>80	[11]
CC (%)	0	1 – 10	11 – 25	26 – 40	>50	[11]

Notes: PH=Proportion of Coastal Habitat, MR=Mangrove, CR=Coral reef, SG=Seagrass, CC=Coastal Conservation

The adaptive capacity dimension consists of two components, namely: (a) Coastal Habitat (CH), which includes coral reef (CR), seagrass (SG), and mangrove (MR) ecosystems, and (b) Conservation areas (CA). The scaling system and parameter assessment scores are presented in Table 3.

The concept of vulnerability referred to for the calculation of the Vulnerability Index is the result of the formulation of the vulnerability index from [10], where vulnerability (V) is an overlay function of Exposure (E), Sensitivity (S), and Adaptive Capacity (AC), expressed in Equation 1:

$$\mathbf{V = (ExS)/AC} \quad (1)$$

Taken from [6], the dimensions of the Exposure Index (IEI), Sensitivity Index (SI), and Adaptive Capacity Index (ACI) are formulated as coastal vulnerability index (CVI) in Equation 2:

$$\mathbf{CVI = EI \times SI/ACI} \quad (2)$$

Based on the scoring value of each parameter that has been identified through the previous Vulnerability Scoping Diagram approach, the scale of the scoring value of each parameter is between 1 to 5; by substituting the maximum and minimum values in equation 2, the minimum value of CVI is 0.20, and the maximum value is 76. Using these maximum and minimum values, the coastal vulnerability assessment scale divided into 4 categories (Doukakis 2005) is:

0,20 - 6,04 : Low vulnerability
6,05 - 18,18 : Moderate vulnerability
18,19 - 40,48 : High vulnerability
40,49 - 76,00 : Very high vulnerability

3. RESULTS AND DISCUSSION

3.1 Coastline Characteristic

The results of [12] report in December 2018 stated that there was a change in the length of the coastline in Pangkep Regency, covering 6 sub-districts by 1.78 km based on Analysis from 2013 to 2018 (5 years), while other physical change characters were Abrasion 13.99 Hectares and Accretion 38.74 Hectares. The data on the area of Abrasion and Accretion from all Districts in Pangkajene and Islands Regency is shown in Fig. 4.

3.2 Coastal Vulnerability Index (CVI)

The vulnerability value of the coastal area is expressed by the value of CVI [13], obtained from the transformation of the value of the score value parameters, and the calculation results in equation 2 show that the range of vulnerability index values in Segeri Beach is in the range of 6.55 - 8.85 which is included in the Moderate vulnerability category [14]. The conclusion is based on the value of the exposure dimension, and the exposure index is 2.38, where the influential coastal dynamics are Erosion, tidal waves are at a value of 3 which is included in the moderate category, while natural disturbances, tsunami events over the past 100 years score 1 (low), Growth and population density at a score of 1 (Low category). The sensitivity dimension ranges from 4.49 - 4.89, which is included in the medium category where the characteristics of the beach, including elevation, slope, and coastal typology, are at a score of 4 - 5, categorized as a high level of sensitivity. While land use score 5 is settlement and aquaculture activities, settlements are behind the coastal boundary and mainly at 1 - 3 meters above sea level. The adaptive capacity score shows a low index value because coastal habitats, including coral reefs, seagrasses, and mangroves, are at a low score regarding coral cover, seagrass density, number, and type of mangrove trees. While conservation areas score low (no conservation areas). The adaptive capacity index (ACI) value of 1.20 - 1.70 is categorized as low.

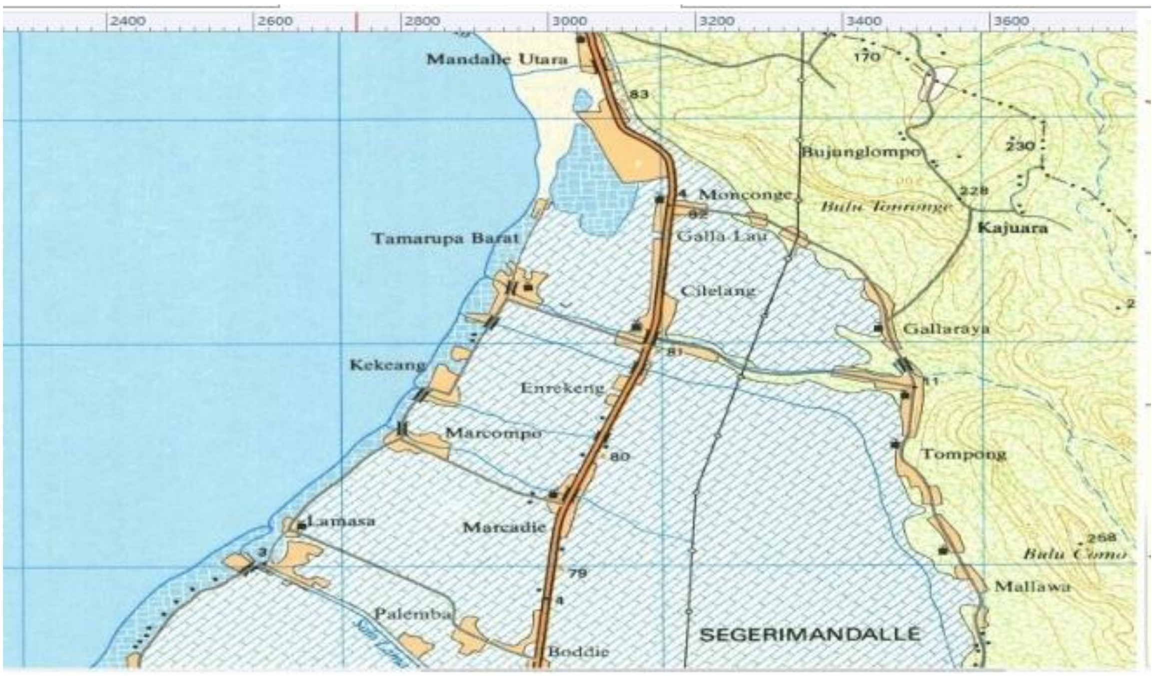

Fig. 3. Characteristics of the Coastline of Segeri district, Pangkajene and Island Regency, Indonesia

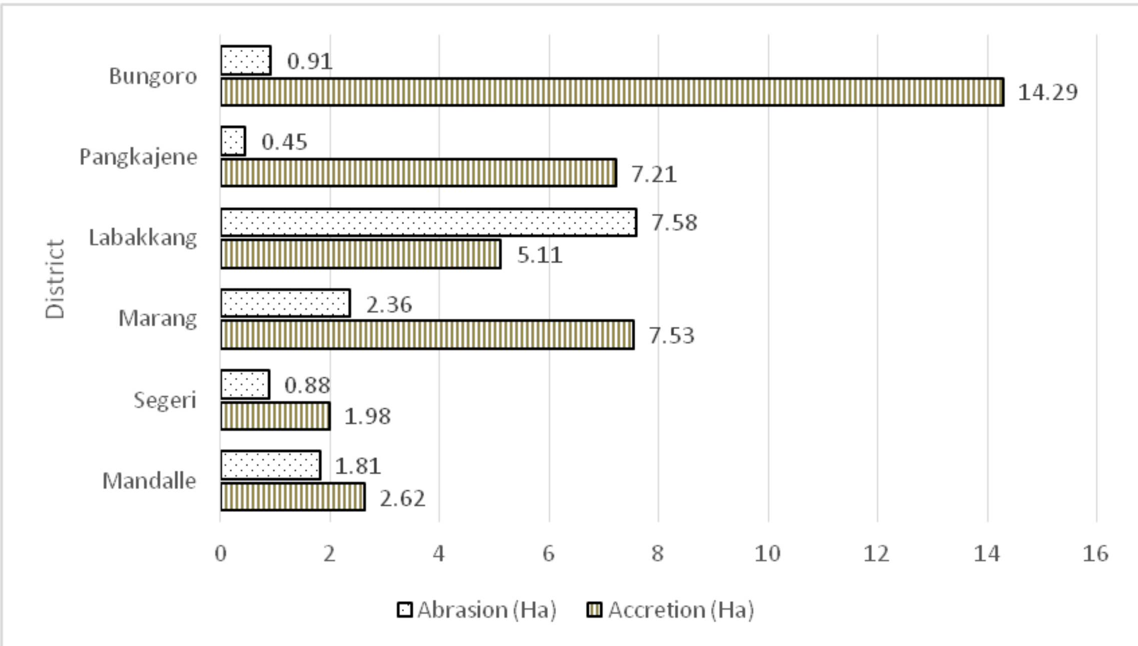

Fig. 4. Beach abrasion and accretion in all districts of Pangkajene dan Kepulauan Regency (hectares)

Table 4. Parameters of Coast Vulnerability Index (CVI) at Segeri District Beach, Pangkajene and Islands Regency, South Sulawesi

No	Index	Beach Area in Segeri District		
		Bone	Bawasalo	Bonto Matene
1	Exposure (EI)	2,38	2,38	2,38
2	Sensitivity (SI)	4,89	4,68	4,46
3	Adaptive capacity (ACI)	1,70	1,70	1,20
4	CVI	6,85	6,55	8,85
5	Vulnerability Category	Moderate	Moderate	Moderate

The factor that significantly influences the CVI is the sensitivity dimension, including Erosion, waves, and tides caused by oceanographic factors so that if you do not make adaptation and mitigation efforts, then the possibility of the next 5 - 10 years, the medium category can become high CVI High or Very high. Adaptation efforts that can be made are strengthening the coastal boundary wall and planting and expanding mangrove trees in the Segeri coastal area. The CVI Analysis parameters are presented in Table 4.

Handling solutions to reduce the rate of damage and coastal vulnerability of the West coast of South Sulawesi are based on three categories: environmental damage, erosion/abrasion and building damage, sedimentation, and land conversion to fish and shrimp ponds. With the Analysis of CVI, this CVI data will be able to help policymakers to identify the West coast of South Sulawesi in this study, taking the example of Segeri sub-district beach, whose current level of vulnerability is moderate and undoubtedly vulnerable to natural disasters so that appropriate prevention or mitigation strategies and actions need to be formulated, taking into account the factors that affect coastal vulnerability to reduce disaster risk and protect the community and the coastal environment.

Several strategies can be used to reduce the value of the Coach Vulnerability Index (CVI), including Proper spatial planning: Regulating spatial planning and land use around the coast can help reduce the risk of natural disasters. For example, avoiding flood or tsunami-prone development and improving drainage and irrigation systems. Improving infrastructure, such as coastal protection structures, embankments, and drainage channels, can help reduce coastal vulnerability [15].

Educating communities about natural disaster risks and how to reduce coastal vulnerability is also essential. This can be done with intensive and continuous counseling and socialization. Moreover, Implementing strict regulations and rules on development around the coast and managing coastal areas can also help reduce coastal vulnerability.

The utilization of modern technology, such as early warning systems, weather sensors and monitoring, and numerical modeling, can help predict and reduce the risk of natural disasters in coastal areas. Increased community awareness and participation is essential, encouraging active community participation in disaster risk reduction programs and raising awareness of the importance of reducing coastal vulnerability can help reduce CVI values.

4. CONCLUSION

1. The coastal vulnerability index (CVI) is in the range of index values 6.55 - 8.85, included in the Medium Vulnerability category.
2. The most influential factor on the CVI is the sensitivity dimension, including Erosion, waves, and tides caused by oceanographic factors to prevent the threat of more significant damage. Adaptation and mitigation efforts must be carried out so that the CVI value in the next 5 - 10 years does not increase to a high or very high vulnerability category considering that abrasion and accretion continue to occur.
3. Adaptation efforts that can be done are strengthening the coastal boundary area and planting and expanding mangrove trees in the Segeri coastal area of Pangkajene Regency and islands and other west coastal areas of South Sulawesi.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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