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Coastal Vulnerability Study on Potential Impact of Tsunami and Community Resilience in Pacitan Bay East Java

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Abstract

A tsunami can be induced by collisions or shifting of earth plates, followed by an earthquake in the ocean. The coastal area in Pacitan Bay East Java faces directly to the Indian Ocean and is prone to tsunami disasters. This study aims to determine the vulnerability level of the area and the resilience of coastal communities against tsunami. The geographic Information System (GIS) method was used in this study. This study applied weighted over-lay calculation with four components, namely elevation, slope, distance from the beach and the distance from the river, to measure the vulnerability level. Moreover, Coastal Community Resilience (CCR) method was applied to measure the predictive response of the communities. The results indicated that most of the area in Pacitan Bay (79.70%) was categorized into high to very high vulnerable against tsunamis. The CCR results showed structure design and post-disaster recovery elements in the low index.

Keywords: potential tsunami, vulnerability, coastal community resilience, Pacitan bay.

1. Introduction

The seismicity of Indonesia and the surrounding area provides substantial evidence for the region's active tectonic pro-cesses. Indonesia archipelago is situated at the intersection of the Indo-Australian, Eurasian and Pacific plates (Caraka et al., 2021; Hutchings & Mooney, 2021). The earth's plates move to certain direction at a rate of 6-7 centimeters per year. The Pacific plate is moving to the west and north west. Meanwhile, the Indo-Australian plate is moving relatively north, and the Eurasian plate is mov-ing south (Niu, 2014). The Indian Ocean stretches from west Sumatra to the south of Java and Bali and is the meeting point be-tween the three plates. This area is commonly known as a subduction zone characterized by the presence of a sea trench and outer arc basin (Tito-Eki & Hall, 2020). The existence of the earth's plates subduction process causes the Indonesia archipelago to have numerous tectonic and volcanic activity, especially in Sumatra, Java, and Nusa Tenggara (Pena-Castellnou et al., 2021), in particular earthquakes at low or high scale. Strong plates subduction followed by earthquakes originating from the sea will lead to potential tsunami disasters and other collateral hazards such as tidal floods and liquefaction (Lestari et al., 2021; Oktiari & Manurung, 2010).

A tsunami is a natural disaster that threatens people who live along the coast. Although it occurs infrequently, this catastrophic event's great destructive power requires sufficient knowledge to mitigate the impact. (Hermon, 2016; Meilianda et al., 2017). Sever-al tsunami events have been recorded to have global or trans-oceanic impacts, for example, the 1854 Nankai tsunami; the 1883 Krakatoa volcanic eruptions that generated a tsunami in the Indian Ocean; the large tsunamis from the 1960 and 2010 due to Chile earthquakes, the 2004 Indian Ocean tsunami and the 2011 Tohoku tsunami (Satake et al., 2020). According to reports from The National Disaster Management Agency, there were 177 tsunami disasters in Indonesia from 1629 to 2018, with eight massives causing severe damage and countless casualties. Since the 2004 tsunami in Aceh, Indonesia has also experienced several large-scale tsunamis, including in 2006 in Pangandaran West Java and 2018 in the Sunda Strait and Palu, Central Sulawesi (De Silva et al., 2021; Lahcene et al., 2021). The Center for Volcanology and Geological Hazard Mitigation (CVGHM) classifies regions in Indonesia that are prone to tsunami disasters into 21 regions, including Nangroe Aceh Darussalam, North Sumatra, West Sumatra, Bengkulu, Lampung-Banten, Southern of Central and East Java, Bali, NTB, NTT, North Sulawesi, Central Sulawesi, South Sulawesi, North Maluku, South Maluku, Biak-Yapen, Balikpapan, Sekurau, Palu, Talaud, and Kendari.

By definition, vulnerability is a particular condition determined by economic, environmental, physical, and social factors which can increase the inability to deal with a disaster (Khairunnisa et al., 2021; Mardiyanto et al., 2013). In some places, tsunamis pose a threat that can cause many casualties and heavy losses, whereas, in other places with the same scale and strength, tsunamis may not cause such impacts (Cai, et al., 2016; Widayanti & Insiani, 2021). It is more likely because, at certain locations, they naturally have landscapes that can reduce the impact of tsunami waves, for example, beaches with rock cliffs or it could be because the condition of the people in the area has better infrastructure, knowledge and preparations against disasters (Lam et al., 2016; Park et al., 2018; Prado et al., 2015). Particular vulnerability types in Indonesia's coastal areas to tsunamis make the concept of hazard mitigation an important part of the Integrated Coastal Zone Management (ICZM). Studying integrated vulnerability between socio-economic and biological-physical aspects should contribute to sustainable coastal planning and management. Implementing a proper coastal management policy can help increase resilience and reduce the impact of disasters on the coastal population and its infrastructure.

Coastal Community Resilience (CCR) guideline was initiated in 2007 by the United States - Indian Ocean Tsunami Warning System (US-IOTWS) program organized by the National Oceanic and Atmospheric Administration (NOAA) (Sempier et al., 2010). The CCR assessment is an approach undertaken as collaborative and participatory efforts with coastal communities, national and local government and other key stakeholders to identify strengths, weaknesses, and opportunities (Kafle, 2012; Sempier et al., 2010). Another crucial function of CCR is to increase disaster resilience at the local and national levels.

The coastal area in Pacitan Bay East Java faces the Indian Ocean. Based on the 2018 East Java Coastal and Small Islands Zonation Plan document, this location is classified as a tsunami-prone area. Therefore, identifying vulnerability based on the level of the physical condition of the area is important. Data regarding the level of community preparedness in dealing with the tsunami threat is needed as basic information to formulate strategic policies in disaster mitigation. The objectives of this study were to map the tsunami's vulnerable area in Pacitan Bay and to measure coastal communities' resilience level against tsunami disaster. This study used several parameters: elevation, slope, land use types, distance from coastline and rivers. The parameters were processed using weighted overlay calculation to model and define the vulnerable area in the study location.

2. Research Method

The coastal vulnerability zones to tsunamis were determined using spatial analysis and the Geographic Information System (GIS) method. The GIS method is a powerful tool for studying and analysing phenomena occurring on the earth's surface to model them into a simpler form. GIS stores all descriptive information about its elements in the database as attributes then constructs and connects them to relational tables. GIS methodology to determine regional vulnerability to natural disasters has the benefit of integrating environmental, socio-economic and disaster information (Hidayah et al., 2018; Santius, 2015). The results, in the form of a vulnerability map, can help with tsunami mitigation planning in tsunami-prone areas (Muhammad et al., 2017; Nucifera et al., 2021).

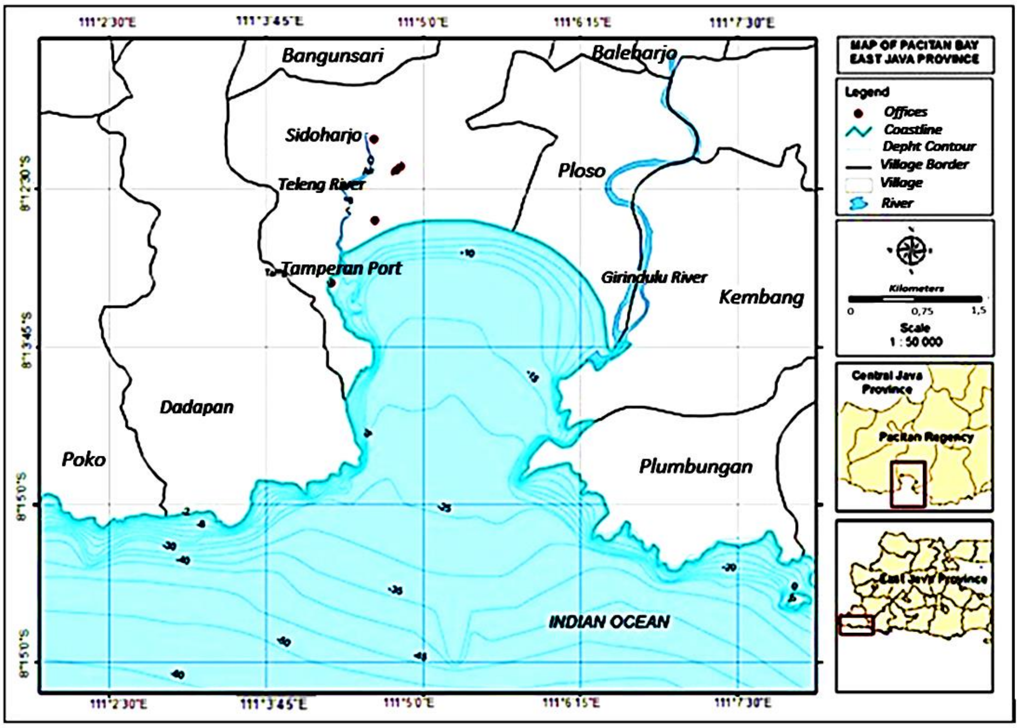

Figure 1. Study Area (Pacitan Bay).

This research was conducted in Pacitan Bay, located approximately 15 km south of Pacitan City, East Java Province. The location administratively consists of 3 villages: Sidoharjo, Ploso and Baleharjo. The total area of study location is approximately 1374.90 Ha (Figure 1). The main method used in mapping the vulnerable areas was using GIS analysis. Vulnerability parameters used in this study were elevation, slope, land use types, distance from coastline and distance from rivers. These parameters were then used to estimate the area's tsunami hazard level. The height and slope area data were obtained from the processing of AS-TER/GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer/Global Digital Elevation Model) retrieved from https://earthexplorer.usgs.gov/. Also, another spatial data were obtained by downloading Pacitan RBI map from https://tanahair.indonesia.go.id/ on a scale of 1:25.000. In this study, grading of each parameter ranges from 15% - 30% and scores in the range of 1-5 show the level of tsunami vulnerability. Vulnerability parameters (Table 1) were grouped into five categories, namely very high (R5), high (R4), moderate (R3), low (R2), and very low (R1) (Faiqoh et al., 2013). The final results from the multiplication of grades and scores were explained in the vulnerability categories (Table 2).

Table 1. Weight and Scores of Parameter for Determining the Vulnerability of Tsunami.

Parameter	Classes	Score
Elevation (m); Weight = 25%	<10	5
	11-25	4
	26-50	3
	51-100	2
	>100	1
Slope (%);Weight = 25%	0-2	5
	3-5	4
	6-15	3
	16-40	2
	>40	1
Land Use Type; Weight = 15%	Settlements, agriculture, river	5
	Forest	4
	Vegetation	3
	Bush, Lake	2
	Clifs, Rocks	1
Distance from coastline (m); Weight : 20%	0-500	5
	> 500-1000	4
	> 1000-1500	3
	> 1500-3000	2
	> 3000	1
Distance from rivers (m); Weight: 15%	0 – 100	5
	101 – 200	4
	201-300	3
	301-500	2
	>500	1

Source : (Faiqoh et al., 2014; Oktaviana et al., 2020)

Table 2. Vulnerability Classes.

Class	Description	Level Interval
1	Very low	25—120
2	Low	121—216
3	Moderate	217—312
4	High	313—408
5	Very high	409—504

Furthermore, this study used the CCR index to measure the resilience level of the coastal communities in Pacitan Bay. The CCR method reviews each element of resilience and the parties involved. Eight CCR elements are (1) government; (2) socio-economic; (3) management of coastal resources; (4) land use and structural design; (5) knowledge about risk; (6) warnings and evacuations; (7) emergency response; and (8) disaster recovery (Prado et al., 2015; Sempier et al., 2010). Table 3 summarizes the key points asked in the questionnaire for each element of CCR.

A particular score was assigned to evaluate each answer quantitatively. The score presented in the questionnaires starts from number 1 (strongly disagree) to number 5 (strongly agree). The results of the questionnaire were then calculated to obtain the resilience index. If the results of the resilience index are less than standard (3.00), the parameters need to be addressed as critical and require urgent attention to strengthen local communities' capacity to cope with the tsunami's impact. The Resilience Index (RI) formula is expressed on Equation 1.

Table 3. Key Points of Questions for CCR.

No	CCR Elements	Description
A	Government	This element discuss community development, public services, the collaboration between various sectors and levels of government, as well as technical and financial support mechanisms from the government in increasing tsunami resilience (Kafle, 2012; Meilianda et al., 2017; Paramesti, 2011).
B	Social and economy	The problems discussed in this element are about the development of social capital and skills, the local economy, social and cultural networks, as well as technical and financial support for economic development in coastal areas (Kim et al., 2017).
C	Management of Coastal Resources	The questions posed in this element are regarding the management of coastal natural resources, protection and maintenance of habitats, ecosystems, and natural products, planning and implementation of management activities, as well as assessment and investment in resource management in coastal areas (Hidayah et al., 2019; Park et al., 2018).
D	Land use and structural design	Questions in this element try to reveal land use policies and structural design standards, location and assessment of critical infrastructure, risk reduction efforts, as well as education and training for land use and design of structures that are resilient to tsunamis (El Moussaoui et al., 2017; Kim et al., 2017)
E	Knowledge of risk	The problems studied in this element are regarding tsunami risk assessment, comprehensive coastal disaster risk assessment, community participation, and access to information on tsunami risk assessment results according to the conditions of coastal communities (Kim et al., 2017; Paramesti, 2011; Susilorini et al., 2021).
F	Warnings and evacuations	The explanation in this element is to address the existing evacuation system, application and use of warning systems and evacuation infrastructure, community response, as well as technical and financial support for tsunami warning and evacuation systems in coastal areas (De Silva et al., 2021; Hall et al., 2017).
G	Emergency response	The main questions in this element are regarding the definition of roles and responsibilities, emergency services and assistance, preparation activities (practices and simulations), as well as organizations and volunteers, to assist in handling the tsunami disaster (De Silva et al., 2021; Hall et al., 2017; Meilianda et al., 2017).
H	Disaster recovery	Explanation in this element is required to describe the initial planning, implementation process, establishing coordination mechanisms, and technical and financial support for the disaster recovery process (Khairunnisa et al., 2021).

$$R.I.(z) = \frac{\sum_{j=0}^{m}((Pj\ x\ 5)+(Qj\ x\ 4)+(Rj\ x\ 3)+(Sj\ x\ 2)+(Tj\ x\ 1)}{m\ x\ n} \quad (1)$$

Description:

R.I. (z) = resilience index on the resistance element (z)

P = number of answers "strongly agree" (5)

Q = number of answers "agree" (4)

R = number of answers "quite agree" (3)

S = number of answers "disagree" (2)

T = number of answers "strongly disagree" (1)

j = number of questions on the endurance element

n = number of respondents

m = maximum number of questions

Table 4. The CCR Classification

Level	Description	Level Interval
1	Very low	1,00-1,79
2	Low	1,80-2,59
3	Moderate	2,60-3,39
4	High	3,40-4,19
5	Very high	4,20-5,00

The CCR instrument was used to assess coastal communities' resilience levels through structured interviews with a set of questions. Respondents were determined purposively using the proportional stratified sampling method. The sample size for each stratum is determined in two stages, finding the sample size for the population and calculating the sample size for each subpopulation. The equations 2, 3, 4, and 5 were used to calculate the number of population samples with the parameter proportion.

$$n = \frac{n_o}{1+\left(\frac{n_o}{N}\right)} \tag{2}$$

$$n_o = \frac{\sum W_h \, x \, p_h \, x \, q_h}{V} \tag{3}$$

$$W_h = \frac{N_h}{N} \tag{4}$$

$$V = \left(\frac{d}{t}\right)^2 \tag{5}$$

Where :

n = number of samples of certain categories

n_o = assumed number of samples

t = 95% confidence level coefficient ($\alpha_{0,05}$ = 1,96)

d = sampling error (10%)

p,q = binomial proportion parameter (0,5)

N = total population size

N_h = sub-population size

Based on the Pacitan Regency's population data, three villages in the study area have a total adult population of 19,899. Based on their occupation, this population is divided into four major groups (sub-population): farmers and fishermen, students, private sector workers and government officers. Afterwards, the sample selection method was used in this study by selecting several key respondents from those community groups. Statistical tests using the Pearson's product moment correlation coefficient and Cronbach's alpha were performed to determine the validity and reliability of the questionnaire results.

3. Results and Discussion

3.1. Vulnerability Analysis

3.1.1. Elevation

According to the DEM map, the dominant elevation of the study area ranges from 0 to 10 meters above mean sea level (MSL), with an area of 963.52 Ha, or 72.59% of the total area, located just behind the coastline. Other areas around 115.06 Ha, have elevations ranging from 10 to 50 meters above MSL (8.67 % of the total area). The other part of the site is located at an elevation of 51-350 meters above MSL and is mostly situated on the west side of the study area (Figure 2). The lower the elevation, the more vulnerable the area to tsunami disasters (Faiqoh et al., 2014). Areas that are potentially vulnerable to tsunami disasters are coastal zones with elevation less than 25 meters above MSL (Meilianda et al., 2017). Similar findings were reported in other studies in various locations, particularly in Indonesia including Bali, Lampung, Padang and Jogjakarta (Febrina et al., 2020; Honesti & Muchlian, 2021; Steinritz et al., 2021; Suhita et al., 2021). The height will have an impact on the tsunami inundation zone. Compared to the highland plains, the lowlands near the coast are the most vulnerable to tsunami disasters.

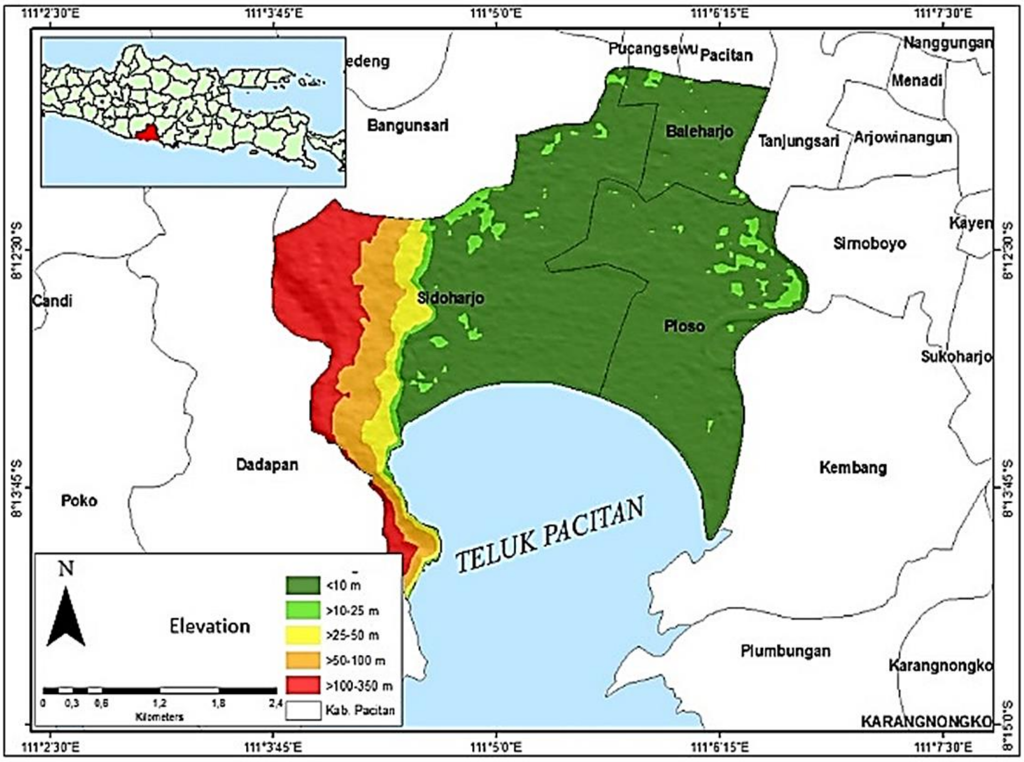

Figure 2. Digital Elevation Model (DEM) of Pacitan Bay.

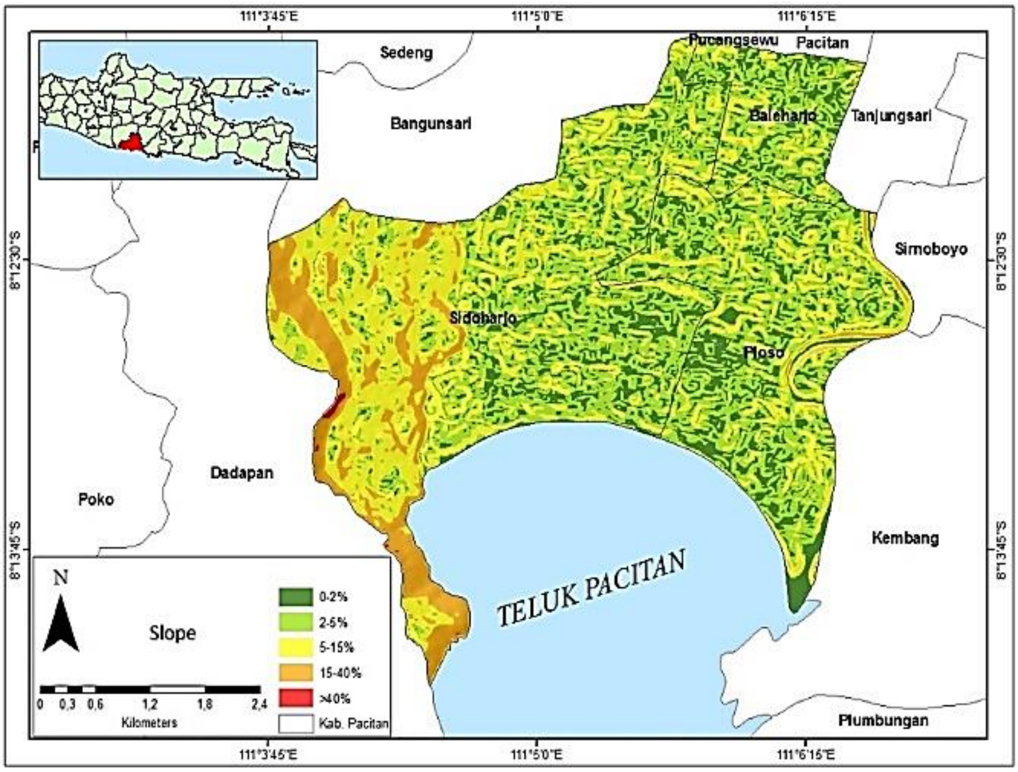

Figure 3. The Slope Map of Pacitan Bay.

3.1.2. Slope

The coast of Pacitan Bay was dominated by gentle slopes ranging from 0-5%, covering around 795,94 Ha or 59,95% of the to-tal area. Meanwhile, other locations in the west tend to have steep slopes ranging from 15 - 40% (Figure 3). Slope affects the vul-nerability of coastal areas to tsunami disasters and sea-level rise (Adriano et al., 2014; Bukvic et al., 2020; Li et al., 2021). The topography of the coast significantly determines the run-up height, wave propagation and distance of tsunami inundation. A gentle slope represents less resistance to the flow of water mass. As a result, the tsunami wave's flow velocity and force are not reduced significantly. Tsunami waves can reach a height of 10-15 meters on gently sloping or flat beaches. On the coast with a flat topography (slope < 5%) the water mass carried by tsunami waves can inundate up to 3-5 kilometres from the shoreline. Meanwhile, when a tsunami occurs in a steep coastal area (slope > 15%), the waves are held and reflected by the existing coastal cliffs (Kubota et al., 2018; Lee et al., 2020).

3.1.3. Land Use

The type of land use is the next factor that influences the vulnerability to a tsunami disaster. It refers to changes intended to make available land suitable for human use, such as settlement, rice fields, built-up areas, and forests (vegetation). According to the land use map (Figure 4), the coastal area of Pacitan Bay was dominated by settlements and productive agricultural areas, accounting for an estimated 828.52 Ha or approximately 62.42 per cent of the total area. Meanwhile, vegetation covered a large portion of the area on the west side of the river. Settlements are a type of land use extremely vulnerable to tsunami disasters (El Moussaoui et al., 2017; Hall et al., 2017; Kim et al., 2017).

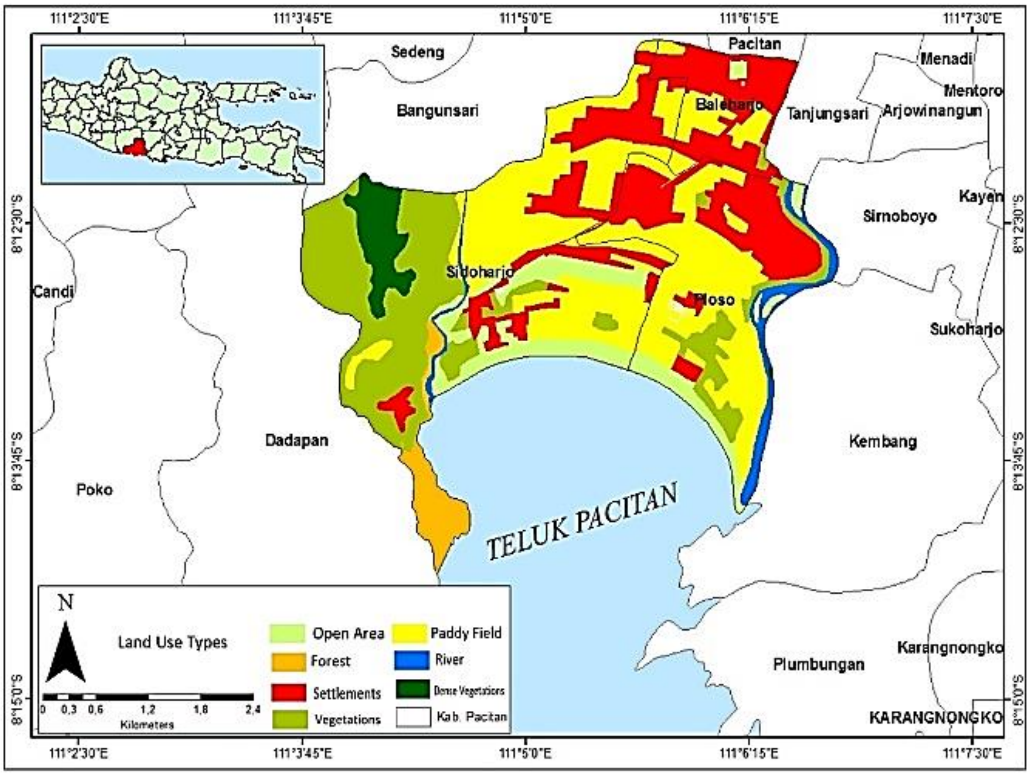

Figure 4. Land Use Map of Pacitan Bay.

Settlements near the coastline are a type of land use extremely vulnerable to tsunami disasters (El Moussaoui et al., 2017; Hall et al., 2017; Kim et al., 2017). Settlements in the study area range from near the coast to about 2-3 kilometres inland. If a tsunami strikes this area, it will cause structural damage and significant loss of life due to the high population density. Based on the previous tsunami events, coastal areas with densely populated residential areas suffered significant damage and casualties. For example, the 2004 Aceh tsunami destroyed villages and cities along Aceh's west and north coasts and claimed 173,741 lives. Meanwhile, over 2000 people were killed in Palu City, one of the central cities in Sulawesi, by an earthquake and tsunami in 2018. Of course, the damage and casualties would be minimal if the tsunami struck a sparsely populated area.

3.1.4 Distance from Coastline and Rivers

The division of the area based on the distance from the shoreline is presented in Figure 5. Multiple buffers of a certain ex-tent are used for zoning. The closer to the sea, the higher the vulnerability and risk to tsunamis. Based on the buffers, approximate-ly 540.61 ha of Pacitan Bay is located within the high-risk area (Table 5). Distance from the river border is also a very important parameter for determining tsunami risk (Figure 6). The coastal area of Pacitan Bay has two large rivers located in the west, i.e. Teleng River and another in the east, i.e. Girindulu River. These rivers were close to the estuary and directly faced the Indian Ocean. Reports originating from previous tsunami events in Aceh (2004), Pangandaran (2006) and Palu (2018) mention that apart from the coastal area, the magnitude of damage caused by tsunami waves was greater in areas adjacent to river systems (Faiqoh et al., 2014; Paris et al., 2009; Polom et al., 2008).

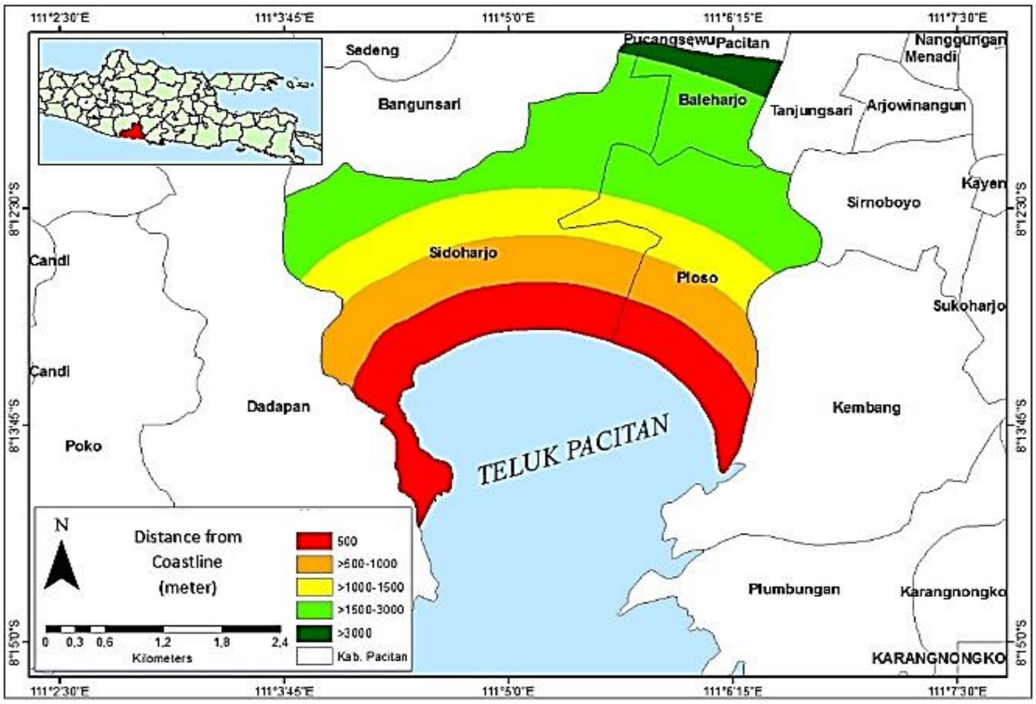

Figure 5. Buffer Zones Based on Distance from the Coastline.

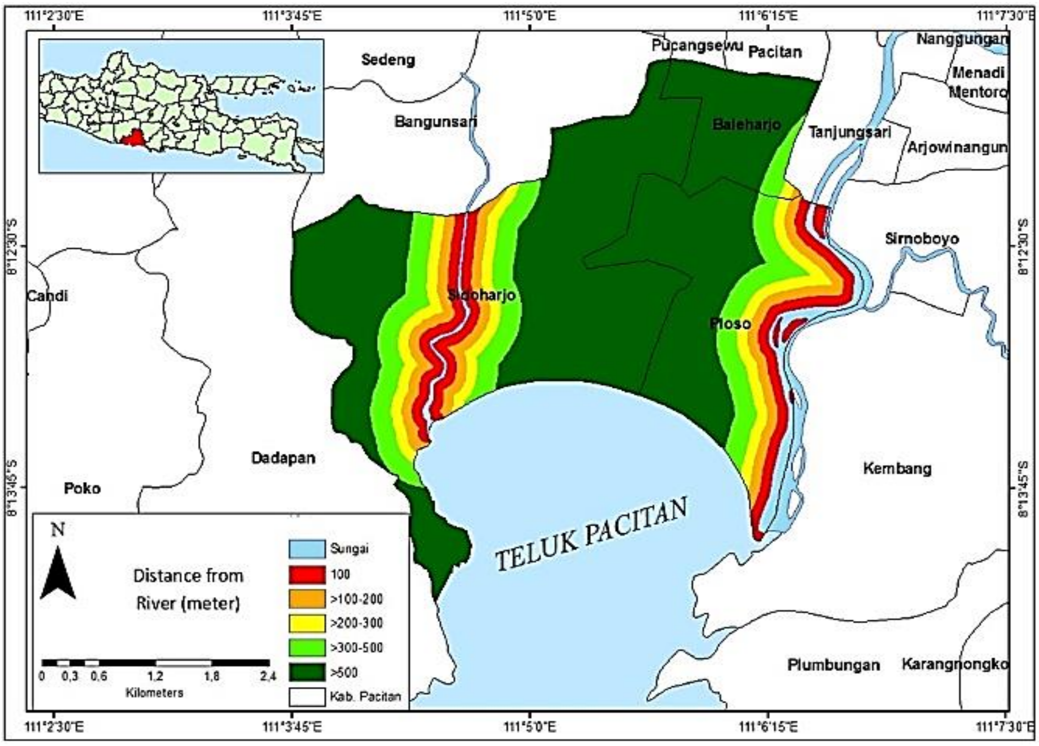

Figure 6. Buffer Zones Based on Distance from the Rivers.

The height of the tsunami waves coming from the sea will develop when it enters shallow water due to the shoaling effect (Lee et al., 2020). The shoaling effect occurs when the velocity of a tsunami wave decreases, resulting in a significant increase in wave height (Kubota et al., 2018). When the water depth is less than 10 meters, the tsunami velocity typically falls to around 50 kilometres per hour. On the other hand, the wave height increased by five to ten meters (Akbar et al., 2020). Rivers and canals influence in the propagation of tsunami waves to the mainland (Steinritz et al., 2021). The energy concentration in narrow spaces such as rivers pushes the waves further inland with greater velocity and create more extensive damage. Based on this potential risk, approximately 223.46 Ha (16.83%) of the area in Pacitan Bay was in a high-risk condition (Table 5).

Table 5. Vulnerability Classification for Each Parameters.

Parameters	Classes	Vulnerability Description	Area	
			Ha	%
Elevation (m)	<10	Very High	963,52	72,59
	10-25	High	60,74	4,58
	26-50	Moderate	54,32	4,09
	51-100	Low	101,25	7,63
	>100	Very Low	147,6	11,12
Slope (%)	0-2	Very High	245,94	18,53
	3-5	High	549,82	41,42
	6-15	Moderate	415,96	31,34
	16-40	Low	114,46	8,62
	>40	Very Low	1,25	0,09
Land Use Type	Settlements, agriculture	Very High	828,52	62,42
	Forest	High	285,33	21,49
	Vegetation	Moderate	49,47	3,73
	Bush, Lake	Low	115,70	8,72
	Cliffs, Rocks	Very Low	48,41	3,65
Distance from coastline (m)	0-500	Very High	284,30	21,42
	> 500-1000	High	256,30	19,31
	> 1000-1500	Moderate	243,63	18,35
	> 1500-3000	Low	502,84	37,88
	> 3000	Very Low	40,33	3,04
Distance from rivers (m)	0 – 100	Very High	135,58	10,21
	101 – 200	High	87,88	6,62
	201-300	Moderate	85,76	6,46
	301-500	Low	171,26	12,90
	>500	Very Low	846,93	63,80

3.2. Vulnerability Mapping Results

The vulnerability map of the coastal area is created to estimate the location's level of exposure to the tsunami disaster. The parameters used in this analysis were chosen by considering the magnitude of the tsunami inundation entering the land. This approach has been used in several studies in Indonesia in the context of regional planning, particularly in locations with high eco-nomic potential as fishing ports, harbours, and tourist destination areas such as Bali, Lombok (West Nusa Tenggara), Cilacap (Central Java), Palu (Central Sulawesi), and other cities (Isdianto et al., 2021; Kurniawan et al., 2017; Mudin & Pramana, 2015; Oktaviana et al., 2020). Furthermore, the tsunami vulnerability maps can be used for a wide range of mitigation efforts, including the formation of evacuation routes, spatial planning, construction of coastal protection, and early warning systems. Area classification based on the level of vulnerability is presented in Table 6.

Table 6. Vulnerability Classification of Pacitan Bay.

Vulnerability Class	Area	
	Ha	%
Very High	167,33	12,60
High	890,74	67,10
Moderate	167,53	12,62
Low	97,91	7,37
Very Low	3,92	0,29
Total Area	1327,43	100

The vulnerability map of the Pacitan Bay to the tsunami disaster is presented in Figure 7. The map shows that the very high vulnerability category dominates the area. According to Table 6, most of the study area, around 1058,07 Ha was classified into the high-very high vulnerability status. This condition occurs because most of the coastline of Pacitan Bay is an open, flat beach and has become a complex residential area. Meanwhile approximately 100 Ha of the area was classified as relatively less vulnerable. The high vulnerability area could experience the most severe impact when a tsunami strikes. With elevations ranging from 0-10 meters and slopes of 0-5%, a tsunami wave will be free to enter the area and destroy everything it passes through. In addition, the presence of rivers on the west and east sides adds to the risks and impacts that occur when a tsunami hits the coast. The tsunami's run-up reaches the hinterland through the area's low elevation and rivers (Guntur et al., 2017).

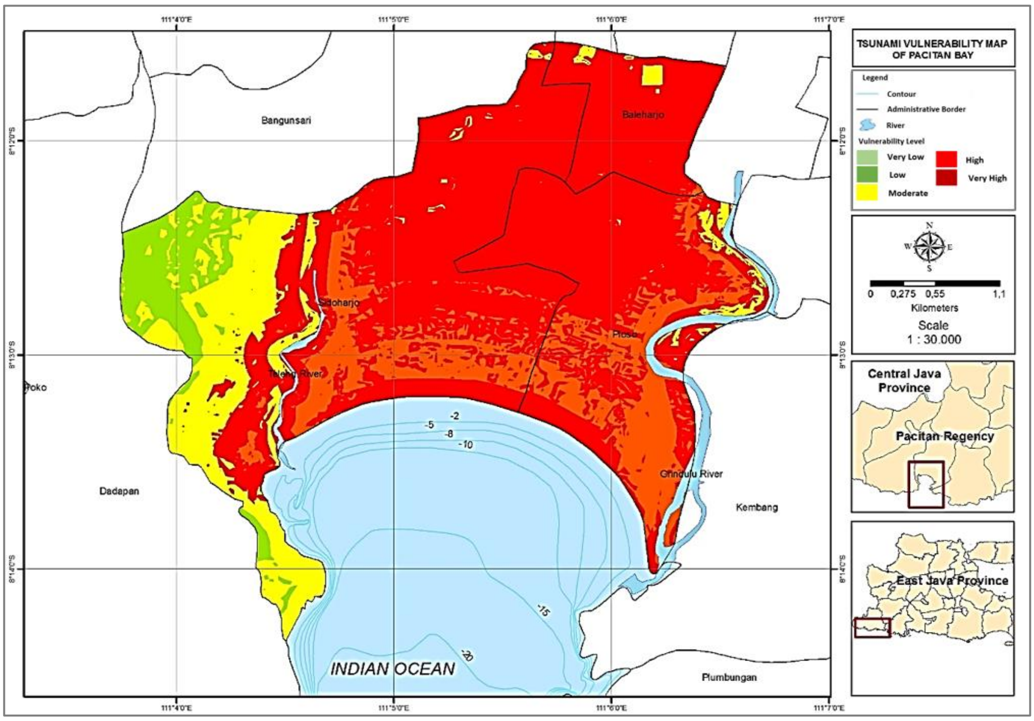

Figure 7. Map of Tsunami Vulnerability Analysis of Pacitan Bay Using GIS Weighted Overlay.

The existing land use in Pacitan Bay contributes significantly to the high level of vulnerability. The residential area in Pacitan Bay is located approximately 300-400 meters from the coastline and is included in densely populated settlements. Tsunami disasters pose a high risk to densely populated and settled areas, resulting in substantial losses. Almost all houses, buildings and other structures in Pacitan Bay were built near the coastline without considering the proper design to deal with tsunamis and earthquakes. It means that people do not understand the dangers of a tsunami coming from the sea (Hall et al., 2017; Kafle, 2012). Due to this existing condition, if a tsunami occurs, it will destroy the villages around the coast and is predicted to cause high casualties, as recorded in the tsunami events in Aceh in 2004 and Palu in 2018 (El Moussaoui et al., 2017; Suhita et al., 2021).

In disaster management, the risk is frequently expressed as the potential physical, absolute, or relative socio-economic losses for single or multiple event scenarios over a specified period (Caraka et al., 2021; Susilorini et al., 2021). Tsunami vulnerability mapping is one method for determining possible affected areas by the tsunami disaster. The vulnerability value can be reduced by taking relocation, adaptation, and protection actions. In addition, combining risk and vulnerability analysis is very important for disaster risk managers to predict the potential consequences of future natural disaster events, allowing them to make risk-informed decisions in particular land-use development (Paulik et al., 2019). Tsunami risk analysis involves a thorough understanding of the tsunami hazard in any given coastal location and its vulnerability, which is supported by historical and projected changes in development and population (Lahcene et al., 2021; Satake et al., 2020).

3.3. Coastal Community Resilience (CCR) of Pacitan Bay

Structured interviews were used to collect information for the resilience index. According to the elements of the CCR, the questions posed to respondents were divided into eight major issues (Table 7). Statistical tests using the Pearson's product moment correlation coefficient and Cronbach's alpha were performed to determine the validity and reliability of the questionnaire results. The results of the tests showed that the questionnaire used is valid and reliable (Pearson correlation sig 2-tailed 0.00 < 0.05; Cronbach's alpha > 0.6). The key respondents in this study were determined based on calculations using a proportional stratified random sampling approach (equations 1 to 4). Based on the calculations, the sample size used in this study was 96 persons, representing 4 groups of communities, namely farmers and fishermen, government officers, high school and university students and private workers (Table 7).

Table 7. The Calculation for Determining the Number of Respondets for CCR.

No	Group	Sub Population (N_h)	N_h/N	$W_h.p_h.q_h$	Sample Size (n)
1	Government Officers	2348	0.1180	0.0295	11
2	Farmers & Fishermen	6964	0.3500	0.0875	34
3	Students	4975	0.2500	0.0625	24
4	Private Sector Workers	5612	0.2820	0.0705	27
	Total Population (N)	19.899			96

Table 8. Resilience Index (RI).

Village	Elements of Resilience							
	A	B	C	D	E	F	G	H
Sidoharjo	2.4	2.9	3.7	2.0	3.4	4.2	4.0	1.5
Ploso	2.8	2.8	2.9	2.8	3.1	2.9	3.1	2.8
Baleharjo	2.5	2.2	3.0	2.6	3.0	2.5	3.2	2.6
Mean	2.6	2.6	3.2	2.5	3.2	3.2	3.4	2.3
Standar Deviation	0.2	0.3	0.4	0.4	0.2	0.8	0.4	0.6

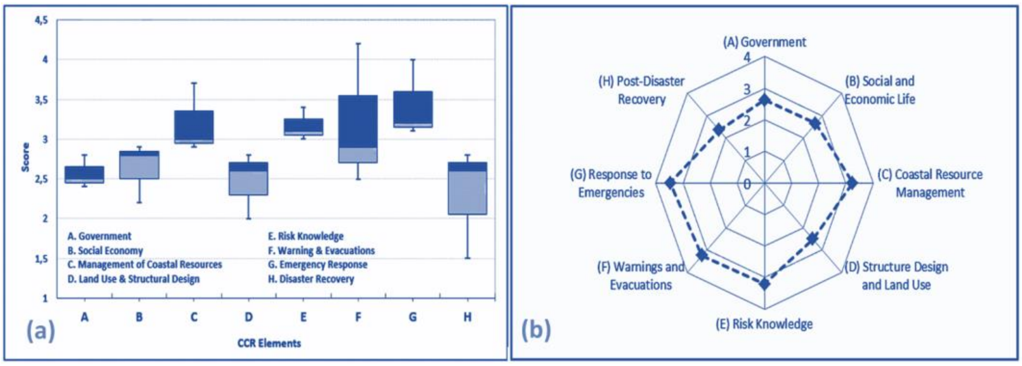

Figure 8. Distribution of RI from Three Villages in Pacitan Bay (a) and Classification of Each Elements According to CCR (b).

Figure 8a shows the variation in scores for each CCR element due to the questionnaire from respondents distributed over three villages in the Pacitan Bay. The score of each element based on the respondent's point of view is not normally distributed. The standard deviation of the scores for each element has a moderate variation (Table 8). The elements of the CCR that have a relatively homogeneous score are the role of the government (A), knowledge of tsunami risk (E) and emergency response (G). It can be assumed that the people's understanding of the three elements is sufficient. In contrast, the elements of CCR that have high response heterogeneity are warning and evacuation (F) and disaster recovery (H). The heterogeneity of these elements indicates that the level of public understanding regarding the issues needs to be improved. In addition, Figure 8b describes the average CCR score for each element. There are two distinctive classifications to describe the results. Six CCR elements (A, B, C, E, F, G) are classified into moderate resilience index. The moderate resilience index indicates that the community has adequate preparedness and self-capacity. However, more effort is required to increase the level of preparedness for a potential disaster. Meanwhile, two CCR elements have scores grouped into the low resilience category, indicating that the community should pay further attention to this category and address the low-rated indicators.

Furthermore, the CCR calculations show that Pacitan Bay's structural design and land use score low. Through Law No. 24 of 2007 on disaster management and Law No. 1 of 2014 on coastal and small island management, the Indonesian government has regulated disaster mitigation efforts from various perspectives, including land use and structural design. In recent decades, tsunamis have caused significant damage and loss to coastal settlements worldwide. It corresponds to socio-economic changes that have increased spatial and temporal risk due to the increasing coastal development and infrastructure (Bukvic et al., 2020; Paulik et al., 2019).

The minimum distance of buildings from tsunami-prone coastlines and the proper construction of earthquake-resistant buildings have also been determined. However, this seems to have not been applied adequately by the people of Pacitan Bay. Therefore, efforts are needed to reduce the threat of tsunami waves. Some studies recommend sea walls or breakwaters (Mitchell & Bilkovic, 2019; Xu et al., 2021), but those options are not suitable for Pacitan Bay, as this area is a busy fishing port. A more appropriate recommendation is to establish a natural green belt by planting coastal vegetation (Adriano et al., 2014; Kim et al., 2017). In addition, since extremely changing the existing land use and structural design require great effort and is almost impossible to do, developing a risk reduction program is a more viable option. Evaluating settlement damages from tsunami impact is a starting point for an effective tsunami risk-reduction program. Understanding damage probability among structures in vulnerable coastal areas may improve the implementation of tsunami mitigation measures and tsunami hazard planning (Adriano et al., 2014).

According to the CCR index analysis findings, the people of Teluk Pacitan appear to have undermined post-disaster preparation and recovery. Post-disaster recovery must address several issues, including infrastructure recovery, community economic revitalization, and restoration of survivors' mental and psychological health. (Paramesti, 2011; Park et al., 2018; Santius, 2015). They do not appear to have a systematic plan for post-disaster recovery. This fact arose because they seemed unaware of the possibility of a tsunami in the area. To manage this condition, the government should play a larger role in developing strategies for raising awareness through socialization and field practice with tsunami scenarios. Furthermore, the government must prepare a well-organized recovery plan for vulnerable areas in Pacitan Bay.

Vulnerability assessments that attempt to capture the complexities and dynamics of coastal systems would benefit coastal management and development policies. In order to ensure that the results can be translated into meaningful policy actions at the appropriate municipal or regional level and eventually implemented, the exchange of ideas between researchers and the government should be intensified. It will also be important to discuss the alignment between the geographic scale of vulnerability assessments and the potential policy interventions and programs designed to address these vulnerabilities. As previously stated, coastal hazards' extent and spatial distribution rarely correspond to administrative boundaries. However, regardless of the scale and scope of the hazard, relying on administrative units for vulnerability analysis is more likely to yield information useful for adaptation and resilience planning (Bukvic et al., 2020).

The community and the government need to improve resilience and preparedness against earthquake and tsunami disasters. Among them by increasing public awareness and knowledge about disaster management (Cai et al., 2016; Prado et al., 2015). The government must formulate acceptable policies based on current regional conditions, for example developing evacuation routes and preparing assembly areas. As reported on the website of the National Disaster Management Agency (www.bnpb.go.id/laporan-keuangan), in 2021 budget allocated for natural disaster management was around 1,3 trillion rupiah (90,45 million USD). However, the nature of this budget is a ready-to-use fund. It means that these funds can only be used after a disaster occurs. In fact, increasing public awareness and minimizing disaster risk requires significant funds but has not become a top priority for local governments. This is in contradiction with the progressive progress of disaster management in Indonesia. Finally, the government needs to optimize its role in increasing public awareness for disaster preparedness. With the enactment of the law, the paradigm adjustment in disaster management should be addressed properly. Disaster management in the old paradigm is reactive, partial, sectoral and incidental. They need to change to be proactive, holistic, comprehensive and sustainable (Kafle, 2012; Nucifera et al., 2021).

4. Conclusion

This study has demonstrated the use of GIS in mapping vulnerable area of Pacitan Bay from the potential tsunami event. The map was developed according to 5 physical features: elevation, slope, land use type, and distance from coastline and rivers. Based on the vulnerability map, approximately 79,70% (1058,07 Ha) of the coastal area in Pacitan Bay was classified as high – very high vulnerable. The flat beach condition and land use along the coastline, which is dominated by settlements, contribute significantly to Pacitan Beach's high vulnerability. According to the CCR analysis, Pacitan Bay has a low to medium level of community resilience. Policies on land use and building structures, as well as post-disaster mechanisms, must be improved to increase resilience.

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