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TSUNAMI DISASTER VULNERABILITY ANALYSIS USING GEOGRAPHIC INFORMATION SYSTEM (GIS) IN PACITAN DISTRICT, EAST JAVA

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ABSTRACT

Tsunami risk monitoring and management planning have become mandatory for the management of Pacitan District due to the high tsunami risk in the region caused by being among the subduction zone of the major plates and an area of active megathrust and ocean floor expansion. Approach in this study used four dimensions of risk to develop a tsunami index value: physical, social, economic, and environmental. The enumeration exercise used secondary data and analysis and processing techniques using QGIS and Microsoft Excel software, with the specific aim of graphically presenting the studied areas of tsunami vulnerability and the vulnerability index score from the regions for editing purposes. The locations such as Pacitan, Pringkuku, and Tulakan sub-districts are relatively vulnerable and therefore need to be upgraded its underdeveloped areas. This is because of poor infrastructure, population congestion, and unwarranted socioeconomic circumstances leading to a high level of exposure.

A. INTRODUCTION

The geological problem of the existence of the country of Indonesia in the conditions of the convergence of plates and areas in Indonesia such as the seismically active zone known as the Pacific ‘Ring of Fire’ (Isfahani et al., 1970), as well as subduction earthquake-prone zones. Moreover, the most populous island, Java, is located in an area of volcanic arcs that expanded from the mid-Paleogene era along the southern margin of the Eurasian continental plate and is also caused by the movement of the tectonic subduction (Husein, 2021). This is one of the results of tectonic activity that is massive or considerable, The movement of this plate produced transform faults and zones of subduction one of which is aseismic subduction caused due to differential movement direction. After that, until the Subduction Zone, the occurrence of earthquakes and tsunamis on Java island is a common phenomenon (Erlangga, 2020).

Subduction zones increase the frequency of seismic events in certain regions because the ‘through the expansion of the ocean floor or floor’ zones create the geological conditions necessary for earthquakes to occur. But on the contrary, due to the possibilities and

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thrusts of shallow and strong earthquakes that can produce tsunamis, if the assertions of horizontal faults that cross plates were employed and the vertical motions were subsidence generated in the process (UNESCO-IOC, 2019).

The Baribis, Cimandiri, and Opak faults are among the active faults that make up Java Island's tectonic landscape (PuSGeN, 2017). These subduction zones' seismicity, along with other geological settings, produced the circumstances for multiple earthquake eruption episodes, primarily on Java Island's southern coast. The Baribis, Cimandiri, and Opak faults are said to be the most active tectonic and subduction faults on Java Island (PuSGeN, 2017).

Based on research, the resulting subduction zone and other geological variables found in South Java caused earthquakes in the Pacitan area in 1994 (Mw = 7.8) and Pangandaran in 2006 (Mw = 7.8), which resulted in huge tsunami waves that reached about 20 meters. According to the statistics above, the subduction zone is a source zone for tsunamis that happen more frequently in places like Pacitan. The East Java region supports this, as Hadimoeljono claimed (PuSGeN, 2017) that a significant earthquake and tsunami struck the region in 1994, with Mw = 7.8.

Paleotsunami records from the island of Java in Pacitan, Teleng, and Prigi, Trenggalek, indicate that tsunami deposits happened in 1921 and 1930 (Anugrah et al., 2015). On June 2, 1994, an earthquake and tsunami struck East Java. Until documented, in Java's southern coast as a result of the March 28, 1875, earthquake (BMKG, 2019).

In the face of recurrent calamities, effective disaster risk management is essential, necessitating a thorough and cooperative approach (Triyanti et al., 2023). The Sunda Megathrust Subduction Zone, which is located in Java Island's southern portion, is a major tsunami risk (Muhammad et al., 2016), Said there is a long history of significant earthquakes that might cause tsunamis in the area where the Indo-Australian Plate meets the Eurasian Plate.

Megathrust earthquakes and tsunamis off the southern coast of West Java and southeast Sumatra are likely to have a significant impact on the infrastructure and population along the coast (Supendi et al., 2022). Disaster risk analysis is therefore necessary due to the problems with disasters and their high potential. An essential part of catastrophe management is risk assessment (Murdhani, 2024).

The proximity of a location to the Sunda Megathrust Subduction Zone, for instance, has a considerable impact on the likelihood of occurrence and the destructive potential of natural disasters such as tsunamis. In addition to disaster exposure, social, physical, environmental, and economic vulnerabilities can be used to gauge a community's preparation and susceptibility to future disasters (Denaner et al., 2021).

Due to its previous tsunamis, Indonesia's physical location—especially Pacitan, East Java, which is close to a subduction zone that is prone to earthquakes along the coast—makes it a research area for disaster susceptibility. risk analysis helps identify the area's level of risk by estimating the possible effects of disasters (Heru Sri Naryanto et al, 2007). As a result, tsunami disaster mitigation stakeholders use vulnerability analysis with expert GIS to map the resources available for disaster response and identify disaster-prone locations (Kyne, 2021). This information serves as the foundation for policy decisions.

B. METHOD

Tsunami vulnerability assessment and its study was made in Pacitan District, East Java Province, Indonesia. The coordinates of the district are 7.55º-8.17º S and 110.55º-111.25º E. In geographical location, the Pacitan Regency is bordered by the Ponorogo Regency in the north, the Indian Ocean in the south, the Trenggalek Regency in the east, and the Wonogiri Regency in the west. The area of the Pacitan Regency is roughly 1,389.87 km², and it is divided into twelve sub-districts (Miftakhudin, 2021).

This study evaluates tsunami susceptibility using a quantitative method and descriptive analysis. Secondary data from reliable literature and official statistics are among the main government sources. In line with earlier research, the literature analysis offers insights into the most recent approaches and conclusions in tsunami catastrophe risk assessment (Smith et al., 2021; Kasman & Erwin., 2021).

Refers to under BNPB Chief Regulation No. 2 of 2012, this research was carried out for risk assessment. A descriptive analysis of all collected data and information will be conducted to detect vulnerable areas in the sub-districts of the Pacitan Regency. This research using QGIS 3.34.11 software, data collected will be processed to determine the vulnerability of parameters including shrubs vegetation and land use classifications. These classifications are crucial to recognizing factors resulting in tsunami susceptibility (Hemati et al., 2021).

The FVI, SVI, EVI, and other vulnerability indices are used in this study to measure risk across sector parameters. Assessments were used such as the Physical Vulnerability Index (FVI), Social Vulnerability Index (SVI), Economic Vulnerability Index (EVI), and Environmental Vulnerability Index (EVI) with reference to the Regulation of the Head of the National Disaster Management Agency (BNPB) No. 2 of 2012 concerning General Guidelines for

Disaster Risk Assessment (BNPB, 2012a). This assessment has been taken into account in the method chosen by the Indonesian Disaster Risk book. The calculation takes into account other literature reviews, such as the significant weight of Population Density in the social vulnerability aspect. This is reinforced if population density can affect evacuation challenges and potential exposure during a disaster (Haryani et al., 2021; Rizqi Safirul Kamal et al., 2025).

Thus, the BNPB regulation used as a reference is derived from a combination of expert knowledge and empirical observations of past disaster events in the national context, translated into weightings (Heß, 2017). one of these aspects is one example of other literature, explaining Regulation of the Head of the National Disaster Management Agency (BNPB) No. 2 of 2012 regulation in the calculation of the tsunami vulnerability method has scoring for each parameter.

A. Physical Vulnerability

The indicators used for physical vulnerability are housing density (permanent, semi-permanent and non-permanent), availability of public buildings/facilities and availability of critical facilities (BNPB, 2012a). The definition of physical vulnerability is described in BNPB Chief Regulation No. 2 of 2012. (BNPB, 2012b). The parameters for physical vulnerability are described in the BNPB Regulation. Houses, public amenities, and vital facilities are the three primary parts. The physical vulnerability index is computed using the formula below (1).

Physical Vulnerability Index (IKF) = (0.4×House) +(0.3×Public Facilities) + (0.3×Critical Facilities) …………..… (1)

Table 1. IKF Variable Used and Definition

Variable	Definition
House Score	A quality and structure assessment of the house structure
Public Facility Score	Rating based on Public services were available
Critical Facility Score	Rating based on Hospitals and evacuation centers.

(Source: BNPB, 2012b)

B. Social Vulnerability

The IKS is the level of vulnerability or potential for physical damage to be caused to buildings or man-made physical objects (infrastructure, buildings, and other physical assets) due to the direct impact of a disaster event (BNPB, 2012a; Carreño et al., 2007). Demographic characteristics of the Social Vulnerability Index (IKS) to tsunamis. It takes demographics, education levels, and vulnerable groups into account. Social vulnerability has the following formula (2):

Social Vulnerability (IKS) = (0.60×Population Density) +(0.10×Gender Ratio) +(0.10×Vulnerable Age Group Ratio) +(0.10×Poverty Rate) +(0.10×Dissability Rate) …………… … (2)

Table 2. IKS Variable Used and Definition

Variable	Definition
Population Density	Divided by population density (per hectare)
Sex Ratio	The ratio of the male population to female population
PVI by Age	Vulnerable Age Group Ratio: Percentage of population made up of vulnerable age groups
Ratio	Percentage of population made up of vulnerable age groups
Poverty Rate	The percentage of people living below the poverty level is known as
Disability Rate	The proportion of people with disabilities in the population

(Source: BNPB, 2012b)

C. Economic Vulnerability

The indicators used for economic vulnerability are the area of productive land in rupiah (paddy fields, plantations, agricultural land and ponds) and GRDP (BNPB, 2012a). A statistic called the Index of Economic Vulnerability evaluates a community's or region's economic susceptibility to the effects of disasters. GDP and the amount of productive land are the two main metrics used to calculate the economic vulnerability parameter.

The following formula is used to determine economic vulnerability: (3) illustrates the unique weighting assigned to each indicator and has the following formula (3).

Economic Vulnerability Score (IKE) = (0.4×GRDP Score) + (0.6 Productive Land Score) ……………. (3)

Table 3. IKE Variable Used and Definition

Variable	Explanation
Productive Land Score	A rating determined by how much land is used for production.
GRDP Score	A rating determined by each subdistrict's Gross Regional Domestic Product (GRDP)

(Source: BNPB, 2012b)

D. Environmental Vulnerability

The study examines the environmental factors ranging from mangroves to aquatic systems to land use that influence the impacts of tsunamis. Environmental vulnerability scores were calculated using the BNPB Regulation No. 2/2012-aligned assessment technique. The indicator used for environmental vulnerability is land cover (protected forest, natural forest, mangrove forest, swamp and shrub). The physical vulnerability index is different for each type of threat and is derived from the weighted average of land cover types (BNPB, 2012a).

Each parameter is then multiplied by the degree of hazard classification: 0% means low risk, 50% means medium risk and 100% means high risk. The final index derives from the Environmental Vulnerability Formula (4), with different relative weightings applied to these groups by category.

Environmental Vulnerability (IKL) = (Protected Forest Score) + (Natural Forest Score) + (Mangrove Score) …………..… (4)

Table 4. IKL Variable Used and Definition

Variable	Explanation
Protected Forest Score	Based on the area of protected forest in its size
Natural Forest Score	Based on the area of natural forest
Mangrove Forest Score	Based on the area of mangrove forest (Ha)

(Source: (BNPB, 2012b)

The results were conducted to identify all areas most vulnerable to tsunami disasters. This vulnerability map will then be used to devise appropriate mitigation strategies (Yavuz et al., 2022). Utilizing the following formula (5), the Tsunami Vulnerability Index (IKT) is calculated.

(IKT) = (IKS×0.40) + (IKF×0.25) + (IKE×0.25) + (IKL×0.10)…………(5)

Information:
IKS: Social Vulnerability Index
IKF: Physical Vulnerability Index
IKE: Economics Vulnerability Index
IKL: Environmental Vulnerability Index
(Source: BNPB, 2012b)

C. RESULT AND DISCUSSION

C.1. RESULT

A comparative analysis of tsunami susceptibility in different places shows that The level of affectability is impacted by different social, financial, physical, and natural components. The following table shows the criteria and weightings that influence tsunami vulnerability. The following describes how to identify the parameters, scoring or weighting, and classes used to calculate the total tsunami risk index, which is shown in (Table 1).

It identifies numerous signs as critical to determining the amount of vulnerability. The method for determining tsunami susceptibility based on the characteristics, weighting, and classes utilized to calculate the overall tsunami risk index, as shown in **Table 1**, is described below.

Table 5. Classes and Weighting Parameters Determining Tsunami Vulnerability

Vulnerability	Parameter	Weight (%)	Class		
			Low	Medium	High
Social	Population Density (per ha)	60	<5 persons/ha	5 to 10 persons/ha	>10 persons/ha
	Gender Ratio (%)	10	>40%	20% to 40%	High: <20%
	Poverty Ratio (%)	10	<20%	20% to 40%	>40%
	Poverty Ratio (%)	10	<20%	20% to 40%	>40%
	Age Group Ratio (%)	10	<20%	20% to 40%	>40%
Economic	Productive Land Area (IDR)	60	<IDR 50 million	IDR 50 million to IDR 200 million	>IDR 200 million
	GRDP (Gross Regional Domestic Product)	40	<IDR 100 million	IDR 100 million to IDR 300 million	>IDR 300 million
Physical	Number of Buildings (IDR)	40	<IDR 400 million	IDR 400 million to IDR 800 million	>IDR 800 million
	Public Facilities (IDR)	30	<IDR 500 million	IDR 500 million to IDR 1 billion	>IDR 1 billion
	Critical Facilities (IDR)	30	<IDR 500 million	IDR 500 million to IDR 1 billion	>IDR 1 billion
Environmental	Protected Forest	45	<20 ha	20-50 ha	>50 ha
	Natural Forest	45	<25 ha	25-75 ha	>75 ha
	Mangrove Forest	10	<10 ha	10-30 ha	>30 ha

Source: Head of (BNPB, 2012b) Regulation Number 2 of 2012)

Table 5 lists some of the elements that increase tsunami danger in coastal areas. This susceptibility is heavily influenced by crucial characteristics such as population density and gender ratio; places with higher population density and gender imbalance are more vulnerable to tsunami impacts. In addition, the existence of vulnerable age groups and socioeconomic levels heightens the risk.

In terms of economics, the availability of productive land and gross regional domestic product (GRDP) are key indications of vulnerability. Areas with less productive land and lower GRDP are more vulnerable to disasters. Similarly, in the physical category, the quantity of buildings, public facilities, and key infrastructure is important in determining vulnerability. Finally, environmental considerations are important, such as the size of protected forests, natural forests, and mangroves. Smaller forested areas are more susceptible to tsunami destruction.

1. Physical Vulnerability

Physical Vulnerability contains a variety of factors including the condition of each housing unit (in the form of categorical prices per unit), including per-house availability. Quality and accessibility of public facilities and the number of critical facilities. As can be seen in the map results shown (**Figure 1.A**), there is a contribution of the calculated index per sub-district to physical vulnerability. As with the Tulakan sub-district, it has the most dwellings in the calculation data so it will help contribute to vulnerability.

There is a risk in physical vulnerability, due to the presence of critical facilities including hospitals, health centers, and other infrastructure that can increase the position of vulnerability if the tsunami becomes high in Pacitan District. Therefore, a special calculation for physical vulnerability will produce the thematic map shown in **Figure 1.A**.

2. Environmental Vulnerability

Environmental vulnerability is a component in evaluating the risk of a disaster. An environmental vulnerability index can be generated by combining several parameters, such as natural forest, mangrove forest, and protected forest. This shows that the land use of a place will have an impact on the vulnerability aspects of a phenomenon, including disasters such as tsunamis. In Pacitan District, the presence of these forest parameters by considering the per-hectare area of each land cover is owned by each sub-district. As shown in the environmental vulnerability map below (**Figure 1.B**), can show a difference in the results of the environmental vulnerability index in each region.

Pacitan and Pringkuku sub-districts show the highest vulnerability, indicating a large area of forest land. On the one hand, the forest provides protection, but on the other hand, it will contribute to environmental vulnerability in the event of a tsunami. In contrast, Kebonagung, Tulakan, Ngadirojo, and Sudimoro show low vulnerability with less land cover than other areas.

3. Economic Vulnerability

The Economic Vulnerability Index in Pacitan District has two factors influencing its value. High economic vulnerability is found in the Tulakan and Pacitan sub-districts. This is based on the calculation matrix, caused by land value and Gross Regional Domestic Product (GRDP). So that when a disaster occurs, it will contribute to a more vulnerable economy. In contrast, Donorojo and Sudimoro sub-districts show low vulnerability. So it will contribute little if a tsunami disaster strikes with the scope of calculation per sub-district in Pacitan.

Indeed the sub-districts with low, medium, and high indices can be seen in the economic vulnerability map below

(**Figure 1.C**). Therefore, with the description of the economic vulnerability index, it is necessary to emphasize the risk of disaster impacts on the economic sector, especially more vulnerable areas.

4. Social Vulnerability

Social vulnerability shows vulnerability per sub-district in Pacitan Regency, based on population parameters and vulnerable groups in disaster conditions. The calculation shows the results of social vulnerability in the vulnerability map below (**Figure 1.D**). The sub-districts of Donorojo, Kebonagung, and Arjosari have low social vulnerability due to the lower factors mentioned above. Conversely, Pacitan and Pringkuku sub-districts have a high vulnerability, based on the vulnerable population to sex ratio showing higher.

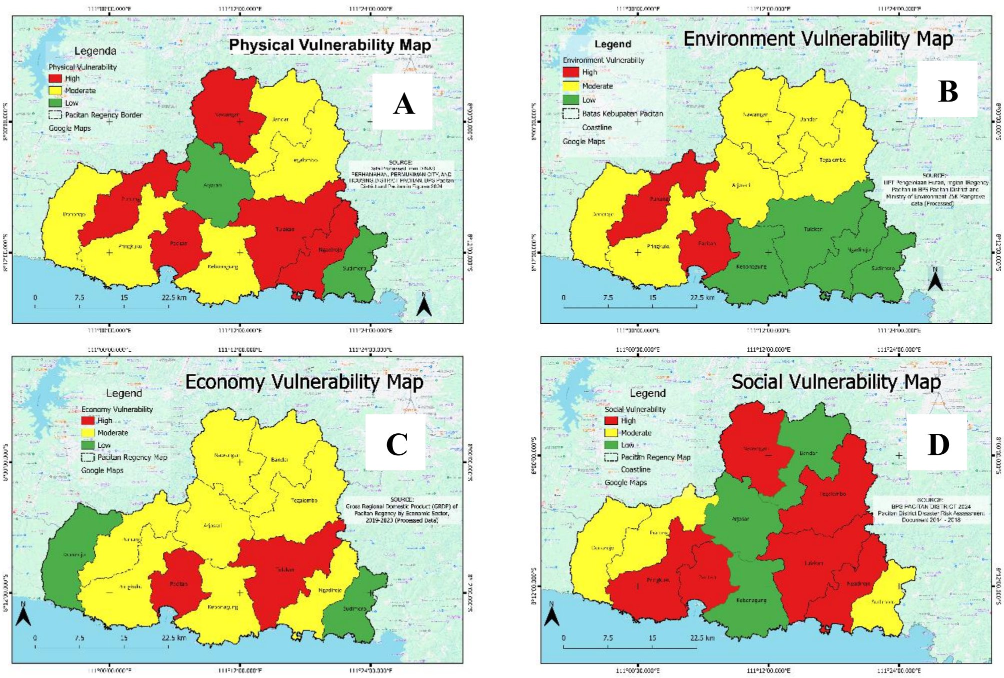

Figure 1. (A) Physical, (B) Environmental, (C) Economic, and (D) Social Aspect
(Source: Processed by the researcher, 2024)

5. Tsunami Vulnerability in Pacitan

The results of the Tsunami Vulnerability Index (TVI) calculation in Pacitan District are based on the parameters presented earlier. Parameters such as the physical vulnerability index (IKF), environmental vulnerability index (IKL), economic vulnerability index (IKE), and social vulnerability index (IKS) are calculated using a special formula for tsunami disasters. The following is a description of each sub-district in the final tsunami vulnerability results (**Table 6**) as follows:

Moderate tsunami vulnerability in Pacitan District is indicated by a vulnerability index in the range of 0.45 to 0.70. The sub-districts within this interval are Donorojo, Kebonagung, Arjosari, Bandar, Ngadirojo, and Sudimoro. These sub-districts have a medium value because they are helped by social factors that can be effectively mitigated and have a smaller contribution value. Therefore, efforts to be prepared for tsunamis need to be prioritised in mitigation. Then Pacitan sub-district holds the highest value to enter the 'Very High Category', due to high environmental, physical and social factors, making it the most vulnerable area in Pacitan District.

Pacitan sub-district is bordered and very close to the coastline directly, as well as high population density and the environment has the potential to be damaged by tsunami waves and makes a note to prioritize preparedness efforts in the most vulnerable areas.

Table 6. Tsunami Vulnerability Index in Pacitan Subdistricts

No	Subdistrict	IKS	IKF	IKE	IKL	IK
1	Donorojo	0.68	0.70	0.01	0.62	0.58
2	Punung	0.68	0.80	0.27	0.62	0.70
3	Pringkuku	0.80	0.70	0.28	0.91	0.73
4	Pacitan	0.90	0.90	1.00	1.00	0.91
5	Kebonagung	0.30	0.70	0.24	0.33	0.45
6	Arjosari	0.30	0.60	0.27	0.62	0.52
7	Nawangan	0.80	0.80	0.36	0.62	0.71
8	Bandar	0.30	0.70	0.31	0.62	0.50
9	Tegalombo	0.80	0.70	0.36	0.58	0.66
10	Tulakan	0.80	0.80	0.59	0.33	0.69
11	Ngadirojo	0.80	0.80	0.15	0.33	0.62
12	Sudimoro	0.50	0.60	0.03	0.51	0.48

(Source: Data processed from Tsunami Vulnerability Index Calculation, book Risiko Bencana Indonesia. Badan Nasional Penanggulangan Bencana (BNPB), 2016)

C.2. DISCUSSION

The analysis of the vulnerability index in Pacitan Regency shows that each sub-district has threats of combined tsunami vulnerabilities as well as different vulnerabilities when examined by each parameter. Physical vulnerability with residential units, the number of public facilities, and vulnerable facilities. Thus, it will affect a dense population in a narrow area by becoming a supporting factor, contributing to a location becoming vulnerable.

On the physical vulnerability index, it occurs in Tulakan and Nawangan. If a tsunami occurs, it can damage buildings and facilities, leading to casualties. Therefore, building structures are important, especially in areas that will be directly facing the coastline. This certainly becomes a concern for the Pacitan District, which has a high index value for physical vulnerability. Strengthened by tsunami hazard modeling calculations by (Aditama et al., 2023), concluding that the inundation-affected area zone is 21.63 km² in the event of a tsunami simulation.

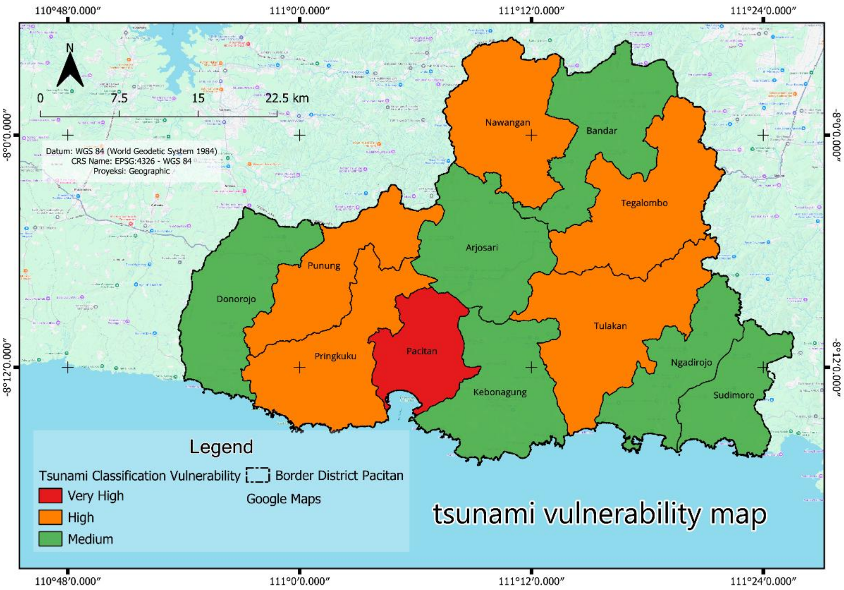

Figure 2. Tsunami Vulnerability Map
(Source: Processed by the researcher, 2024)

Forests and mangroves along the coast can reduce the direct effects of tsunami waves, so the coastal areas of Pacitan and Pringkuku, based on calculations, can be protected by the mangrove forests generally found in the Pacitan district. However, areas close to the beach will be more vulnerable in terms of environmental aspects as well as tsunamis, so it is hoped that the mangrove ecosystem can be preserved. Mangroves or mangrove trees, based on research, can reduce wave height effects by up to 66%. In ideal conditions, certain species, such as Avicennia marina, can reduce wave energy by up to 92.3% (Bowles, 1997; Cuenca-Ocay., 2019).

Physical and environmental vulnerabilities will affect other vulnerabilities, such as economic vulnerability related to the community's ability to sustain their livelihoods in the event of a tsunami disaster. Therefore, economically active districts will be more vulnerable. Especially if the exposure to disasters is related to higher land prices. Furthermore, the Pacitan district is the most affected. Conversely, sub-districts with a low economic index will contribute less to economic vulnerability. The districts are Donorojo, Sudimoro, and Ngadirojo.

However, in the literature review, economic vulnerability is assessed using direct field data collection methods, as mentioned in (Insan et al., 2023) thesis, which states that the Ngadirojo and Pacitan sub-districts experience high economic vulnerability. With the classification of villages in the Pacitan sub-district covering an area of 8,360 Ha and ten villages in Ngadirojo covering an area of 48,817.86 Ha affected. Therefore, primary data collection can provide more accurate information secondary data.

The relationship between physical, environmental, and economic vulnerabilities is also influenced by field conditions with their social vulnerabilities. This is related to post-disaster reconstruction for vulnerable populations such as those in poverty or with disabilities, which makes recovery difficult, as well as the gender ratio related to the ability to repair infrastructure. Thus, districts with a massive population like Pacitan District, with its residents, such as Pacitan. The contribution of resources, such as the large number of elderly people and low-income residents, will result in a high level of social vulnerability. However, on the contrary, if the social vulnerability among the population is lower, such as in the districts of Donorojo and Sudimoro, the effects on casualties and others are fewer, resulting in lower vulnerability. However, in another study, Ngadirojo was classified as having quite high social vulnerability, focusing on only two villages covering an area of 6,833 Ha (Insan et al., 2023).

Conclusion of the vulnerability index assessment analysis for each sub-district in Pacitan Regency. The government is actively engaged in mitigation efforts based on the tsunami disaster capacity index, which will reduce casualties and maintain the structural integrity of buildings, as well as educate the community about disaster mitigation. In addition, other areas have vulnerabilities to flooding disasters, with the lowest economic and social vulnerabilities in Donorojo and the highest in physical vulnerability. Therefore, the approach for each sub-district varies depending on its vulnerability index value.

According to the Tsunami Vulnerability Map above (**Figure 2**), this will be illustrated by the variation in tsunami vulnerability across different sub-districts of Pacitan. Areas with an IKT greater than 0.70, such as Punung, Pringkuku, Nawangan, Tegalombo, and Tulakan, are considered high-risk zones because of their inadequate infrastructure and high-risk environmental conditions. Furthermore, these regions are more vulnerable due to the high degree of economic activity in them. With the highest IKT value of 0.91, the Pacitan sub-district is classified as having very high vulnerability.

Various and interwoven social, physical, and environmental factors combine to make communities more vulnerable, such as high population density, a lack of preparedness against disasters, and degradation of the environment. For instance, Subdistricts Donorojo and Sudimoro are areas with lesser susceptibility because of low population density and reduced exposure to the hazard of tsunami. Tsunami vulnerability analysis for Pacitan district reveals a diverse distribution of vulnerability across its sub-districts. Using the Tsunami Vulnerability Index, the study identifies areas of high to very high vulnerability, particularly those along the coast or in low-lying areas.

The sub-districts of Pacitan, Tulakan, Nawangan, Pringkuku, and Tegalombo have the highest value of IKT. Due to this closeness to the shore combined with inadequate infrastructure and not-so-favorable environmental settings, all these places enhance their risk for tsunamis and are considered more vulnerable. Pacitan, with an IKT value of 0.91, is classified as a very high vulnerability area, considering factors such as high population density, limited preparedness for disasters, and environmental degradation. Subdistricts like Donorojo and Sudimoro, on the other hand, have lesser vulnerabilities because of their low population density and lower exposure to risk. Tsunami vulnerability research in Pacitan using demographic and socio-economic data has official references from secondary data. Limitations inherent to researcher control of quality, accessibility, accuracy, comprehensiveness, and recency of data (Gouvea-Reis et al., 2022). However, urbanisation and migration factors are not accounted for in the secondary data and the research can only provide an overview raises the ecological fallacy (Koks et al., 2019).

Therefore, further research requires field validation with high mapping resolution to obtain more quantifiable information. The weighting scheme used is based on the assumption that each indicator contributes equally to overall vulnerability in Pacitan. However, this does not necessarily reflect the reality on the ground (Birkmann, 2007; Hinkel, 2011).

D. CONCLUSION

The tsunami vulnerability article in Pacitan Regency uses four parameters: physical, environmental, economic, and social, to identify and assess the vulnerability of Pacitan Regency to tsunamis. Based on the results of the research, each index and calculation show that districts such as Pacitan, Tulakan, Nawangan, Pringkuku, and Tegalombo are very vulnerable to tsunamis due to their index values. The tsunami vulnerability in Pacitan Regency is known and requires an evaluation of each vulnerability parameter. Such as physical, environmental, economic, and social. Coastal districts such as Pacitan, Tulakan, Nawangan, Pringkuku, and Tegalombo are places with vulnerabilities that need to be evaluated for disaster mitigation considering they are located in an active subduction zone that can threaten the coast of Java.

There is a need for awareness among the community, especially those living in coastal areas, directly bordering the shoreline, and in densely populated or highly vulnerable group locations, to be prepared to face disasters. If there is no proper handling, it will result in economic vulnerability or post-disaster difficulties in reconstructing the area. Places like Pacitan and Tulakan are in a position where the value of their land is high and thus, they have a greater economic risk. The conclusion of the tsunami vulnerability value is in the Pacitan district with a very high score, reaching 0.91. In addition, sub-districts with lower danger levels such as Donorojo and Sudimoro have lower population densities.

The research suggestion is that further investigation is needed, taking into account the roles of the government, academics, and the community itself in facing disasters, similar to the Pentahelix model. And the lack of secondary data collection, further field research is needed to continuously gather data to facilitate policy-making in the future.

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