Eco. Env. & Cons. 28 (3) : 2022; pp. (1232-1245)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i03.021

A Modelling and Mitigation Strategy for the Impact of the Tsunami Disaster at Tamban Beach, Malang Regency, using a Geographic Information System

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(Received 27 November, 2021; accepted 3 January, 2022)

ABSTRACT

Tsunami events are caused by a series of waves resulted from sudden changes in the water column, seismic activities such as the eruption of underwater volcanoes, landslides on cliffs above or below the sea, and falling asteroids. The Meteorology, Climatology, and Geophysics Agency released a warning of a potential earthquake in the southern part of Java Island, including the Malang Regency, with a magnitude of 8.7 on the Richter's scale. It means that a tsunami with a maximum inundation height of up to 22 meters could destroy Tamban Beach. The objectives of this study were1) to examine the spatial aspect of Tamban Beach and its relevance to the ecological aspect as well as the time aspect related to the estimation,2) to formulate a strategy to save the community, and 3) to estimate the impact of the damage to cover and land use. The methods used were a scoring technique and an overlay analysis using a Geographic Information System (GIS), with parameters including the distance to the coast and river from the sea, slope, elevation, land use, tsunami run-up prediction, and inundation model. The Partial Least Squares (PLS) method was used to determine the relationship between the level of vulnerability of an area to the tsunami disaster with various assessments and efforts to mitigate the disaster. The results showed that most of the coastal areas of Tamban Beach had a moderate level of vulnerability, except for the residential areas that had a high level of vulnerability. A tsunami mitigation strategy was significantly influenced by the area's level of vulnerability to a disaster and the assessment of disaster management efforts.

Key words: *Tsunami, Coastal area, GIS, PLS, Social Vulnerability*

Introduction

According to the UNISDR (2018), the occurrence of atsunami would leave a fairly severe impact on human life, such as loss of life and considerable economic loss. It is estimated that the impact of the disasterwill continue to increase tomore than 100 times in the next twenty years compared to the previous two decades. Tsunamis are caused by several geophysical phenomena that cause disturbances to the water surface. These disturbances mainly come from underwater earthquakes, which were previously low-frequency events. However, when a tsunami does occur, the impact left is marked by an increasing number of casualties due to the increasing number of people living in coastal areas. The problem is that residents have a little or no experience with tsunami disasters that occurred in the past. At present, with the occurrence of the global climate change and with the frequent occurrence of megatsunamis that accompany large earthquakes, the impact is growing bigger to covera large area and the loss of property and life is also inflating (Fumihiko *et al.*, 2019; Meyyappana *et al.*, 2015). Ingrid *et al.* (2013) mentioned that tsunamis are propagating waves characterized by long wavelengths and large amplitudes near the coast. The most prominent feature of a tsunami is the presence of a large trough that precedes apositive wave. The waves are destructive, causing a severe damage to structures and human casualties when they reach coastal areas. To facilitate identification, it is necessary to know the run-up. A run-up is a local characteristic of inland wave flow and this measure, easily identified in the field, is widely used as an indicator of tsunami inundation and impact on the coast. Ella *et al.* (2019) mentioned that tsunamis are characterized by surface waves in seconds, wavelength, and tidal movement. The characteristic wavelength is around 10–100 m, while the tidal movement is characterized by a time scale of 12 hours. Additionally, the wavelength is determined by the size of the local basin (e.g., 100 km). In comparison, the typical period and wavelength of a tsunami are intermediate, being between ocean waves and tides (e.g., 2,400 seconds). In addition, a tsunami's characteristics change significantly as it spreads across the ocean, with an amplitude being several centimeters offshore and a wavelength tending to be longer than the water depth (e.g., 200 km). When the tsunami moves to the coast, the wavelength is significantly reduced (e.g., 20 km) and the wave height is increased, sometimes reaching 10–15 m. The tsunami's energy is conserved as it moves toward the coast because the dissipation caused by a drag on the seabed is negligible. In most inhabited coastal areas, the land slope is small and a height of 15 m corresponds to a great distance inland (e.g., 1.5 km for 1:100). The potential for entry into the ground and damage to infrastructure is significant. Various waveforms and series of waves have been observed in the past, with high waves leading or waves suppressing.

Ella *et al.* (2019) reported some results of their research on the coast of Banda Aceh, showing that the coastal area is an area that is vulnerable to various hazards such as tsunamis and land subsidence due to earthquakes, which are characteristic to Indonesian coastlines. If the climate warming process generates the melting of ice, especially in Greenland, then it is estimated that in Indonesia there will be a sea level rise in 2100 by up to 80–180cm (Sofyan *et al.,* 2010).

Indonesia is at the confluence of 3 active tectonic plates of the world, namely the Indo-Australia, Pacific, and Eurasian plates. The occurrence of a plate movement threatens Indonesia with a fairly large endogenous disaster. This endogenous disaster can be avolcanic eruption, earthquake, or tsunami. In the last two decades, the tsunami has been recorded asthe deadliest endogenous disaster that occurred in Indonesia, with adeath toll reaching 170,000 people.

Srinivas (2021) stated that Indonesia is the country worst affected by the tsunami, considering that the epicenter of the earthquake was less than 40 kilometers from the coast of the island of Sumatra. The resulting tsunami extensively inundated coastal areas, reaching inland from 500 meters to about two kilometers on the west coast. In some areas along rivers and estuaries, ocean waves extend more than six kilometers inland. In addition to the massive loss of life, with more than one million killed or displaced, the economic devastation and environmental damage on the island of Sumatra were extensive. Coral reefs, mangroves, coastal areas, wetlands, agricultural fields, forests, and cultivated areas, among others, were badly damaged.

Tamban Beach as one of the southern coastal areas inMalang Regency has the potential to be hit by a tsunami because it is directly opposite to the Indo-Australian plate. However, it does not have a tsunami barrier. Disaster adaptation scenarios as a mitigation effort can be developed by making evacuation sites, but evacuation sites on the coast of Tamban Beach are not yet available. Therefore, the objectives of this study were to examine the spatial aspect of Tamban Beach and its relevance to the ecological aspect as well as the time aspect related to the estimation, to formulate a strategy to save the community, and to estimate the impact of the damage to cover and land use.

Materials and Methods

The research site

To better understand the tsunami disaster that will possibly impact the coastal areas in the southern part of East Java, Indonesia, a case study was conducted on Tamban Beach, Malang Regency. The research location can be seen in Figure 1.

Tamban Beach borders the Indian Ocean and administratively belongs to the Tambakrejo Hamlet, Tambakrejo Village, Sumbermanjing Wetan District, Malang Regency, East Java. According to the Meteorology, Climatology, and Geophysics Agency (BMKG), Tambakrejo Village, Sumbermanjing Wetan District, Malang Regency, East Java has the status of an earthquake-prone area. This is based on the village's history of being hit by tsunamis in 1996 and 2004 (Julaika, 2021).

Study Methods

The methods used in this study were a scoring technique and an overlay analysis using a Geographic Information System (GIS), with parameters including the distance to the coast and river from the sea, slope, elevation, land use, tsunami run-up prediction, and inundation model (Hloss) developed by Berryman (2006). Questionnaire processing was carried out using the Partial Least Squares (PLS) method to determine the relationship between the level of regional vulnerability to the tsunami disaster with various assessments and efforts to mitigate the disaster. The results showed that most of the coastal areas in Tamban Beach had a moderate level of vulnerability, except for the residential areas that had a high level of vulnerability.

Geographic Information System (GIS)

The research work scheme using the GIS method produced a final result in the form of a tsunami inundation map. This inundation map was used to analyze loss of damaged buildings in the affected areas and to develop a work scheme for mapping the physical vulnerability tothe tsunami disaster, which produced a final result in the form of a map of physical vulnerability to the tsunami disaster.

The working scheme in the data processing for tsunami natural disaster vulnerability mapping can be seen in the flow chart in Figure 3.

Data were obtained by downloading from the data provider's website and from a field survey. The data used in this study were classified into 2, namely spatial and non-spatial data. The spatial data used were Sentinel-2A satellite imagery, ALOS PALSAR Digital Elevation Model, village administration shapefile, coastline shapefile, river shapefile, and building parcel shapefile. Sentinel-2Asatellite image data were obtained by downloading from the European space agency Copernicus' website (https://scihub.copernicus.eu/). ALOS PALSARDigital Elevation Model data were obtained by downloading from the Alaska Satellite Facility's website (https://search.asf.alaska.edu/). Village administration

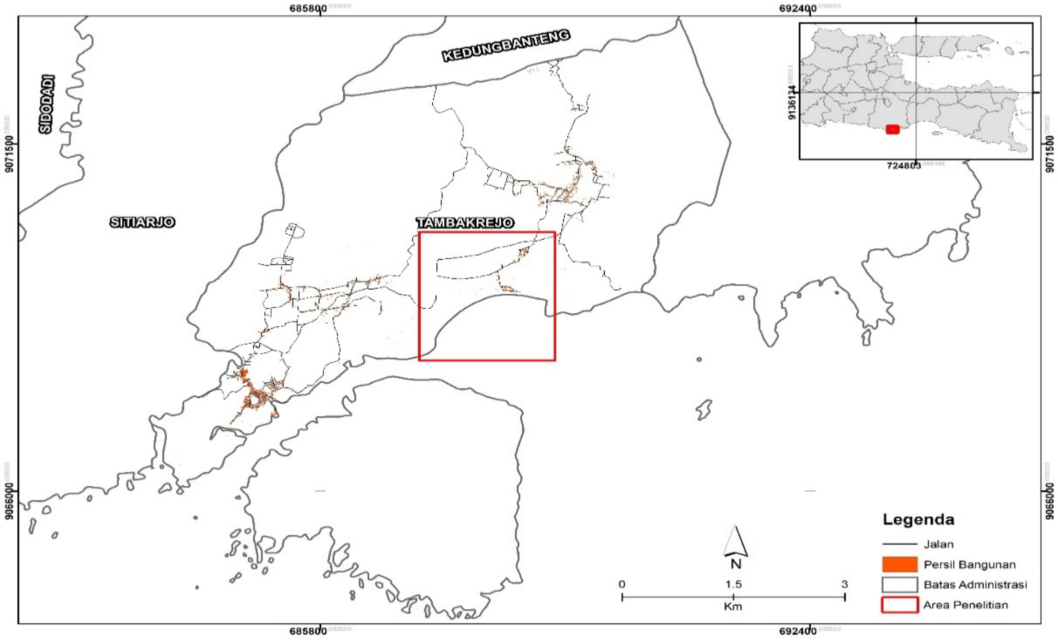

Fig. 1. Reserach Location onTamban Beach, Malang Regency, East Java Province, Indonesia

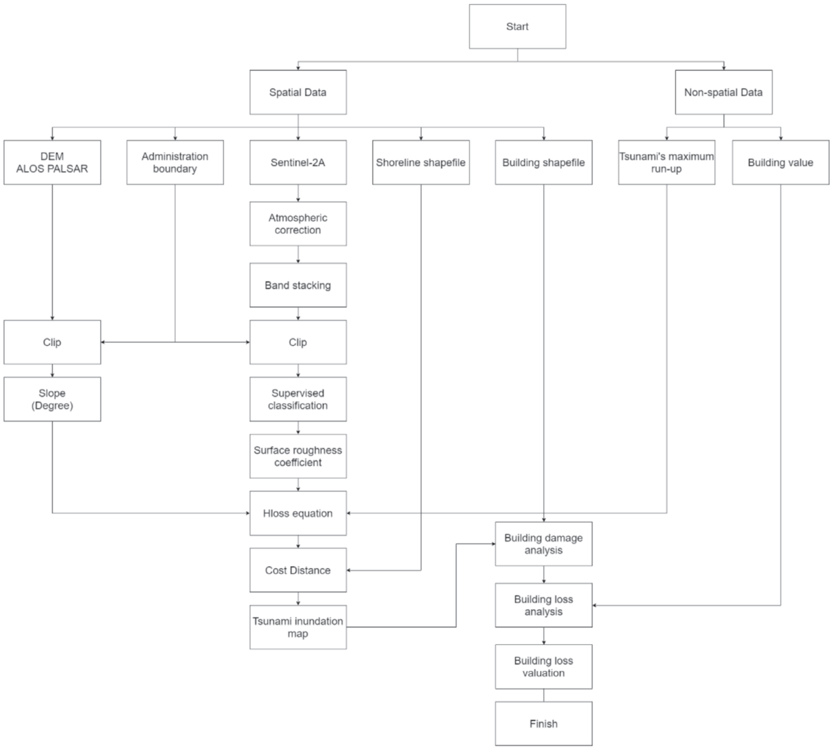

Fig. 2. Tsunami Hazard Mapping Work Scheme

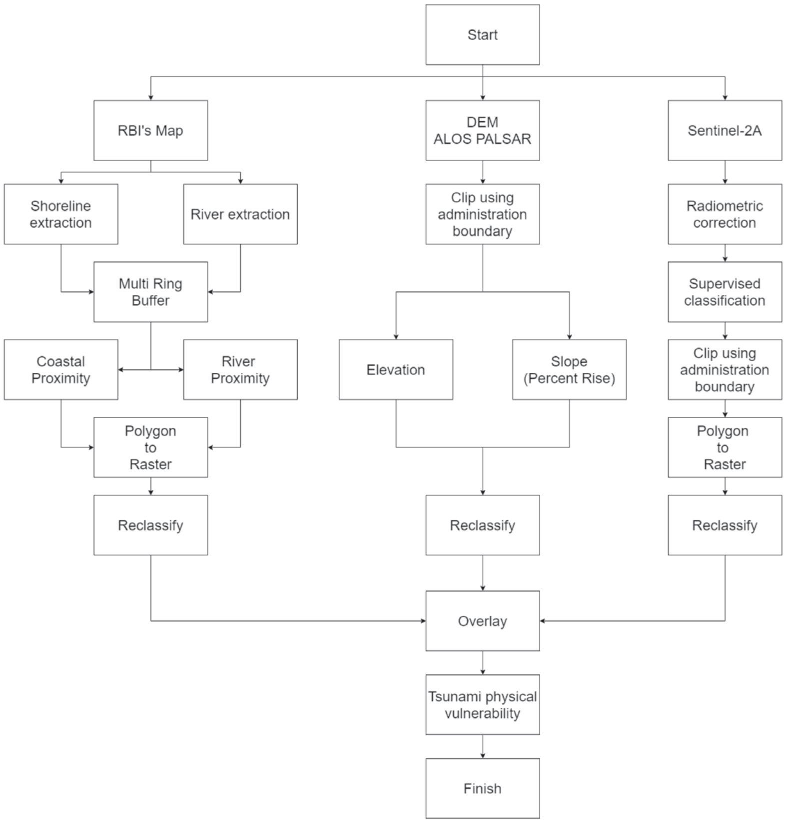

Fig. 3. Physical Tsunami Disaster Vulnerability Mapping Work Scheme

shapefile, coastlines, and rivers data were obtained by downloading from the Indonesia Geospatial Portal's website (https://tanahair.indonesia.go.id/portal-web/). Building shapefile data were obtained by digitizing on screen image Google Earth using the software Google Earth Pro. Meanwhile, the non-spatial data used were those on the maximum tsunami height, building values, and demographics. The maximum tsunami height data were obtained from Appendix 2 of the Regulation of the Head of the National Disaster Management Agency No. 4 of 2012. The building values data were obtained based on the NJOP (Tax Object Sales Value) of buildings per square meter. The NJOP of buildings was obtained from the surrounding community regarding the prices and areas of permanent buildings through a field survey in the coastal areas of Tamban Beach. The demographic data were obtained from the Tambakrejo Village Government through a field survey.

Data processing and analysis were carried out using the applications ENVI, ArcMap (ArcGIS), Google Earth, and Microsoft Excel. The steps and their explanations are as follows:

Mapping of Losses from theTsunami Hazard

The mapping of losses from the tsunami hazard used tsunami inundation parameters, which included the coefficient of surface roughness from land use extraction, maximum tsunami height, and land slope, as well as parcel shapefiles and building values. Data processing was carried out using the software ENVI 5.3 and ArcMap 10.3.

Tsunami Hazard

The tsunami hazard map was modeled using the calculation formula developed by Berryman (2006).

$$Hloss = \left(\frac{167n^2}{{H_0}^{1/3}}\right) + 5\sin S$$

where:

Hloss = Decrease in tsunami height per 1 meter of inundation distance

n = Surface roughness coefficient

H0 = tsunami wave height at the coastline (meters)

S = Slope of the ground (degrees)

Information on the parameter surface roughness obtained from land use data. The parameter tsunami wave height referred to the Regulation of the Head of the National Disaster Management Agency No. 4 of 2012. Information on the parameter slope of the ground was generated from the Digital Elevation Model data processing. The tsunami hazard index could be calculated based on the height of the inundation. The transformation of the tsunami inundation height into a tsunami hazard index was carried out using the fuzzy logic method. Fuzzy logic is one of the components that make up soft computing. The basis of fuzzy logic is the theory of fuzzy sets; the role of membership value (membership function) as a determinant of the existence of elements in a set is the main and central feature. The fuzzy set membership value is continuous on a scale of 0 to 1. The fuzzy logic method can be performed using the Fuzzy Membership function in the Spatial Analyst toolbox on the software ArcMap.

Land Use and Surface Roughness

Land use and surface roughness were parameters that played an important role in the area of tsunami inundation. The barer and smoother a piece of land, the less its ability to absorb tsunami waves. Land use data were obtained from the classification of Sentinel-2A satellite imagery with a spatial resolution of 10 meters. The data were processed using the software ENVI 5.3. The software couldbe used to classify land use from remote sensing images automatically.

The method used to classify land use was the supervised classification technique. The technique used training sample data from several land use classes. Classification of land use types coulduse several algorithms, such as maximum likelihood, minimum distance, and support vector machine (Bona, 2017). Surface roughness wasthe roughness value of the type of land use as a result of the extraction of the soil canopy. The roughness coefficient referred to the value developed by Berryman (2006). The table of surface roughness coefficients can be seen in Table 1.

Land Slope

The slope of the land wasa parameter that played an important role in the area of tsunami inundation. The gentler the slope of the land, the greater the potential for tsunami inundation. Information on the slope of the land was generated through the extraction of the ALOS PALSARDigital Elevation Model data which had a resolution of 12.5 meters

Table 1. Surface Roughness Coefficients

No	Types of Land Use	Roughness Coefficients
1.	Water Body	0.007
2.	Scrub/Bush	0.040
3.	Forest	0.070
4.	Garden/Plantation	0.035
5.	Vacant/Open Land	0.015
6.	Agricultural land	0.025
7.	Settlement/Built-up Land	0.045
8.	Mangrove	0.025
9.	Pond	0.010

(Pramono *et al.*, 2018). The Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) is a shortwave L-band sensor for cloudless land observation. Data recording was carried out during the day and at night (Anggraini *et al.,* 2019). The data were processed into slope data using ArcToolbox 3D Analyst Tools on the software ArcGIS (Islam *et al.,* 2014). The reason for using ALOS PALSARDEM data was that they have a higher resolution than do other open source DEM data, such as SRTM and ASTER Global DEM. Given the narrow research area, high-resolution data were needed for better results. In addition, the use of other open source data such as DEMNAS which have a resolution of about 8 meters was due to the lack of scene data in the study area on the shoreline, so it didnot match the administrative boundaries used.

Tsunami Wave Height

The height of the tsunami wave was the parameter used to calculate the Hloss. The maximum tsunami height in Malang Regency was 11 meters. The arrival time of the wave was about 29 minutes. The data referred to Appendix 2 of the Regulation of the Head of the National Disaster Management Agency No. 4 of 2012.

PLS

The path diagram in PLS was used to determine the influences of the level of disaster vulnerability, assessment of the tsunami natural disaster, assessment of losses due to natural disasters/tsunamis/tidal floods, and assessment of disaster management efforts on efforts to formulate strategies. The questionnaire data processing used the Partial Least Squares (PLS) method. In addition, a Goodness of Fit analysis was also carried out to measure the magnitudes of the influences of the level of disaster vulnerability, assessment of the tsunami natural disaster, assessment of losses due to natural disasters/tsunamis/tidal floods, and assessment of disaster management efforts on efforts to formulate strategies. The Goodness of Fit model was measured using an R-square dependent latent variable with the same interpretation as Q-square regression predictive relevance for structural models, measuring how well the observed values were generated by the model and also the estimated parameters.

In this study, the variables level of disaster vulnerability, assessment of the tsunami natural disaster, assessment of losses due to natural disasters/ tsunamis/tidal floods, assessment of disaster management efforts, and efforts to formulatestrategies were formed of reflexive indicators (with an arrow direction from the latent variable to the construct). This type of indicators was used for the five variables above because the indicators of some of these constructs were reflections of the constructs (latent variables) of interest. This is in accordance with the statement of Fornell *et al.* (1982) that if an indicator is a reflection of its construct or is related to attitudes and personality, a reflexive indicator must then be used.

Because PLS does not assume certain distribution for parameter estimation, then parametric techniques to test the significance of the parameters are not needed (Chin, 1998). The PLS evaluation model is based on predictive measurements that have non-parametric properties. The measurement model or outer model with formative indicators does not require evaluation with corvengent and discriminant validity the indicators and composite reliability for block indicators because the outer model with formative indicators is evaluated based on its substantive content, namely by comparing the relative weight and seeing the significance of the weight size (Chin, 1998). The structural model or inner model is evaluated by looking at the percentage of variance explained by looking at the R^2 value for the dependent latent construct using the Stone-Geisser Q-square test (Jaya *et al.*, 2008) and also looking at the magnitude of the structural path coefficient. The stability of this estimate is evaluated using the t-statistic test obtained by the boostraping procedure.

Results

Tsunami Inundation Modelling

The tsunami inundation was modelled using the

Cost Distance function on the software ArcMap (Alimsuardi *et al.*, 2020). There were 2 variables that were included in the Cost Distance function. One of the variables was the shapefile vector data (line) of the coastline. The result of the Hloss calculation was in the form of raster data. The result of the modelling was the range of the tsunami inundation from the coastline to the mainland.

Tsunami-impacted Buildings Analysis

Analysis of buildings affected by the tsunami was carried out using the Intersect function on the software ArcGIS. According to the Ministry of Public Works and Housing (2017), intersect is a tool to combine two layers by leaving the overlapping part of the two layers as output data. The analysis process wascarried out by entering hazard and exposure data. In this study, the data entered were tsunami inundation and building shapefiles. The data were processed with the Intersect function to derive results in the form of impact. The impact was in the form of buildings that were inundated by the tsunami.

Coastal Proximity

Coastal proximity was generated using the software ArcMap. The proximity to the coast was obtained from the buffering shapefile (line) shoreline analysis process using the Multiple Ring Buffer function in the Analysis Tools toolbox. The results of the Multiple Ring Buffer process were then clipped to the administrative boundaries of the study area using the Clip function in the Analysis Tools toolbox, leaving a buffer toward the mainland. The results of the buffer were vector data, which then were converted into raster data by using the Polygon to Raster function in the Conversion Tools toolbox. After that, the reclassification process was carried out using the Reclassify function in the Spatial Analyst toolbox by setting the value and class of vulnerability referring to Sambah *et al.* (2018), which can be seen in Table 2.

Table 2. Vulnerability Value (Slope)

Interval (%)	Vulnerability Class
0–2	High (5)
2–6	Fairly High (4)
6–13	Medium (3)
13–20	Fairly Low (2)
>20	Low (1)

Land Use

Land use was generated using the software ENVI. Land use was obtained from the image data of Sentinel-2A. Classification of land use was carried out by the supervised classification method. The results of the guided classification were then clipped to the administrative boundaries of the study area using the software ArcMap. The Clip process was carried out using the Clip function in the Analysis Tools toolbox. The results of the guided classification were vector data, which then were converted into raster data using the Polygon to Raster function in the Conversion Tools toolbox. After that, a reclassification process was carried out using the Reclassify function in the Spatial Analyst toolbox by setting the land use class and vulnerability class referring to Sambah *et al.* (2018), which can be seen in Table 3.

Table 3. Vulnerability Class (Land Use)

Land Use Class	Vulnerability Class
Settlement	High (5)
Agriculture	Fairly High (4)
Vacant Land	Medium (3)
Water Bodies	FairlyLow (2)
Forest	Low (1)

Overlays

The overlay process was carried out using the software ArcMap. This process was conducted by using the Weighted Overlay function in the Spatial Analyst toolbox. The Weighted Overlay process was carried out by entering 5 parameters of physical tsunami vulnerability (closeness to the coast and river, elevation/height and slope of the land, and land use) that had been reclassified. Then, each parameter was weighted in aunit of percent (%), with the total weight of all the parameters being 100%. The weighting of the physical tsunami vulnerability parameters refered to Sambah *et al.* (2018), which can be seen in the Table 4.

Table 4. Overlay Weight Value

Parameters of Tsunami Natural Disaster Vulnerability	Weight (%)
Proximity to the Coast	16 %
Proximity to theRiver	7.28 %
Elevation/Altitude	42.03 %
Land Slope	23.59 %
Land Use	11.10 %

Results of PLS Analysis

Table 5. Types and Number of Respondents

Types of respondents	Number of respondents	
Village Government Officials	5	16.7%
Businessmen	5	16.7%
Coastal Community Members	20	66.6%
Total	30	100 %

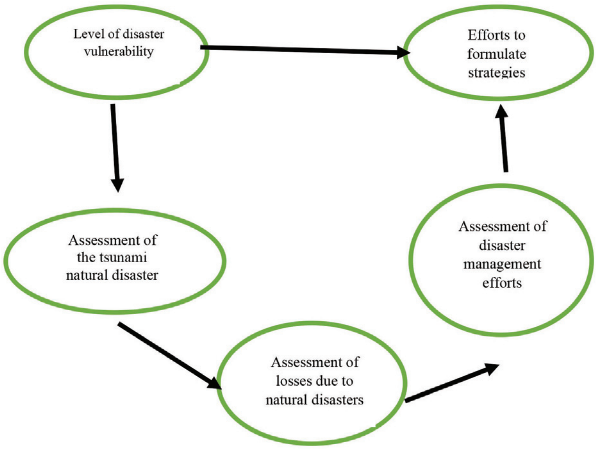

Fig. 4. Relationship between Variables in the PLS Analysis

Figure 4 above shows that the variable level of disaster vulnerability affected the variable assessment of the tsunami disaster. The variable assessment of the tsunami natural disaster affected the variable assessment of lossess due to natural disasters, which subsequently affected the variable assessment of disaster management efforts. The last finally affected the variable efforts to formulate strategies, which was also affected by the variable disaster vulnerability level. This relationship is formulated into a PLS structural model as shown in Figure 5.

The answers to the questionnaire items for the 5 variables are summarized as follows:

1. Of the 30 respondents, 43.3% stated that the vulnerability factor was high.
2. The assessment of 56.7% of the respondents of the tsunami natural disaster washigh.
3. The assessment of 53.3% of the respondents of losses due to natural disasters/tsunamis/tidal floods was high.
4. The assessment of 53.3% of the respondents of disaster management efforts was high.
5. Sixty percent of the respondents classified efforts to formulate strategies as high.

The data obtained from the questionnaire were further analyzed using the Structural Equation Model (SEM) method using the software Smart PLS. The path analysis model was able to explain the phenomenon under study, predict the value of the dependent variable (Y) based on the value of the independent variable (X), determine which independent variable (X) had a dominant effect on the dependent variable (Y) using determinant factors, and explore the mechanism (path) of the influence of the independent variable on the dependent variable. In this case, the path analysis used contained several paths and several latent variables and showed the

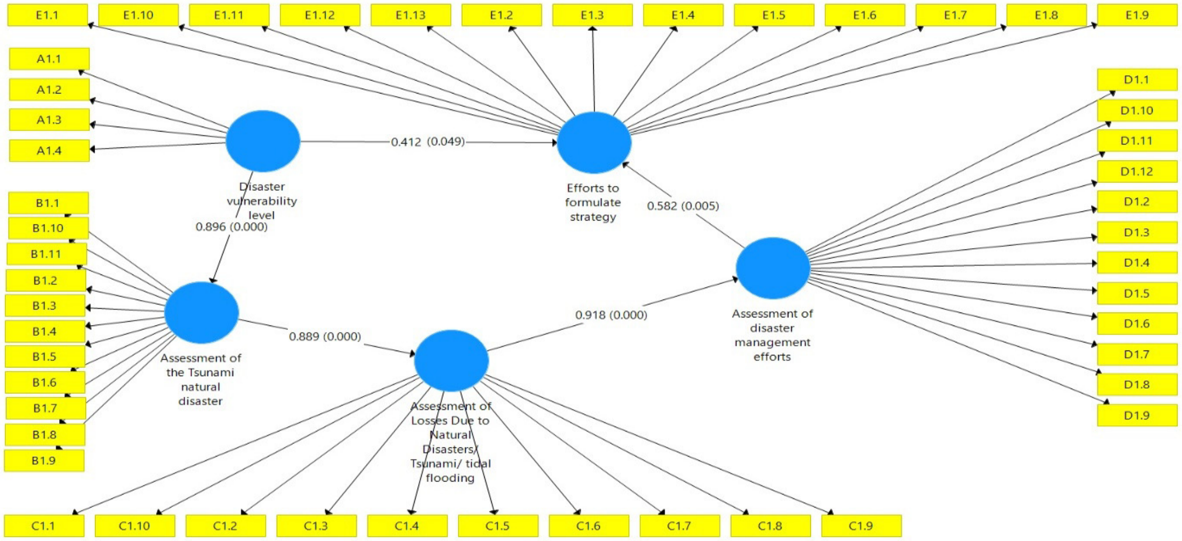

Fig. 5. PLS Structural Model

Table 6. Variables and Indicators for Partial Least Squares Analysis

Code	Variables/Indicators
A	**Level of Disaster Vulnerability**
A.1.1	To assess the level of vulnerability to disaster hazards that seriously endangered the safety of the population and could cause losses of livelihoods.
A.1.2	To assess that the arrival of an unexpected disaster could cause inundation in the area due to the spread of a tsunami and a tidal flood.
A.1.3	To assess that the disasters that occurred on Tamban Beach were due to human activities and climate change.
A.1.4	To assess that the government was not responsive in the event of a disaster in the coastal area of Tamban Beach.
B	**Assessment of the Tsunami Natural Disaster**
B.1.1	To assume that the disasters that occurred in the area were a combined impact of natural disasters (e.g., landslides atslopes due to heavy rain) and disasters caused by human activities (e.g., mangrove trees cutting, reclamation, agricultural planting, and mining).
B.1.2	To assess that conflicts in thearea were caused by human activities, for example, pond development activities, mining excavations, and other activities that led to the destruction of mangrove forests in the coastal areas.
B.1.3	To assess that the natural disasters that occur in the coastal areas of Tamban Beach, such as tidal flooding and tsunami, were caused by climate change.
B.1.4	To assess that the natural disasters had an impact on the health of the population.
B.1.5	To assume that the disasters on Tamban Beach were caused by human activities.
B.1.6	To assessthat the local government did not do much in the event of a disaster.
B.1.7	To believe that the disasters caused considerable losses to the community.
B.1.8	To assess that the disasters that occurred were disasters for the local community.
B.1.9	To assess that the arrival of a disaster could not be predicted in advance.
B.1.10	To assess that the flood that occurred in 2021 was still tolerable.
B.1.11	To believe that the local government needs to have the capacity to managea disaster expected to occur on Tamban Beach.
C	**Assessment of Lossesdueto Natural Disasters/Tsunamis/Tidal Floods**
C.1.1	To assess that the losses incurred by the community due to natural disasters caused prolonged suffering.
C.1.2	To assess the impact of natural disasters caused by human activities.
C.1.3	To assume that the local government was very slow in providing assistance to disaster-affected communities.
C.1.4	To assume that people's economic vulnerability was caused by debt, no savings, and no access to credits and insurance.
C.1.5	To assess that the losses due to natural disasters reduced people's income.
C.1.6	To assess that the losses due to disasters caused many people to experience stress.
C.1.7	To assess that the access to the assistance provided by the local government was very limited.
C.1.8	To assume that the assistance provided by various parties, including the government,was not sufficient for the recovery of the community'seconomic conditions.
C.1.9	In times of danger, women in afamily played an important role in taking care of children, the elderly, and the physically disabled, if any, including in paying attention to their health and nutrition.
C.1.10	During a disaster, the poor were usually the most severely affected.
D	**Assessment of Disaster Management Efforts**
D.1.1	The community members coped with the damage to their properties without asking other people for help.
D.1.2	The community members had never been notified by the government about impending disasters.
D.1.3	Before the onset of a disaster the community members had taken action to prevent or reduce the damaging impact of the disaster.
D.1.4	When a disaster occurred, not everyone in the disaster area experienced the same suffering.
D.1.5	The community members worked together to clean up the debris caused by adisaster.
D.1.6	The local government didnot yet have any procedures in place should the community be affected by a disaster.
D.1.7	The community had never been given counselling by the government in the event of a disaster.
D.1.8	The communitymembers affected by adisaster would be provided with assistance by the government.
D.1.9	The community members tried to avoid the disaster area.

Table 6. Variables and Indicators for Partial Least Squares Analysis

Code	Variables/Indicators
D.1.10	The government did not have any guidelines regarding disaster-affected communities.
D.1.11	The community members in the after math of a disaster were assisted by the police, the army, and local government officials to buy materials and to gain skills to repairtheir houses.
D.1.12	Many social organizations/NGOs came to help the community during a disaster.
E	**Efforts to Formulate Strategies**
E.1.1	The government must have a strategy to prevent the occurrence of a natural disaster.
E.1.2	The main strategy is to save the community and their properties.
E.1.3	The government sought to provide psychological healing the rapies for the community affected by a disaster.
E.1.4	The government provided a way for the community to seek other sources of income after adisaster.
E.1.5	The government provided an alternative for the community to temporarily migrate to find a job during a disaster.
E.1.6	The government provided training for the community to survive after a disaster.
E.1.7	Community members affected by adisaster did not borrow money.

relationship between these latent variables. Therefore, SEM structural equation modelling was performed using the software SmartPLS.

The results of this research thus showed the following:

1. The assessment of losses due to natural disasters/tsunamis/tidal floods had a significant effect on the assessment of disaster management efforts.
2. The assessment of the tsunami natural disaster had a significant effect onthe assessment of losses due to natural disasters/tsunamis/tidal floods.
3. The assessment of disaster management efforts had a significant effect on the efforts to formulatestrategies.
4. The level of disaster vulnerability had a significant effect on the assessment of the tsunami natural disaster.
5. The level of disaster vulnerability had a significant effect on the efforts to formulatestrategies.

Discussion

Analysis of Vulnerability to the Tsunami Disaster

The tsunami hazard parameter data processing carried out produced a map of the tsunami impact on buildings in the coastal areas of Tamban Beach, which can be seen in Figure 6.

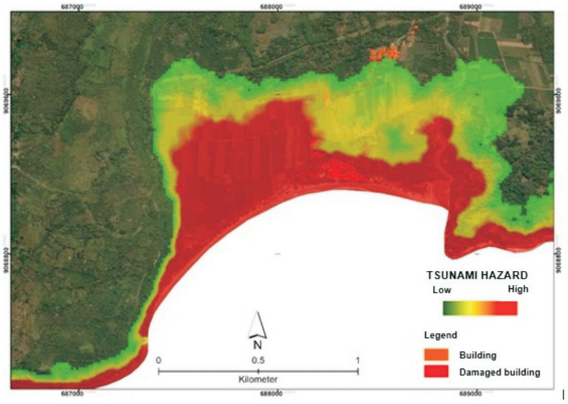

Fig. 6. Tsunami-affected Buildings

The map in Figure 5 above shows the tsunami-affected buildings on Tamban beach. The tsunami inundation was modeled with a run-up height of 22 meters. The red color is a high hazard level. The hazard level decreased in the direction of the wave propagation toward the mainland, which is indicated by the green color. This green color itself represents a low hazard level. Based onthe modeling results, the tsunami had inundated 193 buildings. The buildings that were inundated by the tsunami are shown in red.

The inundation of the tsunami caused losses to the affected areas on Tamban Beach. The following

Table 7. Valuation of Building Losses due to Tsunami Inundation

Affected Area	Quantity
Total area of buildings-affected by the tsunami (m^2)	11,702
Area of permanent buildings affected by the tsunami (m^2) (loss assumption reference)	5,001
Building value per m^2(in Rupiah)	2,300,000
Total loss (in Rupiah)	11,501,377,605

is the valuation of building losses.

Table 7 shows the total area of buildings affected by the tsunami on Tamban Beach (11,702 m^2), the area of affected permanent buildings that was used as a reference for the assumption of loss (5,001 m^2), and the value of abuilding per m^2(Rp2,300,000.00). Based on the result of the multiplication of the value of a building per m^2 by the area of affected permanent buildings (m^2), as a reference for the loss assumption, the total loss of buildings affected by the tsunami on Tamban Beach was Rp11,501,377,605.00. Based on the results of the field survey that was carried out, most of the buildings in the coastal areas were semi-permanent buildings. These buildings were erected on Perhutani land, so they were exempted from the selling value of tax object (NJOP). Therefore, in the calculation of losses, a sample of permanent-type buildings was used, most of which was situated in the Tamban village/hamlet area, which was located more toward the mainland than the shoreline.

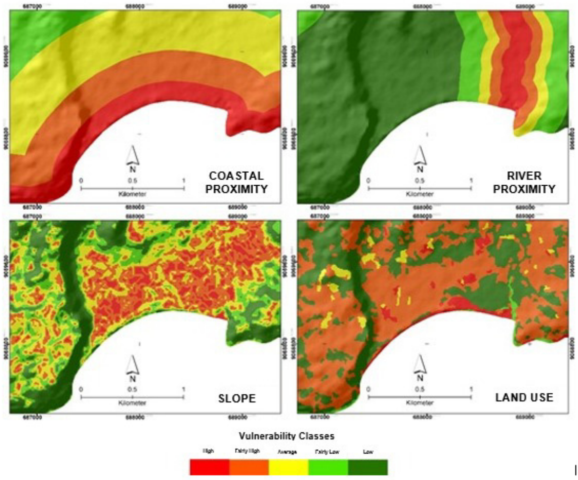

Fig. 7. Tsunami Vulnerability Map Based on the Parameters

From the processing of the physical tsunami vulnerability parameter data that was carried out, a tsunami vulnerability map was produced based on the parameters as a result of the overlay of the vulnerability parameters, which can be seen in Figures 7.

The tsunami vulnerability map of the Tamban Beach was based on its vulnerability parameters. The level of vulnerability is indicated by the color on the map. Red indicates a high level of vulnerability, orange indicates a fairly high level of vulnerability, yellow indicates a moderate level of vulnerability, light green indicates a fairly low level of vulnerability, and dark green indicates a low level of vulnerability. Figure 8 is a map of the physical vulnerability to tsunami of Tamban Beach. The map was obtained based on the data processing of 5 parameters, namely, land use, elevation and slope of the land, and proximity to the coastand river. Red indicates a high level of vulnerability, yellow indicates a moderate level of vulnerability, and green indicates a low level of vulnerability.

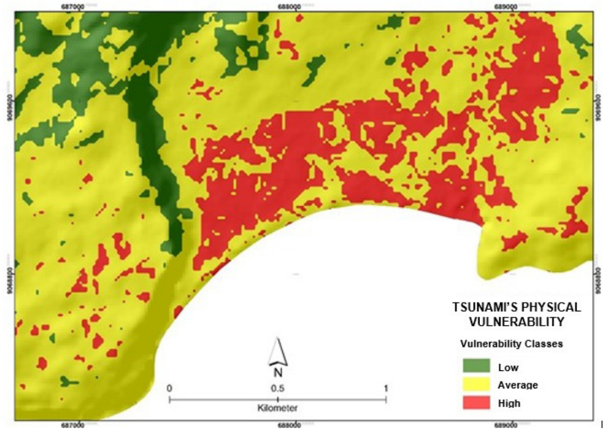

Fig. 8. Physical Tsunami Vulnerability Map

Meanwhile, social vulnerability to tsunami was known from the parameters of tsunami vulnerable group, which can be seen in Table 8.

Table 8. Tsunami Vulnerable Group

Parameter	Category		
	Low	Middle	High
Gender ratio	<20%	20–40%	>40%
Disabled people ratio			
Age group ratio			

Based on some calculations, the gender-based ratio in Tambakrejo Village was 76%. The tsunami-prone group in Tambakrejo Village based on gender was in the high category, with a ratio above the 40% limit according to the Regulation of the Head of the National Disaster Management Agency Number 2 of 2012.

The ratio of disabled people in Tambakrejo Village was 0.13%. The tsunami-prone group in Tambakrejo Village based on disabilities was in the low category, with a ratio below the 20% limit according to the Regulation of the Head of the National Disaster Management Agency Number 2 of 2012.

Lastly, the age-based ratio in Tambakrejo Village was 69%. The tsunami-prone group in Tambakrejo Village based on age group was in the high category, with a ratio above the 40% limit according to the Regulation of the Head of the National Disaster Management Agency Number 2 of 2012.

PLS Analysis

The variables level of disaster vulnerability, assessment of the tsunami natural disaster, assessment of losses due to natural disasters/tsunamis/tidal floods, assessment of disaster management efforts, and efforts to formulate strategies were formed of reflexive indicators (with an arrow direction from the latent variable to the construct). This type of indicators was used for the five variables above because the indicators of some of the constructs were reflections of the constructs (latent variables) of interest. This is in accordance with the statement of Fornell *et al.* (1982) that if an indicator is a reflection of its construct or is related to attitudes and personality, a reflexive indicator must then be used".

The outputs of the measurement model on the variables level of disaster vulnerability, assessment of the tsunami natural disaster, assessment of losses due to natural disasters/tsunamis/tidal floods, assessment of disaster management efforts, and efforts to formulate strategies were reflected in 4, 11, 10, 12, and 13 indicator items, respectively.

It was known that the 4 indicators of the variable level of disaster vulnerability had outer loadings greater than 0.7, with p values <0.05. Thus, it couldbe concluded that the 4 indicators of the variable level of disaster vulnerability met the criteria for convergent validity, meaning that they were good atmeasuring the variable level of disaster vulnerability. The indicators A1.3 and A1.4 were known to have the largest outer loadings, each being 0.926, and the indicator A1.2 indicator had the smallest outer loading, namely 0.806.

As for the variable assessment of the tsunami natural disaster, it wasknown that its 11 indicators had outer loadings greater than 0.7, with p values <0.05. Thus, it couldbe concluded that the 11 indicators of the variable assessment of the tsunami natural disaster met the criteria for convergent validity, meaning that they were good atmeasuring the variable assessment of the tsunami natural disaster. The indicator B1.4 was known to have the largest outer loading (0.909), and the indicator B1.7 had the smallest outer loading (0.731). For the variable assessment of losses due to natural disasters/tsunamis/tidal floods, it was known that its10 indicators had outer loadings greater than 0.7, with p values <0.05. Thus, it couldbe concluded that the 10 indicators of the variable assessment of losses due to natural disasters/tsunamis/tidal floods met the criteria for convergent validity, meaning that they weregood atmeasuring the variable assessment of losses due to natural disasters/tsunamis/tidal floods. The indicator C1.3 wasknown to have the largest outer loading (0.927), and the indicator C1.1 had the smallest outer loading (0.719).

The 12 indicators of the variable assessment of disaster management efforts had outer loadings greater than 0.7, with p values <0.05. Thus, it could be concluded that the 12 indicators of the variable assessment of disaster management efforts met the criteria for convergent validity, meaning that they were good atmeasuring the variable assessment of disaster management efforts. The indicator D1.1 was known to have the largest outer loading (0.933), and the indicator D1.5 had the smallest outer loading (0.756).

Lastly, the 13 indicators of the variable efforts to formulate strategies had outer loadings greater than 0.7, with p values <0.05. Thus, it could be concluded that the 13 indicators of the variable efforts to formulate strategiesmet the criteria for convergent validity, meaning that they were good atmeasuring the variable efforts to formulate strategies. The indicator E1.7 was known to have the largest outer loading (0.886), and the indicator E1.11 had the smallest outer loading (0.731).

The correlations of the construct level of disaster vulnerability with its indicators were higher than the correlations of its indicators with other indicators. The correlations of the construct assessment ofthe tsunami natural disaster with its indicators were higher than the correlations of its indicators with other indicators. The correlations of the construct assessment of losses due to natural disasters/tsunamis/tidal floods with its indicators were higher than the correlations of itsindicators with other indicators. The correlations of the construct assessment of disaster management efforts with its indicators were higher than the correlations of its indicators with other indicators. Similarly, the correlations of the construct of efforts to formulate strategies with its indicators werehigher than the correlations of its indicators with other indicators. This shows that the latent constructs predicted the indi-

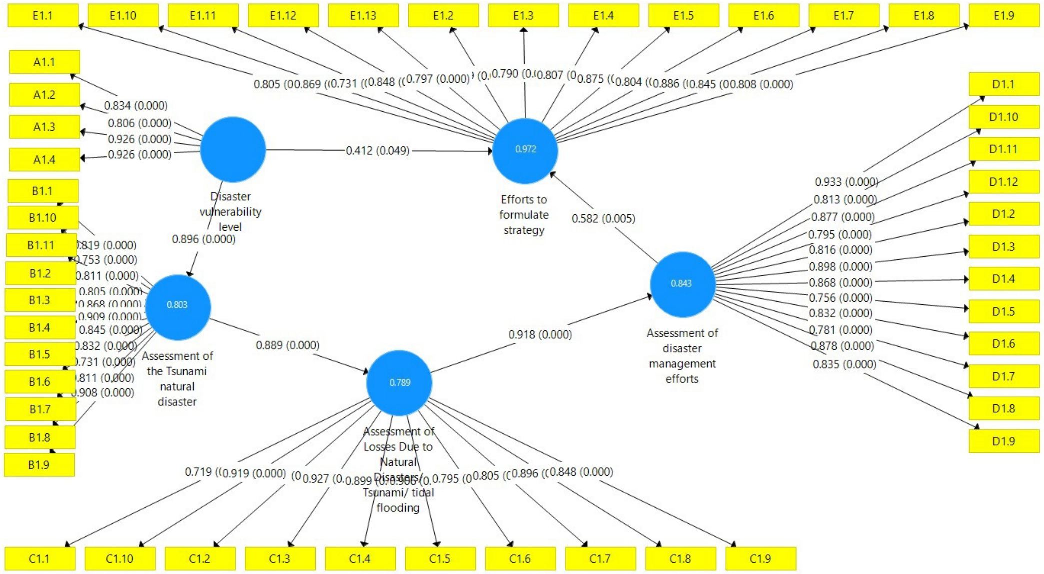

Fig. 9. Path Analysis for PLS Outputs

cators in their respective blocks better than they didthe indicators in other blocks.

The outputs of the structural model (inner model) after the 500x bootstrap calculation process can be seen in the following figure.

Conclusion

From the results of this study, it could be concluded that the efforts to formulate strategies were significantly influenced by the level of disaster vulnerability and the assessment of disaster management efforts. Therefore, to improve strategy formulation efforts, the assessment of disaster management efforts and the level of disaster vulnerability must be improved. However, to improve the assessment of disaster management efforts, better assessment of losses due to natural disasters/tsunamis/tidal floods would beneeded. This improvement of the assessment of disaster management efforts would have a positive impact on the efforts to develop strategies. Meanwhile, to improve the assessment of losses due to natural disasters/tsunamis/tidal floods, better assessment of the tsunami natural disaster would beneeded, in which case the assessment of the tsunami natural disaster was influenced by the level of disaster vulnerability. In other words, the level of disaster vulnerability should be improved to render better assessment of the tsunami natural disaster.

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