ENHANCING COASTAL DISASTER MITIGATION MEASURES: VEGETATION BASED FEASIBILITY STUDY FOR SOUTHERN JAVA, INDONESIA

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Abstract. Indonesia is a country that is prone to disasters especially earthquakes and volcanic eruptions because it's located in the ring of fire. This type of disaster can produce another type of disaster which is: tsunami. The nature of tsunamis that were hard to predict and arrive with little warning, Indonesians can minimize the effect of tsunamis by creating coastal protection. In this study we look for the location to create the coastal forest as an enhancement of the mitigation effort. We conducted our study in the Pangandaran district were a severe tsunami in the 2006 caused more than 400 deaths. We conducted a suitability analysis to identify tsunami-prone area based on the following criteria: should be had elevation <10m, slope gradient <2%, within proximity of 500m from the coastline, and <100m from river and should be settlement or urban area. The creation of a vulnerability map was using map algebra to calculate the weighted parameter from each class. Based our analysis using GIS analysis, the most vulnerable area in the Pangandaran district is the bay area, where we founded 1,419 acres of coastal area for which coastal forests could be planted to enhance protection against tsunamis.

Keywords: tsunami, coastal protection, Pangandaran District, mitigation

1. INTRODUCTION

Indonesia is highly susceptible to devastating tsunamis with a little advance warning with 5% of the global distribution of confirmed tsunamis occurring in Indonesia, primarily because it is located along the ring of fire where 90% of the world's earthquakes occur (NOAA 2020, USGS 2009). The most populous island in Indonesia, Java Island, was struck by tsunamis in 1994 and 2006 with the most severe impact occurring in the Pangandaran district. In this district alone, the tsunami caused 413 – 600 casualties and displaced more than 75,000. There were three major tsunami events occurred in 1840, 1867 and 1875 in Java Island, this historic record indicates that Java Island there will be potential of the same disaster in the near future (Irsyam, et al. 2008). The tsunami was hard to escape as the affected area was close to the epicenter and lack of early warning and mitigation infrastructure (Fritz, et al. 2007, Mori, et al. 2007, NOAA 2020).

When a tsunami arrives in the coastal vegetation can typically function as a buffer against tsunami damage because tsunami energy is dissipated as it passes through the forest belt on the coastal beach (Zhang, et al. 2019).

Enhancing coastal vegetation to reduce tsunami impacts could be one solution. One study examined the effect of coastal vegetation on reducing tsunami impact in Yogyakarta, Indonesia. They found that a 100 m wide swath of forest can reduce damages by up to 17.6% (Ohira, Honda and Harada 2012). A study focused on mangroves forests in Pakarang Cape, Thailand, found that under dense conditions with a 400m wide area, inundation depth was reduced by 30% for a 3 m wave height and a wave period of 30 minutes.

Nevertheless, the forest will be 50% damaged by 4.5m tsunami inundation depth, and more than 75% will be lost if the wave height reaches 6 m (Yanagisawa, et al. 2009). The effect of mangrove forest on the dissipation of the tsunami was determined by the steepness of the wave - the more vertical the wave front, the more expansive the mangrove forests must be to

significantly reduce its energy (Didit, Husrin and Latifah 2019).

The damping effect of vegetated shorelines decreases the tsunami velocity and the force both in and behind the forest belt (Zhang, et al. 2019). Coastal communities may be able to enhance nature-based protection by keeping, managing, and restoring coastal vegetation including mangroves, wetlands, and other coastal forests (Tanaka, et al. 2009). Even though coastal vegetation does not provide complete protection to the coastal area, it can substantially reduce damages. In the 2004 Indian Ocean Tsunami, in the Cuddalore District, Tami Nadu, India villages sheltered behind mangrove forests experienced much less damage than villages along the coast. (Danielsen, et al. 2005).

Natural coastal protection using a coastal forest involves less initial capital investment and offers more ecological value than artificial structures. Coastal forests are suitable for locations with relatively low wave energy (Diposatono 2008). People can use coastal forests as artisanal fisheries to provide food and to generate income for coastal communities as well as promote ecotourism (McNallya, Uchida and Gold 2011). Coastal forests can improve the natural protection for the shoreline by dissipating the tsunami waves, simultaneously trapping the sediment, stabilizing the shoreline, and enhancing the coastal zone's ecology and socio-aspects of the coastal zone (CEM 2006).

Combining coastal vegetation, dunes, coral reefs, mangroves, and different natural coastal ecosystems can be an environmentally friendly and sustainable management strategy to mitigate tsunami and other coast-related natural disasters in developing country contexts (Fernando, et al. 2011). Constructing natural protection takes more time than concrete-based protection. However, the interval between tsunamis is typically longer than the period required for forest development. Therefore, more consideration of the planting and management of coastal vegetation from the viewpoint of landscape and urban planning based on scientific studies is necessary (Tanaka, et al. 2009).

At the minimum, a coastal vegetation belt should be 20 m wide and consist of trees pine trunk diameter of 13 cm and mean spacing between trees of 1.6 m to stop the debris flow such us: boats, jetty. However, it does not reduce tsunami flow (MoMAF, 2012). The coastal forest is providing a protection function against tsunami damage. The severity of damage of settlement and other infrastructure by drifted boats can be minimized with the existence of coastal forests. However, if they disappear from the coastal area the damage will be increased (Miyagi, Yanagisawa and Baba 2013).

This study will use GIS analyses to assess potential tsunami hazards and existing coastal conditions (e.g. settlement size, elevation conditions, distance from escape road, forest condition. This study aims to find suitable areas to preserve or establish new coastal forests in Southern Java to protect against tsunamis. The analysis will be focusing on the vulnerability level of the Pangandaran coastal area.

2.   MATERIAL AND METHOD
2.1   Location and Data

The study will be conducted on the Pangandaran District located on the south coast of West Java province Indonesia, wherein 2006 was hit by a tsunami shown in Figure 1. It lies between 7º24'0" - 7º54'20" S and 108º8'0" - 108º50'0" E. Pangandaran district is a semi-enclosed bay district, it has 91 km coastline, and is connected to the Indian Ocean in the South. Pangandaran is prone to tsunamis (Reese, et al. 2007) because there a subduction zone located southern of Pangandaran District. This is an active subduction zone where some undersea earthquakes that occur in the area generate earthquakes that cause tsunamis (Bilek and Lay 2002).
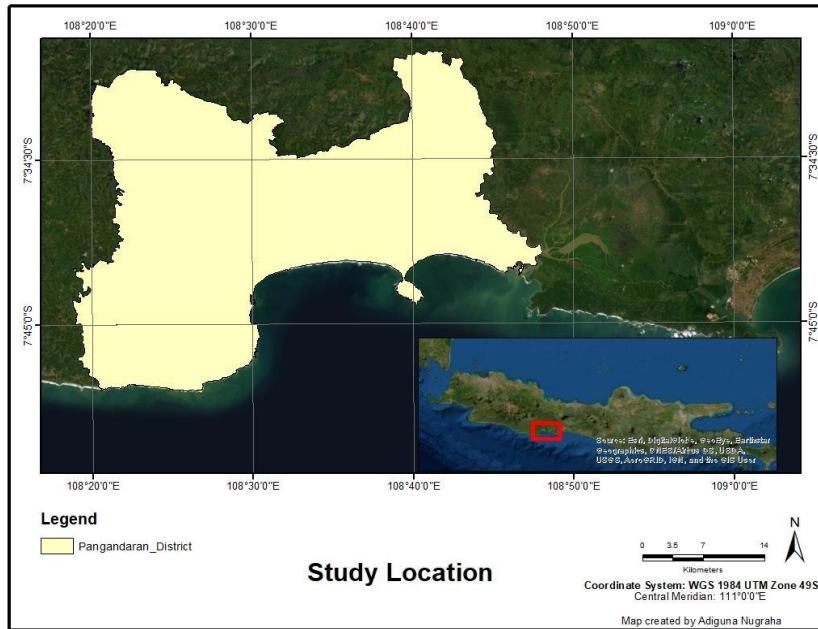
Figure 1. Pangandaran district, West Java Province, Indonesia

This study requires the use of synthesizing various geospatial data to obtain quantitative variables for the suitability analysis. The geospatial data that will be used on the analysis are coastline, elevation, land use (e.g. settlement, forest, farm field, shrub), and slope. The data of this study was obtained from the official website of the data source shown in table 2

2.2   Standardization Data

Parameters of coastal vulnerability will be used in the weighted classification method (Table 1). The analysis will be performed with ArcGIS Desktop 10.7 version to find the location suitable for planting the coastal forest for coastal protection. The study area will be constrained based on several parameters, such as the settlements and urban area, located within 500 m from the coastline, have an elevation below than 10m, have gradients between 0-2% and also the distance from the river is less than 100m.

Table 1. Data source and resolution

No.	Type data	Source	Resolution
1.	● Elevation ● Slope	Shuttle Radar Topographic	1 Arc-S (30 meters)
		Mission (SRTM)	
2.	● Land use	Landsat 8 OLI/TIRS path 121/row 65, Scene date 2019/11/15	30 x 30 m
3.	● Coastline ● River	Indonesia Geospatial Info. Agency	1:25.000

2.3   Methods

In the analysis to create the weighted matrix classification, we will use the model builder in the ArcGIS. The data analysis steps outline is divided into 4 steps. Firstly, the data preparation where the dataset will be clipped into the study area location using extract by mask tool for raster dataset and clip tool for the vector dataset. Additionally, the projections will be set into the same coordinate systems (WGS 1984 UTM Zone 49S) using the project tool. Secondly, the dataset will be assigned into each class parameter using the reclassify tool for the DEM data to get the elevation and slope classification score, then the distance from the river and distance from the coastline parameter will be analyzed using the Euclidean distance tool to change the vector dataset into raster dataset, for the land use data we will be assigned the score

based on each land use type. Finally, after we get the score for each parameter will be used the matrix for further analysis to get the final suitable area for planting the coastal forest.

The matrix indicates weights and scores for the parameters. Parameters were assigned equal weights of 20% and vulnerability scores ranging from 1 – 4 (low, moderate, high, and very high). The class value was then calculated with the following formula 1 (Muzaki 2008):

$$N = \sum Bi \; x \; Si \; ....(1)$$

N = total class value, Bi = weight on each parameter, Si = Score on each parameter.

Formula 2 below will be used to get the final vulnerable area that needs to be protected from the tsunami disaster:

*(("%elevation% ∗ "0.2)+(%distance from the coastline%*0.2)+(%distance from the river%*0.2)+(%land use% ∗ 0.2)+("%slope%" ∗ 0.2))...................... (2)*

Table 2. Coastal vulnerability against tsunami impacts *(Faiqoh, Gaol and Ling 2013)*

No.	Parameters	Weight (%)	Very High vulnerability	High vulnerability	Moderate vulnerability	Low Vulnerability
1	Elevation	20	<10m	>10-25m	>25-100m	>100m
2	Distance from the coastline	20	<500 m	>500-1000 m	>1000-3000m	>30000m
3	Distance from the river	20	<100 m	>100-200 m	>200-300 m	>300 m
4	Land use	20	Settlement or urban area	Agricultural field	Shrub or barren land	Forest
5	Slope	20	0-2%	2-5%	5-15%	>15%
	Total/Score	**100**	**4**	**3**	**2**	**1**

The SRTM data will be used for the analysis of the slope and elevation parameters. The SRTM data will be extracted onto the study area dataset, then processed using the slope tool to get the slope gradient for the Pangandaran area, after we get the slope gradient, we are dividing the slope into each class of vulnerability using the reclassify tool. Furthermore, for the elevation dataset, we directly use the reclassify tool to get the class vulnerability for each elevation.

In this study, land use information was created using an unsupervised iso cluster tool on Landsat 8 OLI/TIRS C1 dataset, we created 50 clusters and then assigned every cluster on each pixel with a value of 1 is settlements and urban area, 2 is agriculture area, 3 is a shrub and barren area, and 4 is forest area. The data vector data will be converted to a raster using the Euclidean distance tool after we get

the raster dataset. The data will be reclassified into each class based on table 3 conditions. Furthermore, the dataset will be processed to get the final suitability area using the map algebra tool.

3   RESULTS AND DISCUSSION
3.1   Elevation

The coastal elevation has a major role in the severity impact of a tsunami disaster, it makes coastal community located in the low elevation area is prone to the tsunami disaster. The impact of the tsunami inundations on the low elevation area can be shown as the sediment deposit founded in that area after the tsunami water receding, and the destruction of the buildings, boats, and fishing nets (Chadha 2007). To assess the different elevations of the Pangandaran district in this study we created the elevation vulnerability score

based on table 2. The result as shown in figure 2 below reveals that elevation classification on the northern part of Pangandaran is dominantly highland areas which have a low vulnerability score with a total area of 161,255 acres. The very high and high vulnerability area have a total area size of 28,709 acres and 32,025 acres respectively, this area is dominated the area within proximity 4 km from the coastline and most of the Pangandaran district bay have low elevation. The greater the vulnerability index the greater the area will be inundated by the run-up of the tsunami, and vice versa (Faiqoh, Gaol and Ling 2013). Thus, making the lower area near the coastline a susceptible area to tsunami disasters.
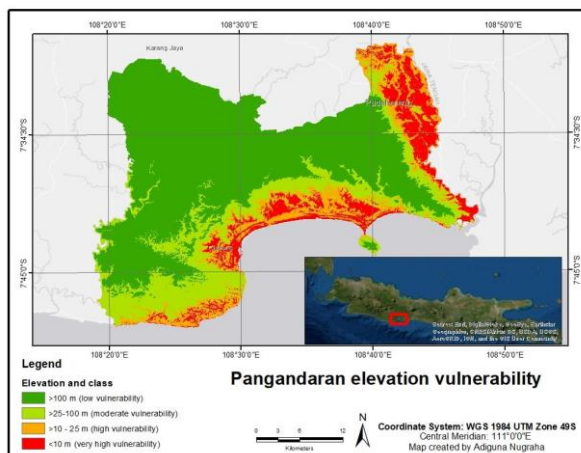

Figure 2. Pangandaran elevation classes.

3.2 Distance from coastline vulnerability

The analysis was carried to divide the vulnerability of certain areas proportional to its distance from the coastline. Using 500m, 1000m, 2000m, and >3000m for each parameter this study had created four buffer zone regarding the vulnerability level of the area based on its distance from the coastline as shown in figure 3. The highest causalities and damaged property from tsunami disaster were in the first 100m distance from the coastline. The most compelling impact of the tsunami destruction was manifested in the accumulation of debris (e.g. boulders, tree branches, building material, and boats) along the coastline and within the bay because the tsunami force swept them inland, thus making

area near the coastline have higher tsunami vulnerability than area further inland (Bryant, et al. 1997). The Pangandaran coastline morphology which is a bay type coast is more prone to tsunami disaster because its morphology can amplify the tsunami wave height and result in more severe damage to the coastal area (Yeh, et al. 1994)
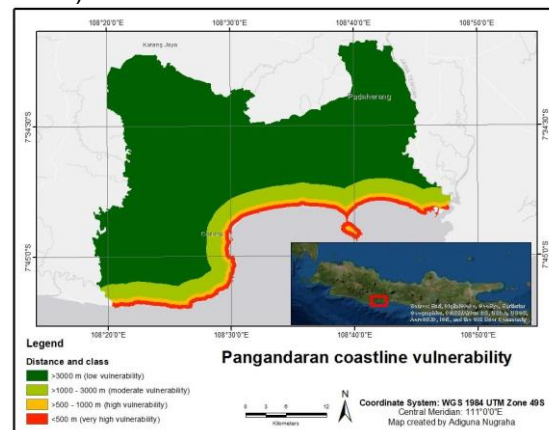

Figure 3. Distance from the coastline classes.

3.3 Distance from river vulnerability

Tsunami has been long known that they also propagated far upstream into the river and then damaging the inland infrastructure. The morphology of the tsunami wave propagates without changing its shape and speed in a straight channel. The failure of a river embankment to mitigate the tsunami inundations was evident from a tsunami that struck the Kanto region in Japan in 2011 (Tanaka, Yagisawa and Yasuda 2012). Another potential impact is that tsunamis can bring seawater up to 5 km inland which can damage river ecosystems and urban areas around along river channel. The reason for the damage was due to the significant increase of the salination and flooding which occurred in Sri Lanka during the 2004 tsunami event (Amaratunga and Fowler 2007). Based on the analysis we found that the coastal area of Pangandaran district has significant river distribution and downstream as shown in figure 4 below, where the channel is a meandering type of morphology and most of the settlement in the coastal area located in the 100 m proximity from the river. The total area

covered by each vulnerability classes is 27,7981 acres, 28,241 acres, 63,383 acres, and 137,104 acres, which is correspondent with the vulnerability class of very high, high, moderate, and low respectively.
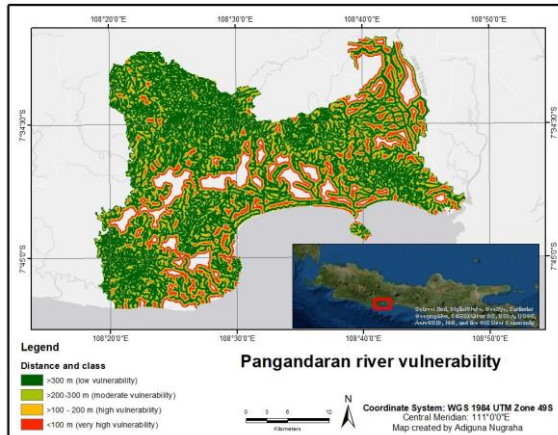

Figure 4. Distance from river classes.

3.4   Land use

Detailed information of the land use conditions such as urban zone which is corresponded with population distribution and density is a major factor of the tsunami vulnerability analysis. This information is a requirement to create a mitigation strategy and disaster readiness in case of tsunami occurrence (Theilen-Willige, et al. 2014)., The results from our analysis are four land classifications which are: Settlement area or urban area (very high vulnerability), Agricultural field (high vulnerability), Shrub or barren land (moderate vulnerability), and Forest area (low vulnerability) as shown in figure 5. The very high vulnerability score mainly located in the bay of Pangandaran proximity, and northeast further inland which is correspondent with the high-density settlement or urban area with area size of 20,252 acres which are only cover 7% of the total Pangandaran district land use. The existing forest in the Pangandaran district is worth nothing because the forest covers 67.71%, which is the amount of 188.047 acres. However, the coastal area in Pangandaran Bay where most of the coastal settlement located are lack of forested area. The settlement area in the western part of Pangandaran is located further inland and protected by the existing forest in that area.
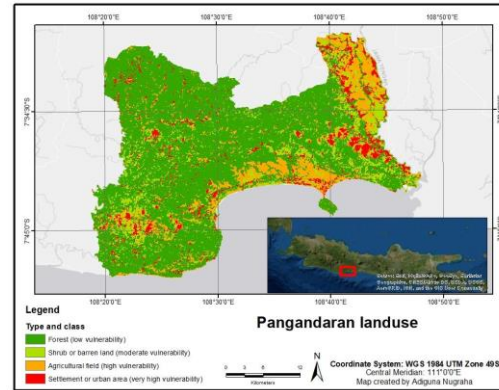

Figure 5. Pangandaran land use classes.

3.5   Slope vulnerability

An understanding of the geophysical of the coastal morphology is essential to understand the relationships between tsunami run-up height and inundation extent. The gentler the slope, the higher vulnerability to the tsunami inundations (Murthy, et al. 2007). The slope morphology of the Pangandaran coast which is dominated by <2% and >2%-5% slopes were categorized as a gentle slope and 5-15% gradient is classified as a moderate slope (Sikdar, et al. 2004), with a severity level very high, high, and moderate vulnerability score respectively based on the parameter that was created for this study. The total area of these three categories covers only 30% of the Pangandaran district slope, in contrast with the low vulnerability score that has a slope >15% dominated 60% of the Pangandaran district as shown in figure 6. However, the gentler slope that has a higher vulnerability score is located in the coastal area, which is more susceptible to tsunami attack.
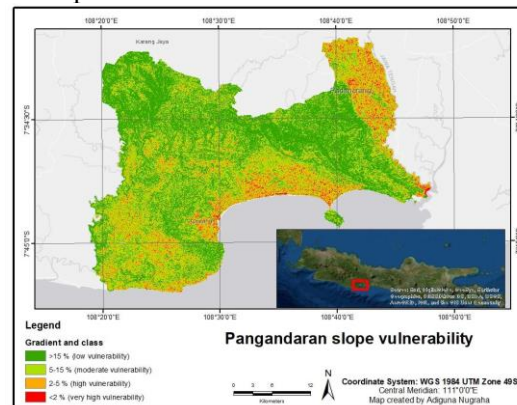

Figure 6. Pangandaran slope classes.

3.6 The vulnerability area

The analysis results are shown in Table 4 below, based on the analysis we found that 7.05% very high vulnerability with the total area for each class are 96,259 acres. Tsunami waves represent extreme often catastrophic events, which significantly and adversely impact coastal areas. Despite the lower frequency of occurrence comparing to storms and storm-induced surges, tsunami-induced coastal flooding often leads to massive casualties and tremendous economic losses. The potential damage from a tsunami is the result of its run-up to the inland area. The run-up distance of seawater inundations to the inland area is directly related to the inland elevation, distance to the coastline, distance to the river, land use patterns, and coastal slope (Kurian, Prakash and Baba 2007). Using all the parameters that we produced from our model subsequently we identified the most vulnerable locations within 500 m from the coastline. We found that the most vulnerable areas located in the coastal area of Pangandaran District is shown in figure 7below with the location size for each class are 1,277 acres, 4,634 acres, and 1,419 acres with the priority level from low, moderate, and high respectively.

Figure 7. The proposed area to create the Pangandaran coastal forest

Data on soils and wave energy were unavailable for the study area and so could not be included in this analysis. The choice of vegetation type used for protection (e.g. mangrove or another plant species) should be decided based on location (proximity to the coastline) and soil type. However, vegetation that can be used for the coastal to create the coastal forest are *R. mucronate, A. marina,* (Anwar 2007).

4 CONCLUSIONS

A tsunami is a rare disaster that we cannot predict because its origin is usually from another disaster like an earthquake or underwater volcanic eruption. However, the severity of this disaster is severe, furthermore, Indonesia is prone to the tsunami disaster, especially on Java Island. We cannot avoid this kind of disaster; therefore, this study is trying to give input for the mitigation plan by creating a natural defense in the form of creating a coastal forest in the Pangandaran district to face the future threat of tsunami occurrence. Based on our findings we found that the Pangandaran district has 1,419 acres of the coastal area that is needed immediate protection from the tsunami.

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