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Tsunami Susceptibility Analysis in Coastal Area Petanahan District, Kebumen Regency

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ABSTRACT

Petanahan sub-district has three villages directly adjacent to the sea: Karangrejo Village, Karanggadung Village, and Tegalretno Village. This study aims to analyze the level of tsunami susceptibility in the coastal area of Petanahan District in the Kebumen Regency. Analysis of the level of tsunami susceptibility using assessment methods, weighting, and map overlays using tsunami hazard parameters, including elevation, slope, land use, distance from the shoreline, and distance from rivers. Then the Weighting of the Tsunami Vulnerability Level uses the formula N = Bi X Si, where Bi is the weight on each criterion, and Si is a score on each criterion. The weighting results are then divided into five classes, very low, low, medium, high, and very high. The results of this study indicate that the tsunami hazard in a coastal area of Petanahan Regency consists of a very high class (93.904 ha/8.33%), a high class (567.804/50.35%), and a medium class of (465.962 ha/41.32%). The results of this research on the vulnerability to tsunamis can be used by the community, especially in the research area, to increase preparedness in dealing with tsunami disasters. At the same time, the Government can take policies in carrying out disaster risk reduction activities of a tsunami, especially in the research area.

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1. INTRODUCTION

Tsunami disasters tend to be rare, but they are very destructive. Tsunami hazard and risk assessment are needed to support effective disaster preparedness and measures to mitigate its impacts. In most highly destructive coastal locations, tsunami events are not well represented in historical records, as their occurrence is shorter than the return period of large tsunamis (hundreds to thousands of years) (UNISDR, 2017). The tsunami events in the Indian Ocean in December and Tohoku-Oki in March 2011 demonstrate the need for tsunami hazard and susceptibility assessments in various coastal areas vulnerable to tsunami disasters (Benchekroun et al., 2015). Tsunamis are caused mainly by tectonic earthquakes, which cannot predict when they occur, so tsunamis become one of the natural disasters that cannot be predicted when and where they appear (Tarigan et al., 2015). For the above reasons, it is essential to conduct tsunami susceptibility research in the research area.

A tsunami is a tidal wave that crashes on the coast caused by earthquakes at sea, sea avalanches, or underwater volcanic eruptions (BNPB, 2008). According to the International Institute for Geo-Information Science and Earth Observation (ITC, 2005), a tsunami is a series of waves generated through a body of water due to a vertically impulsive disturbance in the water. Generally, tsunamis are caused by various processes such as earthquakes, volcanic eruptions, land and sea landslides, meteorological events, and the impact of extra-terrestrial objects (Goff & Dominey, 2013).

Tsunamis have long waves and are not felt in the open sea, but their destructive power will be large when approaching the coast (Röbke & Vött, 2017). The speed of tsunamis is directly proportional to the depth of the sea. The run-up speed of the tsunami waves destroying the coast reaches 25-100 km/h. These waves can damage and even destroy the environment in coastal areas. Low-lying lands can become stagnant to form a new ocean. Tsunamis can destroy buildings and bridges, damage roads, and cut off the region's power lines, telephone networks, and other infrastructure. In addition, clean water sources, agricultural land, and soil fertility can be disrupted due to contamination by seawater (Widodo et al., 2017). A tsunami is a disaster that threatens and causes great losses and fatalities. Therefore, tsunami disaster mitigation is important in various preventive actions to minimize the tsunami's negative impact. Petanahan District, the research area, is densely populated, so if it is affected by the tsunami, it will cause huge losses.

Based on the BMKG Tsunami Catalog, there were several tsunami events in southern Java from 416 to 2018 (Triyono et al., 2018). On the south coast of West Java, there was a tsunami on August 16, 1889, but no clear record was found regarding the height of the inundation and the amount of loss. Meanwhile, on July 17, 2006, there was an earthquake with a magnitude of 7.0, which caused a tsunami in Pangandaran Beach and its surroundings, causing 664 people to die. Focus ball analysis shows that the earthquake on July 17, 2006, with coordinates 9.3° S and 107.4° E, combined a horizontal and ascending fault. This type of fault is also called oblique (Alfaris et al., 2020). On September 2, 2009, an earthquake with a magnitude of 7.3 in Tasikmalaya caused a local tsunami in Pameungpeuk as high as 1 m and in Pelabuhan Ratu as high as 0.2 cm. The BMKG Tsunami Catalog records earthquakes and tsunamis on the southern coast of Central Java and the Special Region of Yogyakarta that occurred in Pacitan (4 January 1840 and 20 October 1859) and on the Parangtritis coast (11 September 1921). For the south coast of East Java, the tsunami was recorded on September 26, 1957 and April 13, 1985, there was a sea level rise due to the earthquake but no casualties were recorded and on June 2, 1994 an earthquake occurred in the south of Banyuwangi and caused a tsunami with a height of 13.9 m causing 121 people died and 27 people were seriously injured. Of the 996 existing houses, 704 collapsed due to the tsunami attack. The model validation results in Sumber Agung village have a maximum run-up height of 5.6 m, an estimated tsunami run-up speed of 4.0 m/s, and an incoming horizontal wave of 750 (Gusman, 2018).

Several studies have shown that the southern coast of Java Island is very vulnerable to tsunamis. The results of tsunami modeling using the *Cornell Multi-grid Coupled Tsunami Model* (COMCOT) v1.7 show that the highest tsunami inundation occurred in Cianjur Regency was 26.7 meters, and the fastest travel time was approximately 10 minutes after the main earthquake. In contrast, the furthest inundation distance is calculated to be in the Sukabumi Regency, about 5.8 kilometers from the coast, due to the presence of a river (Windupranata et al., 2020). Estimating tsunami susceptibility using the Spatial Multi-Criteria Evaluation (SMCE) method in Parangtritis, Yogyakarta, Indonesia (Waskita et al., 2022) shows that susceptibility index classes vary from the lowest to the highest level. The area with the lowest susceptibility level is located in Baturagung Hill.

Meanwhile, the area near the shoreline and the riverbank has a relatively high level of susceptibility. The dunes landform, which has been relied on to decrease the susceptibility level, is covered by various levels of susceptibility from very low to high. The weighting is carried out through an overlay of the coastline-river distance map, topographic map, and elevation map. The map results show Jetis Beach in Cilacap Regency and its surroundings consist of five tsunami hazard zones: high-risk zone, moderate to high-risk, moderate zone, low to moderate zone, and low-risk zone. The most vulnerable zone is located in the southern part of Jetis beach, while the safest zone lies in the northern and eastern parts of Jetis beach (Laksono et al., 2022). The above studies are considered when conducting tsunami susceptibility research in Petanahan District.

The analysis of tsunami susceptibility in this study refers to the results of Faiqoh (2013) research. In the research entitled "Vulnerability Level Map of Tsunami Disaster in Pangandaran Beach, West Java," susceptibility assessment analysis was performed using merger or overlay methods in Geographic Information Systems (GIS). The parameters used to analyze tsunami susceptibility levels were elevation, topography, land use, coastal border, and river banks. The susceptibility was divided into five classes, i.e., very high, high, medium, low, and very low. The author uses this analytical method because (1) the geographical conditions of the Pangandaran coast are almost similar to the Petanahan coast, and (2) the parameters for determining the tsunami susceptibility used are sufficient to indicate the tsunami susceptibility of the research area.

Petanahan District, Kebumen Regency, the research area, is located in South Java Coastal Plain, directly opposite the Indian Ocean. This area has a flat topography, so it is prone to tsunami disasters. This research aimed to analyze the level of tsunami susceptibility in the coastal area of Petanahan District, Kebumen Regency. Knowing the level of susceptibility of the region can be used as a guide for community and government preparedness in disaster risk reduction. The community can use the results of this study to increase preparedness in dealing with the tsunami disaster and for the Government to take policies in disaster risk reduction.

2. METHOD

This research was conducted in the coastal area of Petanahan District, Kebumen Regency, especially the villages that border the sea, there are Karangrejo, Karang gadung, and Tegalretno villages. The research location was chosen because the area adjacent to the sea can potentially be threatened by a tsunami (Figure 1).

This study uses land units as the research population, which is arranged based on landform, land use, altitude, and slope to obtain the unit of analysis using the overlay method. Faiqoh et al. (2013) describe the parameters for determining land units. The land units obtained from the overlay process are 43, which are then used to analyze their vulnerability to tsunamis. Parameters tsunami

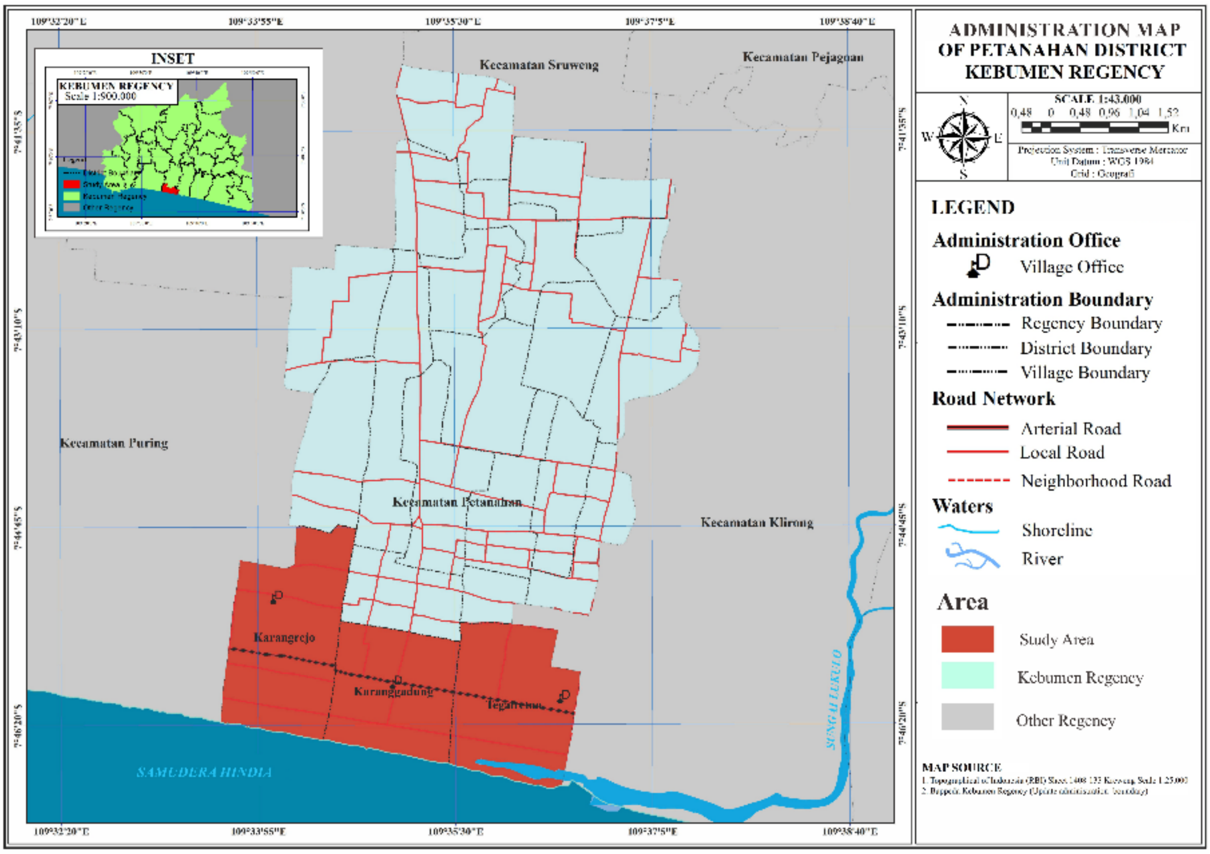

Figure 1. Location of study area

Table 1. Data and sources for tsunami susceptibility

Data types	Data source
Slope	Topographic map of DEMNAS
Elevation	Topographic map of DEMNAS
Landuse	IKONOS Image interpretation, Rupa Bumi Indonesia in 2020 with scale 1 : 25.000 and field observation in 2020
Distance from the river	IKONOS Image interpretation in 2020, and Rupa Bumi Indonesia in 2020 with scale 1 : 25.000
Distance from the shoreline	IKONOS Image interpretation in 2020
Administration boundary	GEOPORTAL KEBUMEN in 2019

Sources: researcher analysis

Table 2. Susceptibility parameters

Parameters	Weight	Category				
		Very high	High	Moderate	Low	Very low
Slope	20	0-2 %	2-5 %	5-15 %	15-40%	>40 %
Elevation	25	<10 m	10-25 m	25-50 m	50-100 m	>100 m
Land use	15	Settlements, rice fields, swamp, ponds	gardens/ terrestrial vegetation	moor	moor, shrubs, grass, vacant land	Forests, rocks, limestone
Distance from river	20	<100 m	100-200 m	200-300 m	300-500 m	>500 m
Distance from shoreline	20	<500 m	500-1000m	1000-1500 m	1500– 3000 m	>3000 m
Score		5	4	3	2	1

Sumber : Faiqoh et al. (2013)

Table 3. Tsunami susceptibility level

Class	Score	Susceptibility level
I	100-180	very low
II	181-260	low
III	261-340	moderate
IV	341-420	high
V	421-500	very high

Source: Faiqoh et al. (2013)

susceptibility using five parameters from Faiqoh et al. (2013): slope, elevation, land use, distance from the river, and distance from the shoreline. The types of data and their sources are as follows Table 1.

The six indicators are overlaid using a Geographic Information System (GIS) application and then scored and weighted to produce tsunami hazard data. The spatial data obtained is first converted into raster data using the Inverse Distance Weighted (IDW) interpolation method. The interpolation method can control the points around the research area, assuming the points far from the sample have a low spatial correlation compared to the points close to the sample. The point can be determined based on the distance of the area to be interpolated. In addition, field observations were also carried out in this study, which aims to determine the general condition of the actual land use conditions and follow the map used.

In addition, to support this data source, Image Interpretation Activities are also encouraged by manual validation activities through images or field observations. This activity is carried out to find out more accurately the conditions of land use in the research area. Analysis of the level of tsunami hazard is overlaid indicator maps using a Geographic Information System (GIS) application, then scoring and weighting (Table 2). It will produce a map of the tsunami hazard level in the coastal area of Petanahan District. Then calculate the level of tsunami susceptibility using Formula 1.

$$N = \sum Bi \times Si \quad (1)$$

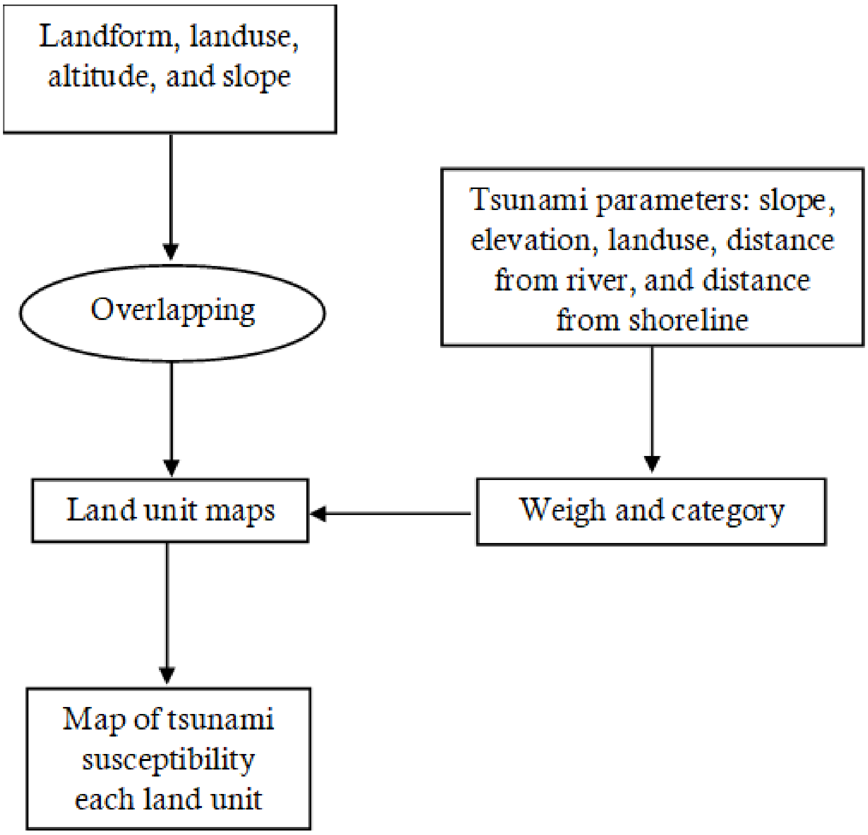

Figure 2. Research flow chart

where: *N* is the total weighted value; *Bi* is the weight on each criterion; *Si* is a score on each criterion. More detail in mathematically, the calculation of the overlay technique analysis above is as follows:

$$N = \sum Bi \times Si$$

= ∑ [(elevation*25) + (slope*20) + (land use*15) + (distance from river*20) + (distance from shoreline*20)]

This scoring range is information in the form of indicators for tsunami susceptibility, namely very high, high, medium, low, and very low. Classes of tsunami susceptibility levels are shown in Table 3. The research flow chart can be seen in Figure 2.

3. RESULTS AND DISCUSSION

3.1. Result

The study area's tsunami susceptibility analysis is based on Faiqoh et al. (2013), consisting of a slope, elevation, land use, distance from the river, and distance from the shoreline (see Table 4). Based on the overlay of the five parameters, 43 land units were obtained, shown in Table 4. The land unit is the unit of analysis used to determine the tsunami susceptibility in the Petanahan district.

Land units with high susceptibility are dominated by areas close to the shoreline with a distance of 500-1000 m. The distance to residential areas with various ranges is between 100-500 m. However, the exceptionally high susceptibility class also pays attention to elevations less than 10 m and slope classes between 0-2%. Besides that, these conditions are also driven by land use conditions in the form of gardens, fields, and ponds.

3.1.1. Slope

In this study, the slope used is percent (%). Determination of the slope of the data source uses the method developed (Arifianti, 2011). The slope of an area affects the height or run-up of tsunami

Table 4. Data of susceptibility tsunami parameters in the study area

Number of land units	Slope (%)	Elevation (m)	Landuse	Distance from the river (m)	Distance from shoreline (m)
1	0-2	< 10	fir forest	>500	0-500
2	0-2	< 10	garden	>500	0-500
3	0-2	< 10	empty land	>500	0-500
4	0-2	< 10	fishpond	>500	0-500
5	0-2	< 10	moor	>500	0-500
6	0-2	10 - 25	garden	>500	0-500
7	0-2	< 10	fir forest	300-500	0-500
8	0-2	< 10	garden	300-500	0-500
9	0-2	< 10	fishpond	200-300	0-500
10	0-2	< 10	garden	200-300	0-500
11	0-2	< 10	empty land	200-300	0-500
12	0-2	< 10	garden	100-200	0-500
13	0-2	< 10	empty land	100-200	0-500
14	0-2	< 10	fishpond	100-200	0-500
15	0-2	10 - 25	garden	100-200	0-500
16	0-2	< 10	fir forest	0-100	0-500
17	0-2	< 10	empty land	0-100	0-500
18	0-2	< 10	fishpond	0-100	0-500
19	0-2	< 10	moor	0-100	0-500
20	0-2	< 10	garden	>500	500-1000
21	0-2	< 10	ricefield	>500	500-1000
22	0-2	10 - 25	garden	>500	500-1000
23	0-2	10 - 25	Settlement	>500	500-1000
24	0-2	10 - 25	ricefield	>500	500-1000
25	0-2	< 10	garden	300-500	500-1000
26	0-2	< 10	ricefield	300-500	500-1000
27	0-2	10 - 25	garden	300-500	500-1000
28	0-2	< 10	garden	200-300	500-1000
29	0-2	< 10	ricefield	200-300	500-1000
30	0-2	10 - 25	garden	200-300	500-1000
31	0-2	< 10	garden	>500	1000-1500
32	0-2	< 10	Settlement	>500	1000-1500
33	0-2	< 10	ricefield	>500	1000-1500
34	0-2	10 - 25	garden	>500	1000-1500
35	0-2	10 - 25	Settlement	>500	1000-1500
36	0-2	10 - 25	ricefield	>500	1000-1500
37	0-2	< 10	Settlement	>500	1500-3000
38	0-2	< 10	ricefield	>500	1500-3000
39	0-2	10 - 25	garden	>500	1500-3000
40	0-2	10 - 25	Settlement	>500	1500-3000
41	0-2	10 - 25	ricefield	>500	1500-3000
42	0-2	< 10	ricefield	>500	1500-3000
43	0-2	10 - 25	ricefield	>500	1500-3000

Source: Measurement and calculation results

waves. The steeper a site, the lower the ocean waves (Sengaji & Nababan, 2009). The slope in the study area is grouped into five classes according to Table 2. The analysis results show that the entire research area has a slope of 0-2%, so judging by the slope of the land, the research area is classified as having a very high level of susceptibility. The tsunami will not be too far inland on the steep coast because it is caught and reflected by the coastal cliffs. Meanwhile, on sloping beaches, tsunamis can hit several hundred meters inland. The slope map can be seen in Figure 3.

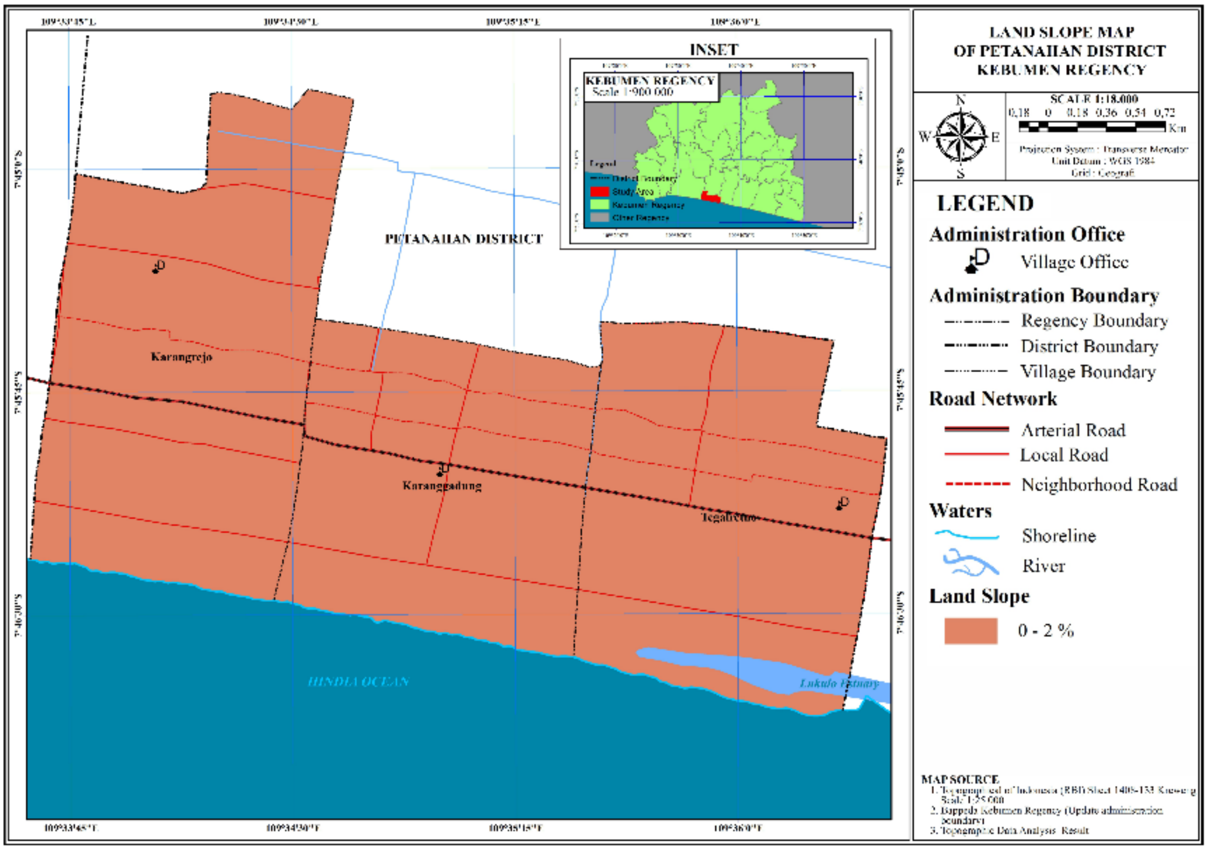

Figure 3. Slope map of Petanahan District

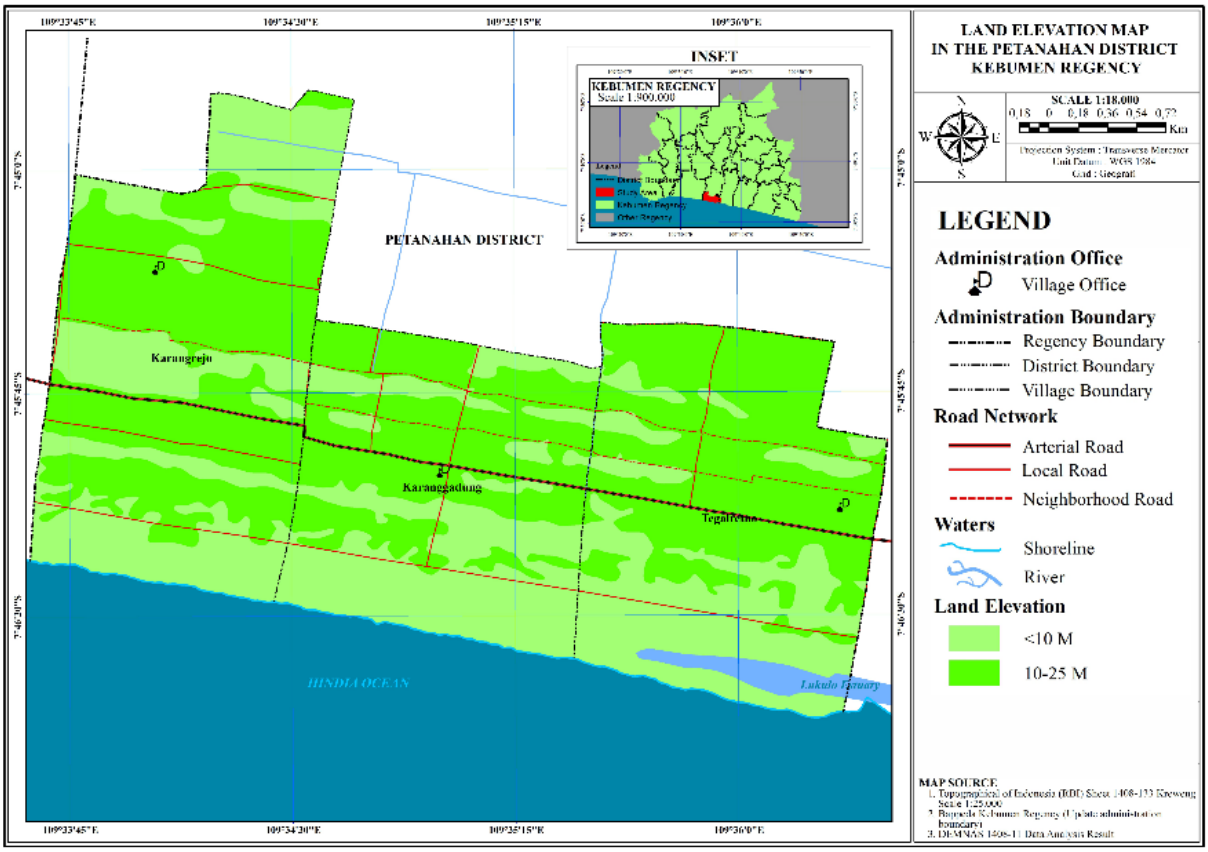

Figure 4. Map of the study area elevation

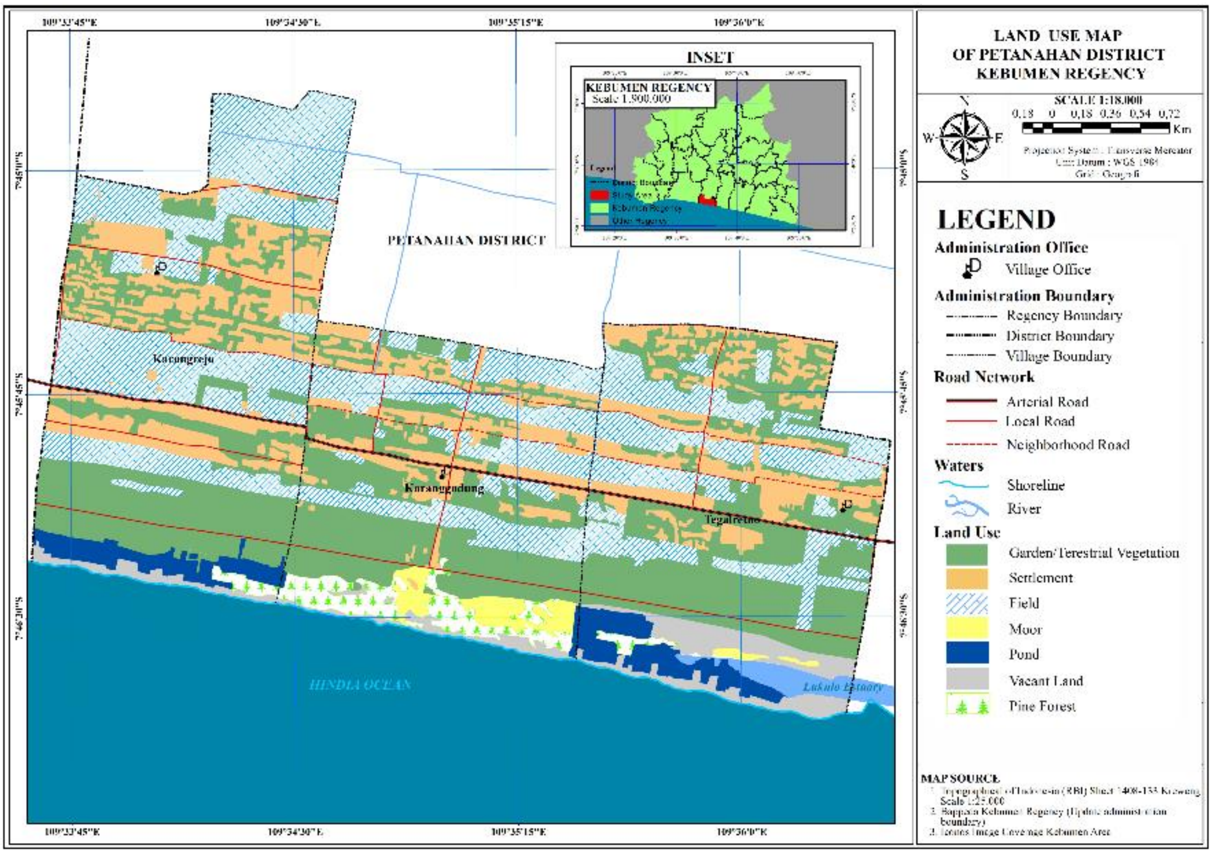

Figure 5. Map of the land use in the coastal area of Petanahan District

3.1.2. Elevation

The distance a tsunami travels to the mainland is largely determined by the altitude of a place (Oktariadi, 2009). The higher a place is, the safer it is from being hit by tsunami waves. The height of the coastal area can be known through the contour lines on the Topographic Map of Indonesia. Altitudes in the study area are grouped according to Table 2. From the following figure, the elevation distribution in the study area is spread out with a range of <10 m, 10-25 m, and 10 m above sea level (Figure 4).

3.1.3. Land use

Areas categorized as tsunami-prone are based on land use for the benefit of the community because if a tsunami occurs, it will have a significant impact on the area. The types of land use with high economic value include settlements, rice fields, gardens, and dry fields. The land use of the research area group can be seen in Table 2 and Figure 5. The results of data analysis showed that rice fields dominate the land use of the research area and gardens with 428.62 ha and 341.42 ha, respectively.

3.1.4. Distance from the river

The river closest to the research area is the Luk Ulo River which passes through the Klirong District to the east of the Petanahan District. The river's estuary can be seen in Figure 6. A river is one factor that increases the susceptibility of the research area to tsunamis. When a tsunami occurs, tidal waves can enter the land through water channels that lead to the sea (Bustomi et al., 2016). In the study area, the Luk Ulo River is a factor in influencing susceptibility to tsunamis. The classification of the distance parameters from the river is then divided into classes, including: < 100 m, 100-200 m, > 200-300 m, > 300-500 m, and > 500 m. The results of the analysis of the distance parameter from the river can be seen in Figure 6.

3.1.5. Distance from the shoreline

The height of a tsunami is caused by the kinetic energy of the waves to potential energy. The condition means that the energy lost due to a decrease in speed is transferred in an increase in wave

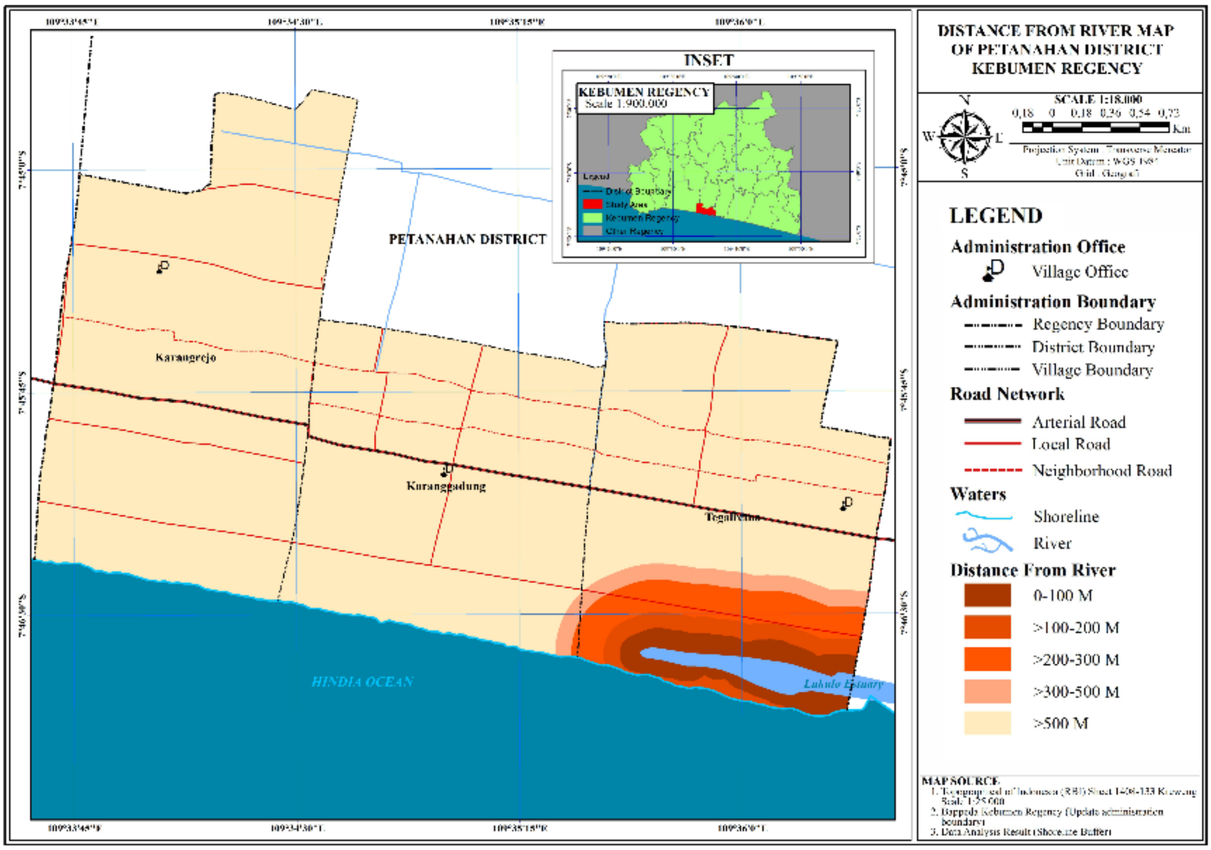

Figure 6. Map the parameter of distance from the river

height (run-up) (Subandono & Budiman 2006). Running speed to the mainland coast can reach 25-100 km/hour. The speed of the tsunami waves will cause damage and loss of life, damage to agricultural land, regional infrastructure, and lowlands to become inundated and form new oceans (Alimsuardi et al., 2019). In understanding a region's susceptibility to tsunamis, the distance of a place from the coastline is one of the determining factors because these conditions can affect the region's security from tsunamis. The distance from the beach is classified into five classifications, including 0-500 m, >500-1000 m, >1000-1500 m, >1500-3000 m, and >3000 m. A visual depiction of the classification is then depicted in Figure 7. At a distance of 0-500 m from the beach, no settlements were found in the villages of Karangrejo, Karanggadung, or Tegalretno. The closest settlements are found at 500-1000 m from the shoreline.

3.1.6. Susceptibility Level in the research area

The tsunami susceptibility level map was obtained from an overlay of five maps: slope, elevation, land use, distance maps from rivers, and distance maps from the tsunami's shoreline. The results of the tsunami susceptibility analysis in the Petanahan District can be seen in Figure 8. Based on the figure, it is known that the research location has a very high level of susceptibility, namely 93.904 hectares (8.33% of the area), high susceptibility of 567.804 hectares (50.35% of the area), and medium susceptibility of 465.962 hectares (41.32% of the total area).

3.2. Discussion

Geologically, the sea waters of south Java Island are a subduction zone, and several earthquakes that occur in this area can potentially cause a tsunami. Several earthquakes in Java with a magnitude of more than seven were associated with a subduction zone located in the southern part of Java (Newcomb & McCann, 1987). This zone is an active plate boundary that accommodates the subduction of the Indo-Australian Plate and the Eurasian Plate with a normal convergence rate of 58.3 ± 0.5 to 61.8 ± 0.4 mm/year in the south of West Java (Koulali et al., 2017). The subduction of the Indian-Australian Plate marks the interaction of the two plates under the Eurasian Plate. It produces an arc trough system that stretches from the Andaman Sea to the Banda Sea (Wisyanto, 2003). This condition causes the southern coast of Java Island to be very susceptible to tsunami

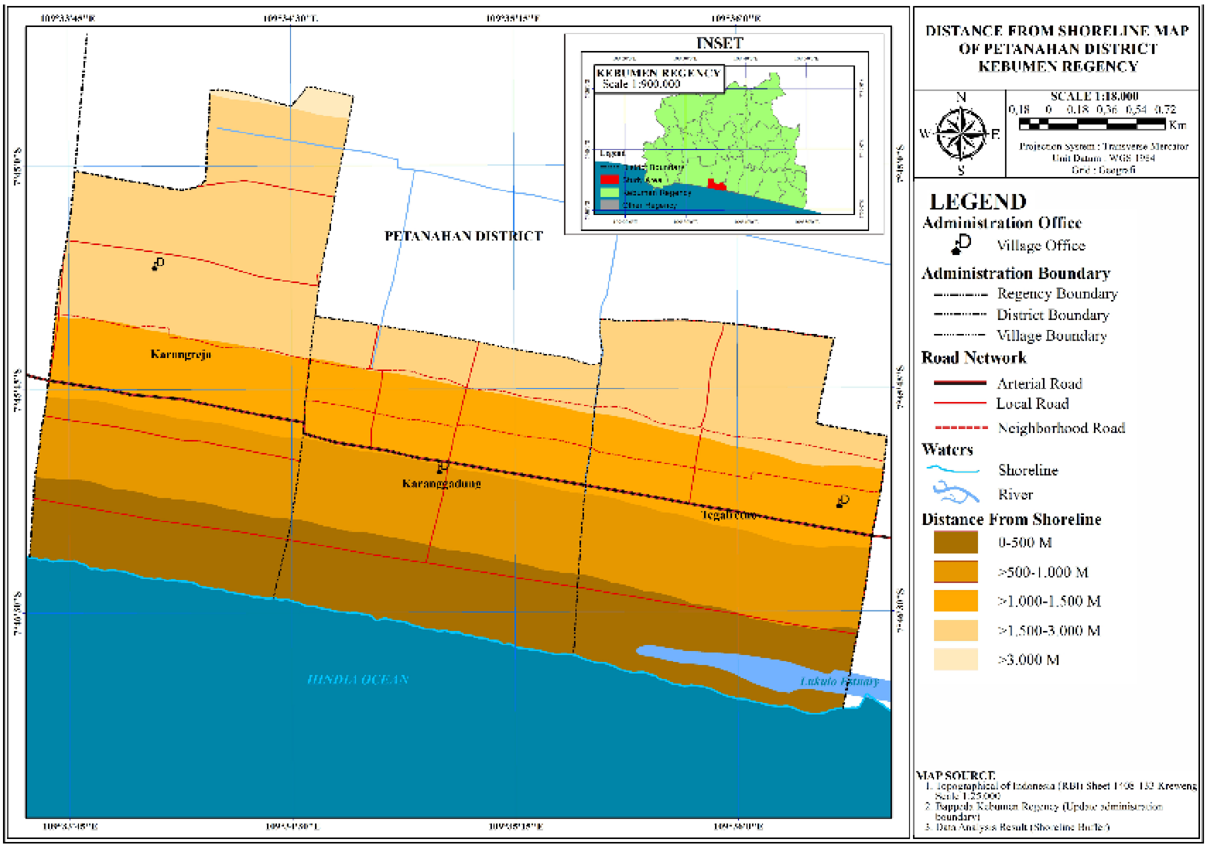

Figure 7. Map of distance from the shoreline parameters

disasters. The worst-case scenario, in which the two megathrust segments spanning Java rupture simultaneously, shows that tsunami heights can reach ~ 20 m and ~ 12 m on the south coast of West and East Java, respectively, with an average maximum height of 4.5 m along the entire south coast of Java (Widiyantoro et al., 2020).

Based on the Physiographic map of Java and Madura Islands (Bemmelen, 1949), the south coast of Java is a mostly hilly area, and only a small part in some places is a flat area (Figure 9). The widest is on the south coast of Central Java Province and the Special Region of Yogyakarta. However, areas with flat topography generally have high population density, so if a tsunami occurs, it is feared that it will cause many casualties. Petanahan District, the study location, has a flat topography, so this area topographically has a high level of susceptibility to tsunamis.

The presence of the Luk Ulo river estuary on the Petahanan coast can also increase the susceptibility of the research area because tsunami waves can creep along the river and threaten the surrounding area. Coastal vegetation can significantly reduce the severity of tsunami waves and dissipate the disastrous amount of energy associated with them (Dahdouh & Guebas, 2005; Norio et al., 2006). Judging from the land cover of the coast, Petanahan District is good because, on the front of the beach, there are pine forests and gardens. The density of spruce forests is relatively high, but the thickness of garden plants needs to be increased to function as beach protectors.

As a result of the hydrodynamics of the tsunami that occurred during the run-up period, tsunami damage occurred mostly in the near-shore zone and the coastal area behind the coastline(Irtem et al., 2009). Based on the analysis of the susceptibility to tsunamis, most of the coastal areas of the Petanahan District are classified as high susceptibility. A very high level of susceptibility is in the area adjacent to the mouth of the Luk Ulo river. The area with a very high level of susceptibility is 93.904 ha or 8.33% of the total coastal area of Petanahan District. Areas with a high level of susceptibility have an area of 567.804 ha or occupy 50.35% of the total coastal area of Petanahan District.

Furthermore, for areas with a moderate level of susceptibility, it has an area of 465.962 ha or occupies 41.32% of the total coastal area of Petanahan District. If a tsunami occurs, this area is estimated to be an affected area. These results are similar to the analysis of tsunami level

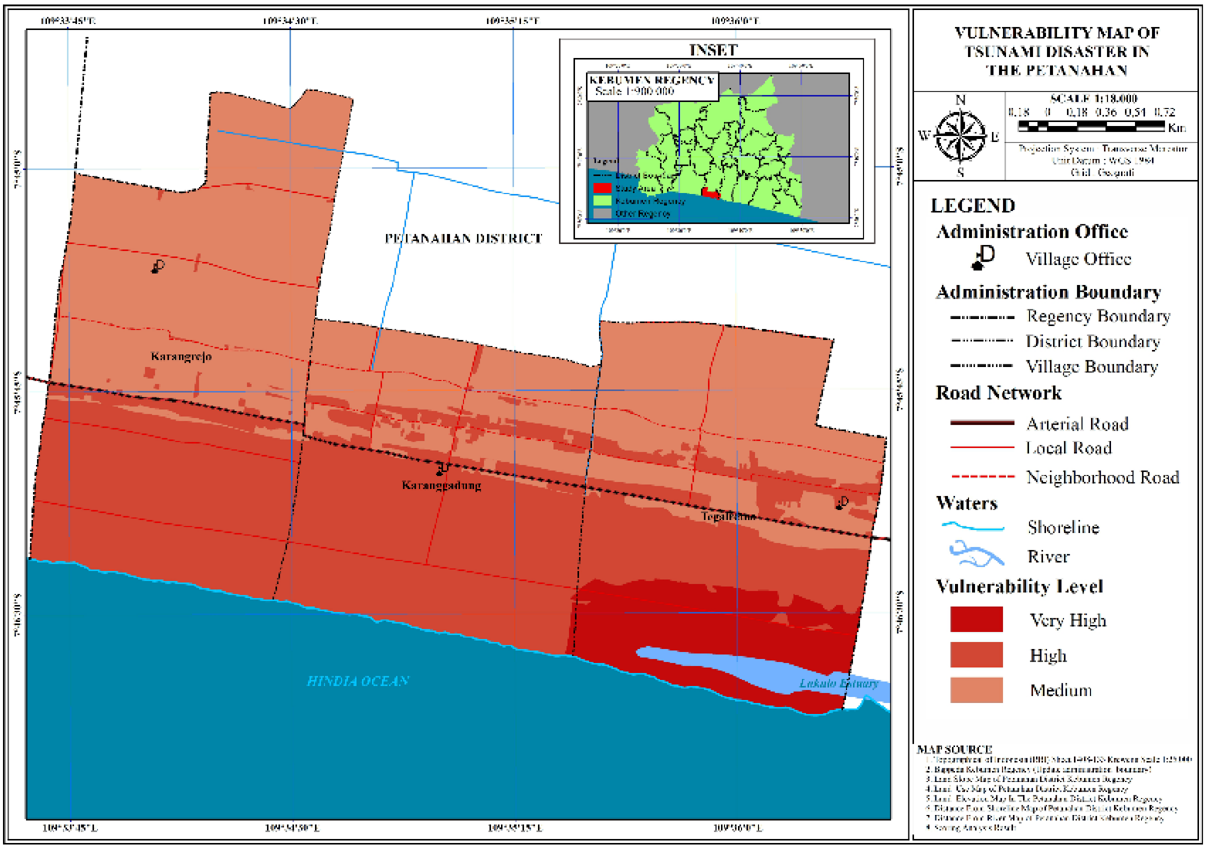

Figure 8. Map of susceptibility level at Petanahan District coastal area

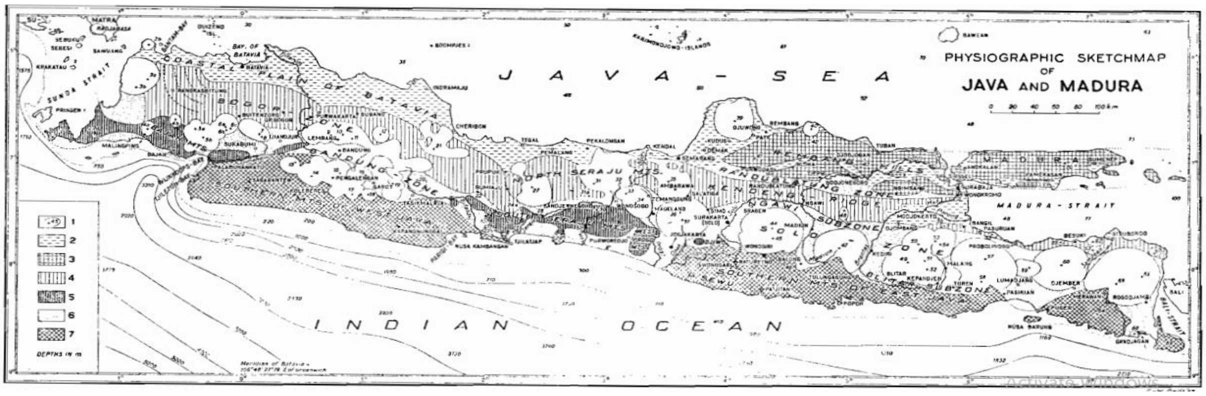

Figure 9. A physiographic map of Java and Madura Islands (Bemmelen, 1949)

susceptibility in the coastal area of Kulon Progo Regency with GIS modeling. There is very susceptibility at 4.21% is 32.10%. Class is moderately susceptible is 21.63% (Tarigan et al., 2015). While the level of tsunami susceptibility in Kretek District, Bantul Regency shows 19.1%, including very high class, 25.6% high, and 13.9% moderate (Subardjo & Ario 2016).

The acquisition results consisting of three susceptibility classes on the coast of Petanahan District differ from those obtained by Faiqoh et al. (2013). The research was conducted at Pangandaran Beach, where the susceptibility was very high, high, medium, low, and very low. The coastal area of the Petanahan District has relatively the same characteristics. Both locations are on a flat topography with a slope of 0-2%, and land use is dominated by terrestrial vegetation. The difference in the results from the two locations was due to the area of the research area, where research by Faiqoh et al. (2013) is broader, covering three districts or Districts.

Based on the fact that the susceptibility level of coastal areas in Petanahan District, Kebumen Regency is very high and high, there are requires policy direction from the Kebumen Regency Government for efforts to disaster risk reduction and increase the resilience of the people living in the area.

4. CONCLUSIONS

Based on overlapping slope maps, elevation maps, land use maps, distance maps from rivers, and distance maps from coastlines, the results of the research showed that the level of tsunami susceptibility in a coastal area of Petanahan District is very high (93.904 ha/8.33%), high (567.804 ha/50.35%) and moderate (465.962 ha/41.32 %). Areas with a very high level of susceptibility are influenced by the Luk Ulo River, which empties into the Petanahan coastal area. This research contributes ideas for research related to the tsunami disaster, especially on community susceptibility. This condition also encourages the Kebumen Regency Government to make policy directions in reducing disaster risk, besides providing an overview of the efforts that need to be carried out to increase community resilience in the face of the tsunami disaster.

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