VULNERABILITY LEVEL MAP OF TSUNAMI DISASTER IN PANGANDARAN BEACH, WEST JAVA

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Abstract. Indonesia is located in a seismic active region where tsunami often occur. One of tsunami prone areas in Indonesia is southern coast of Java, such as the coastal areas of Pangandaran, West Java. One of the instruments in the tsunami disaster mitigation is the vulnerability map of coastal region on tsunami. Analyses of tsunami vulnerability assessment was performed by using merger or overlay methods in Geographic Information Systems (GIS). The parameters used to analyze tsunami vulnerability level were elevation, topography, landuse, coastal border, and river banks. The vulnerability were divided into five classes i.e., very high, high, medium, low, and very low. Results showed that Pananjung, Babakan, Pangandaran (Pangandaran District); and Sukaresik and Cikembulan (Sidamulih District) sub-districts were identified as areas of very high level of tsunami vulnerability with total area of 737.703 hectares. Areas with low level of vulnerability were Pagergunung, Putrapinggan, and Kersaratu sub-districts with total area of 4,816.204 hectares.

Keywords: *Coastal vulnerability, Tsunami, GIS, Pangandaran*

1 INTRODUCTION

Indonesia is located in a seismic active region where tsunami often occur. One of tsunami prone areas in Indonesia is southern coast of Java, such as the coastal areas of Pangandaran, West Java. Sudrajat (1997) included the southern coast of Java into group of vulnerable tsunami disaster based on the cause of tectonic earthquake. Geologically, this area is located in the subduction line or at the confluence of two large plates that can collide each other (Eurasian and Indo-Australian plates). The plates movement in this area, often cause big earthquake that can produce a tsunami. In a period of less than 18 years, in Southern Java has occurred 2 times big tsunamis (tsunami Banyuwangi (East Java) in 1994 and Pangandaran (West Java) in 2006). Indonesian Disaster Prone Index data published by the National Disaster Management Agency (BNPB) in 2011, showed that Ciamis regency (including Pangandaran) is in the third rank of prone area of potential threat of earthquake and tsunami, after Banda Aceh city and Sikka regency, East Nusa Tenggara.

Pangandaran coastal areas have experienced an earthquake and tsunami 7 years ago. On 17 July 2006 precisely at 15:19 a.m., an earthquake occurred in the southern coast of Pangandaran at coordinates 9.33°S and 107.26°E at at distance of 10 from Pangandarn with magnitude of 7.7 Richter scale. The epicenter was located in the Indian Ocean at the southern part of Ciamis regency or located about 245 km from Tasikmalaya (Kongko, 2011). The earthquake was followed by tsunami of about 1-2 m depth flow and runoff distance of inland tsunami approximately 50-200 m from the beach (Bappeda Ciamis**,** 2012). The tsunami disaster caused damages in six districts of Ciamis regency i.e., Pangandaran, Sidamulih, Parigi, Cijulang, Cimerak, and Kalipucang districts. The worst damages were in Pangandaran and Sidamulih districts. From the data of Regional Disaster Management Agency (BPBD) of Ciamis, fatalities were recorded as much as 274 persons injured, 27 persons missing, and 13,198 refugees. The data clearly show that the tsunami was a destructive disaster. Therefore, it is necessary to have a tsunami disaster mitigation efforts, which is a process to seek various preventive measures to minimize negative impacts of the predicted tsunami disaster. One of tsunami disaster mitigations is to produce vulnerability coast map for tsunami disaster.

Vulnerability tsunami mapping should be conducted by multi-criteria approach in accordance with the studied area. Therefore, spatial analysis tools are needed to create tsunami vulnerability map. Geographic Information Systems (GIS) is to spatially visualize tsunami risk level. One of GIS tools can function merging and overlaying techniques. The principle of this method is to combine several weight and score parameters to produce a class interval of tsunami vulnerability level in the study area.

This obejctive of study was to map coast vulnerability level due to tsunami disaster in Pangandaran coast, West Java.

2 MATERIALS AND METHOD

This research was conducted with the integration of remote sensing data and GIS. Preparation of thematic maps were carried out by using ArcGIS 10 software and tsunami vulnerability level map was analyzed by combining all parameters of coast vulnerability on tsunami such as elevation (topography), slope, distance from shoreline (coastal border), distance from the river (river banks), and landuse.

Field survey was conducted on 17-22 April, 2013 in 3 districts (Pangandaran, Kalipucang, and Sidamulih). This field surveys were aimed to obtain data on the condition of the study area and spatial data from local government. The surveys were conducted randomly at 20 points in coastal areas of 3 districts. The observation conducted during the field survey was to visually investigate the appearance of beaches and coastal features, like the shape of the coastline, vegetation coverage, and land use.

2.1 Time and study location

The field surveys were conducted in April 2013, and data processing from May to June 2013 in the Computer Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, Bogor Agricultural University. The research study was located around Pangandaran beach with coordinates of 7.63° - 7.75° S and 108.50° - 108.75° E (Figure 1).

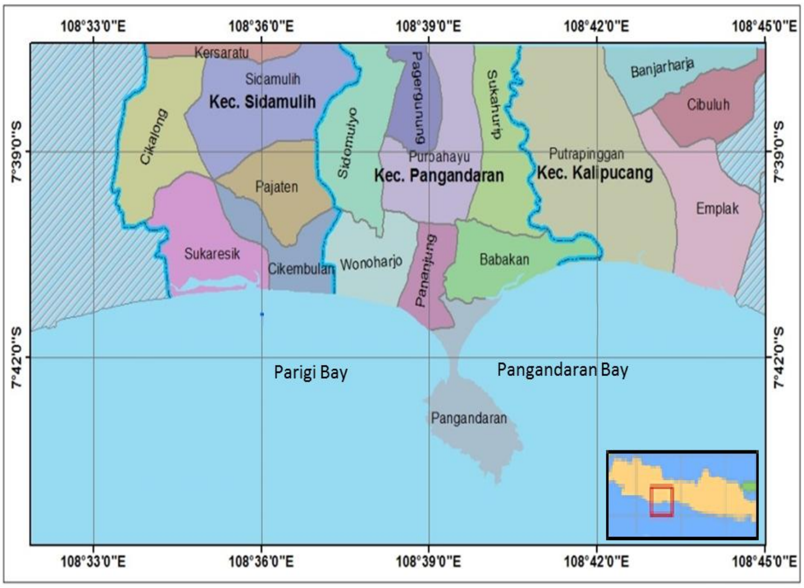

Figure 1. The location of research study, Pangandaran Beach.

2.2 Data and tools

Data used in this study were secondary data and field survey data. Field surveys were conducted using GPS equipment. Image, elevation and bathymetric data were obtained from the official website of data provider (Table 1). Population and spatial data of Pangandaran area were obtained from the relevant government agencies of Ciamis regency.

2.3 Data analysis

Analysis of tsunami vulnerability level was determined using merging and overlay methods. Parameters used to determine tsunami vulnerability were slope, elevation, landsuse, distrance from shoreline (coastal border, and distance from the river (river banks). Based on those 5 parameters, a matrix to define tsunami vulnerability level was prepared as displayed in Table 2.

Table 1. Sources of Information and Data Acquisition

No.	Kinds of Data	Data Source	Scale/Resolution
1.	Slope	- Map of slope Ciamis Regency 2009 - Spatial data (Bappeda)	1 : 150.000
2.	Topography	Global Digital Elevation Model (GDEM) from Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER)	30 X 30 m
3.	Landuse	- Land use map of Ciamis Regency - Topographical map of Indonesia (RBI)	1 : 150.000 1 : 25000
4.	Satellite imagery	- Landsat 7/ETM^{+} path/row 121/65 2010 and ALOS 2011	30 m and 10 m

Table 2. Matrix of coastal vulnerability parameters againts tsunami disaster

No	Parameters	Weight (%)	Very high vulnerability	Score	High vulnerability	Score	Moderate vulnerability	Score	Low vulnerability	Score	Very low vulnerability	Score
1	Slope (%)	20	0 – 2%	5	2 – 5%	4	5 – 15%	3	15 – 40%	2	> 40%	1
2	Elevation (m)	25	<10	5	>10-25	4	>25-50	3	>50-100	2	100 - 350	1
3	Landuse	15	Settlement, fields, forest swamp	5	Garden/ terrestrial vegetation	4	Field/more	3	Shrubs, grass, bare soil	2	Forests, rocks and limestone rock	1
4	Distance from the shore line (m)	20	500	5	>500-1000	4	>1000-1500	3	>1500-3000	2	>3000	1
5	Distance from river (m)	20	100	5	100-200	4	>200-300	3	>300-500	2	>500	1
Weight x Score		100		5		4		3		2		1

(Sources: Firmansyah, 2012; Bappeda Ciamis, 2012; Sengaji and Nababan, 2009; Setiawan, 2006).

The determination of distance fom shoreline was based on *Mean Sea Level* (MSL) value, so that the distance from shoreline was not effected by highest or lowest tidal level. Data processing and analyses to determine vulnerability level of coast on tsunami is presented in Figure 2.

The matrix was determined by weighting and scoring. The scoring was intended to assess the limiting factor on each parameter. Assigning weights to each parameter in this study ranged from 15-25% and score in the range of 1-5 indicating the class of tsunami vulnerability level (very high, high, medium, low, very low). Class values weare based on the following calculation formula (Muzaki 2008):

$$N = \sum B_i \times S_i \quad (1)$$

N = total weight of the value, B_i = weight on each criteria, S_i = score on each criteria. Mathematically, calculation of technique overlay analyses was as follows:

[(elevation*0,25)+(slope*0,2) + (landuse* 0,15)+(distance from shoreline*0,20) + (distance from the river*0,20)]

Calculation analyses for overlaying technique was a multiplication of the weights and score on five parameters in each cell. Multiplication of weights and the score results total weight value (N) for each parameter. N value was used to determine the level of vulnerability class interval. The calculation of each class interval was obtained from multiplication of maximum value of each weights and scores ($N_{maksimum}$) minus the multiplication of its minimum value ($N_{minimum}$) which was then divided by five (5) according to the number of parameters used with formula as follows (Muzaki 2008):

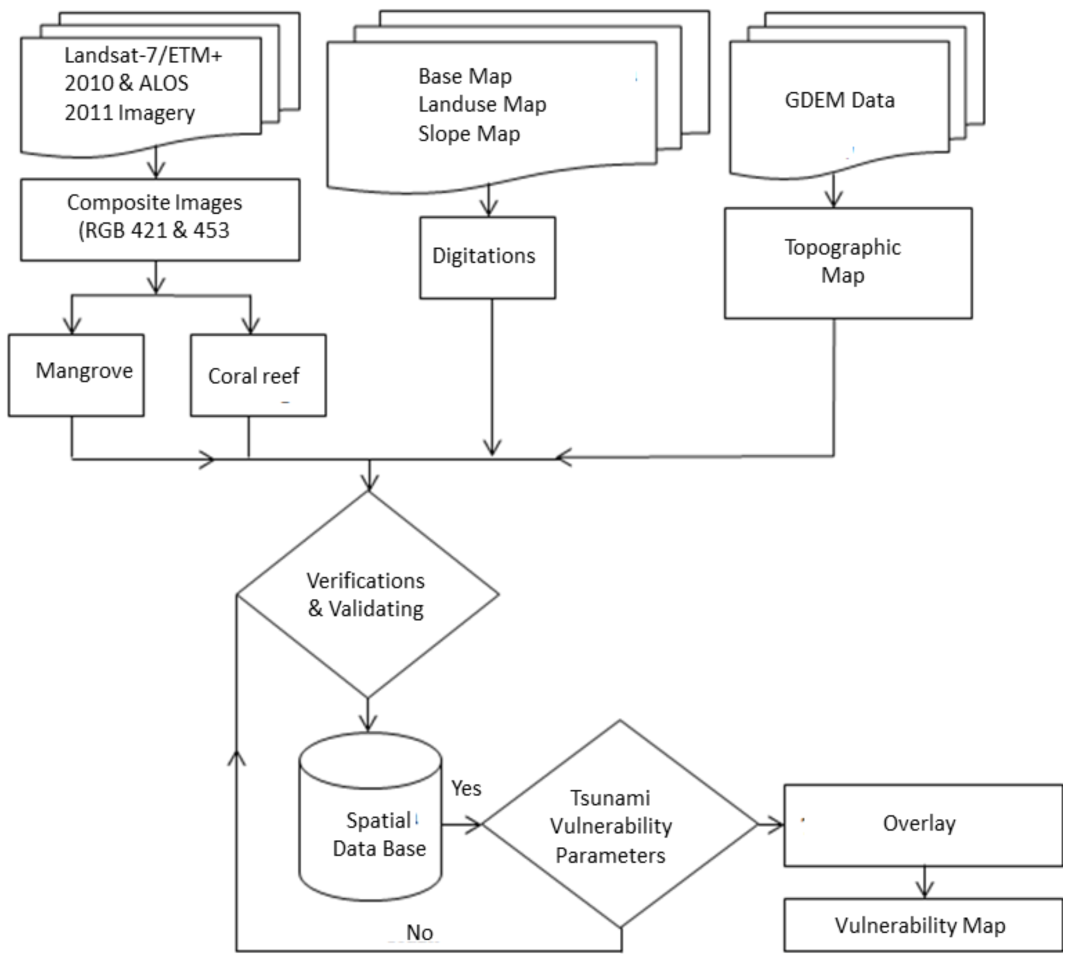

Figure 2. Flow chart of data proscessing and analyses.

$$L = \frac{\sum(B_i \times S_i)\max - \sum(B_i \times S_i)\,min}{n} \quad (2)$$

Where, L=width of class interval,
n=number of class parameters.

Based on calculations using the above formula (2), the class interval width of 0.95 with N_{min} value 0.25 and N_{max} value 5 were obtained. The lowest vulnerability level (R1) was obtained from N_{min} 0.25 added by the width of class interval 0.95. Low vulnerability level (R2) was obtained from class interval maximum R1, which was 1.2, added by 0.95. Likewise onwards to the vulnerability levels medium, high, and very high as summarized in Table 3.

Table 1. Tsunami vulnerability class interval

Class	Vulnerability level	Class Interval
1	Very low	0,25 – 1,2
2	Low	1,21 – 2,16
3	Medium/Moderate	2,17 – 3,12
4	High	3,13 – 4,08
5	Very high	4,09 – 5,04

3 RESULTS AND DISCUSSION

3.1 Parameter tsunami vulnerability level land elevation

The results of topographic mapping indicated that most of the study area was low-lying land with elevation of 10-25 m along the coast of Pangandaran, particularly in Sidamulih and Pangandaran districts. In this study area, highland (plateau) was located in the northern coast of Pangandaran, with elevation of 100-350 m. Plateau was also found in Pangandaran sub-district (Pangandaran District), where the area was a hilly cape and natural conservation area.

Figure 3 showed tsunami vulnerability for land elevation (topography) which was divided into 5 classes i.e., very high vulnerability class (1- 10 m), high (10 – 25 m), medium (25 – 50 m), low (50 – 100 m), and very low (100 – 350 m).

Table 4 showed that the area of elevation between 1-10 m was including in a very high vulnerability class. The region that had an area of 1559.422 hectares was located in Pejaten, Sukaresik, Cikembulan, and Wonoharjo sub-districts, Pananjung, and Babakan sub-districts in Pangandaran District. The region with elevation of 10-25 m had an area of 3911.379 hectares and belongs to a high vulnerability class, dominantly in the northern part of Pangandaran and Sidamulih district, which had a very close proximity to the sea.

In general, the northern coast of Pangandaran area that close to the sea and low elevation was higher vulnerability than other regions. The lower the land elevation of an area, the greater the level of tsunami hazard vulnerability (Oktariadi, 2009). The greater level of vulnerability, the greater the risk, and vice versa. The lower the land elevation of an area the more often this region inundated by runoff from tsunami.

3.2 Land slope

The land slope was a measure of the slope relative to the horizontal plane which was generally expressed in percent (%) or degree (0). In this study, the slope unit was in percent (%). The land slope affected to the height of tsunami wave (run-up). The steeper the land, the lower the tsunami wave height (Sengaji and Nababan, 2009).

Slope map of the land (Figure 4), showed that the land slope in Pangandaran varied between 2% and 40%. In Sidamulih District (Sukaresik, Pajaten, Cikembulan sub-districts) and Pangandaran District (Wonoharjo, Pananjung, and Babakan sub-districts), the land slope were relatively flat around 0-2% and were classified as class I (flat) (Arifianti 2011), while the land slope of Kalipucang District was relatively flat and corrugated 5-15% slope and classified in class III (corrugated) (Arifianti, 2011).

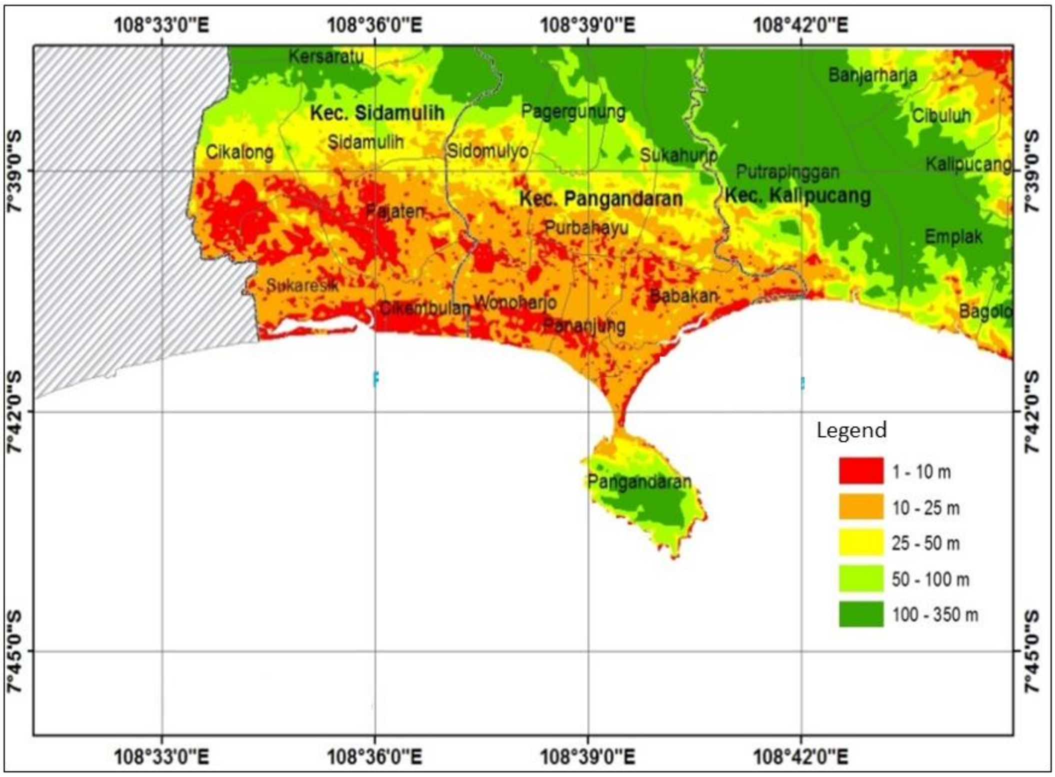

Figure 3. Land elevation map of Pangandaran coastal region.

Table 2. Total area of elevation class (ha)

No	Vulnerability level	Elevation (m)	Areas (Hectare)
1	Very High	1 - 10 m	1.559,422
2	High	10 - 25 m	3.911,379
3	Medium/Moderate	25 - 50 m	2.173,124
4	Low	50 - 100 m	2.320,955
5	Very Low	100 - 350 m	4.236,830
	Total		1.4201,710

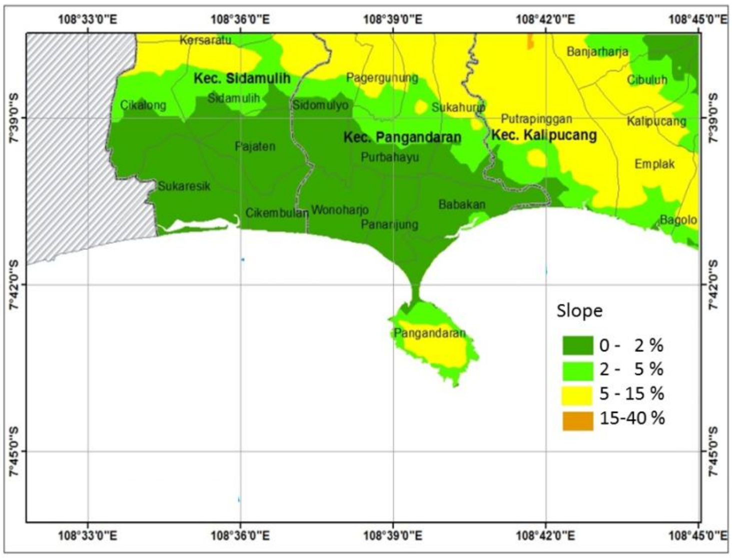

Figure 4. Land slope map of Pangandaran.

The land slope in the study area was mostly dominated by class 1 slope ranging of 0-2% with total area of 5686.725 hectares. This region belongs to the very high level of tsunami vulnerability (Table 5). It was clear that the coastal area of Pangandaran (Sidamulih and Pangandaran Districts) had a very high level of tsunami vulnerability from a view point of land slope factor.

3.3 Landuse

Land use was a complex use by nature or human intervention according to its own needs to meet financially of the physical needs (Vink, 1975). The areas around Pangandaran, namely Kalipucang, Pangandaran, and Sidamulih Districts; consisted of 8 types of land use i.e., forest, swamp forest, fields, vacant land, residential, irrigated fields, shrubs, and terrestrial vegetation (Figure 5). The dominant type of land use in the three districts was terrestrial vegetation with area of 9,292 ha, irrigated rice area of 2,087 ha, and residential area of 1,352 ha (Table 6). Densely residential land use were found in Sidamulih District (Cikalong, Sidamulih, and Pajaten sub-districts) and Pangandaran District (Babakan, Pananjung, and Pangandaran sub-districts). Field observation indicated that the type of land use for Pangandaran area did not undergo much change compared to the conditions depicted in the landuse map of Ciamis regency in 2006.

Table 3. Total area of slope land class

No	Vulnerability level	Slope (%)	Areas (Ha)
1	Very high	0 - 2%	5.685,725
2	High	2 - 5%	3.203,709
3	Medium/Moderate	5 - 15%	5.308,910
4	Low	15 - 40%	10,011
5	Very Low	> 40%	0
	Total		14.208,356

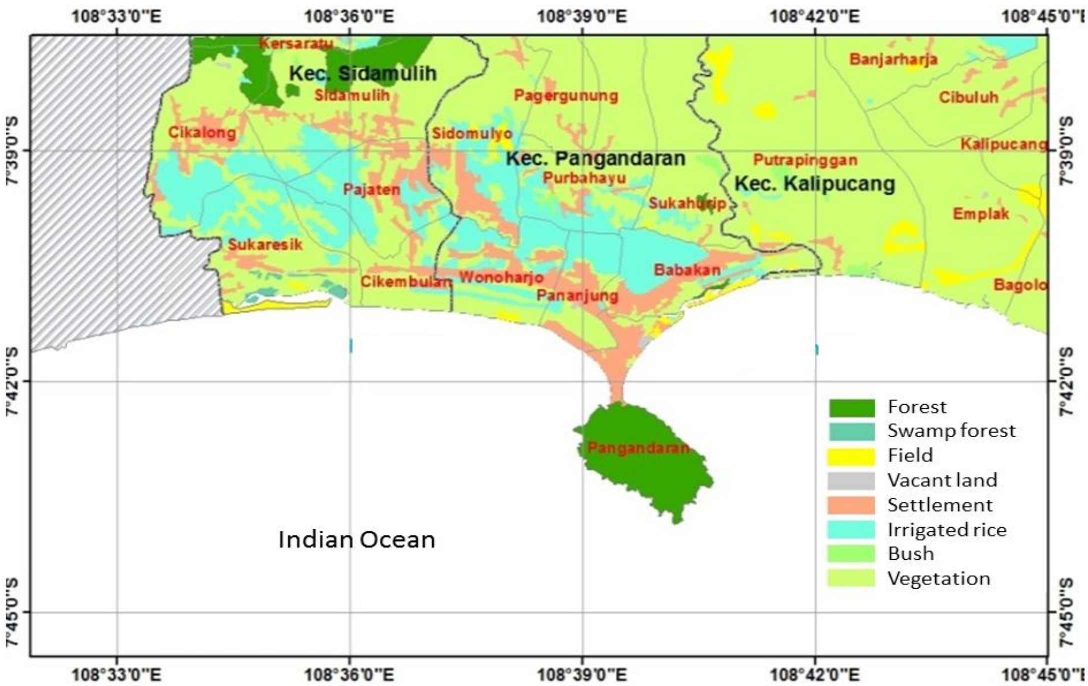

Figure 5. Landuse map in Pangandaran area

The impact of tsunami on each type of land use varied because each land use had a certain degree of reduction when tsunami hit. Types of land uses such as residential, irrigated fields, and terrestrial vegetation (garden) were type of land use having high economic value, but low rate of reduction on tsunami’s impact. Irrigated fields were inundated by seawater during a tsunami runoff causing the soil degrade and therefore, the fields would no longer use for paddy and crops fields. If residential hit by tsunami runoff, it can cause very large number of damage and loss in life and properties. The extent of each type of land use is presented in Table 6.

A tsunami hit a particular area can lead to land use change. Therefore, it was needed to see the level of land use vulnerability on tsunami. Figure 6 showed that the study area had a relatively high degree of tsunami vulnerability in terms of land use types. This was because land use type in the region was dominated by terrestrial vegetation. Regions belonging to the very high vulnerability were at Sidamulih and Pangandaran districts because these regions were used as residential areas and irrigated paddy field. Most of the residential areas located in coastal areas were in very high potential of tsunami hazards.

Table 4. Total area of landuse type

No	Landuse type	Areas (ha)
1	Forest	927
2	Swamp forest	36
3	Field/tegalan	305
4	Vacant land	19
5	Settlement	1352
6	Wet rice field irigated	2087
7	Bush	127
8	Terrestrial vegetation	9292
	Total	14145

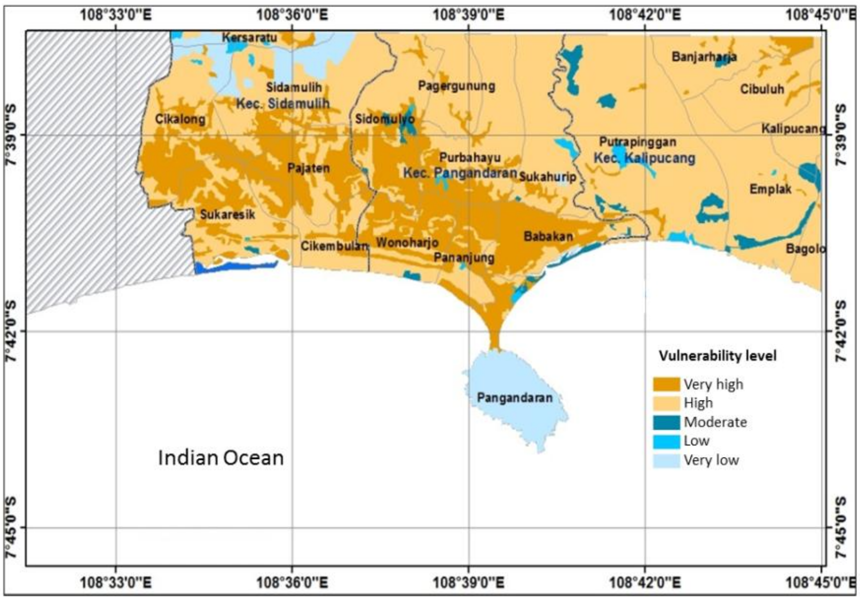

Figure 6. Land use vulnerability map on tsunami impact.

3.4 Distance from shoreline (coastal border)

Tsunami disaster is destructive, therefore it is necessary to have a buffer zone in the spatial planning. In this case, spatial planning by applying a buffer zone at study area was conducted by making the distance from the shoreline. The creation of distance from the shoreline was carried out to determine which areas were safe from tsunami attacks view point of developed land measured from the shoreline. Distance from the shoreline or the coastal border is the land along the shore that has proportional width to the shape and physical condition of the beach, at least 100 m from the highest tidal point towards the land. In this research, coastal border was made at a distance of at least 500 m towards the land. The determination of coastal border of 500 towards the land refers to the Regional Disaster Management Plan (RPBD) Ciamis regency.

A map of the distance from the shoreline, showing the most vulnerable areas on tsunami impact (pink areas) had a distance of 500 m from the shoreline (Figure 7). The closer an area to the sea, the higher the vulnerability level of the region to the tsunami risk (Diposaptono and Budiman, 2006).

Observations in the field indicated that settlements particularly vulnerable to the tsunami were located in Wonoharjo, Pananjung, and Babakan sub-districts because those settlements were located in a narrow plain between the two bays (Bays of Pangandaran and Parigi). In general, the important facilities at this region had a relatively close distance to the shoreline of 100-200 m from the shoreline. This made the settlements in the region were classified as highly vulnerable to tsunami waves. Therefore, a good spatial planning to reduce the tsunami risk is needed.

3.5 Distance from the river (river banks)

In addition to the distance from the shoreline, distance from the river is also an important parameter in determining the level of tsunami risk. A river bank should be at least 50 m width to the right and left along the river flow. River banks in this study were

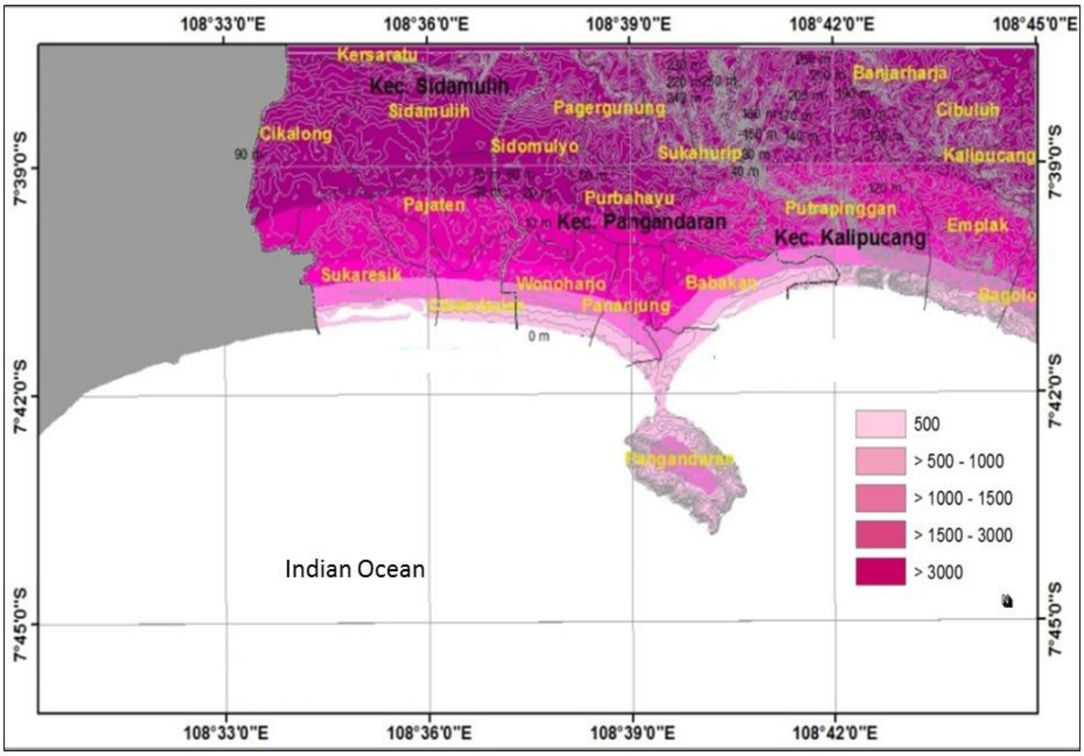

Figure 7. Map distance from the shoreline in the area of Pangandaran Beach

at least 100 m along the river flow. In general, tsunami that passes through the river would cause great damage. When tsunami passes through a narrow area such as a river, there will be an increase of velocity and water level because the same water mass flow must travel through the narrow slit at the same time (Pedersen and Glimsdal, 2010). Based on this, the placement of tsunami safe area should be far away from the river. Mapping the distance from the river was presented in Figure 8.

Figure 8 showed that the Kalipucang, Sidamulih, and Pangandaran districts had four major rivers i.e., west and east Cikidang, Cikembulan, and Ciambulungan rivers. Sukaresik and Cikembulan sub-distrcits in Sidamulih district were regions of very high degree of vulnerability to tsunami because there were two major rivers (Cikembulan and Ciambulungan rivers) facing each other and located close to the estuary (Citonjong estuary). The tsunami runoff can accumulate in these two rivers and casue a great damage in their surrounding region (Pedersen and Glimsdal, 2010). This condition can cause a tsunami runoff going further inland in the area near the river, compared to areas away from the river (Mardiyanto *et al*., 2013). Therefore, the placement of densely populated residential areas and important economic areas should be built at a relatively far distance from the river which is about > 500 m from the river. Map of tsunami threat in coastal Pangandararan is shown in Figure 9.

The height of tsunami run up in Pangandaran ranged from 1.6 to 7.6 m. Tsunami waves were at a minimum within the region far from the sea and maximum at a distance adjacent to the sea. Further away from the coast, the tsunami height decreased (Rahmawan, 2012). Map of tsunami threat in coastal Pangandararan is shown in Figure 10.

An area with a high level of threat to the tsunami is a region with a high level of risk and vulnerability to tsunami, and vice versa. Analyses of runoff and height of tsunami waves in the Pangandaran area were examined using the main input of topographic data (DEM). Tsunami wave height used as an example in this study was 7.6 m. It was based on the maximum height of the tsunami waves that occurred in Pangandaran.

3.6 Tsunami Vulnerability Map

Classification level of tsunami vulnerability in coastal area of Pangandaran was divided into five classes based on the level of region vulnerability to the tsunami. The classification consisted of very low, low,

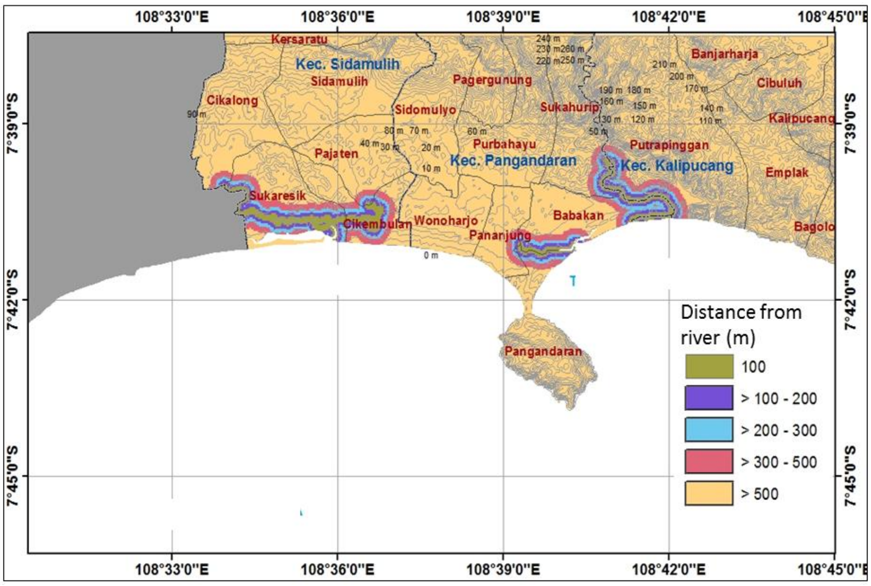

Figure 8. Map distance from the river area Pangandaran beach.

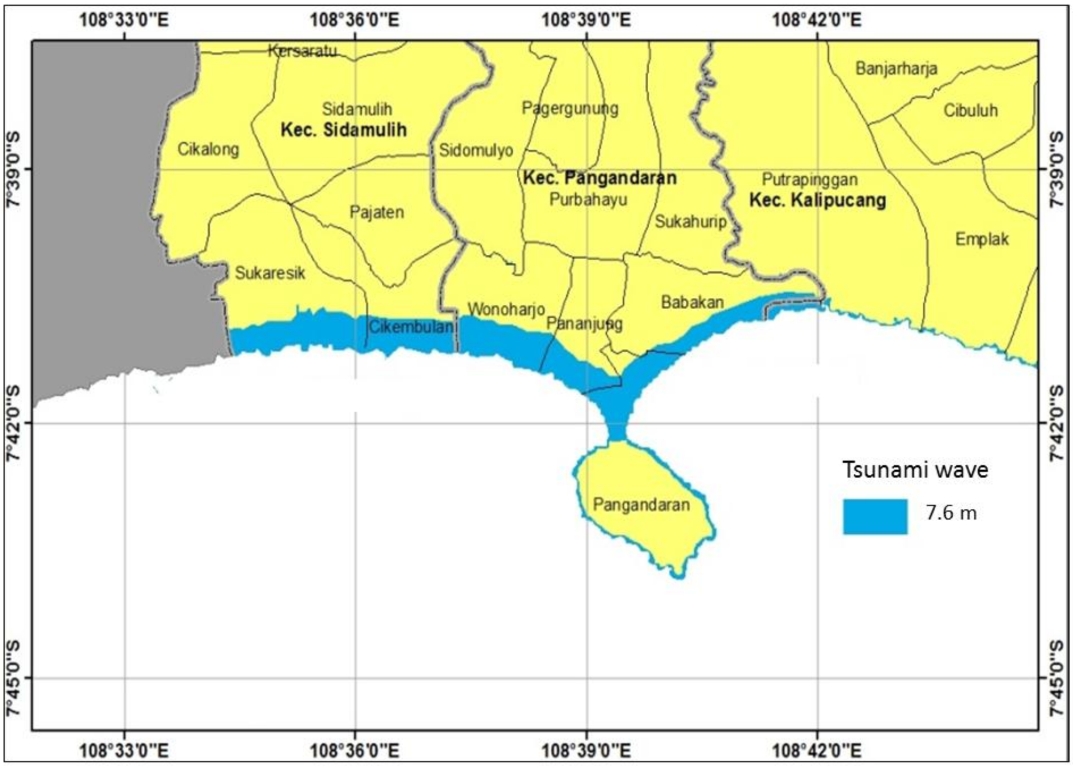

Figure 9. Map of 7.6 m tsunami run off in Pangandaran area.

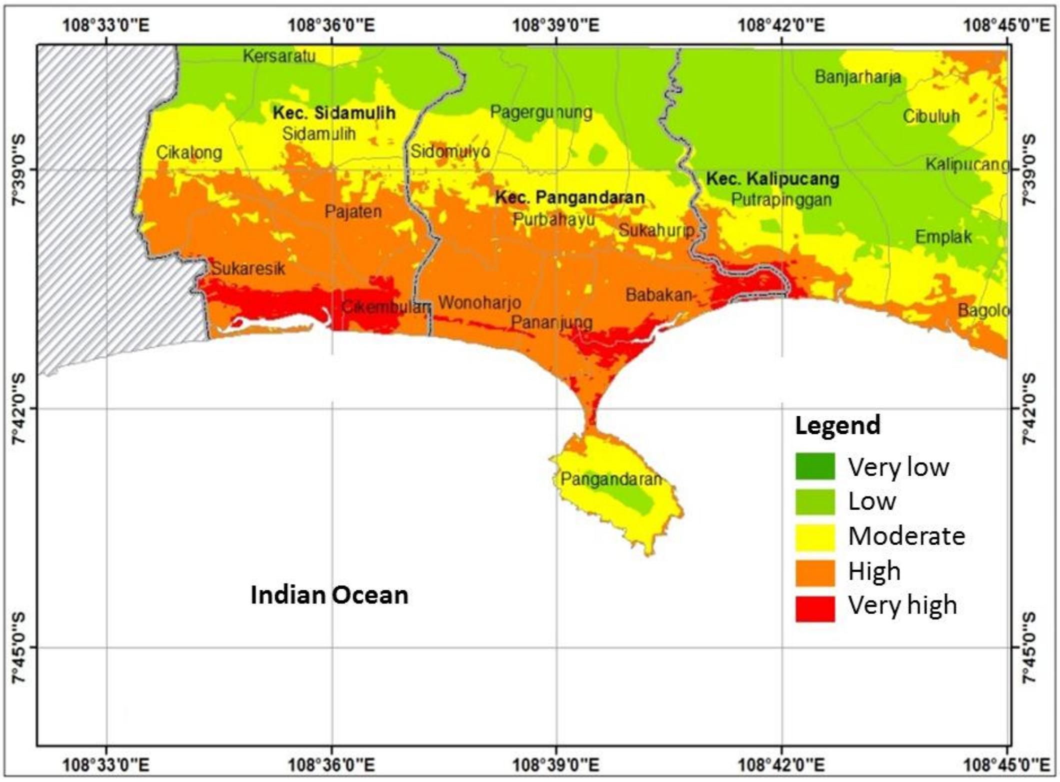

Figure 10. Map the coastal vulnerability againts tsunami in the coastal area of Pangandaran.

medium, high, and very high classes. Areas with low and very low vulnerability were dominant in the northern part of Pangandaran, but areas with low risk were also located in Pangandaran sub-district where natural conservation area was found. This was because area of the natural conservation has high topographic (100-350 m) and slope so that the region as a region is modeled as a low level of vulnerability.

Areas of moderate vulnerability were mostly located in the middle part of the study area. The zone was located at a distance of 2000 - 3000 m from the shoreline. The northern Cibuluh, Banjarharjo, and Kalipucang sub-districts; as well as in outskirt of Natural Conservation area were categorized al moderate risk area (yellow color).

Areas of high and very high risk were located in the southern part of Pangandaran, namely Cikembulan, Pananjung, Babakan, Wonoharjo, and Sukaresik sub-districts. Those areas directly adjacent to the sea at the zone of 500 - 1000 m from the shoreline. In addition, the area was affected by tsunami runoff as far as 400 meters to the land with tsunami height of 4-6 m (Fritz, 2007).

The high and very high tsunami vulnerability areas had the greatest potential damages for environment physical damages, infrastructure damages, and loss of life. The region was characterized by beaches and coastal with gentle slope, lower land elevation, land vegetation in the form of terrestrial vegetation (gardens), shrubs, fields, relatively short distance from the shoreline, the presence of the river, and a relatively dense settlement.

The low and very low tsunami vulnerability areas were safe from tsunami inundation and located in the northern Pangandaran in Putrapinggan, Pagergunung, and Kersaratu sub-districts. This area was characterized by high topography, large land slope, distance from coastal and river relatively far, vegetation land of forest and vacant land, and rare settlement.

Sub-districts of Babakan, Pangandaran, Pananjung, Sukaresik, and Cikembulan consisted of very high vulnerability areas and categorize in Tsunami Hazard Zone I (Firmansyah, 2012). Sub-districts of Pajaten, Wonoharjo, and some parts of northern Babakan and Pananjung consisted of high vulnerability areas and categorized in the Tsunami Hazard Zone II (Fimansyah, 2012). Districts of Cikalong, Purbahayu, Sidomulyo, and Sukahurip consisted of high levels of vulnerability areas and classified in the Tsunami Hazard Zone III with moderate damages.

The areas of tsunami vulnerability level in Pangandaran are presented in Table 8. The areas with very high vulnerability level were about 737.703 ha, with moderate level of 4875.773 ha, and with low vulnerability of 4816.204 ha. Although areas with very high vulnerability were relatively small area compared to the total study area, but the locations were densely populated and infrastructure development in the regions were close to the beach, as well as the topography was relatively low (1-10 m). Therefore, the region has a relatively high vulnerability level on tsunami impact. It was, therefore, necessary to have strategies and policies to minimize damage and life loss due to tsunami impact.

The tsunami waves that hit an area will result in damage to important infrastructure in the region. In this study, to determine the level of vulnerability of the tsunami on the infrastructure, then we overlaid maps with the tsunami vulnerability data and existing infrastructure in the area of Pangandaran. Critical infrastructure map among other government offices, means of economic, health facilities, educational facilities, places of worship, and tourist attractions located in the high tsunami hazard vulnerability areas was presented in Figure 11.

Table 8. Area of tsunami vulnerability level

No	Class	Vulnerability level	Areas (Ha)
1	R1	Very Low	0,654
2	R2	Low	4.816,204
3	R3	Medium/Moderate	4.875,773
4	R4	High	4.395,755
5	R5	Very High	737,703
	Total		14.826,090

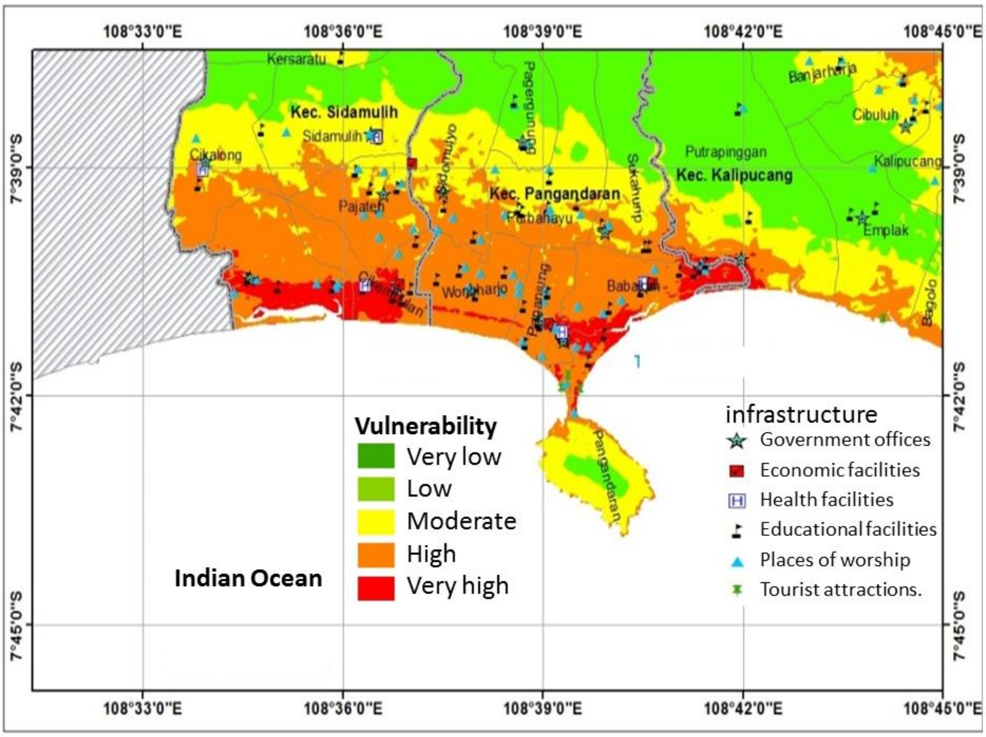

Figure 11. Infrastructure to tsunami vulnerability map.

Critical infrastructure in Pangandaran area was built close to the beach and the sea in approximity of the zone of 500 m from the shoreline, so that when the tsunami hit the region, the level of infrastructure damage will be relatively high. This study did not calculate the number of damage to infrastructure due to the limitations of the data. Only spatial mapping of infrastructure to tsunami risk. Thus, the mapping results were expected to be used as input for decision-makers in taking mitigation measures and strategies for a suitable and safe infrastructure from the tsunami disaster.

4 CONCLUSIONS

The level of tsunami vulnerability in Pangandaran beach areas varied depending on slope, elevation, land use, distance from the coast, and distance from river. Regions classified in very high level of vulnerability were Pangandaran district (Babakan, Pangandaran, and Pananjung sub-districts) and Sidamulih district (Sukaresik and Cikembulan sub-districts) with area of 737.703 ha. These areas potentially encountered to the highest damage of tsunami disaster because the areas close to the sea, low topography and slope, and densely populated area. The areas included in low vulnerability level were located in the north of Pangandaran particularly Putrapinggan, Pagergunung, and Kersaratu sub-districts with area of 4816.204 ha. This region was located far from the sea and not densely populated.

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