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Tsunami risk levels mapping in Puger Sub-District, Jember Regency

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Abstract. Puger sub-district is categorized as a tsunami-prone area because of its location in the South Coast, directly facing the Indian Ocean, which is the meeting point for two active tectonic plates. The active plate zone is prone to causing earthquakes that raise tsunamis. This article will describe the tsunami hazard and vulnerability level in Puger sub-district using the Geographic Information System (GIS) application. The method in this study uses a weighted overlay method. The weighting method is carried out to determine the level of tsunami hazard and vulnerability by following the weighting criteria in previous studies. Physical vulnerability criteria include land elevation, slope, beach type, land use, coastline distance, and rivers. The tsunami hazard level is determined based on the tsunami run-up map from previous studies. Based on the results of the risk mapping, it was found that there were five risk categories in Puger sub-district, namely the very low level (13.90 Ha), low level (271.99 Ha), medium level (7133.25 Ha), high level (644.22 Ha), and very high level (23.29 Ha).

Keywords: earthquakes, tsunami hazard, tsunami risk

1. Introduction

Jember Regency, East Java, has six sub-districts that are categorized as tsunami-prone areas [1]. One of the sub-districts that fall into this category is Puger. Puger sub-district is categorized as a tsunami-prone area because of its location on the South Coast directly facing the Indian Ocean, which is the meeting point for two active tectonic plates. The plate is the Indo-Australian Plate and the Eurasian Plate, a subduction zone of segments of the megathrust in southern Java. The zone is formed when the oceanic plate moves down into the continental plate and causes an earthquake that causes a tsunami.

Therefore, it is important for disaster mitigation efforts to minimize casualties. One of these efforts is to create a tsunami hazard and vulnerability map. Tsunami hazard and vulnerability mapping must be carried out by paying attention to the criteria of the area itself, so it is necessary to have tools for analyzing and identifying them in making the map. With the support of qualified technicians, a Geographical Information System (GIS) is one of the tools necessary through a tsunami hazard and vulnerability analysis approach.

Besides its importance, a tsunami risk map is not yet available for every coastal district in Indonesia. Several tsunami risk maps that researchers have developed are tsunami risk map in Sikka sub-district, West Nusa Tenggara [2], Pariaman Sub-district [3], and Halmahera sub-district, Maluku [4]. While based on Jember Regional Disaster Management Agency [5], a tsunami hazard map is available for Jember district, but not for the sub-district level. It is highly important to develop a tsunami risk map for the sub-district scale. Thus, this study aims to develop a tsunami risk map for Puger sub-district, Jember.

2. Materials and Methods

The methodology of this study is explained in Fig, 1. The first step is data collection. Two parts are calculated, namely physical vulnerability and hazard. Physical vulnerability is calculated using five parameters: elevation, slope, beach type, land use, and distance from shoreline and river. In order to develop a vulnerability map, DEMNAS data and RBI maps were utilized.

Hazard parameter is obtained from tsunami modelling result. The tsunami propagation model was firstly simulated. The tsunami height in Puger Beach (5.9 m) is analyzed using the bathtub model [6] to obtain run-up height in Puger Sub-District.

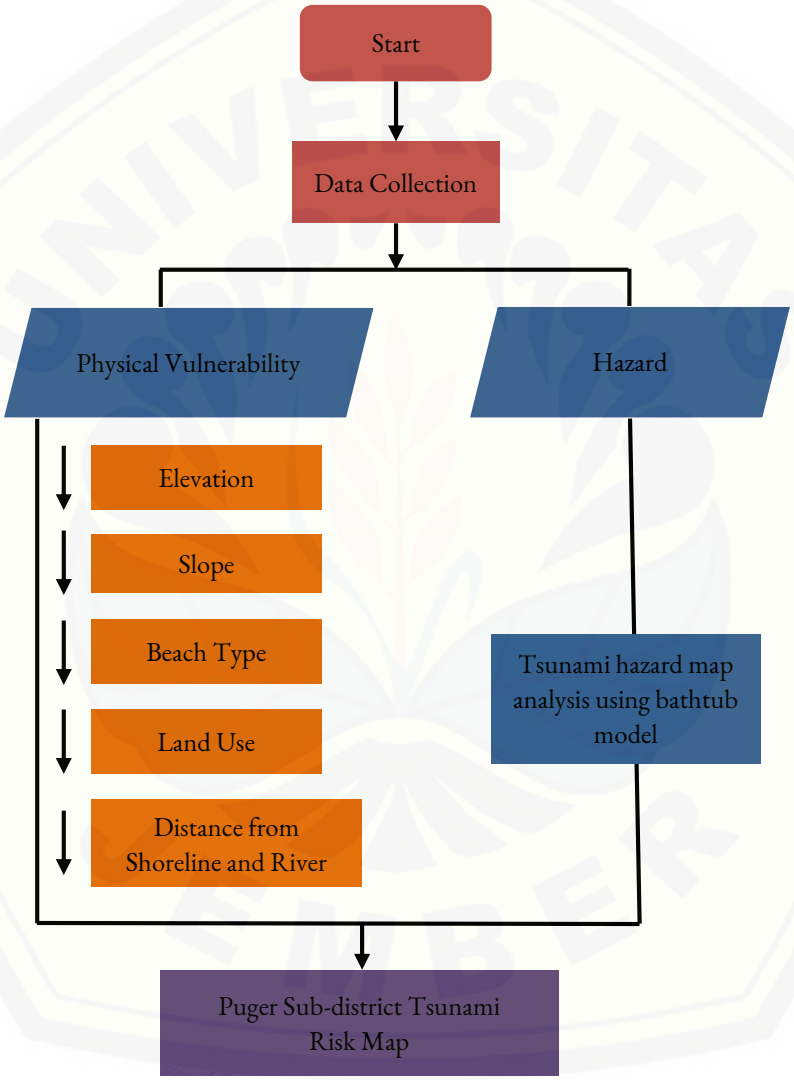

Figure 1. Study Flow Chart

This study utilized a weighted overlay method on a hazard and vulnerability map using geographic information system software. Finally, to develop a tsunami risk map, the hazard and vulnerability scores are classified and mapped based on the tsunami risk matrix [2], as shown in Table 1.

Table 1. Tsunami Risk Matrix

No.	Parameter	Weight (%)	Very High Risk	Score	High Risk	Score	Medium Risk	Score	Low Risk	Score	Very Low Risk	Score
Hazard												
1	Run up tsunami (m)	20	>16	5	6-16	4	2-6	3	0.75-2	2	<0.75	1
Vulnerability												
2	Elevation (m)	15	<10	5	10-25	4	25-50	3	50-100	2	>100	1
3	Slope (%)	15	<10	5	10-20	4	20-30	3	30-40	2	>40	1
4	Coastal morphometry	15	V shape bay	5	U shape bay	4	cape	3	straight	2	Non-bay/cape	1
5	Land use	10	Residential area, rice fields, mangrove, swamp	5	Garden	4	Field/ Moor	3	Shrubs, grass/ empty field	2	Florest, rock, lime	1
6	Distance from coastline (m)	15	0-200	5	200-500	4	500-1000	3	1000-1500	2	>1500	1
7	Distance from river (m)	10	0-100	5	100-200	4	200-300	3	300-500	2	>500	1
Total weight x score		100		5		4		3		2		1

Source: Sengaji and Nababan (2009)

The table shows that the tsunami risk map (100% weight) is constructed by summation of hazard/tsunami run-up (20%), elevation (15%), slope (15%), coastal morphometry (15%), land use (10%), distance from the coastline (15%), and distance from the river (10%). Each parameter was scored by number 1 until 5.

3. Result And Discussion

3.1. Tsunami Hazard Map

The hazard map in this study was obtained from tsunami propagation simulation in Puger Beach that is further processed using GIS using the bathtub model to obtain hazard levels in Puger Sub-District. Hazard map at Puger sub-district is shown in Fig.2. The red color on the map shows the areas with a very high probability of being affected by the tsunami. The orange color shows the high level of tsunami hazard, yellow shows the medium level of tsunami hazard, green color shows the low level of tsunami hazard, and dark green color shows a very low level of tsunami hazard. The dark green area is considered a safe area and has a very low probability of being inundated.

Table 2. Tsunami Hazard Classification

No	Risk	Area (Ha)	Σ%
1	Very Low	53.13	0.64
2	Low	7494.82	90.78
3	Medium	209.64	2.54
4	High	406.51	4.92
5	Very High	92.08	1.12

Area of five hazard levels is shown in Table 2 as follows: very high (1.22%), high (5.38%), medium (5.62%), low (87.14%), and very low (0.65%). The coastal area shows red color because the elevation in the coastal area is lower than elevation in the northern area of Puger sub-district. In the middle area, the yellow and orange color is dominant. The green color shows a low hazard level area. Most of the area in the northern part of Puger is colored by light green except the small spot with dark green color.

The elevation in this area is higher than in other areas. Tsunami inundation is expected not to reach the dark green area.

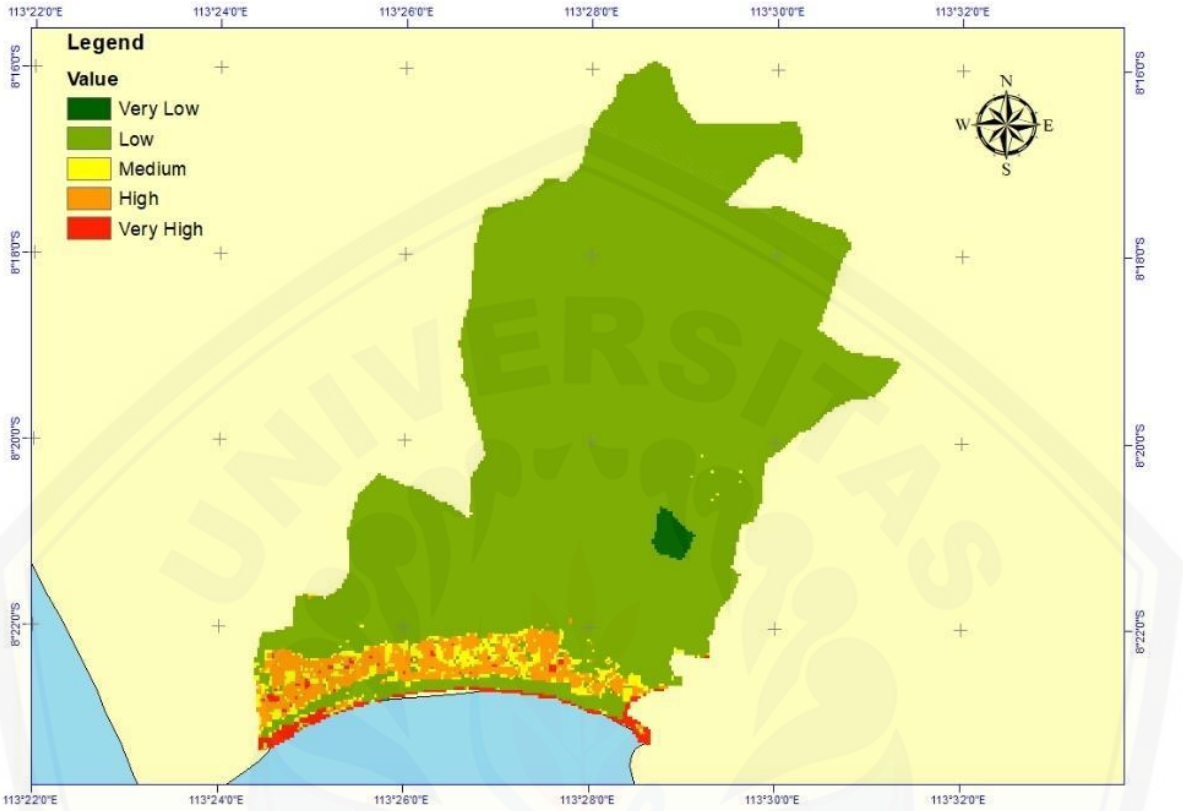

Figure 2. Tsunami Hazard Map

3.2. Physical Vulnerability Map

The vulnerability analysis includes six parameters, namely land elevation (15%), slope (15%), coastal morphometry (15%), land use (10%), distance from the coastline (15%), and distance from the river (10%). The total weight of vulnerability parameters is 80%. The results of this map are combined with a hazard map to develop a risk map.

The elevation of Puger sub-district was classified into five-level. Most of the area shows elevation less than 10 m, so they are classified as high and very high risk of being affected by the tsunami (Table 2). A relatively small area between Puger Wetan and Grenden is higher than 25 meters and classified into the medium, low, and very low risk of being affected by the tsunami. The elevation map is shown in Fig. 3.

Table 3. Classification of Elevation

No	Elevation	Area (Ha)	Level
1	<10 m	3867.51	Very High
2	>10-25 m	4091.69	High
3	>25-50 m	91.60	Medium
4	>50-100 m	80.01	Low
5	>100 m	134.40	Very Low

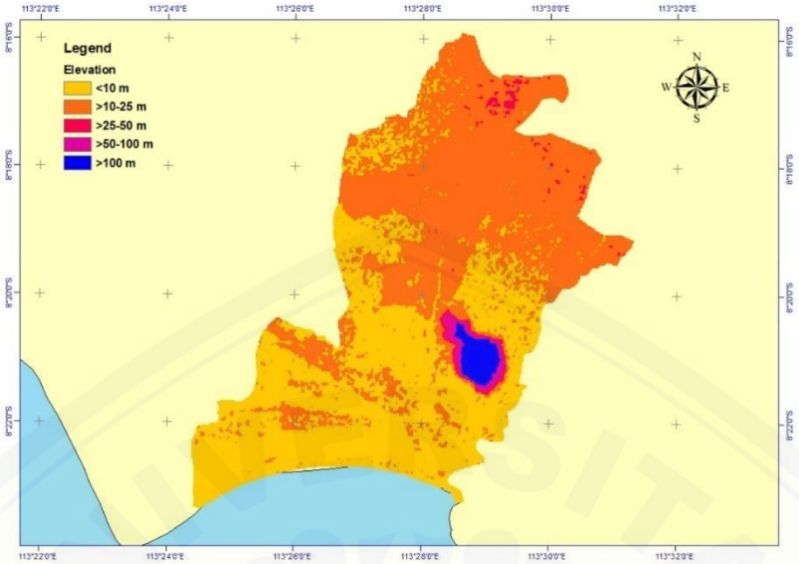

Figure 3. Elevation Map

Most Puger sub-district (7671.25 Ha) has a very low slope, less than 10% (see Table 4). Thus, most of the area has a very high risk of being affected by the tsunami. The area with a slope higher than 10% is between Puger Wetan and Grenden, as shown in Fig. 4. The location is similar to the high elevation area shown in Fig.3.

Table 4. Classification of Slope

No	Slope	Area (Ha)	Level
1	<10%	7671.25	Very High
2	10-20%	220.10	High
3	20-30%	99.02	Medium
4	30-40%	62.36	Low
5	>40 m	59.33	Very Low

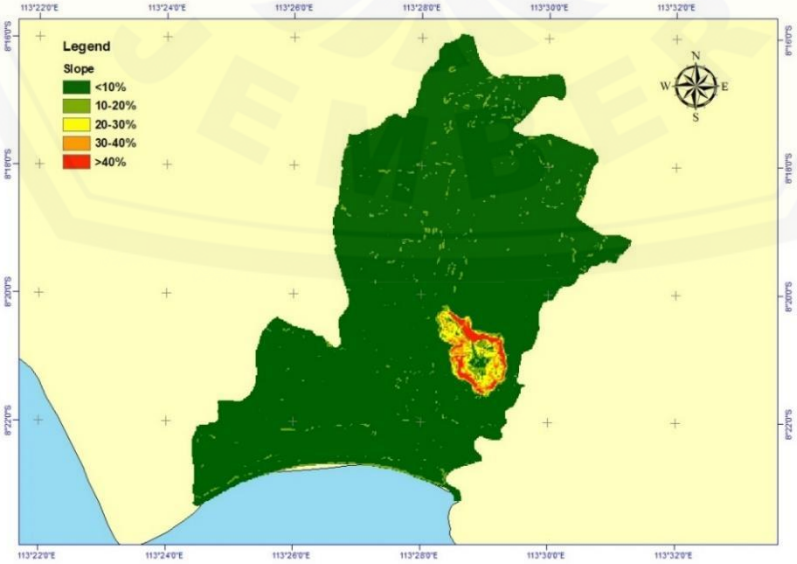

Figure 4. Slope Map

There are five types of the bay, namely V shape bay (very high risk), U shape bay (high risk), cape (medium risk), straight (low risk), and non-bay/cape (very low risk) [2]. By looking at three main elements: geology, morphology, and shoreline characters, Puger Beach has a straight and wide coastline dominated by sloping morphology and interspersed with steep morphological beaches [7]. Thus, it is classified into a straight bay with low risk.

Puger sub-district consists of rivers, ponds, residential areas, plantations, meadows, grasslands, and rice fields. The area of each land-use type is shown in Table 5. The land use map is shown in Fig. 5. Puger sub-district is dominated by rice fields (4982.89 Ha) colored by dark green in Fig. 5. Rice fields spread in the north, west, east, and south area of Puger sub-district. Unlike the rice field located on the sides of the Puger sub-district, the residential area (1935.43 Ha), colored by pink, is mainly located in the center of the sub-district, near the main road. Puger sub-district is covered with grasslands, plantations, and meadows with 522.54 Ha, 449.76 Ha, and 188.26 Ha, respectively. Other land uses with less than 100 Ha area are river, pond, field, and buildings.

Table 5. Classification of Land Use

No	Name	Area (Ha)	Risk
1	Building	1.07	Very High
2	Meadow	188.26	Medium
3	Plantation	449.76	High
4	Pond	57.38	Very High
5	Residential area	1935.43	Very High
6	Field	2.05	Low
7	Grasslands	522.54	Low
8	River	99.18	Very High
9	Rice Fields	4982.89	Very High

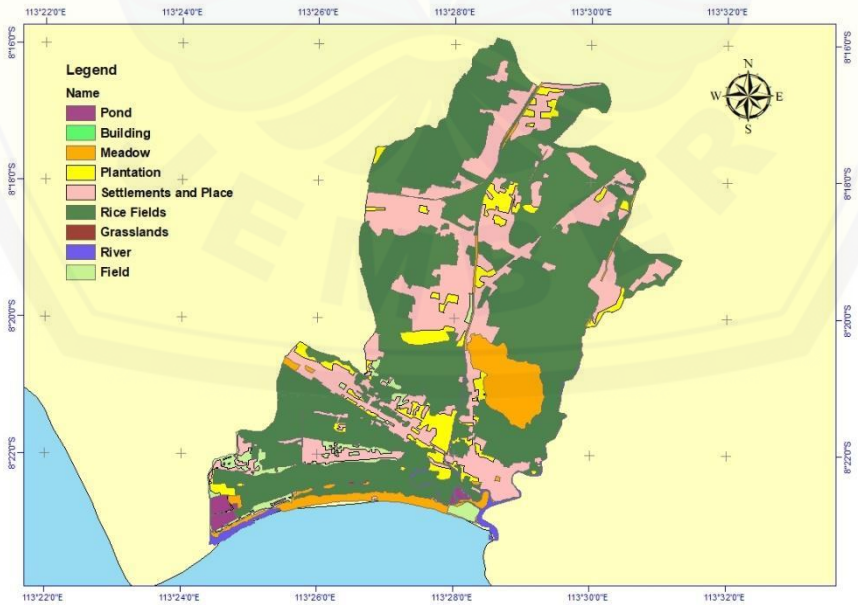

Figure 5. Land Use Map

Analysis of coastline distance is conducted by buffering the shoreline with a distance of 0-200 m, 200-500 m, 500-1000 m, 1000-1500 m, and more than 1500 m, respectively. The distance from the shoreline map is shown in Fig. 6. The map shows that most of Puger Sub-district area is classified as more than 1500 m distance from the shoreline.

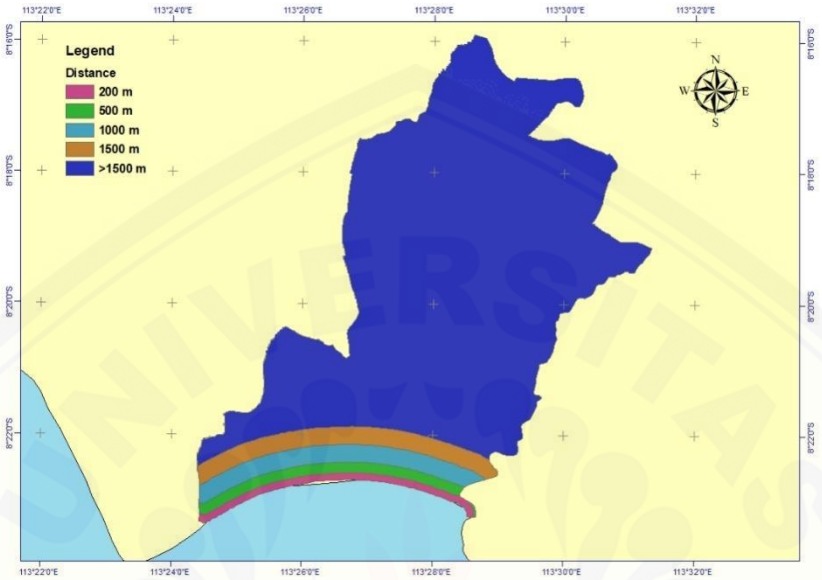

Figure 6. Distance from Shoreline Map

Analysis of the distance from the river was carried out by buffering the river with a distance of 0-100 m, 100-200 m, 200-300 m, 300-500 m, and more than 500 m, respectively. The distance from the river map is shown in Fig. 7. The map shows that most of the area is located more than 500 m from the river. The closer the area to the river, the higher risk of tsunami is.

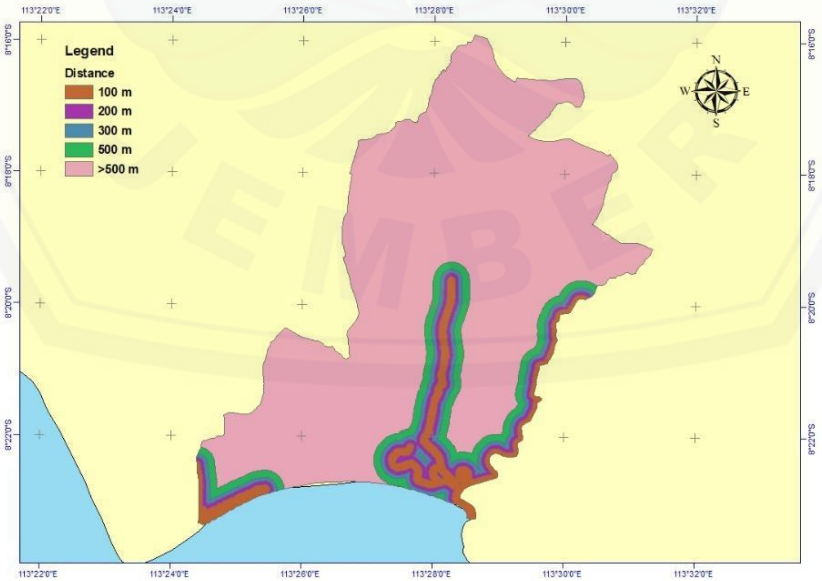

Figure 7. Distance from River Map

In order to obtain a tsunami risk map, all vulnerability and hazard parameters are overlayed based on weighting shown in Table 1. There are four risk classes in the Puger sub-district risk map: low, medium, high, and very high.

The result of Puger Sub-district risk map is shown in Fig. 8. The coastal area with red color in the southwest area has a very high tsunami risk because it is a low elevation area located near the shoreline. In the southeast and southwest area, there are also very high-risk areas. The areas are river areas, so they are low- elevation and riskier than other adjacent areas.

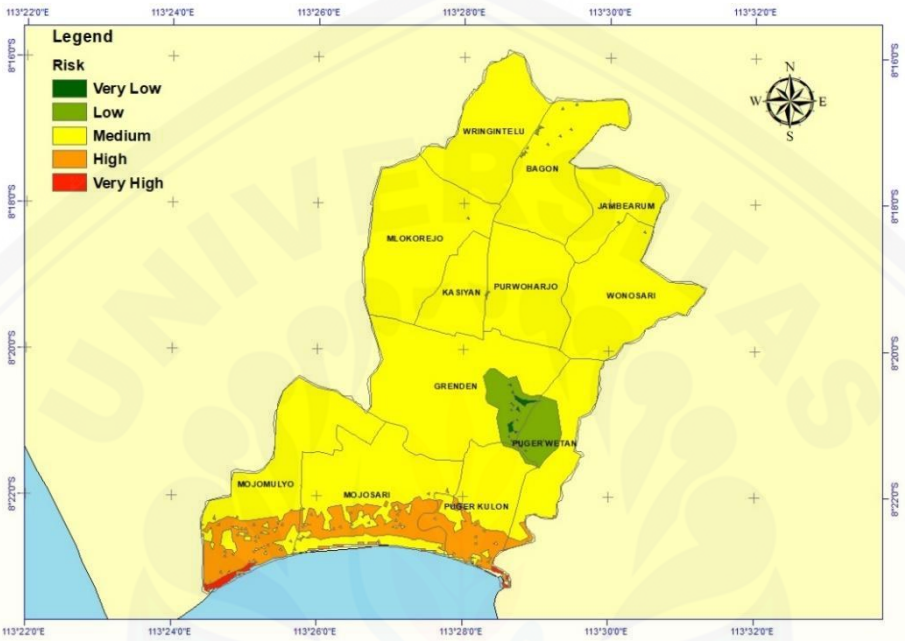

Figure 8. Puger Sub-district Tsunami Risk Map

The yellow area shows a high-risk area. The Middle area of Puger sub-district is mostly classified in this category because the elevation is lower than 25 m. Most of the northern area of Puger has medium risk (green) because the area has a higher elevation, higher distance from river and shoreline. The dark green area is shown on the right-middle side of Puger. The area has an elevation of more than 50 m and more than 20% slope. The area has the lowest risk of tsunami in Puger sub-district.

In order to know the risk level in every village, each village is assumed to be 100% area. The percentage of risk is compared between villages (Table 6). It is shown that the highest percentage of very high-risk and high-risk areas among all villages is Mojomulyo (0.234%) and (2.960%). Almost all villages have a high percentage in high-risk areas, namely Mojosari (2.807%) and Puger Kulon (1.999%). At the same time, the highest percentage of medium risk area (13.252%), low risk (1.612%), and very low risk (0.156%) are obtained by Grenden.

Table 6. Percentage of Risk Level by Village (%)

Percentage of risk level by village (%)						
Village Name	Very Low	Low	Medium	High	Very High	Total (%)
Mlokorejo	0.000	0.002	10.427	0.000	0.000	10.429
Grenden	0.156	1.612	13.252	0.000	0.000	15.020
Wringintelu	0.000	0.000	7.625	0.000	0.000	7.625
Kasiyan Timur	0.000	0.007	6.840	0.000	0.000	6.847
Kasiyan	0.000	0.002	3.755	0.000	0.000	3.757

Percentage of risk level by village (%)						
Mojomulyo	0.000	0.000	8.312	2.960	0.234	11.506
Mojosari	0.000	0.000	9.010	2.807	0.000	11.817
Puger Kulon	0.000	0.111	4.297	1.999	0.054	6.461
Puger Wetan	0.016	1.589	4.548	0.200	0.000	6.352
Wonosari	0.000	0.002	8.614	0.000	0.000	8.616
Jambearum	0.000	0.002	3.908	0.000	0.000	3.911
Bagon	0.000	0.036	7.622	0.000	0.000	7.658
Σ	0.172	3.364	88.210	7.966	0.288	100.000

Based on the percentage of Puger sub-district area, more than half area are categorized into the medium-risk area (88.21%). The high-risk area in Puger is 7.97%, while 0.29% of the area has very high risk, 3.36% area has low risk, and 0.17% area has very low risk against tsunami.

Table 7. Tsunami Risk Area

No	Risk	Area (Ha)	Σ%
1	Very low	13.90	0.17
2	Low	271.99	3.36
3	Medium	7133.25	88.21
4	High	644.22	7.97
5	Very High	23.29	0.29
Total		8086.66	100.00

Risk categories and percentages in this map may be different from other risk maps at the same location. It may be caused by the number of parameters utilized to develop the map, such as capacity, social, and economy maps. Furthermore, many types of simulations could be run to develop a hazard map. Thus, it is necessary to consider other parameters and utilize a higher resolution of the hazard map to enhance the reliability of the risk map.

4. Conclusion

In this study, a tsunami risk map in Puger District area was developed from hazard parameters, physical vulnerability parameters consisting of land elevation, slope (slope), beach type, land use, distance from the coastline, and distance from the river. As a result, Puger sub-district is categorized into five risk categories, namely areas with very low risk (13.90 Ha), low risk (271.99 Ha), medium risk (7133.25 Ha), high risk (644.22 Ha), and very high risk (23.29 Ha). Well understanding at the risk level in Puger district is very important for regional disaster management agencies and local governments to make a further plan for tsunami risk mitigation such as evacuation route map.

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