Mapping vulnerability level of tsunami disaster in Coastal Villages of Pariaman City, West Sumatera

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Abstract. Pariaman city is one of the cities that is indicated prone to tsunami disasters because it is close to the shoreline and directly adjacent to the Indian Ocean. Coastal village of Pariaman City that faces directly to the offshore makes the coastal villages more vulnerable to tsunami. Settlement is a residential area that must be protected, so mapping the vulnerability’s region to the tsunami that is focused on the settlements is needed to protect the residents. This study aims to map vulnerability level of settlements to tsunami disaster in the coastal village of Pariaman City. Vulnerability region is seen from exposure, sensitivity, and resilience. The data in this study are elevation, distance from shoreline, slope, distance from river, population, quality of the building, knowledge of disaster mitigation, and socialization of disaster mitigation. Each component is then overlaid with overlay techniques (scoring and weighting) of Geographic Information System (GIS) to obtain the vulnerability. The results showed that settlements in the coastal villages of Pariaman are dominated by “Low” vulnerability, followed by “Moderate” and “High” vulnerability. The “High” vulnerability levels are in low elevation, close to shorelines, low slopes, close to river, low building’s quality, high population, and no socialization.

1. Introduction
Pariaman City is one of the city on the west coast of Sumatra Island, precisely in West Sumatra Province, which is prone to earthquake and tsunami [1]. This is because the location of Pariaman City is directly adjacent to the Indian Ocean which is a meeting place of two tectonic plates, the Eurasian Plate and the Indo-Australian Plate. One of these plates dips into the bottom of the other plate resulting in subduction. This highly active subduction causes an earthquake which generates tsunami waves [2].

Geographically, Pariaman City is one of the cities in the province of West Sumatra that faces offshore and is close to the Indian Ocean shoreline, meaning that Pariaman city has a threat of getting more affected by tsunami hazard compared to City or other districts which are far from the shores of the Indian Ocean in West Sumatera Province. This is because by being closer to the shoreline, subject will be more vulnerable to the tsunami [3]. Among the villages located in Pariaman City, coastal villages closer to Indian Ocean are certainly more vulnerable than inland villages in Pariaman City.

Vulnerability is the rate at which systems, subsystems, or system components are prone to hazards due to exposure to hazards, both disturbances and stress or stressors [4]. Vulnerability consists of three factors: exposure, sensitivity, and adaptive capacity. Exposures indicate the degree, length or magnitude

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of a system's probability of contact with interference. Sensitivity is the internal condition of the system that showing its degree of susceptibility to interference [5]. Adaptive capacity is the combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities [6].

Element at risk is population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area [7]. Populations, property, economic activities, including public services are located in settlements. This is because the settlement is part of a residential environment consisting of more than one housing unit that has an infrastructure, facilities, public utilities, and other supporting functional activities in urban areas or rural areas [8]. Settlements are not just houses or housing alone (representing the population in the element at risk), but there are also infrastructure, facilities and other supporting functional activities (representing property, economic activities, including public services, and other assets in the element at risk) in the settlements. Therefore, further research on tsunami vulnerability in coastal villages of Pariaman City is required. This study of regional vulnerability to tsunamis is also expected to be used as a reference in disaster mitigation and minimizing losses due to the tsunami disaster.

2. Methodology
The research area in this research is the settlements in coastal villages of Pariaman City. Coastal villages are villages including nagari or other areas that directly adjacent to shoreline (or island villages) with lifestyle of the people either dependent or independent from sea potentials [9]. Coastal villages in Pariaman City consist of fourteen villages. Astronomically, it is located at the coordinates of 0° 33' 34.47" S - 0° 40' 32.47" S and 100° 5' 25.31 "E - 100° 9' 50.56"E.

Table 1. Scores and weights of exposure, sensitivity, and adaptive capacity parameters classes

| Variable                      | Parameter                                | Classes | Scores | Weight |
|-------------------------------|------------------------------------------|---------|--------|--------|
| Exposure                      | Elevation (m.a.s.l)                       | 0 – 12  | 3      | 30     |
|                               |                                          | 13 – 24 | 2      |        |
|                               |                                          | 24 – 36 | 1      |        |
|                               |                                          | 0 – 700 | 3      |        |
|                               | Distance of the Shoreline (meter from the shoreline) | 701 – 1400 | 2 | 30    |
|                               |                                          | >1400   | 1      |        |
|                               |                                          | 0 – 2   | 5      |        |
|                               |                                          | 3 – 5   | 4      |        |
|                               | Slope (%)                                | 6 – 15  | 3      | 25     |
|                               |                                          | 16 – 40 | 2      |        |
|                               |                                          | >40     | 1      |        |
|                               | Distance of River (meter from river)     | 0 – 200 | 3      |        |
|                               |                                          | 201 – 500 | 2 | 15    |
|                               |                                          | >500    | 1      |        |
|                               |                                          | <513    | 1      |        |
|                               | Total Population (person)                | 513 – 1025 | 2 | 50    |
|                               |                                          | 1026 – 1539 | 3 |        |
| Sensitivity                   | Bad (Wood)                               | 3       |        |        |
|                               | Moderate (Wood-Cement)                   | 2       | 50     |        |
|                               | Good (Cement)                            | 1       |        |        |
| Adaptive Capacity             | Perceptions and Knowledge of Tsunami Mitigation | Low     | 1      |        |
|                               |                                          | Moderate | 2 | 50    |
|                               |                                          | High    | 3      |        |
|                               | Socialization of Tsunami Mitigation      | Existent | 1 | 50    |
|                               |                                          | Nonexistent | 2 |        |

Source : Modification from matrix of coastal vulnerability parameters againts tsunami disaster [10]
This study consists of four parts, that are determining the level of exposure, sensitivity, adaptive capacity, and vulnerability to a tsunami in the coastal villages of Pariaman City. Exposure to a tsunami is seen from the distance from shoreline, elevation, slope, and distance from river. Sensitivity is seen from total population and building quality. Adaptive capacity is seen from the perceptions and knowledge of tsunami disaster mitigation and socialization of tsunami disaster mitigation. After these, it will be overlaid to obtain the level of tsunami vulnerability in the coastal villages of Pariaman City.

The data in this research are contour line, shoreline, settlement, river, building quality, perception and knowledge of tsunami disaster mitigation, and socialization of tsunami disaster mitigation. Spatial data validated with Google Earth imagery. Perceptions and knowledge of tsunami disaster mitigation, and socialization were obtained by interviewing 118 respondents. Perceptions and knowledge of tsunami disaster mitigation is seen from basic knowledge about a tsunami, awareness to live in a tsunami hazard area, knowledge of evacuating, pre-tsunami preparation, knowledge of tsunami evacuation sites, and knowledge of appropriate evacuation routes. Socialization of tsunami disaster mitigation is seen from presence or absence of socialization activities.

Data processing is started by giving scores and weights to each class of exposure, sensitivity, and adaptive capacity parameters (Table 1). Each of these parameters is then overlaid to gain exposure, sensitivity, and adaptive capacity levels. Furthermore, these parameters level are also given scores and weights and then overlaid to get vulnerability level.

The vulnerability level map of the tsunami was made by overlaying tsunami exposure level map, sensitivity level map, and adaptive capacity level map. The overlaying process of the map uses scoring and weighting process. Each variable is given equal weight (33,33) and vulnerability value is classified into the level of vulnerability to tsunami (low= score 1, moderate=score 2, high=score 3).

3. Result and Discussion

3.1 Exposure of The Tsunami

Exposure in this mapping is seen from elevation, distance from shoreline, slope, and distance from river. Elevation area in settlements of coastal villages of Pariaman City are dominated by an elevation of 0 - 12 m.a.s.l (1.56 km²), followed by an elevation of 12 - 24 m.a.s.l (0.33 km²), and 25 - 36 m.a.s.l (0 km²). Very low land area causes the area to be a hazardous area of the tsunami, because the tsunami can freely get inland [11]. The coastal villages of Pariaman City based on elevation areas tend to be in "High" vulnerability of the tsunami. The elevation of the coastal villages of Pariaman City tend to be low.
Settlements of coastal villages of Pariaman City are dominated by areas that range from 0 - 700 m from shoreline (1.60 km²), followed by 700 - 1400 m (0.26 km²), and > 1400 m (0.08 km²). Getting closer to the shoreline will be even more exposed to tsunami [3]. Coastal villages of Pariaman City are dominated by "High" vulnerability to the tsunami because it tend to close to shoreline.

The settlements in the coastal villages of Pariaman City are dominated by "0 - 2%" slopes (0.93 km²), followed by 3 - 5% (0.68 km²), 6 - 15% (0.26 km²), 16 - 40% (0 km²), and > 40% (0 km²) slopes. If the slope is getting steeper, that means the influence of tsunami wave height is getting lower [12]. The coastal villages of Pariaman City are dominated by the "Very High" vulnerability level to tsunami because of the slopes of the coastal villages of Pariaman City are very low (0 - 2%).

Based on the distance from river, settlements of coastal villages of Pariaman City have a distance of more than 0 - 200 m (0.89 km²), followed by areas that have a distance of 201 - 500 m (0.43 km²), and more than 500 m (0.59 km²). Getting closer to the river that is perpendicular to the shoreline would be getting vulnerable to tsunami waves, as it can freely enter the land without any obstructions (objects that are in the river) if encountered by a river [5]. The coastal villages of Pariaman City are at "High" vulnerability to tsunami because it is dominated by an area that are close to river.

The level of exposure of settlements to the tsunami in the coastal villages of Pariaman City can be seen in the map of exposure levels in Fig 1. Settlements in the coastal villages of Pariaman City are dominated by "High" exposure to tsunami (1.52 km²), followed by "Moderate" (0.36 km²) and "Low" exposure (0 km²). High exposure settlements are in the north and the middle of the coastal village of Pariaman City with low elevation, close from the shoreline, low slopes, and close from the river.

3.2 Sensitivity of The Tsunami

The level of sensitivity to tsunami in this mapping is based on population size and quality of buildings. Most of the settlements in the coastal areas of Pariaman City are areas whose population ranges from 2160 - 3238 person (an area of 0.95 km²), followed by a population of "less than 1080 person" (0.54 km²) and 1081 - 2159 person (0.39 km²). Increasing the number of residents leads to an increase in the number of people at risk [13]. As the number of people at risk increases, vulnerability increases. It is dominated by the "High" vulnerability.

Settlements in the coastal villages of Pariaman City are dominated by the quality of buildings within category of "Good" (an area of 1.92 km²), followed by quality of buildings "Moderate" (0.0017 km²) and "Bad" (0.0012 km²). Quality of buildings in the coastal villages of Pariaman City is really dominated by the quality of buildings with the level of "Good". Quality of buildings with "Good" dominates in each group of settlements. Getting worse the quality and condition of the building, getting higher the level of vulnerability [14]. The coastal villages of Pariaman City are dominated by "Low" vulnerability to the tsunami.

Level of sensitivity of tsunami in coastal village of Pariaman City is dominated by the "Moderate" (0.95 km²), followed by the "Low" (0.92 km²) and "High" level (0.01 km²). The "moderate" sensitivity are located in northern and central, and "Low" level is in most of the southern and small parts of northern coastal village of Pariaman City, "Low" sensitivity settlements are located in areas with "<1.080" (Low) and "Good" building quality levels (Fig 2).

3.3 Adaptive Capacity of The Tsunami

Level of adaptive capacity is seen from level of perception and knowledge of tsunami disaster mitigation and socialization of tsunami disaster mitigation. Level of "perception and knowledge" in coastal villages of Pariaman City is only filled by "High" level. Settlement group has a 100% in the "High" level (1.94 km²). Average respondent knows what a tsunami is, realizing that they live in areas with potential tsunami hazards, knowing what to do when tsunami warnings arise, preparing before tsunami, knowing location of tsunami evacuation, and knowing exact evacuation route. Increased knowledge of disaster can improve attitude and awareness of community to be ready when anticipating a disaster [15]. Disaster knowledge can increase people's anticipation of a disaster so as to increase community resilience in the face of a disaster. Meanwhile, high level of perception and knowledge of tsunami disaster mitigation
has increased community's high anticipation of tsunami, thus enhancing adaptive capacity of tsunami and making coastal villages of Pariaman City dominated by "Low" vulnerability level.

Figure 3. Map of adaptive capacity level of tsunami in coastal villages of Pariaman City.

Figure 4. Map of vulnerability level of tsunami in coastal villages of Pariaman City.

The socialization of tsunami disaster mitigation is dominated by "Existent socialization" (1.49 km$^2$), followed by “Nonexistent socialization” (0.39 km$^2$). Socialization can increase public awareness the deal with disaster [16]. With dissemination of disaster mitigation, community knowledge about disaster and its mitigation can be increased, so that it can also increase community preparedness in anticipating disaster. With increase of community preparedness in anticipating disaster means increasing adaptive capacity of area in the face of disaster so as to make coastal villages of Pariaman city is dominated by "Low" level.

Level of adaptive capacity of tsunamis dominated by "High" adaptive capacity level (1.43 km$^2$), followed by "Moderate" (0.51 km$^2$), and "Low (0.0 km$^2$)". Its because it have the “High” perception and knowledge of tsunami disaster mitigation, and "High" level of mitigation socialization of tsunami disaster mitigation. “High” adaptive capacity level is mostly located in the north and south coastal villages of Pariaman City (Fig 3).

Level of vulnerability of tsunamis in the coastal villages of Pariaman City dominated by the “Low” (0.946 km$^2$), followed by "Moderate" (0.941 km$^2$) and "High" (0.002 km$^2$). The "Moderate" level is partially located in the north and central, low vulnerability rates are mostly located in the southern and high levels of vulnerability exist only in a small part of the central settlements of the coastal villages of Pariaman City (only 0.002 km$^2$). "Low" level of vulnerability is located in high exposure, high sensitivity, and moderate adaptive capacity level. "High" vulnerability is located in the settlements with low elevation, close from shorelines, low slopes, close from rivers, high population, poor building quality, and nonexistent socialization. "Low" vulnerability levels are located in the settlements with low exposure, low sensitivity, and high adaptive capacity. The “Low” level is located in low population, good building quality, high perceptions and knowledge, and existent socialization settlements (Fig 4).

4. Conclusion
The region's vulnerability to tsunami based on exposure, sensitivity and adaptive capacity in coastal villages of Pariaman City is dominated by "Low" level, followed by "Moderate" and “High". The "Low"
vulnerability levels located at settlements with “Low” exposure, “Low” sensitivity, and “High” adaptive capacity. The “Low” level of vulnerability exists in settlements with low population, good building quality, “High” perceptions and knowledge of tsunami disaster mitigation, and existent socialization. The "High" level of vulnerability to tsunamis exists in a small portion of settlements of the coastal villages of Pariaman City (only 0.002 km$^2$) with "High" exposure, "High" sensitivity, and "Moderate" adaptive capacity. "High" vulnerability areas are located at a low elevation, areas with close from shorelines, low slopes, close from rivers, high population, and nonexistent socialization.

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