Spatial modelling of tsunami exposure areas at Ujung Genteng coastal, Sukabumi, West Java

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Abstract. Indonesia is a country located between three tectonic plates. It is the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. The location caused Indonesia to be prone to disasters caused by the movement of plates, one of which was a tsunami. Tsunamis are high waves that hit ports or beaches. Relatively sloping beaches with low beaches can cause larger tsunami waves. This study was carried out on the coastal of Ujung Genteng, Sukabumi. The purpose of this study is to analysis the area of tsunami exposure that occurred on the coast of Ujung Genteng. GIS-based spatial modelling is used to combine different types of data, both spatial and non-spatial data to be processed into tsunami exposure area information. Modelling of the inundation was carried out with mathematical calculations developed by Berryman (2006). By modeling the tsunami with a worst-case scenario of wave height of 20 meters, it was obtained that the tsunami exposed area reached 663.29 Ha. The area belongs to a low hazard class of 2.59 Ha, a medium hazard class of 29.05 Ha, and an area that belongs to a high hazard class of 631.65 Ha. The results of this modeling are expected to be a reference for tsunami disaster mitigation planning in Ujung Genteng.

Keyword. Tsunami, exposure area, spatial modelling, inundation

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1. Introduction

Indonesia is a country located between three tectonic plates. The three plates are the Eurasian Plate, Indo-Australian Plate, and the Pacific Plate. This location puts Indonesia in the ring of fire [1]. This condition makes Indonesia a disaster-prone region mainly caused by the movement of tectonic plates that can cause collisions between plates. Collisions between these plates can cause tectonic earthquakes. An earthquake on the seabed triggers a tsunami if it has considerable strength. The term tsunami is derived from the Japanese word for "tsu" and "nami" means wave. A tsunami means a high wave that hits a port or beach. Tsunamis are often caused by tectonic earthquakes that occur on the seabed, although in other instances tsunami can be caused by volcanic eruptions, landslides on the seabed, and even the impact of falling meteors.

Tsunamis have occurred in various parts of the world for a long time but the impact of this disaster is still unavoidable. Therefore, research on tsunamis in various regions of the world is carried out to minimize the impact of the disaster. This disaster was also recorded several times in Indonesia. One of the tsunami disasters that had the biggest impact ever in Indonesia was the Aceh tsunami that occurred on December 26, 2004 [2]. The tsunami that occurred at that time took many lives and damaged the environment affected by the tsunami. The tsunami event at that time had become a national disaster even
gained the attention of more than various countries. Tsunami events have also occurred in the southern sea of Java, which occurred in Banyuwangi in 1994 and Pangandaran in 2006 [3]. The most recent tsunami in Indonesia occurred in 2018 that hit Palu and Donggala. The tsunami was triggered by a magnitude tectonic earthquake with a magnitude of 7.4. The damage caused by the tsunami was quite severe and took many fatalities as well. Records of tsunami events in Indonesia have proven that the region in Indonesia is prone to tsunami disasters. The main determining factors tsunami size is characteristic of vertical seabed deformation resulting from the large earthquakes, epicentre depths (depths below the seabed where earthquakes occur) [4].

Tsunamis that occur on bay-shaped beaches produce waves larger than straight-lined beaches. The potential for tsunamis will increase if the morphology of beaches with the coastline of the bay ramps has no protectors such as mangroves, coconut trees, and other coastal forests [5]. There are previous studies that say that the southern waters of Java Island have the potential for tsunami waves up to 20 meters. One of the bays located in the southern part of Java Island is located on the coast of Ujung Genteng, Ciracap sub-district, Sukabumi. Ujung Genteng has the shape of the coastline in the form of a ramped bay. Ujung Genteng coastline is directly connected to the Indian Ocean. These conditions make the area vulnerable to tsunami hazards. This research was conducted to analyze the area of tsunami exposure that occurred on the coast of Ujung Genteng. Spatial modeling in GIS is chosen as the right method because it can aid decision making by integrating a variety of factors. This research is also expected to be information and reference for local governments in tsunami disaster mitigation along the coast of Ujunggenteng.

This research was conducted along the coast of Ujung Genteng. Ujung Genteng is one of the villages located in Ciracap sub-district, Sukabumi Regency, West Java. Ujung Genteng is one of the tourist destinations located on the south coast of Java Island. The south coast of Java island including Bayah Coast and surrounding areas (including Ujung Genteng) is one of the tsunami areas in Indonesia [6]. The Ujunggenteng coastal has a shallow beach and large waves [7]. Therefore, analysis of tsunami-prone areas needs to be done at this site for disaster mitigation planning to reduce the losses that will occur when a tsunami hits this area [8]. The study area can be seen in Figure 1.

![Figure 1. The study area located in Ujung Genteng, West Java.](image)

2. Methods
The method used in this study is spatial modeling based on Geographic Information Systems (GIS). Spatial modeling with GIS was chosen as a research method because it can combine different types of
data, both spatial and non-spatial data to be processed into information. GIS can help to determine the distribution of tsunami exposure areas [9]. The use of GIS in natural disasters can be used to create mitigation planning and strategies to minimize disaster impacts. In making spatial layout of an area is not separated from the variable distance and height of the coastline [10].

The method used for tsunami modeling refers to the modeling techniques that have been used by the National Disaster Management Agency (BNPB). The method used is numerical modeling with mathematical calculations developed by Berryman (2006) [11]. This modeling analysis is based on the calculation of tsunami height loss per 1 m of inundating distance (inundation height) based on the value of distance to slope and surface roughness. The formula used is as follows:

\[ H_{loss} = \left( \frac{167 n^2}{H_0^{1/3}} \right) + 5 \sin S \]

Description:
- \( H_{loss} \): loss of tsunami height per 1 m inundation distance
- \( n \): surface roughness index
- \( H_0 \): the height of tsunami waves on the coastline (m)
- \( S \): surface slope size (degrees)

Modeling tsunami inundation with mathematical equations require three variables. The variables used are slopes, the maximum wave potential of tsunamis, and the coefficient of surface roughness. The maximum tsunami wave potential is the maximum wave level of tsunami to the ground obtained from tsunami modeling by tsunami experts. The maximum wave height of tsunami in the Sukabumi Regency is based on the Regulation of the Head of National Disaster Management Agency No. 2 of 2012 which is 10 m. The coefficient index value of surface roughness comes from land-use data. The data is converted from vector to raster for the \( H_{loss} \) calculation process. The maximum wave potential of a tsunami is combined with the flow of water flowing on rough or irregular topographic surfaces to determine how far puddles might go. The coefficient value of surface roughness refers to the determination of Berryman (2006) can be seen in table 1.

| Land cover/ Land use     | Surface Roughness Coefficient |
|--------------------------|--------------------------------|
| Water                    | 0.007                          |
| Shrubs / Bushes          | 0.040                          |
| Forest                   | 0.070                          |
| Agricultural land        | 0.025                          |
| Fields                   | 0.020                          |
| Mangrove                 | 0.060                          |
| Built-in Settlements     | 0.050                          |
| Ponds                    | 0.010                          |
| Plantation               | 0.035                          |
| Sand                     | 0.018                          |

3. Result and Discussion

The spread of tsunami-exposed areas in this study was obtained from spatial modeling which refers to tsunami modeling techniques used by the National Disaster Management Agency. The model used is a mathematical calculation model developed by Berryman (2006). This modeling is based on the calculation of tsunami height loss per 1 m of inundation height distance obtained from slope data processing, coefficient of surface roughness, and maximum wave height.
Figure 2. Tsunami inundation zone in Ujung Genteng coastline

The results of modeling the area of tsunami exposure can be seen in Figure 2. On the map we can know that along the coastline at Ujung Genteng has a maximum inundation height. Land use along the coastline in the form of fields, open land, and few coastal plants in the form of mangroves resulted in tsunamis reaching land with maximum inundation. In addition, the slopes that ramp in this region cause a wider range of tsunami inundation compared to areas that have steep slopes.

Based on the value of the inundation that has been obtained, we can then analyze the tsunami hazard index. Tsunami hazard index values are in the range of 0 to 1 by following a continuous classification pattern performed using fuzzy logic suppression. In accordance with National Agency Head Regulation 2/2012, there are three classifications of the tsunami hazard index. The three classifications are low hazard (inundation ≤ 1), moderate hazard (1 < inundation ≤ 3), and high hazard (inundation > 3) [12]. The fuzzy membership of the inundation determined that the greater the inundation value (>3), then the value of the fuzzy membership inundation will be closer to the value of 1 or be at the limit of the value that can be referred to as the high danger class. Conversely, if the smaller the inundation value (≤1), then the value of the fuzzy inundation membership will be closer to the value of 0 or be at the limit of a value that can be referred to as a low hazard class.

Hazard analysis is carried out to obtain conclusions from the results of hazard index analysis (H) in the form of a hazard class. Hazard classes are classified based on the following grouping of hazard index values:

- Low \( (H \leq 0.333) \)
- Medium \( (0.333 < H \leq 0.666) \)
- Height \( (H > 0.666) \)

The tsunami hazard classification map on the Ujung Genteng coast can be seen in Figure 3. From the results of the processing of the data, it is known that along the coast of Ujung Genteng is a tsunami exposure area that belongs to the high hazard class. The farther from the coast, the safer the area is from the exposure of tsunamis that are classified in areas with low hazard classes. The total area exposed to the tsunami was 530.34 Ha. This area is half of the village area of 1,009.91 Ha. Areas included in the low hazard class include 54.71 Ha, areas with medium hazard classes covering 91.62 Ha, and areas with a high hazard class of 383.01 Ha.
Figure 3. Classification of tsunami hazard in Ujung Genteng coastline

The tsunami modeling above uses a maximum tsunami wave estimate of 10 meters. Meanwhile, there are previous studies that say that the southern waters of Java Island have the potential for tsunami waves up to 20 meters [13]. In the study, it is said that judging from earthquake data and GPS data inversion, there is a gap seismic in the south of Java Island. The study used earthquake data, bathymetry, and data obtained from GPS. The worst-case scenario is that two megathrust segments in the south of Java Island can break simultaneously. If the earthquake occurs it could potentially trigger a tsunami with wave heights reaching 20 meters on the southern coast of West Java. From the research, on this occasion will also be done modeling tsunami area in Ujung Genteng with a maximum wave height of up to 20 meters to update the information of areas exposed to the tsunami.

Figure 4. Tsunami inundation zone with maximum height 20 meters in Ujung Genteng coastline
Modeling of tsunami exposed areas with a wave height of 20 meters in Ujung Genteng can be seen in Figure 4. Tsunami-exposed areas cover almost the entire area of the village. The total area exposed to the tsunami reached 663.29 ha. While the total area of Ujunggenteng reached 1,009.91 ha. The tsunami-exposed area is divided into three classes. Areas included in the low hazard class include 2.59 Ha, areas with medium hazard classes covering 29.05 Ha, and areas with a high hazard class of 631.65 Ha. The tsunami hazard classification map on the Ujung Genteng coast can be seen in Figure 5.

Figure 5. Classification of tsunami hazard with maximum height 20 meters in Ujung Genteng

From the results of the modeling, we can know the extent to which the tsunami will damage the Ujunggenteng area. The absence of coastal forests such as mangroves or coconuts along the coast causes the absence of barriers that can break the waves when a tsunami occurs. This resulted in the coverage of tsunami exposure areas in the region. As previously known, the shape of the coastline in the form of bays has a greater potential for tsunami height due to the accumulated waves of seawater to the coast. The results of the tsunami modeling can be used for tsunami disaster mitigation planning by local parties.

4. Conclusion
The exposure of the area along the Ujung Genteng coast to the tsunami is influenced by the condition of ramp slopes and land use on the coast. Along the coastline is classified as an area with a high danger class and increasingly avoiding the coast, the area is safe from tsunami exposure that belongs to low hazard class areas. By modeling the tsunami with a worst-case scenario of wave height of 20 meters, it was obtained that the tsunami exposed area reached 663.29 Ha. The area belongs to a low hazard class of 2.59 Ha, a medium hazard class of 29.05 Ha, and an area that belongs to a high hazard class of 631.65 Ha. The results of this modeling are expected to be a reference for tsunami disaster mitigation planning in Ujung Genteng.

Acknowledgement
Thanks to DRPM of Universitas Indonesia which has supported and funded this research grant PUTI 2020.
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