Exposures of Building and Population to Tsunami Hazard in Pangandaran Beach, Indonesia

Martha Alvianingsih1*, Willy Ivander Pradipta1, Intan Hayatiningsih1, Nuraini Rahma Hanifa2
1Research Group of Hydrography, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung
2Research Center of Geotechnology, Indonesia Institut of Sciences

*e-mail: marviasih@gmail.com

Abstract. Pangandaran and Pananjung villages are located in the southern coast of Java Island, prone to tsunami hazard originating from a megathrust earthquake off south of Java Island. Those villages experience a tsunami earthquake on 2006 from an M7.8 earthquake. The National Center for Earthquake Studies released a map of the sources and hazards of Indonesia's earthquake in 2017 with a potential earthquake of magnitude 8.7-9.2 in the megathrust of Java Island. This research aims to estimate the potential number of buildings and the population affected by tsunami inundation from two scenario; first scenario is based on historical event of a M7.8 intraplate earthquake, and second scenario is based on a plausible M8.7 intraplate earthquake. The first scenario tsunami modeling resulted an inundation of 108,606 ha, while in the second scenario estimate an 867,351 ha of inundation area. Building data is obtained by digitizing aerial photographs taken in November 2021. The calculation of potential affected buildings is carried out by overlaying the tsunami inundation data with the existing building data in the study area. Meanwhile, the population data used is obtained from the local government in 2021. To obtain the number of the affected population, population distribution is first carried out in each class of land cover, overlaid with the tsunami inundation data. The estimated number of buildings and population affected by scenario 1 and 2 in Pangandaran Village is 1,040 buildings along with 2,765 people, and 4,216 buildings with 11,209 people respectively. While in Pananjung Village, it is estimated a total of 149 buildings with 350 people affected, and 4,039 buildings with 9,493 people affected respectively. This indicate that scenario 2 impact is potentially 4 times greater than scenario 1 in Pangandaran village, and 27 times greater in Pananjung village, implying a different strategy of tsunami risk reduction should be taken to save more lives. The results of this study can be used as a basis for policymaking by the government in carrying out a more effective tsunami disaster mitigation efforts in Pangandaran and Pananjung Villages. This study also calls for reevaluation of coastal villages tsunami risk based on each plausible scenario.

Keywords: Tsunami; Exposure; Buildings; Population
1. Introduction

Pangandaran and Pananjung Villages are one of the villages in, Pangandaran Regency and are known as Pangandaran Tourism Areas. Pangandaran Tourism Area is a famous tourist attraction area and is visited by tourists. The west coast and east coast in this tourist area are the areas most visited by tourists, making the pattern of local community activities more in coastal areas than other areas. This, of course, makes infrastructure development in coastal areas support tourists and increase income for the community and the entry of the Pangandaran Village area. However, behind the beautiful and dense activities in the Pangandaran Tourism Area, there is a potential for natural disasters, namely tsunamis, that can occur this area. This can happen because Indonesia is formed from the confluence of three active earth's crustal plates, namely the Eurasian plate, the Indo-Australian Plate and the Pacific plate, which are moving convergently. This causes Indonesia to become one of the countries with a high level of seismicity. One of the possible disasters due to shallow earthquakes is a tsunami [1]. Based on historical records, in 2006, an earthquake measuring 7.7 Magnitude occurred, followed by a tsunami with a height of about 5-8 meters and a tsunami inundation about 500 meters from the coastline [2]. The earthquake, followed by the tsunami, resulted in at least 500 casualties and damage to infrastructure in the Pangandaran Tourism Area. The National Earthquake Study Center (PuSGeN) released a map of the source and hazard of an 8.7-9.2 Magnitude earthquake in a megathrust on the island of Java. The potential for the earthquake can be followed by a tsunami that can hit along the island of southern Java. This study uses earthquake relocation data with GPS measurements to identify seismic gaps as active seismic zones that store energy and the possibility of earthquakes occurring in the future. However, it should be noted that Indonesia is a meeting place for three plates, as shown in Figure 1, namely the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. This makes Indonesia a country with a high potential for earthquakes and tsunamis. The potential for an earthquake that is located under the sea is shaken by a tsunami that can take lives and damaged infrastructure in the Pangandaran Tourism Area in the future. Therefore, an action is needed to anticipate the damage and losses that will be experienced. In this study, several maps have been produced, namely tsunami inundation maps, building maps, and the affected population number of occurrences to see how much loss will be caused by the tsunami disaster both in terms of life and infrastructure. Anticipation that can be done is government policies to carry out more effective disaster mitigation efforts in the Pangandaran Tourism Area, namely Pangandaran Village and Pananjung Village. Thus, the results of this study can be used as a basis for making these policies.

![Figure 1. Indonesia Tectonic Map (Source: Pusat Studi Gempa Nasional, 2017)](image-url)
2. Data and Method

2.1 Study area

The research area was carried out along the Pangandaran coast covering two villages, namely Pangandaran Village and Pananjung Village, Pangandaran Regency, West Java Province, Indonesia with coordinate ranges 7°43’00”S - 7°40’00”S and 108°38’30”E - 108°40’30”E. The research area can be seen in Figure 2.

![Figure 2. Research Area Map](image)

Although this Pangandaran Beach tourist area is an area that is vulnerable to natural disasters, this area is a strategic area for tourism, fisheries, and agriculture which is the centre of the local community's economy.

2.2 Data

In this study, numerical modelling will be used from Windupranata et al., (2020). The data used in this study are tsunami inundation data from Windupranata et al 2020, orthofoto, buildings, and population data from Pangandaran and Pananjung villages.

2.2.1 Tsunami inundation data for scenarios 1 and 2

The tsunami inundation model used in this study results from existing modelling by Windupranata et al., (2020). Tsunami generator parameters are earthquake source data that have the potential for a tsunami. The tsunami generator data used in this study were two scenarios. The first scenario is historical, using data from the 2006 Pangandaran tsunami generator. Historical scenarios are tsunami scenarios that have occurred in the past, including those that occurred in 2006. The second scenario is probabilistic, using segmented tsunami generator data in West Java-Central Java. Probability scenarios are tsunami scenarios that are likely to occur in the future Windupranata et al 2020.
2.2.2 Orthophoto data of Pangandaran and Pananjung Villages

The orthophoto data used in this study was obtained from the acquisition of aerial photo images using a fixed-wing UAV vehicle. The acquired area coverage of 8.7 km² with a flight height of 214 meters resulted in 4.76 cm/pix. Data acquisition and processing were carried out in November 2020.

2.2.3 Buildings

The building data was obtained from the orthophoto digitization of the two villages. Digitization was done using ArcMap 10.5 software. The digitization is carried out per building in Pangandaran Village and Pananjung Village. Furthermore, the building data will be used to see the level of exposure based on the tsunami inundation based on the modelling of Windupranata et al. (2020). The existing buildings are 8,255 buildings. After the building data is overlaid with tsunami inundation data, the existing buildings will be classified into three classes, namely low, medium, and high, based on the level of exposure to tsunami inundation. [6].

2.2.4 Population

Population data used in this study is sourced from the Central Statistics Agency in 2021. Population data is used to analyze the population affected by the tsunami in scenarios one and scenario 2. The total population in Pangandaran Village is 11,209 people. Meanwhile, the population in Pananjung Village is 9,493 people.

2.3 Method

2.3.1 Classification of exposure levels

The tsunami wave heights obtained from the numerical modelling results from Windupranata et al., (2020) were classified. Classification of exposure levels based on the height of the tsunami waves located in the topography of Pangandaran Village. Classification is divided into three classes: low, medium, and high, as shown in Table 3. (BNBP, 2012).

| No. | Tsunami Inundation Height | Class |
|-----|--------------------------|-------|
| 1   | < 1 meter                 | 1     |
| 2   | 1-3 meter                 | 2     |
| 3   | > 3 meter                 | 3     |
2.3.2 Overlay tsunami inundation data with buildings

The tsunami inundation obtained based on the results of the Windupranata et al. (2020) tsunami model was overlaid with building in Pangandaran and Pananjung Village. The tsunami inundation height generated from the model will be classified into four classes: harmless, less dangerous, dangerous, and very dangerous. Then, based on the two tsunami generator scenarios (earthquake), it will be analyzed how many buildings are exposed in Pangandaran and Pananjung Village. Buildings exposed to the propagation of tsunami waves will be classified based on the classification of tsunami wave heights generated.

2.3.3 Distribution of tsunami affected population

The distribution of the population affected by tsunami scenarios 1 and 2 is seen to estimate the victims caused by the natural tsunami disaster. The distribution of the affected population is obtained from the affected buildings. It is assumed that the population in the village is only found in each building. The affected buildings are the result of overlaying tsunami inundation data and buildings. The distribution of the affected population results from a comparison between the population and the buildings in the village. After obtaining the number of residents per building, the result is multiplied by the number of buildings affected by the tsunami.

3. Result and Discussions

3.1 Scenario 1 tsunami inundation map and area of topography affected

Based on the results of numerical modelling on the COMCOT v1.7 software. Carried out by Windupranata et al. (2020) using two scenarios of a tsunami generating earthquake, namely scenario one, which is a historical event in Pangandaran 2006 and scenario two which is a probabilistic scenario in the West Java-Central Java segment, resulting in a tsunami inundation map as shown in Figure 3. In Figure 3, it can be seen that the submerged area is mostly only in the coastal part of the village, which only produces two classes. Class 1 is a class with an immersion height of less than 1 meter, shown in green. In the Pangandaran Village area, there is an area of 83,845 hectares of tsunami inundation and 14,848 hectares in Pananjung Village. Then in class 2, a class with a height of 1-3 meters in Pangandaran Village with a tsunami wave inundation area of 7,839 Ha and Pananjung Village of 2,074 Ha. While class 3 with wave heights above 3 meters do not have topography or affected areas. Based on these results, it can be said that 10% of the Pangandaran Tourism Area, which includes Pananjung Village, was affected or submerged by the tsunami, with most of it submerged with a wave height of 0-1 meters.
3.2 Scenario 2 tsunami inundation map and area of topography affected

Based on the results of numerical modelling on the COMCOT v1.7 software. Carried out by Windupranata et al. (2020) using two scenarios of a tsunami generating earthquake, namely scenario one, which is a historical event in Pangandaran 2006, and scenario 2 is probabilistic in the West Java-Central Java segment, the results of which are tsunami inundation maps as shown in Figure 4. In Figure 4, it can be seen that all Pananjung Villages were affected. While in Pangandaran Village, 73.76% were affected. Class 1 is a class with an immersion height of less than 1 meter, shown in green. In the Pangandaran Village area, there is an inundation area of 328,765 ha of tsunami waves and 11,746 ha of Pananjung Village. Then in class 2, a class with a height of 1-3 meters, Pangandaran Village has a tsunami wave inundation area of 2,652 Ha and Pananjung Village of 49,755 Ha. Then class 3 with wave heights above 3 meters in Pangandaran Village was affected by 506,790 ha. While in Pananjung Village, it is 360,561 ha.
Based on previous results, the tsunami inundation in the Pangandaran Tourism Area can harm this tourist center area. Being the center of the economy, this area has many buildings on the coast where there is potential for damage due to the tsunami disaster and can kill the region's economy. That way, an analysis is needed to see how large the buildings are affected by the tsunami disaster. Through the analysis results, a conclusion can be given, which can be a prevention or mitigation effort in the future. The analysis of the affected buildings was obtained from the intersection between the digitized orthophoto data of the Pangandaran Tourism Area and two scenarios of tsunami inundation data. In scenario 1, the map of the affected buildings can be seen in Figure 5.

Based on the map of affected buildings in scenario 1 for Pangandaran Village, there are 1,189 buildings affected by the tsunami disaster and 149 buildings affected in Pananjung Village from 8,255 buildings in the two villages on the coast of the Pangandaran Tourism Area. It can be said that 14.40% of buildings in the Pangandaran Tourism Area were exposed to the tsunami disaster. The building was submerged in the low and middle classes, while there were no exposed buildings for the high class.
3.4 Map of buildings affected by tsunami scenario 2

Based on the results of the map of the affected buildings in scenario two, which can be seen in Figure 6 for Pangandaran Village, there are 4,216 buildings affected by the tsunami disaster and 4,039 buildings affected in Pananjung Village from a total of 8,255 buildings in the two villages on the coast of the Pangandaran Tourism Area. It can be said that 100% of buildings in the Pangandaran Tourism Area were exposed to the tsunami disaster. The building is submerged in all classes, both low, high, and medium classes.
3.5 Distribution of affected population scenario 1

In this study, the affected population is seen based on the distribution of the population in each building where there is a population obtained from the Central Statistics Agency for Pangandaran Village as many as 11,029 residents and Pananjung Village many as 9,493. From the number of residents owned and then divided by the number of buildings affected in scenario 1, the total population per house is obtained. Then, to find out the number of affected populations, you can multiply the results of the population per house by the number of buildings affected. Based on these calculations, the results of the affected population in scenario 1 for Pangandaran Village are 2,765 people, and Pananjung Village are 351 people. By knowing the distribution and the number of affected populations, further analysis can be carried out, whether used to create an evacuation route map or to determine evacuations sites.

3.6 Distribution of affected population scenario 2

In this study, the affected population is seen based on the distribution of the population in each building where there is a population obtained from the Central Statistics Agency for Pangandaran Village as many as 11,029 residents and Pananjung Village many as 9,493. From the number of residents owned and then divided by the number of buildings affected in scenario 1, the total population per house is obtained. Then, to find out the number of affected populations, you can multiply the results of the population per house by the number of buildings affected. Based on these calculations, the results of the affected population in scenario 1 for Pangandaran Village are 11,209 people, and Pananjung Village are 9,493 people. By knowing the distribution and the number of affected populations, further analysis can be carried out, whether used to create an evacuation route map or to determine evacuations sites.

4. Conclusions

Based on the results of data processing, it can be seen that the affected area in scenario 1 in Pangandaran Village is 91,684 Ha or 13.34% of the total area of Pangandaran Village and Pananjung Village of 16,922 Ha or 4.69% of Pananjung Village area. While in the scenario two tsunami inundation map, the area affected in Pangandaran Village is 687.113 ha or 73.76% of the total area of Pangandaran Village. Meanwhile, the affected area in Pananjung Village is 360.561 ha or 100% of the affected area.

The buildings affected in scenario 1 for Pangandaran Village are 1,040 buildings and 149 buildings for Pananjung Village. On the map of buildings affected by scenario 2 in Pangandaran Village, there are 4,216 buildings. In Pananjung Village, there are 4,039 buildings or all buildings in the village are affected by the tsunami.

As for the population distribution affected in scenario 1 for Pangandara Village, as many as 2,765 people and 351 people were affected in Pananjung Village. The population affected by scenario 2 in Pangandaran Village amounted to 11,029 people, while in Pananjung Village, there were 9,493 residents or the entire population in the village was affected by the tsunami.

Based on the results obtained, Pangandaran and Pananjung Villages are areas that are prone to tsunami natural disasters.

5. Suggestion

Data on buildings in Pangandaran Village and Pananjung Village have not been classified based on their use. The building data should be classified into economic facilities, critical facilities, public facilities, and others. This is to see the location of the affected buildings whose usefulness is essential based on their function.
Based on the map of the potential for tsunami inundation that has been made and the impact of the affected buildings, a mitigation strategy can be made in the form of an evacuation map in the event of a tsunami for the next research. And the map can be used as a basis for socializing and simulating tsunami evacuation for the community in the Pangandaran Tourism Area.

6. Reference

[1] I. R. Palupi, W. Raharjo, E. Wibowo, and H. Hamdalah, “Pemodelan Tsunami Sederhana dengan Menggunakan Persamaan Diferensial Parsial,” *Indones. J. Appl. Phys.*, vol. 8, no. 1, p. 26, 2018, doi: 10.13057/ijap.v8i1.16284.

[2] W. Windupranata, N. R. Hanifa, C. A. D. S. Nusantara, G. Aristawati, and M. R. Arifianto, “Analysis of tsunami hazard in the Southern Coast of West Java Province - Indonesia,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 618, no. 1, 2020, doi: 10.1088/1755-1315/618/1/012026.

[3] Disparbud Jabar, “Kabupaten Pangandaran,” *Dinas Pariwisata dan Kebud. Jawa Barat*, 2016, [Online]. Available: http://www.disparbud.jabarprov.go.id/wisata/disc-det.php?id=28&lang=id.

[4] I. Faiqoh, J. L. Gaol, and M. M. Ling, “Vulnerability Level Map of Tsunami Disaster in Pangandaran Beach, West Java,” *Int. J. Remote Sens. Earth Sci.*, vol. 10, no. 2, pp. 90–103, 2014, doi: 10.30536/i.jreses.2013.v10.a1848.

[5] R. Redyansyah, A. Satriadi, and S. Saputro, “Pemodelan Penjalaran Gelombang Tsunami Dan Analisa Daerah Jangkauan Di Teluk Sumbreng, Trenggalek,” *J. Oceanografi*, vol. 6, no. 1, p. 120247, 2017.

[6] BNPB, “Menuju Indonesia Tangguh Menghadapi Tsunami,” *Masterplan Pengurangan Risiko Bencana Tsunami*, p. 146, 2012, [Online]. Available: https://bnpb.go.id/uploads/migration/pubs/578.pdf.