Range, capacity, and closest evacuation route analysis to tsunami evacuation shelter in Pandeglang Regency Banten Indonesia

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Abstract. The Regency of Pandeglang is an area prone to tsunami, so the development of disaster preparedness and mitigation system needs to be done. This study aims to analyze the range of the evacuation shelter, calculate the capacity that can be accommodated by the evacuation shelter, and to identify the closest route to the evacuation shelter in Pandeglang Regency. The study was conducted from March until May 2020. The analysis of tsunami hazard zones shows that area of tsunami hazard zone is 579.68 km², and located in sub-districts bordering the West Coast and the South Coast. There are 28 evacuation shelter in Pandeglang Regency. The analysis of the range of evacuation shelters showed 52.21% of the tsunami hazard zones were covered, while 47.79% were still beyond the range of the evacuation shelters and tsunami safe zones. The results of shelter capacity analysis showed that the evacuation shelter in Pandeglang Regency could only accommodate 44661 refugees. Pandeglang Regency needed at least 64 new evacuation buildings that can accommodate a minimum of 2592 refugees per shelter. This study identified 38 closest routes to tsunami evacuation shelter and tsunami safe zones in Pandeglang Regency.

1. Introduction
Pandeglang Regency is a regency prone to tsunami disasters. This is because there are several earthquake source zones in the Sunda Strait region, including the subduction earthquake source zone, which is the area where the Indo-Australian plate meets the Eurasian plate. One of the natural disaster occurred is the tsunami incident in the Sunda Strait in 2018. The tsunami incident in the Sunda Strait in 2018 resulted in 2 provinces being worst affected by the tsunami disaster, namely Banten Province (Serang Regency and Pandeglang Regency) and Lampung Province (South Lampung Regency, Pesawaran Regency and Tanggamus Regency). The disaster was triggered by the eruption of Mount Anak Krakatau with an avalanche of slope material that entered the Sunda Strait with a depth of 0.08 km with an intensity of 255 mm³. The worst affected areas were Pandeglang and South Lampung with tsunami wave heights reaching 2 to 5 m [1]. This incident resulted in 267 people died, 1143 people were injured, 36 people died, and 5361 people were displaced. According to Perka BNPB No. 2 of 2014, the potential run up height for Pandeglang Regency based on historical data is as high as 10 m. The potential for earthquakes and tsunamis in Pandeglang Regency is very large, so that a disaster preparedness and mitigation system needs to be developed to minimize the impact of the tsunami disaster.

GIS is a system that can support spatial decision making and is able to integrate location descriptions with the characteristics of the phenomena found in that location [2] The function of geographic information systems is to improve the ability to analyze spatial information in an integrated manner for planning and decision making. Geographical information systems can provide information to decision
makers for analysis and application of spatial databases [3], as well as applications for disaster purposes [4,5].

Tsunami evacuation shelter building (ESB) is defined as a building that functions as a tsunami evacuation destination[9]. This building is intended for an evacuation place in the event of a disaster and if there is no disaster it can be used as public facilities such as places of worship, socialization, and others [10]. According to BPBD Banten Province, there are only 28 buildings that can be used as tsunami evacuation shelters in Pandeglang Regency. This number is still insufficient when compared to the population who could potentially become refugees during the tsunami disaster. In order for the evacuation to be carried out effectively, the number, capacity and placement of the shelter buildings must be considered and taken into account so that the needs for shelter buildings in Pandeglang Regency can be met. This study aims to calculate the range of service area of the tsunami evacuation shelter in the tsunami hazard zone, the capacity of the shelter, as well as analyzing the closest evacuation route to the evacuation shelter and the tsunami safe zone.

2. Materials and Methods

2.1. Data
The elevation and slope data used in this study was obtained from Digital Elevation Model Nasional (DEMNAS). DEMNAS is built from several data sources including IFSAR, TERRASAR-X, and ALOS PALSAR. Apart from drone or unmanned aircraft vehicle [7, 8], this study used Landsat-8 data for land cover mapping and population density raster data from WorldPop. Moreover, this study used inundation historical data, evacuation shelter coordinates, and evacuation shelter areas. The step of analysis starts from data collection, analysis of tsunami hazard zone, analysis of the number of affected population, analysis of the range of tsunami evacuation shelter, analysis of evacuation shelter capacity, and ends with analysis of the closest route to the evacuation shelter.

2.2. Study Area
The study area was Pandeglang Regency, Banten, Indonesia (Figure 1). This area is one of the areas affected by the 2018 Sunda Strait earthquake tsunami. In 2019, the city has an estimated population of 1,209,011. The topography of Pandeglang Regency varies between lowlands and mountains with variations between 0 and 1778 msl, most of which are lowlands with an area of about 80.07% of the total area where the highest point is at the top of Mount Karang and the lowest point is in the coastal area with an altitude of 0 msl.

![Figure 1. Pandeglang Regency](image-url)
2.3. Spatial Analysis

Tsunami Hazard Zone Analysis
The creation of tsunami prone areas using DEMNAS data, Landsat 8 data, administrative boundary shapefile data, and Pandeglang Regency coastline shapefile data. DEMNAS data was reclassified to classify elevation and slope into five vulnerability classes [6] which can be seen in Table 2.

| Elevation (m) | Slope (%) | Vulnerability Class |
|---------------|------------|---------------------|
| <5            | <2         | High                |
| 5 – 10        | 2 – 6      | Slightly high       |
| 10 – 15       | 6 – 13     | Medium              |
| 15 – 20       | 13 – 20    | Slightly low        |
| >20           | >20        | Low                 |

Tsunami vulnerability maps based on land cover were created using the ISO Cluster Unsupervised tool in ArcGIS. The land cover map is divided into 5 vulnerability classes as can be seen in Table 2.

| Land Cover     | Vulnerability Class |
|----------------|---------------------|
| Urban area     | High                |
| Agriculture    | Slightly high       |
| Bare soils     | Medium              |
| Water          | Slightly low        |
| Forest         | Low                 |

The next step is making a tsunami vulnerability map based on coastline distance. The calculation of the distance from the coastline to the ground is carried out by dividing the area into 5 classes of vulnerability. Distances are determined based on the range the probability of the tsunami reaching the ground. The distance depends on the historical report of the maximum run up in the study area, which is 10 m. The distance from the coastline is expressed by equation (1) [11].

$$\log X_{\text{max}} = \log 1400 + 4 \log \left( \frac{Y_0}{10} \right)$$

(1)

Where $X_{\text{max}}$ defines maximum reach of tsunami wave in land (m), $Y_0$ is equal to tsunami height at the coast (m).

Then a weighted overlay of the tsunami vulnerability map results is carried out based on elevation, slope, land cover, and coastline distance using the weighted overlay tools from ArcGIS. The weights used for the weighted overlay step can be seen in Table 3.

| Parameters          | Weights (%) |
|---------------------|-------------|
| Elevation           | 45.96       |
| Slope               | 25.53       |
| Coastline Distance  | 16.71       |
| Land Cover          | 11.81       |
A tsunami vulnerability map based on the impact of inundation is then made using a simple numerical modeling method of tsunami inundation based on the run up height of the coastline, the slope of the slope, and the surface roughness coefficient stated in equation (2) [12].

\[
H_{loss} = \frac{167 n^2}{H_0^3} + 5 \sin S
\]

Where \( H_{loss} \) defines Height loss of tsunami height per 1 m inundation distance, \( n \) is equal to surface roughness coefficient, \( H_0 \) is equal to tsunami height at the coast (m), and \( S \) defines slope (%).

Tsunami vulnerability map was made using the tool clip from ArcGIS between the results of the weighted overlay and the calculation of the loss of tsunami height. The resulting data is then processed using InaSAFE in QGIS to obtain the number of residents in the tsunami hazard zone. Data processing in InaSAFE uses two data, namely data on population density and tsunami vulnerability zones. The tsunami vulnerability zones consist of two scenarios, namely with a run up height of 10 m and 5 m. The data is inputted into QGIS and assigned with population density data as exposure, and tsunami vulnerability zones as hazard. Then InaSAFE was run to get the number of people exposed to the tsunami in the tsunami hazard zone of Pandeglang Regency.

**Analysis of Evacuation Shelter Range**

The range of evacuation shelter was performed using the multiple ring buffer tools available in the ArcGIS software. The travel time classification specified is 5 minutes very near, 10 minutes near, 20 minutes medium, 30 minutes far, and more than 30 minutes is very far. Buffering process is done with a distance determined using equation (3):

\[
S = V \times t
\]

Where \( S \) defines distance (m), \( V \) defines walking speed (m/minutes), and \( t \) equal to evacuation time (minutes).

**Analysis of Evacuation Shelter Capacity**

Analysis of the capacity of the evacuation shelter is carried out by calculating the area of the roof of the building which is used as an evacuation location by measuring the dimensions of the building with Google Earth software. Building capacity can be calculated using equation (4) and continued with a comparison with the number of residents in the tsunami hazard zone with the available shelter building capacity. Space density is determined by assuming the refugees sit cross-legged or with their legs bent forward with an average of taking up the surrounding space 0.5 m\(^2\)/person. The effective area can be seen in Table 5.

\[
TEBC = (CS \times BA \times NrF) \times SD
\]

Where \( TEBC \) defines tsunami Evacuation Building Capacity (person), \( CS \) defines Capacity score (%), \( BA \) equal to Building area (m\(^2\)), \( NrF \) equal to Number of floors and \( SD \) defines Space density (person/m\(^2\)).
Table 4. The effective area of the evacuation building [13]

| Building | Effective area (%) |
|----------|-------------------|
| Mosque  | 78                |
| School  | 30                |
| Office  | 23.6              |
| Market  | 23                |
| Hotel   | 26.3              |

Closest Route Analysis

Closest route analysis was performed using network analyst tools in ArcGIS software. Network analyst tools is applied to every village that is included in the tsunami hazard zone. The output of this analysis is a map of the route to the nearest evacuation shelter or tsunami safe zone.

3. Results

3.1. Tsunami Hazard Zone

The making of tsunami hazard zone based on elevation is carried out by classifying DEMNAS data according to the vulnerability class in Table 2. The land elevation is one of the factors that affects the level of vulnerability of an area to a tsunami disaster. In addition, the slope of the slope affects the hazard value of tsunami wave immersion. The immersion that enters the land will decrease if the slope is large [14]. The lower the elevation, the more vulnerable it will be and will cause a higher damage. Conversely, the higher the elevation, the smaller the damage caused [15]. The results of the tsunami hazard zone map based on land elevation can be seen in Figure 2 and the tsunami hazard zone map based on slope can be seen in Figure 3.

Figure 2. Tsunami hazard zone based on elevation

Figure 3. Tsunami hazard zone based on slope

Tsunami hazard zones based on coastline distance is done by calculating the distance from the coastline to the land. The distance is determined based on the range the probability of a tsunami reaching
the ground using historical data for the maximum tsunami wave propagation of Pandeglang Regency, which is 10 m. The distance used for buffering is based on the probability of a tsunami reaching the mainland [6]. Based on that, 4 classes under it are made, namely the tsunami inundation height of 8 m, 6 m, 4 m, and 2 m, and calculated by equation (1) so that 5 ranges of coastline prone to tsunamis are produced as shown in Table 5 and The results of a tsunami vulnerability map based on the distance from the coastline can be seen in Figure 4.

**Table 5.** Vulnerability class based on coastline distance

| Coastline Distance (m) | Vulnerability Class |
|------------------------|---------------------|
| 0 - 164                | High                |
| 164 - 413              | Slightly high       |
| 413 - 708              | Medium              |
| 708 - 1040             | Slightly low        |
| 1040-1400              | Low                 |

Tsunami hazard zones based on land cover were made using Landsat 8 bands 4, 3, and 2. The map made by classifying the image into 5 classes, namely urban area, agriculture, bare soil, water, and forests with the ISO Cluster Unsupervised Classifications tools in ArcGIS. The determination of the tsunami prone areas used in this study is based on the tsunami run off area at its land cover. The map used a combination of Landsat 8 bands which is 4, 3, and 2 because they are the bands combination for the original color. The results of tsunami hazard zone based on land cover can be seen in Figure 5. The map is dominated by green, which is a symbol for forest with the lowest vulnerability. The classification of land cover is determined by the density of plants (vegetation index) in which the lowest vulnerability class due to the density of vegetation. The highest vulnerability is urban area, where usually they consists fewer vegetation. Areas with the lowest vegetation density are assumed to have the highest vulnerability to tsunamis.

![Figure 4. Tsunami hazard zone based on coastline distance](image1)

![Figure 5. Tsunami hazard zone based on land cover](image2)

Tsunami run-up hazard zone based on inundation impact was made using a simple numerical modeling method of tsunami inundation based on the wave height from the coastline, slope, and surface roughness coefficient [8]. The map is made with the aim of delimiting the area inundated by the tsunami waves. A tsunami vulnerability map based on the impact of inundation can be seen in Figure 6. Tsunami
hazard zone maps based on elevation, slope, land cover, and coastline distance are then overlaid by using the weighted overlay tool to add up all the values that exist in each parameter to be used as a vulnerability value. Weighted overlay is a technique for applying a rating scale to differentiate and disregard input into an analysis and give consideration to the factors or criteria determined in a suitability selection process [16]. Each parameter has a different overlay weight depending on the influence of the tsunami susceptibility parameters on the land. The weighted percentage for each parameter are 45.96% elevation, 25.53% slope, 16.71% distance from coastline, and 11.81% land cover. The overlaid tsunami hazard zone then clipped by the tsunami run-up hazard zone based on inundation impact map. The clipped map can be seen in Figure 7.

**Figure 6.** Tsunami hazard zone based on inundation distance  
**Figure 7.** Weighted overlay result

3.2. Total Population Affected by Tsunami

Population exposure scenarios were carried out using the InaSAFE plug-in in QGIS 2.14.3 software. Indonesia scenario assessment for emergency (InaSAFE) is a tool used to form disaster impact scenarios that can be used for disaster preparedness [17]. Analysis of the number of populations affected by the tsunami used two scenarios using tsunami hazard zone map with a run-up height of 10 m and 5 m. Tsunami vulnerability maps are classified with very high, medium, and low vulnerability classes. The results of data processing with InaSAFE can be seen in Figure 9 for a 10 m run-up height and Figure 10 for a 5 m run-up height. Data processing resulted in an estimate of the total population affected at a run-up height of 10 m as many as 212300 people and run-up 5 m as many as 78700 people.
Figure 8. Total affected population at run-up height of 10 m

Figure 9. Total affected population at run-up height of 5 m
3.3. The Range of Evacuation Shelter Building

There are 28 evacuation shelters located in Pandeglang Regency. Based on the contour of the land, buildings that are below 4 meters above sea level, floors that can be used for evacuation are floors 4 and above, for elevations 4–8 meters above sea level, floors that can be used for evacuation are floors 3 and above, and for elevations 8-12 masl, the floor that can be used for evacuation is the 2nd floor and above. A building with a height of 10 m and above can assume that the building is safe from tsunamis because it is above the inundation height so that it can still be used as an evacuation site.

The speed of tsunami evacuation is taken from the walking speed of dependent elder, which is 1 m/s [18]. The time span for disaster evacuation can be as long as 20 minutes after an earthquake. Thus, the classification of the reach of the tsunami evacuation shelter building is obtained based on walking speed and evacuation time which can be seen in Table 6. The distance classification is used in each shelter and safe zone building. The buffer process then produces a coverage map which can be seen in Figure 14 and the area of each class can be seen in Table 7. Based on the classification that has been done, it is found that 52.21% of the area has been reached by the shelter but the other 47.79% is still outside the range of the evacuation shelter. The map of the evacuation shelter coverage in Pandeglang district can be seen in Figure 10.

| Shelter Range | Travel Time (minutes) | Distance (m) |
|---------------|----------------------|--------------|
| Very near     | 0 – 5                | 0 – 300      |
| Near          | 5 – 10               | 300 – 600    |
| Medium        | 10 – 20              | 600 – 1200   |
| Far           | 20 – 30              | 1200 – 1800  |
| Very far      | >30                  | >1800        |

| Shelter Range Classification | Area | %  |
|------------------------------|------|----|
| Very near                    | 104.93 | 17.34 |
| Near                         | 81.39  | 13.44 |
| Medium                       | 129.74 | 21.43 |
| Far                          | 82.31  | 13.60 |
| Very far                     | 206.95 | 34.19 |
| Total                        | 605.32 | 100  |

Areas that are still far from the shelter building are re-analyzed to determine the number of evacuation shelter buildings needed. The coverage area of shelter buildings for medium classification with a radius of 1200 m is 4.52 km² and the total area in the far and very far categories is 289.26 km². In order for all areas in the tsunami hazard zone to be classified as medium, the minimum required number of shelters is calculated by dividing the area of far and very far classifications. It was found that the minimum required number of additional shelter buildings is 64 evacuation shelters. The additional evacuation shelters were then created using the Polygon Thiessen tool in ArcGIS. Additional shelters are placed in areas with a classification of far and very far reach. Map of the location of additional evacuation shelters with their service areas can be seen in Figure 11.
3.4. Evacuation Shelter Capacity in Pandeglang Regency

The shelter capacity analysis is carried out by comparing the area of each building with the area of space needed for each refugee. Each refugee is assumed to be in a sitting position without a chair (cross-legged or bent his legs forward), and it can be seen that people sitting cross-legged need space of 0.47 m²/person, and people sitting with their legs bent forward need space of 0.55 m²/person [19]. To simplify calculations, both positions are rounded to 0.5 m²/person.

Based on the calculation, the capacity of evacuation shelter in Pandeglang Regency is 46441 people, with the number of exposed residents of 212300 people for the 10 m run-up and 78700 people for the 5 m run-up. This shows that at a run-up height of 10 m, only 21.87% of the refugees can be accommodated by the evacuation shelters, while the other 78.13% cannot be accommodated and at a run-up height of 5 m, 59.01% of refugees can be accommodated by the evacuation shelters, while the other 40.99% cannot be accommodated. From these data, Pandeglang Regency still needs 64 shelter buildings that can accommodate as many as 165859 refugees, or as many as 2592 refugees per shelter.

3.5. Closest Route to Tsunami Evacuation Shelter

The principle of network analyst is to find the most efficient network route from a starting point to a destination point [20]. One of the determining factors for a disaster evacuation route is to move away from the coastline [21]. The analysis is carried out in each village that falls into the tsunami hazard zone. Based on the results, there are only 8 affected urban villages that have the closest evacuation route to the tsunami evacuation shelter, while 30 other villages are heading for the tsunami safe zone. There is 1 sub-district that does not have the closest evacuation route, namely the Ujungkulon National Park Village. There are 38 routes that can be used to get to the evacuation shelter and safe zone in Pandeglang Regency. The tsunami evacuation shelter in Pandeglang Regency is located between 51 and 17966 m from the coastline. In sub-districts located further from the coastline than the nearest shelter building that should be addressed during a disaster, it is better to save yourself by staying away from the beach, namely to a higher place or a safe zone.
Figure 12. The closest route to the evacuation shelter from Carita District

Figure 13. The closest route to the evacuation shelter from Labuhan District.
Figure 14. The closest route to the evacuation shelter from Pagelaran District.

Figure 15. The closest route to the evacuation shelter from Sukaresmi District.
Figure 16. The closest route to the evacuation shelter from Sumur District.

Figure 17. The closest route to the evacuation shelter from Panimbang District.
Figure 18. The closest route to the evacuation shelter from Cigeulis District.

Figure 19. The closest route to the evacuation shelter from Cikeusik District.
4. Conclusions
The conclusions of this study are:
1. The results of the range of tsunami evacuation shelter buildings analysis in Pandeglang Regency is 52.21% of the tsunami hazard zone has been inside the range by the shelter but 47.79% is still outside
the range of the shelter buildings. As many as 64 additional shelter buildings are required so that all areas are within the range of the evacuation shelter building.

2. The evacuation shelter in Pandeglang Regency can accommodate 44661 people. The existing shelters can accommodate 21.87% of refugees in the event of a tsunami with a run up height of 10 m, or 59.01% of refugees if a tsunami occurs with a run up height of 5 m.

3. The analysis produces 38 routes, including 30 sub-district with a closest path to the tsunami safe zone and 8 urban villages to the tsunami evacuation shelter building. The Ujungkulon National Park area is prone to tsunami impacts because it is far from a safe zone and there are no shelter buildings in the area.

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