Development of tsunami inundation map for the coast of Palu City

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Abstract. The 2018 Sulawesi Earthquake and Tsunami severely damaged the coast of Palu City, Indonesia. The city did not have adequate mitigation system for a tsunami. A tsunami inundation map is required. This study based on modelling four scenarios of possible earthquake-induced tsunami. The earthquakes were identified based on data from PUSGEN. The generated tsunami wave is simulated using Delft3D and Delft Dashboard. The wave propagation is modeled using nesting method. This method couples different grid sizes. Nesting process helps to ensure the model efficiency and accuracy. The results provide the maximum inundation map along the Palu City Coast. These results can be used by decision maker to develop the coastal zone management of Palu City. Furthermore, they can be utilized to propose a disaster risk management plan.

1. Introduction
Tsunami may cause severe damages to coastal area. Past incident such as The Great Indian Ocean Tsunami 2004 [1] and The Great North East Japan Tsunami 2011 [2] had shown the massive destruction of coastal area. On September 28, 2018, a shallow strike-slip earthquake of 7.4 Mw struck Central Sulawesi, Indonesia [3]. The epicenter was located at 27 km northeast from Donggala with a 10 km depth. This event triggered a tsunami with a height of 10 meter that damaged coastal areas along the Palu City Coast [4]. It has been speculated that the tsunami was generated by an underwater landslide [5]. The tsunami caused heavy loss in the affected area due to the lack of mitigation system. Thus, tsunami inundation map is very important for future mitigation plan.

Probabilistic Tsunami Hazard Assessment (PTHA) studies showed that Palu City Coast has a probability of 1/50 to 1/10 for 0.5-3.0 m wave [6]. In this study, a set of scenarios are simulated to obtain inundation map for earthquake-induced tsunami in the coast of Palu City. The tsunami sources
are determined based on data from Pusat Gempa Nasional PUSGEN [7]. The wave propagation is simulated using Delft3D and Delft Dashboard [8].

2. Research methodology
The study was carried out in the Coast of Palu City, Central Sulawesi as can be seen in Figure 1. As a capital city, this area had approximately 367,424 people living inside and 395.06 km² of total area [9].

![Figure 1. Study area.](image)

Tsunami propagation and inundation were simulated using Delft3D and Delft Dashboard. The model generates tsunami using finite fault deformation by Okada [10]. This method assumes that an earthquake can occur due to the failure of fault. This failure is explained further in seismic parameters [11]. The wave propagation overland is highly influenced by its landcover. The surface roughness value (Manning) is determined based on the landcover. Manning value of 0.1 is used for the housing area, 0.03 for vegetation area, [12] and 0.002 for seaward area [13].

PUSGEN identifies 3 tectonic thrust or reverse faults around Palu Bay that may trigger a tsunami wave as shown by yellow line in Figure 1. They are North Sulawesi Megathrust, Makassar Strait North, Makassar Strait Central. There are 4 scenarios in this study based on those faults. The scenarios are given in Table 1. The simulation results produce information on the tsunami propagation and inundation. Two numerical wave gauges are placed in the Palu Bay as shown in Figure 1.

| Scenario | Fault                              | Mw (max) | Depth (max) | Dip degree | Rake Degree | Length (km) |
|----------|------------------------------------|----------|-------------|------------|-------------|-------------|
| 1        | North Sulawesi Megathrust          | 8.5      | 20          | 22         | 80          | 480         |
|          | Makassar Strait North              |          |             |            |             |             |
| 2        | Makassar Strait Central            | 7.1      | 14          | 45         | 75          | 100         |
| 3        | Makassar Strait North+             | 7.5      | 14          | 25         | 83          | 170         |
| 4        | Makassar Strait Central            | 8.35     | 14          | 25         | 83          | 270         |
The model uses three different grids, as shown in Figure 2. The first grid (GRID 1) covers domain from the source. The second grid (GRID 2) covers Palu Bay. The last grid (GRID 3) is the finest covering Palu City Coast. The grids are nested in the simulation. The data for bathymetry and topography of Indonesia are available from Badan Informasi Geospasial (BIG). BIG data has a resolution of 8 meters and 20 meters, for topography and bathymetry, respectively. However, the data may not covered area in the deep sea. Therefore, the data were combined to those available from General Bathymetric Chart of The Oceans (GEBCO) which has a resolution of 30 m. GRID 1 uses bathymetry data from GEBCO. GRID 2 contains bathymetry and topography data from GEBCO and BIG. GRID 3 uses only BIG.

3. Results and discussions

3.1. Tsunami wave propagation and inundation simulation

3.1.1. Scenario 1. Tsunami wave propagation and inundation simulation were carried out with 8.5 Mw earthquake magnitude parameters. The maximum initial height of tsunami wave at the fault failure, shown in Figure 3 and Figure 4, is 2.5 to 4 meters.
3.1.2. **Scenario 2.** Tsunami wave propagation and inundation simulation were carried out with 7.1 Mw earthquake magnitude parameters. As can be seen in Figure 5 and Figure 6, the maximum initial height of tsunami wave at the fault failure is 0 to 1 meter.

![Tsunami wave propagation Scenario 1](image1)

**Figure 5.** Tsunami wave propagation Scenario 1: a) t=5 mins, b) t=10 mins, c) t=45 mins, and d) t=120 mins.

![Tsunami wave height and observation point](image2)

**Figure 6.** a) Initial tsunami wave height, b) wave height at observation point.

3.1.3. **Scenario 3.** Tsunami wave propagation and inundation simulation were carried out with 7.5 Mw earthquake magnitude parameters. The maximum initial height of tsunami wave at the fault failure, as in Figure 7 and Figure 8, is 0 to 2 meters.

![Tsunami wave propagation Scenario 1](image3)

**Figure 7.** Tsunami wave propagation scenario 1: a) t=5 mins, b) t=10 mins, c) t=45 mins, and d) t=120 mins.

![Tsunami wave height and observation point](image4)

**Figure 8.** a) Initial tsunami wave height, b) wave height at observation point.
3.1.4. Scenario 4. Tsunami wave propagation and inundation simulation were carried out with 8.35 Mw earthquake magnitude parameters. As can be seen in Figure 9 and Figure 10, the maximum initial height of tsunami wave at the fault failure is 1.5 to 4 meters.

![Figure 9. Tsunami wave propagation scenario 1: a) t=5 mins, b) t=10 mins, (c) t=45 mins, and d) t=120 mins.](image1)

![Figure 10. a) Initial tsunami wave height, b) wave height at observation point.](image2)

3.2. Tsunami inundation map

Tsunami simulation provides the inundation maps for each scenario as shown in Figure 11. The maps were compared and processed further to obtain the maximum inundation map as shown in Figure 12. It was found that the total inundated area is 3.355 km2. Area closer to the coastline may experience tsunami with a height of more than 5 meter.

![Figure 11. Tsunami inundation map for: a) scenario 1, b) scenario 2, c) scenario 3, d) scenario 4.](image3)
Figure 12. Maximum tsunami inundation map.

4. Conclusion
This study assessed the tsunami hazard in Palu City. Palu Bay in general, are located near 3 possible earthquake induced tsunami sources. Palu Coast inundation map was developed based on these faults, deterministically. A combination of failures from the Makassar Strait North and Central (Scenario 4) generates a massive tsunami. The generated wave may reach Palu Coast, affecting an area of 3,355 km². The wave height at the coastline may exceed 5 meters. The developed inundation map can be used by decision maker to develop the coastal zone management of Palu City. It also provides valuable information for future mitigation plan of the city. It is also important to improve the quality of the models around the area of Palu Estuary by adding a massive structure like Palu Bridge which is contained bridge pillars. Further research is needed on tsunami propagation and inundation modelling by considering this aspect.

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