Cut and fill analysis of Palu Bay seabed topography pre and post-tsunami

Khomsin, D G Pratomo and L O F Susanto

Geomatics Engineering Department, Institut Tenologi Sepuluh Nopember, Keputih, Sukolilo, Surabaya, 60111, Indonesia.

Abstract. Palu Bay is an earthquake-prone area, in September 2018 tectonic earthquake occurred in Donggala District, Central Sulawesi, which caused tsunami due to underwater landslides. One of the impacts caused by the tsunami was changes in bathymetry. In tsunami post-disaster reconstruction, further studies regarding seafloor topography information of affected areas are needed. This study examines and analyzes the underwater landslide in Wani, Palu Bay 2018 before and after the underwater landslide using bathymetry, and coastline data to determine cut and fill volume. The analysis was conducted on the three components: contouring, slope/gradient, and volumetric (cut and fill). The contouring results show significant depth changes at the 200-meter contour on Tanjung Labuan, Palu. The volume calculation from two surfaces shows 59,512,720.790 m$^3$ cut and 12,466,252.630 m$^3$ fills in the landslide area.

1. Introduction
The Palu Koro fault is a fault that divides Sulawesi into two, starting from the waters of the Sulawesi Sea with the Makassar Strait to the Bone Bay. This fault is said to be very active due to its movement reaching 35 to 44 mm per year [1]. Palu Bay is an area that is prone to earthquakes; this is due to its position in the active fault area of Koro Palu which has high seismic activity. On September 28th, 2018, there was a flat type tectonic earthquake with magnitude 7.4 SR in Donggala District, Central Sulawesi, which resulted in a tsunami due to landslide of the seafloor [2]. According to the Navy's Hydro-Oceanographic Center (PUSHIDROSAL), underwater landslides that caused tsunamis in Palu Bay were in Tanjung Labuan, Wani, Central Sulawesi [3].

One of the possible impacts of the tsunami was changes in bathymetry, destruction of vital public facilities and infrastructure in the coastal areas, and the carrying of material from the land. Bathymetry or underwater topography is one of the main components that affect the hydrodynamics that occurs on a seafloor [4]. In post-disaster reconstruction, further studies are needed regarding topographic information on the seafloor of the affected areas.

In this study, pre and post-tsunami seafloor topography information analyzed in three components: contour, slope, and volume. The contour analyzed to identify topographic changes in the seabed. Slope changes are often associated with tsunamis [5]. In this study, the slope making aims to provide an overview of the topographic changes that occur due to underwater landslides and tsunamis. Calculation of changes in topographic volume is carried out to determine landslide material and the method used for that volume is a cross section method.
2. Methodology

2.1. Study area
The location used as a case study in this study is Tanjung Labuan, Wani Sea, Palu Bay, Central Sulawesi Province, Indonesia.

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

2.2. Data survey
The data survey used to support this research are:

- Bathymetry data with 1: 10,000 scale for Wani Sea, Palu Bay obtained in 2012 from the Indonesian Navy's Hydrographic and Oceanographic Center.
- Bathymetry data with 1: 10,000 scale for Wani Sea, Palu Bay obtained in 2018 from the Indonesian Navy's Hydrographic and Oceanographic Center.

2.3. Data processing
Contouring is done to identify topographical changes in the seabed that occur using Wani sea bathymetry data in 2012 and 2018 with 1:10,000 scale. The first step in making a contour is to interpolate depth data from known points using the IDW method. The Inverse Distance Weighted (IDW) method is an interpolation technique that assumes each plot has a local influence, and the plot value decreases with distance [6]. This method assumes that the interpolation value is more similar in the near sample data than the further one. Weight change linearly according to the distance with sample data [7]. The results of depth interpolation are then processed into contour data and then overlayed contour data in 2012 and 2018.

The slope calculation is carried out on the pre and post-tsunami bathymetry data to identify the slope changes. The results of depth interpolation are processed into slope data, then classified into several classes [8]. Volume calculation is done to determine the changes in bathymetry that occurred due to the tsunami. The principle of volume calculation in this study is to calculate the cut and fill the volume of two depth data using the cross-section method. The volume is calculated based on post-tsunami depth data on pre-tsunami depth data [9].
3. Result and discussion

3.1 Contour analysis

From the results of the contour overlap, it is known that significant topographic contour changes occur in the Wani waters which indicate the occurrence of underwater landslides in the area. There was an increase in depth at the contours of 150 m and 200 meters, but at a contour of 250 meters siltation occurred in the west and northwest areas.

![Figure 2. Study area map](image)

To visualize the topographic changes, in Figure 3 showed the topographic difference between 2018 and 2012. Addition of depth occurred in coastal area and siltation in the western area up to 90 meters deep.
3.2 Slope analysis
Slopes are natural sightings caused by significant differences in two places. The slope is one of the topographic elements and is a factor in erosion. In the calculation of the 2012 slope, the slope varies from 0% to 100%. Based on the classification in Table 1, the topography of the Wani sea is dominated by a moderate slope (8% -25%) [10].
Table 1. Slope Class

| Range     | Class    |
|-----------|----------|
| 0% - 8%   | Low      |
| 8% - 25%  | Moderate |
| 25% - 40% | High     |
| 40% - 100%| Very High|

In the calculation of the 2018 slope, the slope varies from 0% to 78%. Based on the classification in Table 1, the topography of Wani sea is dominated by a moderate slope (8% - 25%) [10]. There was a change in the slope in the northern area. In 2012, the slope in the coastal area was in the category of high and low in the deepest area.

![Figure 5. 2018 Slope](image)

3.3 Volume Analysis

After the area of topographic change is known, to determine the volume of pre and post-tsunami topography changes, volume calculations are carried out using a cross-section method with a distance of 50 meters per section. The following is the result of the area and volume in each section by calculating using cross-sections.

Table 2. Total Volume

| Station | Cut Area (m²) | Fill Area (m²) | Cumulative Cut Volume (m³) | Cumulative Fill Volume (m³) |
|---------|---------------|---------------|---------------------------|-----------------------------|
| 1+50    | 1462.77       | 26750.75      | 57091493.12               | 9274960.13                  |
| 1+100   | 3212.97       | 24313.31      | 57208385.93               | 10551561.60                 |
| 1+150   | 5642.09       | 16345.35      | 57429761.75               | 11568027.89                 |
| 1+200   | 9202.15       | 7184.05       | 57800867.63               | 12156262.71                 |
From the calculation of the volume between two depth surfaces, the volume of decreasing material is 59,512,720.79 m$^3$, and the piled material is 12,466,252.63 m$^3$. The most abundant material stack occurs at the western end of the area, as shown in Figure 3. The significant difference in material volume can be caused by landslide material that accumulates in an area more than 350 meters deep or outside the observation area.

4. Conclusion

a. The seabed topography on the Wani sea after the tsunami has increased the depth of 150 m to 200 m contours, but at 250 m contour to the west area, there is siltation due to the accumulation of material reaching 90 m.

b. The pre-tsunami slope of the northern coastal area is steeper than the post-tsunami slope, and in the western area, the slope changes from high class to moderate class.

c. The underwater topography volume calculation between pre- and post-tsunami surfaces show an increase in the volume by 12,466,252,630 m$^3$ and volume decreased by 59,512,720,790 m$^3$ after the tsunami.

5. References

[1] B. S. Wicaksono, “Apa itu Sesar Palu Koro yang Menyebabkan Tsunami dan Gempa Bumi?,” Kompas, Jakarta, 29-Sep-2018.

[2] H. Latief, “Pakar ITB Pastikan Tsunami Palu Akibat Longsoran Endapan,” Tempo. co, 2018.

[3] E. A. Retaduari, “KRI Spica Temukan Longsoran Dasar Laut di Teluk Palu,” Jakarta, 2018.

[4] P. Widyanto, Muslim, H. Suseno, and M. Makmur, “Pengaruh Batimetri Perairan Terhadap Distribusi Plutonium-239/240 (239/240pu) Dalam Sedimen Di Perairan Gresik,” J. Oseanografi, vol. 3, pp. 448–453, 2014.

[5] S. G. Wright and E. M. Rathje, “Triggering mechanisms of slope instability and their relationship to earthquakes and tsunamis,” Pure Appl. Geophys. , vol. 160, no. 10–11, pp. 1865–1877, 2003.

[6] M. A. Widiawaty, M. Dede, and A. Ismail, “Kajian Komparatif Pemodela Air Tanah Menggunakan Sistem Informasi Geografis di Desa Kayuambon, Kabupaten Bandung Barat,” J. Pendidik. Geogr. , vol. 18, no. 1, pp. 63–71, 2018.

[7] G. H. Pramono, “Akurasi Metode IDW dan Kriging untuk Interpolasi Sebaran Sedimen Tersuspensi di Maros, Sulawesi Selatan,” Forum Geogr. , vol. 22, no. 2, p. 145, 2008.

[8] A. Hidayat, B. Sudarsono, and B. Sasmito, “Survei Bathimetri Untuk Pengecekan Kedalaman Perairan Wilayah Pelabuhan Kendal,” J. Geod. Undip J. Geod. Undip, vol. 3, no. April, pp. 28–43, 2014.

[9] I. Muda, Teknik Survei dan Pemetaan. Jakarta: Departemen Pendidikan Nasional, 2008.

[10] M. Khoiri, L. M. Jaelani, and A. Widodo, “Landslides Hazard Mapping Using Remote Sensing Data in Ponorogo Regency, East Java,” Internet J. Soc. Soc. Manag. Syst. , vol. 11, no. 2, pp. 101–110, 2018.

Acknowledgments

Authors thank to Hydrography and Oceanography Center, Indonesian Navy (PUSHIDROSAL), for data support and guidance during this research.