Analysis of the area affected by the tsunami in Pandeglang, Banten: a case study of the Sunda Strait Tsunami

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Abstract. Pandeglang District becomes a concern because one of the locations had an impact on the Tsunami on December 22, 2018. Its position in the western waters and directly facing the Anak Krakatau Volcano is very potentially vulnerable. The Tsunami triggered by the volcanic activity of Anak Krakatau Volcano, mountain avalanche material. Evaluation regarding coastal land affected is also needed to anticipate future disasters. The study of the coastal areas affected by extraordinary events, such as the Tsunami, was carried out by stakeholders in evaluating coastal land to be more responsive to disasters. Three sub-districts with different morphology selected as samples of the affected areas, Labuan, Sumur, and Panimbang. We used high-resolution Sentinel 2.0 images and Elevation Model Data (SRTM DEM) with unsupervised classification method to perform analysis of the area affected by Tsunami condition on coastal features. The results showed that the area affected especially the low land, as open land area at Labuan Sub-district was 189,298 Ha, Sumur Sub-district, 144,837 Ha, and Panimbang Sub-district was 282.852 Ha. Varied inundation range 50 - 200 meters from the coastline. The elevation of the three sub-districts shows vulnerable areas with an elevation of <2.5 m to 0.5 m above sea level.

1. Introduction
Anak Krakatau, a volcanic mountain located in the Sunda Strait, between the southern coast Sumatra and west coast Java [1]. Unusual events happened such as Tsunami, occur as a result of seismic activity, but on December 22nd, 2018 tsunami occurred due to volcanic activity, rapidly flank collapse impacting the waters [2]. History records that volcanic activity from Krakatau has occurred twice, in 1883 and 1928, resulting in Tsunamis and self-blasting [2][3].

That tsunami-affected Pandeglang Regency, Banten. Its position in the western waters and directly facing Mount Anak Krakatau. Previous simulation studies mentioned, the location of the Pandeglang area that was directly affected by the Mount Anak Krakatau Tsunami, including Anyer, Merak, Carita, Labuan, and Panimbang [2]. Tsunami is the most dangerous natural disasters, besides earthquake [4].

The coastal environment is a phenomenon with complexity. Land use is an essential problem for coastal zone management at the regional level, where the Tsunami is an indication of land-use changes [5]. A tsunami that occurred in 2004 showed the presence of changes in the area, especially in coastal areas to the land with low elevation [6][7]. This case can also be sure to occur in the coastal areas of Pandeglang. A quick post-event assessment can provide valuable information that will be very useful for assessing the extent of the area affected so that further level mitigation studies and evaluation of spatial plans can carry out [4][8].

This study aims to recognize the changes in area size as the impact of the Tsunami by comparing land-use classifications before and after the disaster happened. This study focuses on land-use area...
changed on three Sub-district locations, namely Labuan, Panimbang, and Sumur (Figure 1). Imagery data used are Sentinel 2.0 satellites and Elevation Model Data (DEM SRTM) of Java.

2. Methodology and application

2.1. Data collection

The data collected from Sentinel 2.0, remote sensing satellite with multi-spectral passive sensors have 13 bands, four bands with a resolution of 10m, sweeping area of 290 km [9]. The location of satellite imagery is in the north and south coast of Pandeglang Regency (Figure 1), the condition before and the Tsunami (November 16, 2018) and after the Tsunami (January 5, 2019), used for the classification area affected by Tsunami. This data also used as a ground-truth reference. SRTM DEM (8m) Java and other maps are also used to improve image interpretation. The date of image acquisition, classification, and resolution are shown in Table 1 and Figure 2.

Ground-truth samples used to support remote sensing studies for validation of the study area affected by the tsunami waves. Spatial ground-truth is carried out by visual impact monitoring and observation [10]. This method used to improve and strengthen the validation of the results satellite analyzes [11].

Figure 1. The imagery of the study area the western coast of Java, Pandeglang Regency with Mount Anak Krakatau. Labuan, Panimbang, and Sumur sub-district are the focus of the study location of affected areas by Tsunami.

2.2. Analysis of imagery spatial

The spatial analysis process consists of combining sentinel satellite imagery, image correction, image cropping based on sub-district classification, unsupervised classification, and polygon area calculation before and after the Tsunami. The flow chart displayed by Figure 2 shows the flow of work processes in carrying out the analysis.

The combined sentinel satellite image band consists of bands 2, 3, and 4 (visible light), and band 8 (near-infrared) on the Sentinel-2 imagery. Correction analysis of the image was applied before classifying the study area, then the and existing conditions images were geographically co-registered. Cutting areas per sub-district (Sumur, Panimbang, and Labuhan) uses the district administration map with the latest digitized coastline data. The work system of the unsupervised classification method was applied to the next stage, which is to group pixel values of an image into spectral classes with clustering algorithms each interaction were calculated with reclassification pixel to new form [12].
Then the before after imagery are classified into thematic classes including green vegetation (forest, grass, mangrove, etc.), farmland (lading, rice fields, etc.), settlement (housing, building, etc.) water area (river, lake, etc.) and open land (indicated land change impact by tsunami) [4][5][8].

| No | Imagery Code | Source | Resolution | Acquisition      |
|----|--------------|--------|------------|------------------|
| 1. | Sentinel 2.0 - L1C_T48MWT_A010039 20181116T031458 | https://earthexplorer.usgs.gov/ | 10 meters | November 16, 2018 |
| 2. | Sentinel 2.0 - L1C_T48MWT_A018476 20190105T030703 | https://earthexplorer.usgs.gov/ | 10 meters | January 5, 2019  |
| 3. | Sentinel 2.0 - L1C_T48MWU_A017761 20181116T031814 | https://earthexplorer.usgs.gov/ | 10 meters | November 16, 2018 |
| 4. | Sentinel 2.0 - L1C_T48MWU_A018476 20190105T030703 | https://earthexplorer.usgs.gov/ | 10 meters | January 5, 2019  |
| 5. | DEM SRTM Java | http://tides.big.go.id/DEMNAS/ | 8 meters | January 8, 2019 |
| 6. | Map of Geological Region (Serang, Cikarang, Ujung Kulon) | Pusat Penelitian dan Pengembangan Geologi (P3G) | - | 1992 |
| 7. | Map of Administrative Sub-district | Badan Informasi Geospasial | 1: 1000000 | 2009 |

Figure 2. Flowchart for the proposed area analysis affected by the Tsunami run-up on three Sub-district (Labuan, Panimbang, and Sumur Sub-district).
3. Result

3.1. Land-use in Panimbang Sub-district, the changes area due to the impact of the tsunami

The results of satellite imagery analysis show that the area in 3 Sub-districts namely Sumur, Panimbang, and Labuan, respectively 9408.055 Ha, 9173.422 Ha, and 6344.23 Ha. Visually shown in Figure 4 - 6, the massive disaster of Tsunami occurred a significant impact on the changes in coastal area.
Figure 4. Land-use type before Tsunami on November 16, 2018 (left panel) and after Tsunami on January 5, 2019 (right panel) result by unsupervised classification from Sentinel 2.0 image, Labuan Sub-district area, Pandeglang Banten.

Interpretation of Sentinel 2.0 imagery before the Tsunami (November 16, 2018) and after the Tsunami (January 5, 2019) in the Labuan sub-district showed an impact on land use throughout the Labuan sub-district, shown in Figure 5. The total area of the sub-district is 6377.234 ha, land use is classified by 5 classifications namely green vegetation (forest, vegetation, gardens etc.), farmland (lading, rice fields etc.), settlements (housing, buildings etc.) water areas (river, lake etc.) and open land (indicating the impact of land changes due to the tsunami) [4][5][8]. The land use of the Labuan Sub-district is mainly by green vegetation and farmland, focusing on the west coast before the green vegetation in the area that dominates the coast.

Before the Tsunami, the results of the unsupervised method had an area of 6342.835 ha, then after the Tsunami, the area of land had increased by 0.022% to 6344.234 ha. Changes in the land area occurred in 5 land-use classifications in Labuan Sub-district. The results are shown in Figure 4 and Table 2. Before the tsunami, the green vegetation had an area of the land cover of 4413.210 ha, change of 6.435%, which reduction in the land cover area of 283.975 ha. Farm land before the tsunami classification calculation results show an area of 1107.388 ha, then area reduction 187.546 ha or around 16.936% to 919.842 ha. Settlement cover shows the same condition, the reduction of land area by 28.146%, which is 276.470 ha, this value shown urban areas as settlement are complex situation area damaged [4]. The water area (ponds, rivers, and others.) reduce 46.419% from 16.929 ha. Figure 4 shows that there is a water area on the north side along the coastline of the Labuan Sub-district recorded before the Tsunami, after the Tsunami the water area classification is no longer visible on the north coast, replaced by open land.

The classification of open land-use is an indication the impact of Tsunami on the coastal area of Labuan Sub-district. Open land does not only cover areas along the coast of Labuan Sub-district; it covers almost the entire area. Figure 4 shows the increase in the open land area along the coast which is shown in red at the results, before the tsunami (Figure 4, left panel) and after the Tsunami (Figure 4, right panel). The addition of open land area is 176.9%, which is 189.298 ha from 107.009 ha to 296.307 Ha.
Table 2. Changes in area in land-use classification and percentage change area before and after Tsunami, Labuan Sub-district.

| Land-use      | Area Sub-District | Labuan Sub-district | Changes in Area (ha) | Percentage Change Area (%) |
|---------------|-------------------|--------------------|----------------------|---------------------------|
|               | Before Tsunami;   | After Tsunami;     |                      |                           |
|               | November 16, 2018 | January 5, 2019    |                      |                           |
| Green Vegetation | 4413.210         | 4129.235           | -283.975             | 6.435                     |
| Farm Land     | 1107.388          | 919.842            | -187.546             | 16.936                    |
| Settlement    | 982.274           | 705.804            | -276.470             | 28.146                    |
| Water's Area  | 16.929            | 9.071              | -7.859               | 46.419                    |
| Open Land     | 107.009           | 296.307            | 189.298              | 176.900                   |
| Total Area (ha) | 6342.835         | 6344.234           |                      |                           |

3.2. The land-use in Labuan Sub-district, the changes area due to the impact of the tsunami
Panimbang Sub-district is on the southwest side of the Labuan Sub-district, a coastal area with bay morphology. Panimbang Sub-district change in the land area both an increase in land area and a reduction in land area that occurred against five land use classifications in this area. Almost along the coastline of Panimbang Sub-district shown in Figure 5 which was dominated by green vegetation to farmland before the Tsunami (Figure 5, top panel), after the Tsunami, it became open land (Figure 5, bottom panel).

Figure 5. Land-use type before Tsunami acquired on November 16, 2018 (top panel) and after Tsunami acquired on January 5, 2019 (bottom panel) result by unsupervised classification from Sentinel 2.0 image, Panimbang Sub-district area, Pandeglang Banten.
Figure 5 and Table 3 show the significant land-use changes that occurred in Panimbang District. The area of Panimbang District before the Tsunami was 9168.087 Ha after the Tsunami showed an increase of the area 9173.422 Ha, this is the result of analysis with the unsupervised classification of Sentinel 2.0 imagery. Land-use land area changes in the form of a reduction in the land area occurred to green vegetation, farmland, settlement, and water areas, while the open land area had increased.

Green vegetation changes 3.611% with area 5696.565 ha to 5490.851 Ha the total of the change was 205.714 ha. Land-use on farmland experienced a reduction in land area by 41.507 ha or 1.596% from the previous of 2600.439 ha. The settlement area before the Tsunami had an area of 590.490 ha to 565.319 ha with a reduction of 25.170 ha (4.263% of the land area before the Tsunami). Water area is a representation of the area of ponds, rivers and so on experiencing changes in land area with a decrease of 5.131 ha or as much as 4.988% of the area of land before the Tsunami 102.873 ha. Land-use open land is indicated as vacant land due to the impact of Tsunami sweep [13]. Figure 5 in the bottom panel shows the increase of open land area along the coastline of Panimbang Sub-district, the area of land before the Tsunami was 177.720 ha, after the Tsunami an increase in the area of open land is 460.578 ha or 282.858 ha, 159.159% of the previous land area. Figure 5 shows the open land along the coast (red area) increased a lot after the Tsunami, it most affected on area changes [5].

### Table 3. Changes area in land-use classification and percentage change area before and after Tsunami, Panimbang Sub-district.

| Land-use                  | Area (ha) Before Tsunami; November 16, 2018 | Area (ha) After Tsunami; January 5, 2019 | Changes in Area (ha) | Percentage Change Area (%) |
|---------------------------|---------------------------------------------|------------------------------------------|----------------------|----------------------------|
| Green Vegetation          | 5696.565                                    | 5490.851                                 | -205.714             | 3.611                      |
| Farm Land                 | 2600.439                                    | 2558.932                                 | -41.507              | 1.596                      |
| Settlement                | 590.490                                     | 565.319                                  | -25.170              | 4.263                      |
| Water's Area              | 102.873                                     | 97.742                                   | -5.131               | 4.988                      |
| Open Land                 | 177.720                                     | 460.578                                  | 282.858              | 159.159                    |
| Total Area (ha)           | 9168.87                                     | 9173.422                                 |                      |                            |

3.3. The land-use in Sumur Sub-district, the changes area due to the impact of the tsunami

Extensive changes significant changes in open land area to land along the coastline of the Sumur Sub-district are shown in Figure 6. Sumur Sub-district is on the west coast of Banten on the south side; its location is parallel to the wavefront [1][2]. Changes in land area along the coast of Sumur Sub-district as shown in Figure 6, are displayed in the form of a table of land area presented in Table 4. Along the coast of Sumur Sub-district, quite a lot is dominated by land-use classification in the form of green vegetation, farmland, settlement, and water area. After the Tsunami many of these areas reduce and the open land area expanded. Open land at the time before the Tsunami was 27.001 ha, an increase of up to 536.422% or around 144.837 ha to 171.837 ha.

Significant changes in the area of open land along the coastline of the Sumur Subdistrict are shown in Figure 6. Sumur Subdistrict is on the west coast of Banten on the south side; its location is parallel to the wavefront [2]. Changes in the land area along the coast of Sumur Subdistrict as shown in Figure 6, are displayed in the form of a table of the land area presented in Table 4. Along the coast of Sumur Subdistrict, quite a lot is dominated by land-use classification in the form of green vegetation, farmland, settlement, and water area. After the Tsunami, many of these areas have been reduced, and the open land area expanded. Open land at the time before the Tsunami was 27.001 ha, an increase of up to 536.422% or around 144.837 ha to 171.837 ha.
Figure 6. Land-use type before Tsunami acquired on November 16, 2018 (left panel) and after Tsunami acquired on January 5, 2019 (right panel) result by unsupervised classification from Sentinel 2.0 image, Sumur Sub-district area, Pandeglang Banten.

Table 4. Changes area in land-use classification and percentage change area before and after Tsunami, Sumur Sub-district.

| Area Sub-District | Sumur Sub-district | Land-use          | Area (ha) Before Tsunami; November 16, 2018 | Area (ha) After Tsunami; January 5, 2019 | Changes in Area (ha) | Percentage Change Area (%) |
|-------------------|--------------------|-------------------|--------------------------------------------|------------------------------------------|-----------------------|-----------------------------|
|                   |                    | Green Vegetation  | 7642.907                                   | 7535.141                                 | -107.765              | 1.410                       |
|                   |                    | Farm Land         | 1485.780                                   | 1476.456                                 | -9.324                | 0.628                       |
|                   |                    | Settlement        | 220.764                                    | 205.162                                  | -15.601               | 7.067                       |
|                   |                    | Water's Area      | 23.077                                     | 19.458                                   | -3.619                | 15.681                      |
|                   |                    | Open Land         | 27.001                                     | 171.837                                  | 144.837               | 536.422                     |
|                   | Total Area (ha)    |                   | 9399.53                                    | 9408.055                                 |                       |                             |

3.4. Open–land area assessment overlayed on SRTM DEM Of Java

Based on overlay analysis with DEM Java SRTM from Labuan, Sumur, and Panimbang Sub-districts given in Figure 7 the coastal area as a whole is low land with elevation <2.5 m - 0.5 m above sea level with a distance of 50 - 200 m from the coastline are vulnerable area. The relief conditions of the three districts are tsunami-prone areas with a category [14] that reliefs with heights ≤ 5 m are included in the very vulnerable category and also mentioned that the Sub-districts of Labuan, Sumur, and Panimbang are included in that category with the extent of the area affected sequential 189.298 ha, 144.837 ha, and 282.858 ha. Low elevation of much on this area are significant risk by Tsunami damage [2].

Table 5. shows the comparison of land changes between the three districts. Labuan Sub-district experienced an increase in the land area of 189.296 ha, a percentage of 176.900%, Panimbang Sub-district experienced an increase in the land area of 282.858 ha, the percentage increase was 159.159%,
and the Sumur sub-district was 144.387 ha with a percentage of 536.422%. Sumur Sub-district are the areas that have the most significant impact, although significant changes in land area to the classification of open-land with a percentage change of 536.422% from previous land area conditions, the Sumur Sub-districts coastline position is quite open with the direction of the wavefront from the source, resulting in a run-up of waves far enough inland [2].

![Figure 7. Map of damage assessment indicated area change, overlayed on SRTM DEM on three Sub-district, Labuan Sub-district (left-top panel), Sumur Sub-district (right-top panel), and Panimbang Sub-district (bottom panel).](image)

**Table 5.** Total Changes area in land-use classification and percentage change area before and after Tsunami, compared by three sub-district (Labuan, Panimbang, and Sumur), Pandeglang, Banten.

| Land-use       | Labuan Sub-district |          | Panimbang Sub-district |          | Sumur Sub-district |          |
|----------------|---------------------|----------|------------------------|----------|--------------------|----------|
|                | Changes in Area (ha)| Percentage Change Area (%) | Changes in Area (ha)| Percentage Change Area (%) | Changes in Area (ha)| Percentage Change Area (%) |
| Green Vegetation | -283.975             | 6.435    | -205.714               | 3.611    | -107.765           | 1.410    |
| Farm Land      | -187.546             | 16.936   | -41.507                | 1.596    | -9.324             | 0.628    |
| Settlement     | -276.470             | 28.146   | -25.170                | 4.263    | -15.601            | 7.067    |
| Water's Area   | -7.859               | 46.419   | -5.131                 | 4.988    | -3.619             | 15.681   |
| Open Land      | 189.298              | 176.900  | 282.858                | 159.159  | 144.837            | 536.422  |
Figure 8. Some pictures of coastal locations around Panimbang Sub-district after the Tsunami event as a result of ground truth with visual observations and documentation.

Figure 9. Some pictures of coastal locations around Sumur Sub-district after the Tsunami event as a result of ground truth with visual observations and documentation.

4. Conclusion
Based on the results of this study, it can be concluded that the massive disaster Tsunami had an impact on changes in coastal area (open land) in the form of additional land. Each of the additional land in the open land classification is Labuan Sub-district of 189.298 ha with a percentage change 176.9%, Panimbang Sub-district 282.858 ha with a percentage of area change 159.159%, and Sumur Sub-district 144.837 ha with the most significant percentage of area change 536.422%, with elevation < 2.5 m - 0.5 m above sea level.

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