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Post-Tsunami Shoreline Changes in Parts of Palu Bay

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ABSTRACT

This research was conducted in part of Palu Bay which is included in the administrative area of Palu City. The problems in this study are: (1) How is the change of coastline in some parts of Palu Bay? (2) How much area was affected by the Tsunami in parts of Palu Bay? This study aims to: (1) To know the changes of coastline in some parts of Palu Bay. (2) Know the area affected by the Tsunami in part of Palu Bay. This type of research is quantitative descriptive research. The method used to obtain data is by using Geographic Information System (GIS) analysis with overlay techniques. The results showed that there were changes in the coastline in the form of abrasion or loss of land with a total area of 61.53 hectares and additional land (accretion) with a total area of 5.1 hectares. The total area affected by the tsunami in parts of Palu Bay amounted to 622.83 hectares. The sub-districts that experienced the largest tsunami impact were the Tawaeli district with an area of 169.96 hectares, Mantikulore sub-district with an area of 145.55 hectares, the North Palu sub-district with an area of 116.25 hectares, the Ulujadi sub-district with an area of 104.66 hectares, the West Palu sub-district with an area of 58.39 hectares, while East Palu sub-district was the smallest tsunami impacted area with an area of 28.02 hectares.

1. Introduction

The city of Palu and its surroundings are one of the areas that often experience earthquake events. This event occurs because there is a large-dimension fault that stretches from northwest to southeast, starting from the Sulawesi Sea to the north coast of the Bay of Bone, this fault is the active Palu Koro fault which often causes tectonic earthquakes.

The 7.4 magnitude earthquake that occurred on September 28, 2018, resulted in a tsunami in Palu Bay and surrounding areas. The tsunami resulted in damage to infrastructure, casualties, and damage to coastal areas. One of the damages that occurred was the loss of beach material which had implications for changes in the coastline.

The shoreline changes in question are forward changes (accretion) and backward changes (abrasion). The coastline is said to advance if there are indications of deposition and or land uplift (*emerge*). While the coastline is said to retreat if there is an abrasion process and/or sinking of land (*sub-merge*) [1].

A beach is a geographical shape that consists of sand and is found in coastal areas. The coastal area is the boundary between land and sea waters. [2]. The part that separates the land from the ocean is called the shoreline. The shoreline is defined as the boundary between land and water surface. Several factors affect shoreline changes, namely hydrology, geology, climate, and vegetation. Therefore, it is necessary to update the shoreline change map continuously. This update is needed to determine the driving factors and information for coastal resource management, coastal environmental protection, and also for sustainable development planning in coastal areas. [3].

The results of the initial survey in some parts of Palu Bay after the tsunami were observed to have submerged or lost some land and significantly damaged infrastructure. Therefore, information in the form of maps of shoreline changes, data on the area of lost beaches, and the extent of the impact of the tsunami in parts of Palu Bay is needed considering that the coastline in the coastal area of Palu City has changed after the Tsunami.

Shoreline changes can be monitored using remote sensing technology. This is in accordance with the statement [4] that the use of remote sensing techniques on Landsat image datasets and Geographic Information System (GIS) techniques plays a very important role as a cheap and easy method of providing data on the coverage of coastal areas and the dynamics therein and this combination technique is ideal in mapping the distribution of land and water changes needed in extracting shoreline changes.

Currently, the availability of post-tsunami shoreline change maps is needed as information and if possible as a reference for the Palu City government for more focused and directed development in the coastal areas of Palu City.

2. Method

This type of research is quantitative descriptive research. The method used to obtain data is Geographic Information System (GIS) analysis with overlay techniques, where this research identifies changes in the coastline and lost beach area after the tsunami that occurred in part of Palu Bay. The approach used in this research is a spatial approach. The spatial approach is a method to understand certain symptoms in order to have in-depth knowledge through the medium of space, in this case, the space variable gets the main position in every analysis [5]. [5]

This research was conducted in part of Palu Bay which is included in the administrative area of Palu City, Central Sulawesi Province as presented in Figure 1. Astronomically, Palu City is located between 0º.36" - 0º,56" LS, and 119º.45" - 121º.1" EAST.

The tools used in this research are a laptop that has been installed with image processing software and GIS analysis, a camera, GPS, and stationery. The materials used are IKONOS images in 2017 before the tsunami & IKONOS images in 2018 after the tsunami as well as RBI maps related to the research location.

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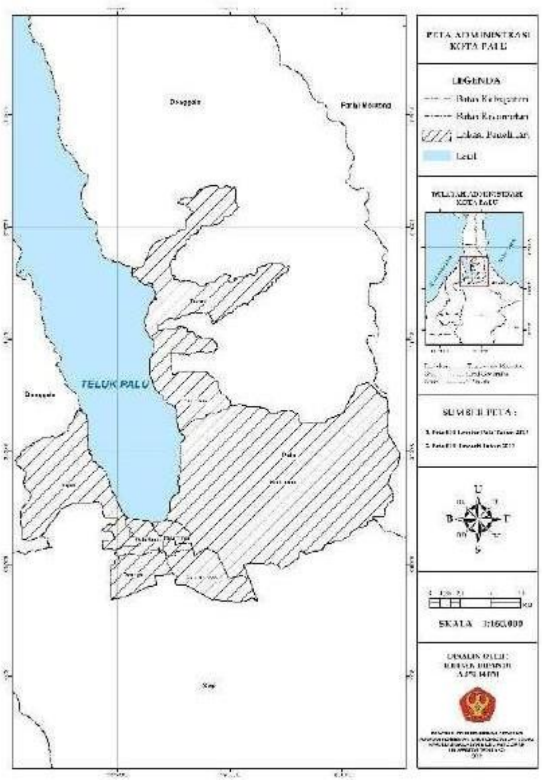

Image 1. Research Location Map

The initial processing of data in this study was carried out by utilizing Quantum GIS 2.18 and ENVI 5.3 *software*, as for the data management stages are as follows:

1. Processing the Indonesian Earth Shape Map of Palu, East Palu, Tawaeli, and Ulujadi Sheets resulted in the administrative boundaries of the study area.
2. Cutting the image (cropping) according to the research area with the aim of facilitating the image interpretation process and selecting a combination of bands in the image to clarify the visual image during the layer digitization process.
3. Geometric correction of the 2017 IKONOS image before the tsunami and the 2018 IKONOS image after the tsunami was carried out on each image in order to improve the position of the image due to the geometric distortion process. Geometric correction is carried out by utilizing ENVI 5.3 software by selecting *Ground Control Points* (GCP) using GPS. The field control points selected are points that will not change for a long time, such as bridges and road intersections.
4. Interpretation using the layer *digitizing* technique (*digitizing on screen*) produced a pre-tsunami coastline map in 2017 and a post-tsunami coastline map in 2018. The 2017 & 2018 coastline maps were then processed through attribute data to produce pre- and post-tsunami coastline length data.
5. Conduct an accuracy test by making 30 sample points consisting of 15 land prediction points and 15 sea prediction points.
6. Shoreline maps before and after the tsunami were then processed using *overlay* techniques to produce shoreline change maps for 2017 - 2018. The overlay results were then processed through attribute data to produce post-tsunami shoreline change data in parts of Palu Bay.

The data analysis used in this research is:

1. *Overlay* Method (Map *Overlay*)

The map overlay method was conducted by processing pre-tsunami (2017) and post-tsunami (2018) shoreline data in parts of Palu Bay. The map overlay method was used to determine post-tsunami shoreline changes in parts of Palu Bay.

2. Descriptive Analysis

This method is to further explain and describe the previous method. This descriptive analysis method explains the results of post-tsunami shoreline changes in Palu Bay and the factors that influence shoreline changes.

3. Results and Discussion

Astronomically, Palu City is located between 0º,36" - 0º,56" South latitude and 119º.45" - 121º.1" East Longitude just below the Equator with an altitude of 0 - 700 meters from sea level. Based on its geographical position, Palu City has boundaries:

a. North bordering with Donggala Regency
b. East bordering Parigi Moutong and Donggala Regencies
c. South of the border with Sigi Regency
d. West bordering with Donggala and Sigi regencies

3.1 Data Processing

The initial processing of data in the form of IKONOS imagery in 2017 before the tsunami and IKONOS imagery in 2018 after the tsunami was carried out by utilizing Quantum GIS 2.18 and ENVI 5.3 *software*. Image processing in the form of *cropping is* intended to focus the research area so that it is easier to analyze the image. In addition, the geometric correction stage is an important stage in the initial processing of the image with the aim of improving the position of the image due to the geometric distortion process during image recording.

1. Area Cropping and Band Combination

Cropping was done based on the research location, which is part of Palu Bay and is included in the administration of Palu City. The *cropping* was done with the raster extraction tool in QGIS2.18, while the band combinations in the 2017 IKONOS image and 2018 IKONOS image are Red = Band 1, Green = Band 1 Blue = Band 2. This band combination is a *natural color* combination. The selection of *natural color combinations* because the appearance of the image is very clear using this combination.

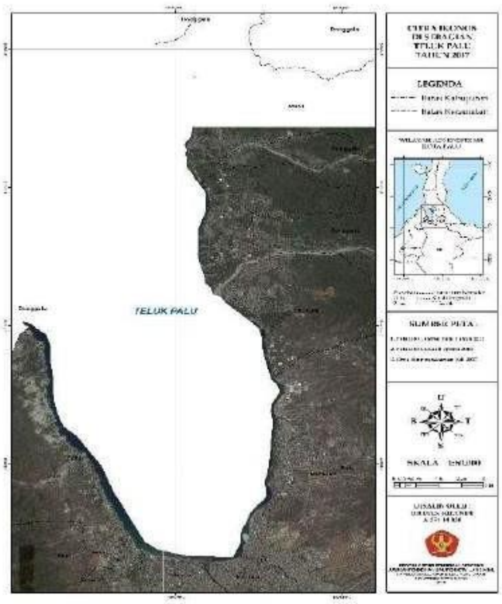

Image 2. IKONOS image in 2017

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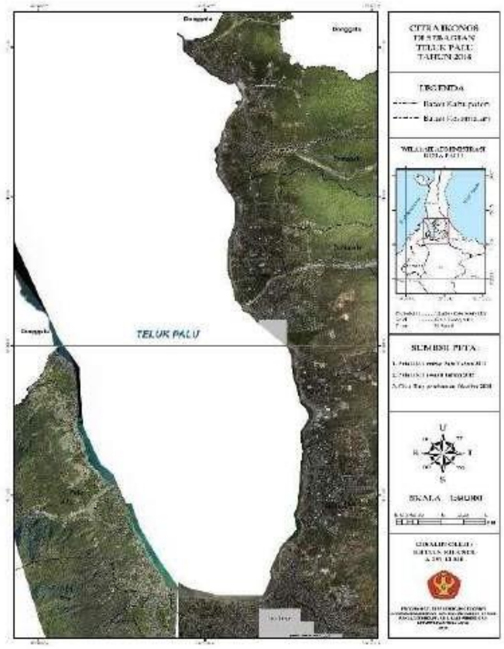

Image 3. IKONOS image in 2018

2. Geometric Correction

Geometric correction aims to correct errors in the position/location of objects recorded in the image caused by geometric distortion. This geometric distortion can be caused by several things, namely: the rotation of the earth at the time of recording, the influence of the curvature of the earth, the panoramic effect (viewing angle), the influence of topography, the influence of the earth's gravity which causes changes in satellite speed and altitude and platform height instability. [6].

The geometric correction process was carried out by utilizing ENVI 5.3 software. Geometric correction is carried out by comparing the digital RBI map that already has a *georeference* with the IKONOS image before the tsunami in 2017 and the IKONOS image after the tsunami in 2018. The geometric correction process was also assisted by determining points in the field directly using GPS (*Global Positioning System*). In addition, the determination of points in the field is also used in the accuracy test stage of image classification results.

The coordinate system in the geometric process uses the Universal Transverse Mercator (UTM) projection with zone 50 south, with the WGS 1984 datum. The initial stage of geometric correction is done by selecting the *Ground Control Point* (GCP). GCP determination is done with the help of GPS. The selected *Ground Control Point* is a point that will not change in the long term, such as bridges and road intersections.

The results of geometric correction on IKONOS imagery in 2017 show the largest RMS value on GCP 2 with an RMS of 0.45 and the lowest RMS value on GCP 6 with an RMS of 0.22. The average RMS on all GCPs is 0.34. The results of geometric correction on IKONOS imagery in 2018 show the largest RMS value on GCP 3 and 14 with RMS 0.43 and the lowest RMS value on GCP 12 with RMS 2. The average RMS on all GCPs is 0.33. These results show that the geometric correction results on IKONOS images in 2017 and 2018 have good enough accuracy because the maximum average error is 0.5 RMS.

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3.2 Coastline before Tsunami (2017)

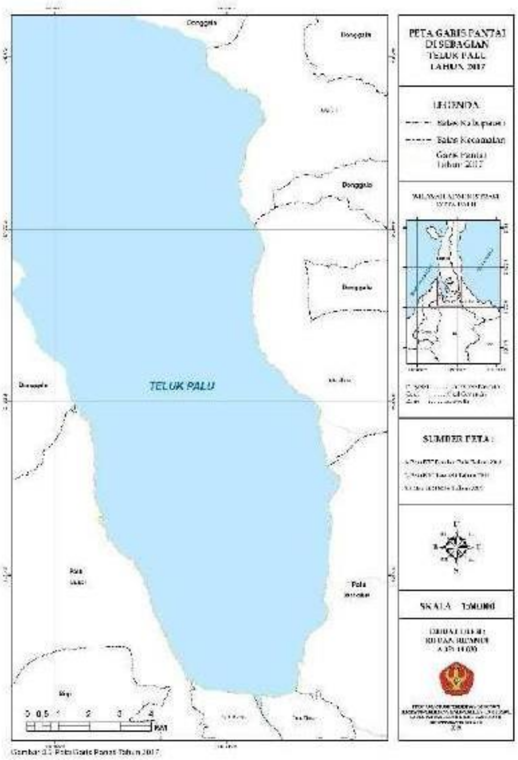

Image 4. Shoreline map 2017

Based on the 2017 coastline map, it is known that the total length of the coastline in parts of Palu Bay in 2017 was 42,563 meters. Ulujadi sub-district has the longest coastline of 12,486 meters while the eastern Palu sub-district has the shortest line of 1,280 meters. The following details the length of the coastline in meters based on sub-districts in Palu City in Table 1.

Table 1. Length of coastline in parts of the Gulf in 2017

No.	District	Length (m)
1	Ulujadi	12.486
2	North Palu	9.450
3	Tawaeli	8.545
4	Mantikulore	8.470
5	West Palu	2.332
6	East Palu	1.280
	Total	42.563

Source: Primary Data Analysis, 2019

3.3 Post Tsunami Shoreline (2018)

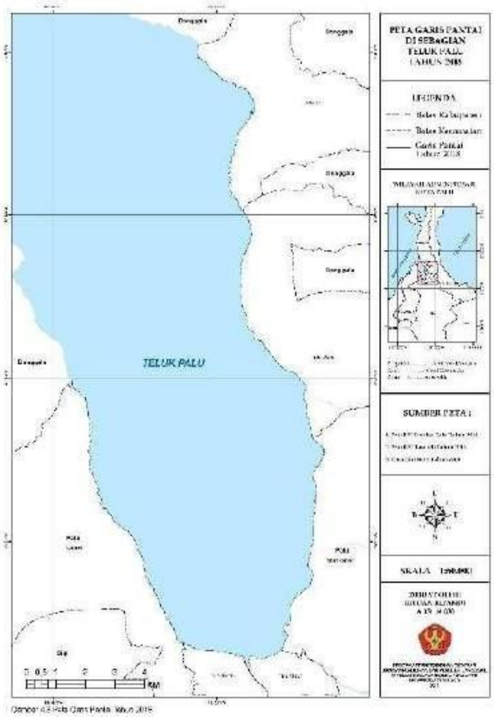

Image 5. Shoreline map 2018

Based on the 2018 coastline map, it is known that the total length of the coastline in parts of Palu Bay in 2018 was 40,447 meters. Ulujadi sub-district has the longest coastline of 10,960 meters, while the eastern Palu sub-district has the shortest line of 1,214 meters. The following details the length of the coastline in 2018 in meters based on sub-districts in Palu City in Table 2.

Table 2. Length of coastline in parts of Palu Bay in 2018

No.	District	Length (m)
1	Ulujadi	10.960
2	North Palu	9.280
3	Tawaeli	8.547
4	Mantikulore	8.252
5	West Palu	2.194
6	East Palu	1.214
	Total	40.447

Source: Primary Data Analysis, 2019

3.4 Post-Tsunami Shoreline Changes in Parts of Palu Bay

Based on the results of overlaying the 2017 line map and the 2018 coastline map after the tsunami in part of Palu Bay, a map of post-tsunami coastline changes in part of Palu Bay was obtained. Shoreline changes in parts of Palu Bay are found in the sub-districts of Ulujadi, West Palu, East Palu, Mantikulore, North Palu, and Tawaeli. The image processing results then produced a map of post-tsunami shoreline changes in parts of Palu Bay. The map is presented in Figure 6.

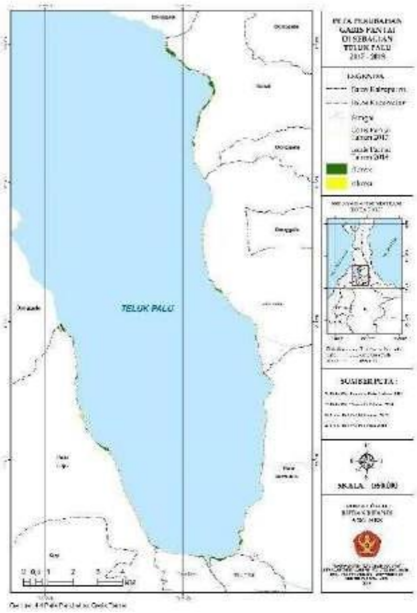

Image 6. Map of Post-Tsunami Shoreline Changes in Parts of Palu Bay

Based on the coastline change map, it is known that there have been changes in the coastline in the time span before and after the earthquake, namely based on image recordings from July 2017 to October 2018. Changes in the coastline are in the form of forward changes (accretion) and backward changes (abrasion), where accretion is the deposition and or removal of land, while the abrasion process is the sinking of land.

The following is a breakdown of post-earthquake shoreline changes in parts of Palu Bay in Hectares by sub-district in Palu City in Table 3.

Table 3. Shoreline changes Abrasion and Accretion

No.	District	Type of Change	
		Abrasion (Ha)	Accretion (Ha)
1	Ulujadi	14,36	1,99
2	West Palu	3,09	0,03
3	East Palu	5,75	0
4	Mantikulore	6,58	0,86
5	North Palu	5,49	1,55
6	Tawaeli	26,27	0,68
Total		61,53	5,1

Source: Primary Data Analysis, 2019

Shoreline changes in the form of land loss (abrasion) with a total area of 61.53 hectares and land gain (accretion) with a total area of 5.1 hectares in parts of Palu Bay included in the administrative area of Palu City.

Shoreline changes that occur can be caused by several factors, namely wave factors, topography or slope conditions, and sediments. Very significant shoreline changes in parts of Palu Bay were caused by the dominant factor of tsunami waves that occurred on September 28, 2018. This statement is in line with the opinion of [7] Normal wave energy and tsunami wave energy generated have a ratio of 1: 127, meaning that the energy of tsunami waves is very large, so that it can have a very large impact, especially in changing the coastline.

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[8] suggests that tsunami waves are long waves so that their energy is not easily lost even if they hit a cliff. Tsunami waves are unique because their waveforms extend throughout the water column, from the surface to the seabed, resulting in a large energy generated by the tsunami waves. Therefore, even though the city of Palu was far from the epicenter of the earthquake, it was still heavily impacted by the tsunami waves, resulting in the sinking (abrasion) of some coastal areas.

Another factor affecting shoreline change is the condition of sediments in several research locations in the form of sand found in the estuary area, beach material in the form of sand has a low level of resistance to waves. This also supports the occurrence of abrasion and accretion in the research location. Abrasion occurs due to the low level of resistance of sand to tsunami waves so that sedimentary material is carried away by tsunami wave currents, while in some research locations, there is accretion or an increase in the area of the beach. The addition to the coastal area occurs because sedimentary material in the form of sand carried by tsunami waves forms deposits on the coast.

Shoreline changes in the form of abrasion or submergence of the largest land area occurred in the Tawaeli sub-district with an area of 26.27 hectares, while the lowest coastal abrasion was in the West Palu sub-district with an area of 3.09 hectares. The land area lost sequentially starts from the Tawaeli sub-district with 26.27 hectares, the Ulujadi sub-district with 14.36 hectares, the Mantikulore sub-district with 6.58 hectares, east Palu sub-district with 5.75 hectares, north Palu sub-district with 5.49 hectares and west Palu with 3.09 hectares.

Changes in the coastline in the form of abrasion that varies in each sub-district are caused by several factors. Based on direct observation in the field, factors that affect the difference in the area of abrasion in each sub-district are land cover factors, tsunami waves, and the length of the coastline.

Tawaeli sub-district has the largest abrasion rate at 26.27 hectares while West Palu sub-district has the smallest coastal abrasion rate at 3.09 hectares. This significant difference in coastal abrasion occurs due to differences in land cover, where the West Palu sub-district has a seawall built along the coast to reduce the impact of tsunami waves that hit the coastline. In contrast to the coastal area of the Tawaeli sub-district, which has a seawall only in residential areas but in several other areas no seawall was built, so that areas that do not have seawalls experience a large impact from tsunami waves.

Another factor that influences the significant difference in coastal abrasion is the length of the coastline. Tawaeli sub-district has a coastline of 8,545 meters, while the West Palu sub-district only has a length of 2,332 meters, so the possibility of abrasion along the coastline of the Tawaeli sub-district is greater than the West Palu sub-district.

The largest shoreline change in the form of accretion or land addition occurred in Ulujadi sub-district with an area of 1.99 hectares, North Palu sub-district with an area of 1.55 hectares, Mantikulore sub-district with an area of 0.86 hectares, Tawaeli sub-district with an area of 0.68 hectares, West Palu sub-district with an area of 0.03 hectares and East Palu sub-district was the only sub-district that did not experience accretion or land addition. In general, shoreline changes in the form of additional land (accretion) in coastal areas occur due to coastal sediment factors. East Palu sub-district is the only sub-district that does not experience the accretion process, this situation is caused by the condition along the coast which is built by a seawall, so that no deposition or sedimentation process occurs when a tsunami occurs.

The influence of tsunami waves on shoreline changes that occurred in parts of Palu Bay is supported by image analysis results that show tsunami runoff reaching 565 meters inland. The tsunami wave runoff of 565 meters inland caused erosion of the shoreline, resulting in submergence or reduction of land area.

Changes in shoreline area were followed by changes in shoreline length. Changes in the length of the coastline in the form of the longest shoreline addition occurred in Ulujadi sub-district for 1,526 meters, and sequentially Tawaeli sub-district for 293 meters, the North Palu sub-district for 170 meters, the West Palu sub-district for 138 meters, East Palu sub-district for 66 meters, and

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Mantikulore sub- district was the only sub-district that did not experience an increase in the length of the coastline. In addition to the increase in the length of the coastline, there was also a reduction in the length of the coastline, which occurred in the sub-district of Mantikulore which was reduced by 77 meters.

Changes in the length of the coastline in the form of increasing or decreasing the coastline occur due to abrasion and accretion, therefore areas that experience large amounts of abrasion do not necessarily experience large changes in the length of the coastline. Similarly, areas that experience a large amount of accretion do not necessarily experience large changes in the length of the coastline.

3.5 Tsunami Affected Areas in parts of Palu Bay

The results of the 2018 post-tsunami image analysis show the significant impact of the Tsunami on the coastal areas of parts of Palu Bay. The area affected by the tsunami is shown through image analysis by looking at the traces of tsunami runoff that appear in post-tsunami recording images. The tsunami-affected area observed through image analysis reached a length of 550 meters towards land.

The impact of the tsunami resulted in the loss of coastal material, causing changes to the coastline and damage to infrastructure. A map of the tsunami-affected areas can be seen in Figure 7.

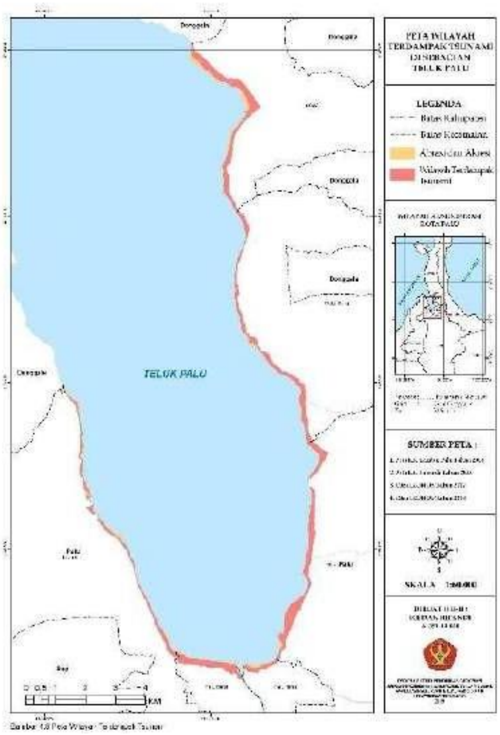

Image 7. Map of tsunami-affected areas

Based on the map of tsunami-affected areas, it appears that the Tawaeli sub-district was the most affected, while the East Palu sub-district was the least affected.

The area affected by the tsunami in parts of Palu Bay can be seen in Table 4 below:

Table 4. Tsunami Affected Area

No.	Subdistrict Name	Tsunami Affected Area (Ha)
1	Ulujadi	104,66
2	West Palu	58,39
3	East Palu	28,02

4	Mantikulore	145,55
5	North Palu	116,25
6	Tawaeli	169,96
	Total	622,83

Source: Primary Data Analysis, 2019

Based on Table 4, it is known that the impact of the tsunami on parts of Palu Bay was very large, covering an area of 622.83 hectares. The sub-districts that experienced the largest tsunami impact were Tawaeli sub-district with 169.96 hectares, Mantikulore sub-district with 145.55 hectares, North Palu sub-district with 116.25 hectares, Ulujadi sub-district with 104.66 hectares, West Palu sub-district with 58.39 hectares, and East Palu sub-district with the smallest tsunami impact with 28.02 hectares.

The extent of the area affected by the tsunami was proportional to the extent of the changes to the coastline. This correspondence can be proven by looking at the data that the Tawaeli sub-district, which experienced the largest tsunami impact with an area of 169.96 hectares, is also the sub-district that experienced the largest shoreline change with an area of 26.96 hectares, while West Palu and East Palu sub-districts are the areas that experienced the smallest tsunami impact with an area of
58.39 & 28.02 hectares respectively, as well as the areas with the smallest shoreline change impact of 3.11 hectares & 5.75 hectares respectively.

In addition to the impact on shoreline changes, tsunamis also cause damage to settlements and facilities & infrastructure. This damage occurred along the coast of the study location with varying degrees of damage. Settlements and infrastructure built on the coastal fringe suffered severe damage, making them uninhabitable, while some other buildings suffered moderate to light damage.

3.6 Accuracy Test and Ground Check

The accuracy test stage is an important stage in evaluating image classification results to match image processing data with the actual situation in the field. An accuracy test in part of Palu Bay was conducted by taking 30 *samples* consisting of 15 land prediction points and 15 sea prediction points. *Sampling* was carried out using GPS at the land prediction point and *Google Earth* data at the sea prediction point.

The results of image classification and the facts of the field can be seen in Table 4.10 as follows

Table 5. Accuracy Test

No.	Reference (Google Earth and Ground Check)		Total Rows	Accuracy
	Land	Sea		
Land	14	1	15	27
Sea	2	13	15	3
Total Column	16	14	30	90

Source: Primary Data Analysis, 2019

The Accuracy Test Table shows that taking land prediction points in the field is 15 points and proven in the field as many as 14 points while taking sea prediction points is 15 points, and proven as many as 13 points, so the average accuracy test results have a percentage of 90% or very good.

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4. Conclusion

Based on the research results, it can be concluded that:

1. Based on the results of overlaying the 2017 line map and the 2018 coastline map after the tsunami in part of Palu Bay, a map of post-tsunami coastline changes in part of Palu Bay was obtained. Based on the map of post-tsunami shoreline changes in parts of Palu Bay, it is known that there has been (abrasion) or loss of land area with a total area of 61.53 hectares and additional land (accretion) with a total area of 5.1 hectares. Tawaeli sub-district experienced the highest abrasion or land loss with an area of 26.27 hectares while the West Palu sub-district experienced the lowest abrasion change with an area of 3.09 hectares, while Ulujadi sub-district became the sub-district with the highest accretion area of 1.99 hectares and East Palu sub-district was the only sub-district that did not experience accretion or land gain.
2. Based on the image analysis, the total area affected by the tsunami in parts of Palu Bay was 622.83 hectares. The sub-districts that experienced the largest tsunami impact were the Tawaeli sub-district covering 169.96 hectares, Mantikulore sub-district covering 145.55 hectares, North Palu sub-district covering 116.25 hectares, Ulujadi sub-district covering 104.66 hectares, West Palu sub-district covering 58.39 hectares, while East Palu sub-district was the smallest tsunami impacted area of 28.02 hectares.

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