Modeling of Sedimentation Patterns in Palu Bay, Indonesia After the Tsunami and Earthquake Disaster Using MIKE 21

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***Abstract*- The tsunami disaster on September 28 2018 in Palu Bay was caused by an avalanche on the seabed due to an earthquake, resulting in changes in the bathymetry in Palu Bay. Changes in bathymetry affect hydrodynamics activity, which is one factor that influences sediment transport. This study aims to determine the effect of changes in post-tsunami bathymetry on sediment transport patterns in Palu Bay. This research was conducted by analyzing bathymetry changes before and after the disaster, followed by modeling currents and sediment transport using the MIKE 21. The results of the bathymetry change analysis showed a total landslide area of 6.552 km^2 with a total volume of 0.163 km^3 and a total stockpile area of 6,689 km^2 with a total volume of 0.580 km^3. Modeling results in hydrodynamics using the MIKE 21 application. The current velocity value after a disaster occurs increases with a range of values from 0.003 m/s to 0.145 m/s. The results of the Sediment transport modeling show that there was a change in sediment transport patterns at several points. It can be concluded that changes in bathymetry in Palu Bay affect the current velocity, and are directly proportional to bed level change.**

***Keyword*- Bathymetry, Currents, Sediment Transport, MIKE 21.**

I. INTRODUCTION

The earthquake disaster on September 28 2018 resulted in tsunami waves in several locations in Central Sulawesi, one of the worst occurred on the Palu Bay Coast. The tsunami in Palu Bay was caused by a seafloor landslide. This seafloor slide is an unconsolidated sediment slide [1]. The sediment that settles on the coast of Palu Bay is the transport of sediment from the rivers that flow into Palu Bay.

Sediment transport can result in shoreline changes resulting in shoreline setbacks (abrasion) or cause silting which results in shoreline advances (accretion), this can reduce the function of the beach and coastal buildings [2]. Based on previous studies, changes in bathymetry on the coast will result in changes in hydrodynamics [3] where hydrodynamics is one-factor affecting sediment transport [4].

The objectives to be achieved in this study are to determine the effect of changes in post-tsunami bathymetry on sediment transport patterns in Palu Bay Beach and to determine sediment transport patterns in Palu Bay Beach before and after the tsunami.

The benefits of this research can be used as information about the effect of sediment transport on shoreline changes so that it can be used as a reference for stakeholders in planning appropriate coastal protection developments or planning in rehabilitating coastal buildings that have been built in the coastal area of Palu Bay after the tsunami disaster.

To determine the effect of changes in bathymetry on sediment transport patterns, that is using a concept based on data availability by analyzing data that affect sediment transport patterns so that in the future it can be known the type of damage that occurred on the Palu Bay Coast. There are several parts in this framework, namely by analyzing bathymetry data before and after an earthquake, so that changes that occur in the topography of the seabed can be seen. Furthermore, modeling waves, currents, and sediments using the MIKE 21 program so that sediment transport patterns can be identified.

II. RESEARCH METHODOLOGY

This research was located in Palu Bay Beach, Palu City, Central Sulawesi, Indonesia. This location is one of the recreation areas for the people of Palu City. The observation area for primary data collection is carried out around the location point with coordinates 119°52'15.35"E and 0°52'23.35"S. As for the modeling area, it is carried out in areas limited by location points as follows.

Table 1 Boundary Coordinate

Point	East longitude	South latitude
Offshore 1	119°49'1.08"E	0°40'10.36"S
Offshore 2	119°45'49.13"E	0°42'17.28"S
Upstream 1	119°52'1.09"E	0°54'7.04"S
Upstream 2	119°51'59.62"E	0°54'7.17"S

Figure 1 Research Site

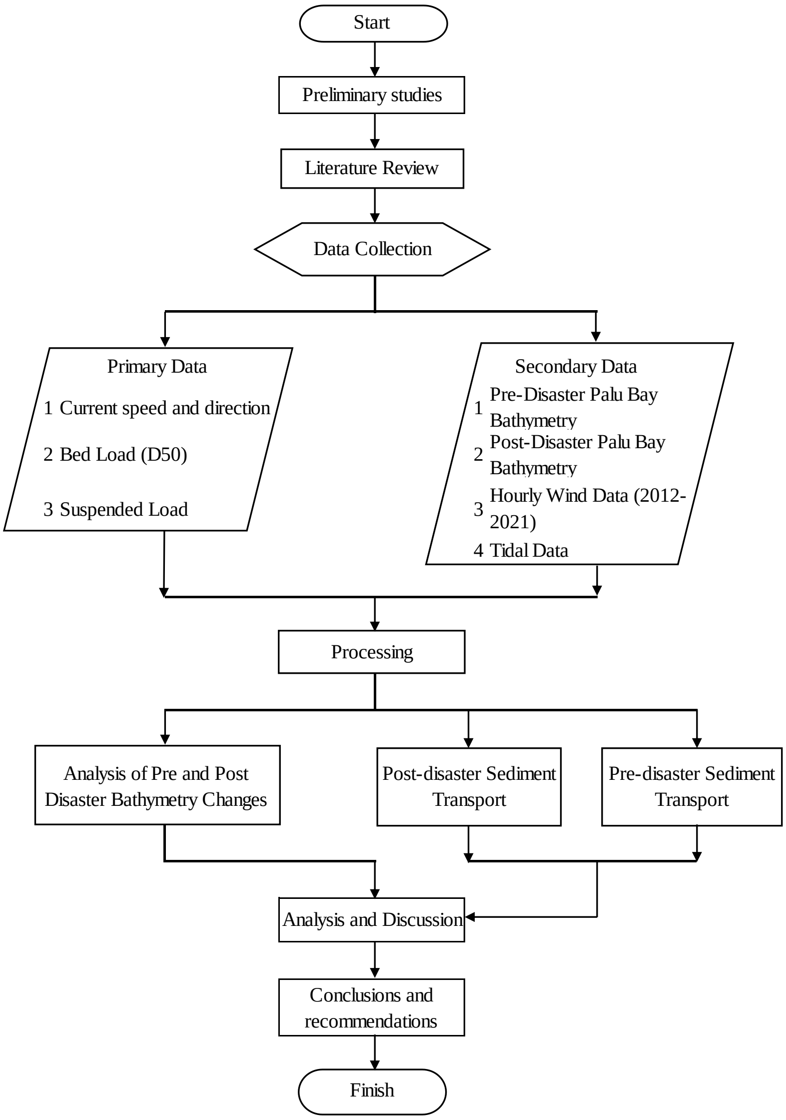


Figure 2 Research Flow Chart

III. HYDRODYNAMIC MODELING SOFTWARE

In planning designs such as coastal buildings, it is necessary to forecast these conditions so that the design results are maximized. Forecasting can be done using an approach through numerical modeling methods [5]. Software for hydrodynamic modeling is now widely available, one of which is MIKE 21/3. MIKE 21/3 is a software developed by the Danish Hydrodynamic Institute [6].

Hydrodynamic Modeling by MIKE 21

The equations of conservation of mass and momentum are the main equations used in hydrodynamic modeling in the MIKE 21 Flow Model, as follows [6]:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \tag{1}$$

$$\begin{aligned}
&\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{pq}{h}\right) + gh\frac{\partial \zeta}{\partial x} \\
&+ \frac{gp\sqrt{p^2+q^2}}{C^2 \cdot h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right) + \frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right] - \Omega q \\
&- fVV_x + \frac{h}{\rho_w}\frac{\partial}{\partial x}\left(p_a\right) = 0
\end{aligned} \tag{2}$$

$$\begin{aligned}
&\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) + gh\frac{\partial \zeta}{\partial y} \\
&+ \frac{gq\sqrt{p^2+q^2}}{C^2 \cdot h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right) + \frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right] + \Omega p \\
&- fVV_y + \frac{h}{\rho_w}\frac{\partial}{\partial y}\left(p_a\right) = 0
\end{aligned} \tag{3}$$

The following symbols are used in the equations:

$h(x,y,t)$	water depth (= $\zeta - d$, m)
$d(x,y,t)$	time varying water depth (m)
$\zeta(x,y,t)$	surface elevation (m)
$p,q\ (x,y,t)$	flux densities in x- and y-directions ($m^3/s/m$) = (uh,vh); (u,v) = depth averaged velocities in x- and y-directions
$C(x,y)$	Chezy resistance ($m^{½}/s$)
g	acceleration due to gravity (m/s^2)
$f(V)$	wind friction factor
$V, V_x, V_y(x,y,t)$	wind speed and components in x- and y-direction (m/s)
$\Omega(x,y)$	Coriolis parameter, latitude dependent (s^{-1})
$p_a(x,y,t)$	atmospheric pressure ($kg/m/s^2$)
ρ_w	density of water (kg/m^3)
x,y	space coordinates (m)
t	time (s)
$\tau_{xx}, \tau_{xy}, \tau_{yy}$	components of effective shear stress

Sediment Transport Modeling by MIKE 21

Sediment Transport Modeling In the combined case of currents and waves, the sediment transport rate is obtained by linear interpolation in the sediment transport table. Values in the table are calculated using the utility program MIKE 21 Toolbox “Generation of Q3D Sediment table”. The core of this utility program is the pseudo-three-dimensional sediment transport model (STPQ3D). The model (STPQ3D) calculates the instantaneous and time-averaged hydrodynamics and sediment transport in the two horizontal directions. The model calculates the base load and suspended load separately, and the value in the sediment transport table is the total load [7]. Quasi-3D hydrodynamic modeling is a solution for the balance of forces throughout the water column.

$$\tau = \rho v_t \left|\frac{\partial \overline{U}}{\partial z}\right| \tag{4}$$

Where is the time average flow velocity $\vec{u}$ found by integration and sediment transport is calculated as:

$$qt = qb + qs \tag{5}$$

Where qt is the total sediment transport, qb is the base load transport and qs is the sediment transport in suspension. In the STPQ3D model, the base load transport model is used, where the base load transport is calculated from the Instantaneous Shields parameter.

The time evolution of the boundary layer due to combined wave/current motion is solved using Fredsøe's integrated momentum approach. The force balance includes contributions from the near orbital motion of the wave, the force being related to breaking waves (radiation pressure gradient), and a sloping water surface. A necessary aspect is noticed in the STPQ3D model, average flow, wave motion, subsoil boundaries, turbulence, shear stress, and waves.

For a 'uniform' description of sediments, the geometric characteristics of the bed material are represented by the median grain size d50 when calculating suspended sediment concentration and sediment transport numerically. Using graded sediment descriptions, it is possible to describe the effect of the presence of different grain size fractions on the amount of bedload and suspended material and the total rate of sediment transport [7].

IV. RESULT AND DISCUSSION

Changes in Seabed Topography in Palu Bay After the Disaster

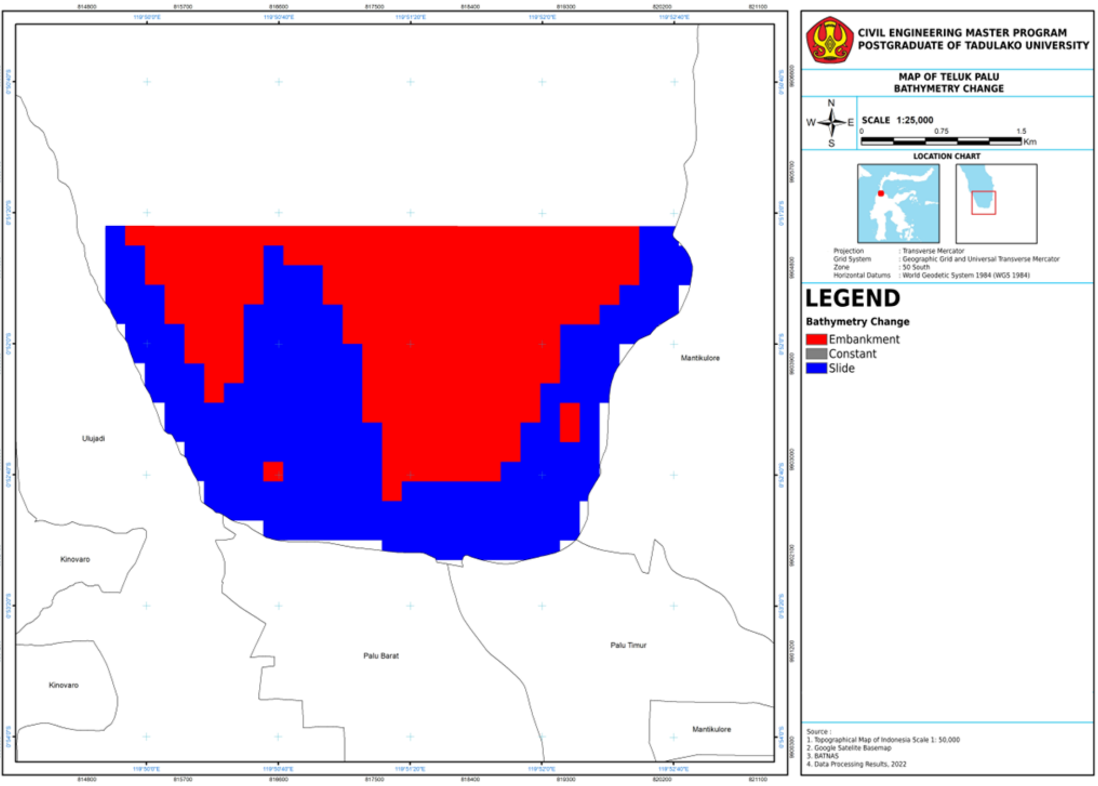
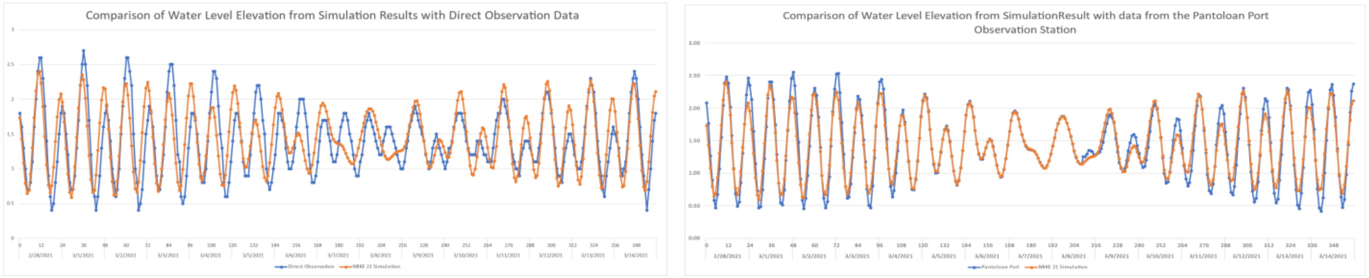


Figure 3 Cut and Fill Map of Palu Bay Seabed Topography

It can be seen in Figure 3 that the dominant landslides occurred on the edges and the dominant piles occurred in the middle of the waters. The total area of the landslide is 6,552 km^2 with a total volume of 0.163 km^3, while the total area of the embankment is 6,689 km^2 with a total volume of 0.580 km^3. From the results of the data analysis, it can be concluded that the dominant change that occurs is the heap. Previous studies have also shown that changes in the topography of the seabed in the waters of Palu Bay are embankments with a ratio between the volume of landslides and embankments of 27% (slide) and 73% (embankment) [1].

Tidal Model Calibration

Tidal data is used as calibration in modeling. Tidal data obtained from direct observation [8] is used as the first comparison data because the observation location is close to the location of this study. The second comparative data is tidal data from the Geospatial Information Agency (BIG) with the observation station located at Pantoloan Port. Tide observations were carried out by previous researchers for 15 days starting from 28 February 2021 to 14 March 2021. The results of the calibration at 2 tidal observation locations for the modeling results can be seen in Figure 4 as follows:



A. Direct observation B.Pantoloan Observation Station

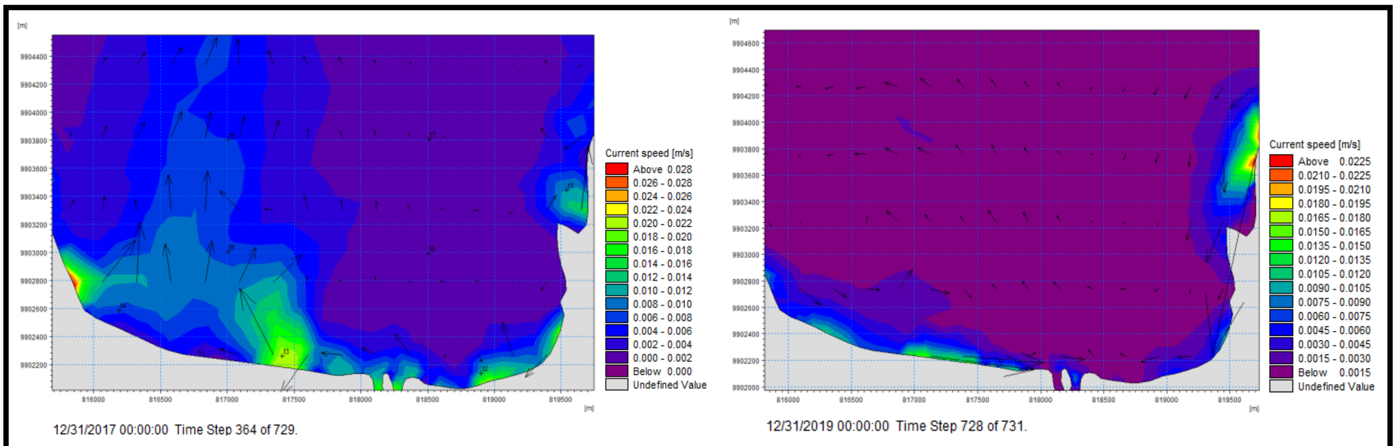
Figure 4 Tidal Calibration Chart

It can be seen from the comparison of the water level graphs that the resulting graphic patterns are similar between direct observations and model simulation results as well as between stations observation Pantoloan with model simulation results, that both have a pattern of two highs and two lows in one day, this is in line with previous studies which stated that the observed tidal characteristics in Palu Bay are Mixed Predominantly Semi Diurnal [9]. The calibration carried out on direct observation data obtained an RMSE value of 0.331 and at the Pantoloan Port Observation Station an RMSE value of 0.145. It can be concluded that the use of MIKE 21 is considered good for modeling at the study site.

The Relation of Current Velocity and Bathymetry Changes

Flow modeling was carried out during the conditions before the disaster which started from 27 September 2017 to 27 September 2018, while for conditions after the disaster started from 1 January 2019 to 1 January 2020. Four points of the review were determined in the section foreshore namely at point t1 with coordinates (819542.549178, 9903444.286830); point t2 with coordinates (818901.9435909, 9902138.272907); point t3 with coordinates (817411.549311, 9902260.771067); and point t4 with coordinates (816190.6509821, 9902587.432827). In section offshore, also determined 4 review location points, namely at point t5 with coordinates (818505.8662068, 9902991.676756); point t6 with coordinates (817003.2221103, 9903003.926572); point t7 with coordinates (818509.9494788, 9903808.331156); and point t8 with coordinates (817007.3053823, 9903804.247884).

The results of current modeling using the MIKE 21 application show that there was a change in the magnitude of the speed and direction of the current in Palu Bay between conditions before and after the disaster.



A. Before the Disaster B. After the Disaster

Figure 5 Results of Modeling Current Speed and Direction Using the MIKE 21 Application

The occurrence of the earthquake and tsunami disaster resulted in changes in the bathymetry of Palu Bay. This causes an increase in the current speed after the disaster. Before this happened, the topography of the seabed of the hammer bay was steep and after the disaster, it became sloping due to an avalanche. It is known that the more sloping the topography of the ocean, the faster and more regular the speed or movement of the currents, whereas in this topography there are laminar currents [10].

The change in currents in Palu Bay after the disaster affected the pattern of sediment transport, this will affect the coastal engineering planning around Palu Bay which was carried out before the disaster.

Table 2. Comparison of the Velocity of the Palu Bay Current

Point	Before the Disaster		After the Disaster	
	Velocity Max (m/s)	Direction	Velocity Max (m/s)	Direction
Foreshore Area				
t1	0.020	SW	0.165	SW
t2	0.027	W	0.030	W
t3	0.025	E	0.100	E
t4	0.009	N	0.018	E
Offshore Area				
t5	0.002	N	0.017	W
t6	0.012	N	0.043	S
t7	0.002	N	0.018	SW
t8	0.010	N	0.068	NW

The Relation of Current Velocity and Transport Sediment Pattern

Based on the results of modeling using modules sand transport In the MIKE 21 software, a model of sediment transport patterns in Palu Bay was obtained with two conditions, namely before the disaster occurred and after the disaster occurred. The sediment transport pattern presented is in the form of bed level change from Palu Bay. The coordinates of the review locations follow the review points in the current modeling.

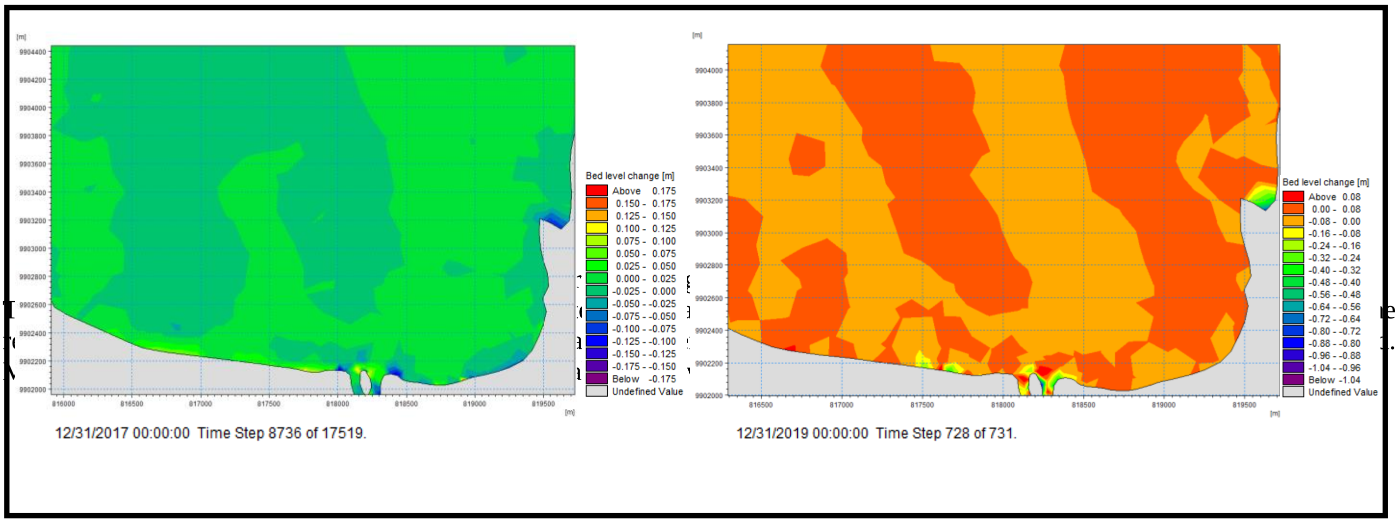


Table 3 Comparison of the Velocity of the Palu Bay Current

Point	*Bed Level Change* (m/year)	
	Before the Disaster	After the Disaster
Foreshore Area		
t1	-0,0050	-0,0598
t2	-0,0090	-0,0002
t3	0,0280	-0.0072
t4	-0,0010	0,0371
Offshore Area		
t5	0,00006	-0,00030
t6	-0,00180	-0,00230
t7	-0,00010	0,00010
t8	-0,00018	0,00030

Of the eight review points, five review points experienced changes in sediment transport patterns, two points experience a decrease in sediment heaps, namely at t3 and t5, and the points experienced an increase in sediment heaps, namely t4, t7, and t8.
Compared to the change in current speed, the bed level change at the review point is in line with the magnitude of the current speed. If there is a significant change in current, then the bed level change will also change significantly.

V. CONCLUSIONS

From the results of the study conducted by the author, the following conclusions can be drawn:

1. Changes in the topography of the seabed (bathymetry) in Palu Bay affect the speed of currents on the coast.

2. Changes in current velocity in Palu Bay are directly proportional to changes in the seabed (bed level change). The more significant the change in current velocity, the more significant the change in the seabed will be.
3. Five review points that experience changes in sediment transport patterns in Palu Bay. This will affect the design of coastal engineering planning carried out before the disaster.

VI. ACKNOWLEDGMENT

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