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Tidal and bathymetry characteristics after the 2018 earthquake and tsunami in Watusampu Waters, Palu Bay, Central Sulawesi

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Abstract

The Watusampu Water Coast was one of the waters affected by the tsunami waves on September 28, 2018. The height of the tsunami waves reached 6.6 meters and submerged as far as 71.4 meters inland. This study aims to see the bathymetry and tidal characteristics of Watusampu waters after the 2018 tsunami. The results of bathymetry measurements are corrected with tidal data. The results of tide measurements are compared with the predicted results and then analyzed by T-tide to calculate the tidal constituents used in the calculation of the planned water level in Watusampu waters. The bathymetry depth in the Watusampu waters ranges from 66.5 meters. The slope of the coastal waters has increased from north to south. The type of tide in Watusampu waters is mixed tides with a double daily inclination. The dominant tidal constituents are M2 and S2, respectively, with an amplitude of 0.5336 m and 0.4025 m. The tide wave height at the neap tide and spring tide is 0.2622 and 1.8722 m, respectively.

INTRODUCTION

The earthquake occurred on September 28, 2018, with a magnitude of 7.4 Mw which was followed by a tsunami wave that hit the coasts of the cities of Palu and Donggala. Watusampu coastal waters are one of the waters that experienced tsunami waves with a wave height of 6.6 meters and submergence as far as 71.4 km from the coastline (Fritz et al. 2018; Widiyanto et al. 2019). The tsunami waves were thought to have been caused by landslides in Palu Bay which was a consequence of the earthquake (Heidarzadeh et al. 2019; Pakoksung et al. 2019; Umar et al. 2019). The earthquake and tsunami events caused changes in the watershed which had an impact on the depth of the inundation area due to tides.

Previous research has shown that the Palu Koro fault activity has resulted in uplifting and landslides near the coast (Frederik et al. 2019; Pakoksung et al. 2019; Takagi et al. 2019; Liu et al. 2020). The process of rising seabed and landslides affects the bottom bathymetry of waterways. The height and type of tide in each area are different depending on the bathymetry, the width of the strait, the shape of the bay, and so on (Surinati 2007) so that it affects the tidal characteristics of the location. Knowledge of the amplitude and type of tide is very important in water because it will determine the height of the inundation and the period of occurrence of inundation.

Watusampu waters are an area affected by the tsunami, so this study aims to see the tidal characteristics and bathymetry of Watusampu after the earthquake and tsunami on September 28, 2018.

MATERIALS AND METHODS

Tide measurements (tides) in Watusampu Waters were carried out in situ for three days (16 March-19 March 2021) in open water so that the tidal propagation from Palu Bay did not experience many geometric obstacles. The tide measurement results are compared with the predicted results from Geospatial Information

Agency (BIG) at the same point, the predicted results for one month are then analyzed using the least-squares method to obtain the tidal constituents in determining the design water level in Watusampu Waters. The tides of the prediction results that have been validated with measurement data are used to correct the bathymetry data from the measurement results in Watusampu Waters.

The least-squares method used to determine the relative phase and amplitude of each frequency (Ongkosongo 1989):

$$H(t_i) = s_0 + \sum_{j=1}^{N} \left(a_j f_i cos(\omega_j t_i + V_j - g_j)\right) \ldots..(1)$$

$H(t_i)$ is the predicted sea level; s_0 is mean sea level; α is amplitude constant; ω is the rate of change in phase; G is initial phase tidal constant (when t = 0); F and V is Astronomical argument; N: the number of components.

The tidal component obtained from the least square method obtained by T_Tide (Pawlowicz *et al*. 2002) was used to determine the Formzhal number. The Formzahl number is a number for determining the type of tide, using the equation:

$$F = \frac{(O_1+K_1)}{(M_2+S_2)} \ldots.. (2)$$

where, F is Formzahl Number, $K1$ is amplitude of $K1$, $O1$ is amplitude of $O1$, $M2$ is amplitude of $M2$, dan $S2$ is amplitude of $S2$. The relation of Formzahl Number with type of Tidal (Table 1):

Table 1. Type of tide based on Formzahl Number

Tidal Types	Value of F
Double daily (semi-diurnal)	0 < F ≤ 0,25
Mixed (double dominant)	0,25 < F ≤ 1,50
Mixed (single dominant)	1,50 < F ≤ 3,00
Single daily (Diurnal)	F >3,00

Tidal harmonic constituents are used for the calculation of the vertical datum (National 2004) which is the reference area for the water level system. Harmonic analysis was carried out on the predicted data and tide observations to obtain the amplitude of the tidal constituents. The values of the tidal constituents are used to calculate the vertical datum. The equation for tidal riding, if the tidal type is Semidiurnal / Mixed Tide Prevailing Semidiurnal (Purwandito and Isma 2020):

$$HAT = LAT + 2(AK1 + AO1 + AS2 + AM2)$$
$$MHHWS = LAT + 2(AS2 + AM2) + AK1 + AO1$$
$$MHHWN = LAT + 2AM2 + AK1 + AO1$$
$$MLLWN = LAT + 2AS2 + AK1 + AO1$$
$$MLLWS = LAT + AK1 + AO1$$
$$LAT = MSL - AK1 - AO1 - AS2 - AM2 \ldots..(3)$$

HAT : Highest Astronomical Tide;
MHHWS : High Higher Water Spring;
MHHWN : High Higher Water Neap;
MSL : Sea Level;
MLLWN : Low Lower Water Neap;
MLLWS : Low Lower Water Spring;
LAT : Lowest Astronomical Tide.

To obtain actual bathymetry data, tide corrections are carried out at the time that corresponds to the bathymetric measurement and the tides using the equation (Soeprapto 2001):

$$r_t = TWL_t - (MSL + Z_o) \ldots.(4)$$

Where r_t is the value of reduction at time t; MSL is mean sea level; Z_oIs the position of the receding; water level below the sea level.

$$d = dT - r_t \ldots.. (5)$$

Where d is true depth; dT is depth corrected transducer and r_t is tide reduction

RESULT AND DISCUSSION

Tidal Characteristics

The tide measurement results are compared with the predicted results from BMKG at the appropriate time to see the predicted results with the measurement results. The measurement results and predictions are presented in Figure 1.

From the measurement results compared with the predicted results (Figure 1), it can be seen that there is a good fit so that in the next analysis that requires a longer range of tidal data, the prediction results can be used for Watusampu waters. The correlation between the predicted results and the measurement results is 0.99 (the tide of the measurement and prediction results has a very good correlation). The tidal constituents calculated using the least square (t-tide) method shown in Table 2.

Table 2. Type of tide based on Formzahl Number

Constituents	Amplitude(m)	Phasa
So	1.1998	
O1	0.1711	126.1
P1	0.0786	152.23
K1	0.2375	154.29
N2	0.1115	60.9
M2	0.5336	319.42
S2	0.4025	341.82
K2	0.1095	202.37
M4	0.0023	164.47
MS4	0.0020	0.001

The dominant tidal constituent in Watusampu waters is the M2 constituent (semi-diurnal constituent with the influence of the moon) with an amplitude of 0.5336 meters followed by the S2 component (amplitude of the semi-diurnal tidal constituents caused by the sun's gravitational force) with an amplitude of 0.4025 meters, this finding is consistent with the results of research conducted. by Hatayama et al. (1996) in the Makassar Strait.

From the calculation of the constituents of the tide using equation 2, the Formzahl F = 0.44 is obtained so that the tide type is mixed tide, prevailing semidiurnal which states that the tide that occurs twice a day and ebbs different height and time. This type of tide corresponds to the type of tide in the Makassar Strait (Susanto et al. 2000) which is the source of tidal propagation into Watusampu waters. Calculation using equation 3 shows that the height of the air plan (Table 3 and Figure 2).

Bathymetric characteristics

The corrected depth data was transferred to the software, in the bathymetric contour presentation using Qgis software with the Triangulated Irregular Network (TIN) method. The results of bathymetric interpolation of Watusampu waters are presented in Figure 3.

The bathymetric map is the result of direct measurements in the field on Tuesday, 23 March 2021 which has been corrected with the tide data measured on the same day. This bathymetry map accommodates that there is a change in bathymetry due to the earthquake and tsunami on September 28, 2018. Figure 3 shows that the water depth of Watusampu reaches a depth of 65 meters with varying distances from the coast, in the south, there is a steeper slope when compared to the slope of the coast in the north. in the southern part, the depth of the beach has reached 50 meters at a distance of 30 meters from the coast, while in the north it is 50 meters deep at a distance of 50 meters from the beach.

The potential height of a tsunami wave in the northern waters of Watusampu has the potential to experience higher waves than the southern waters. This situation is caused by the higher friction happen in the northern waters so that the speed of the tsunami waves decreases which is followed by an increase in the height of the tsunami waves (Briggs *et al*. 1995; Degueldre *et al*. 2016). The correct bathymetry measurement results are needed to predict the tsunami wave height properly.

Table 3. Prediction Water level plan Watusampu Waters

Level Name	Level Value(m)	Tide Hight (cm)	
HAT	2.5445		
MHHWS	2.1359		
MHHWN	1.3309	Neap Tide	Spring Tide
MSL	1.1998	0.2622	1.8722
MLLWN	1.0687		
MLLWS	0.2637		
LAT	-0.1449		

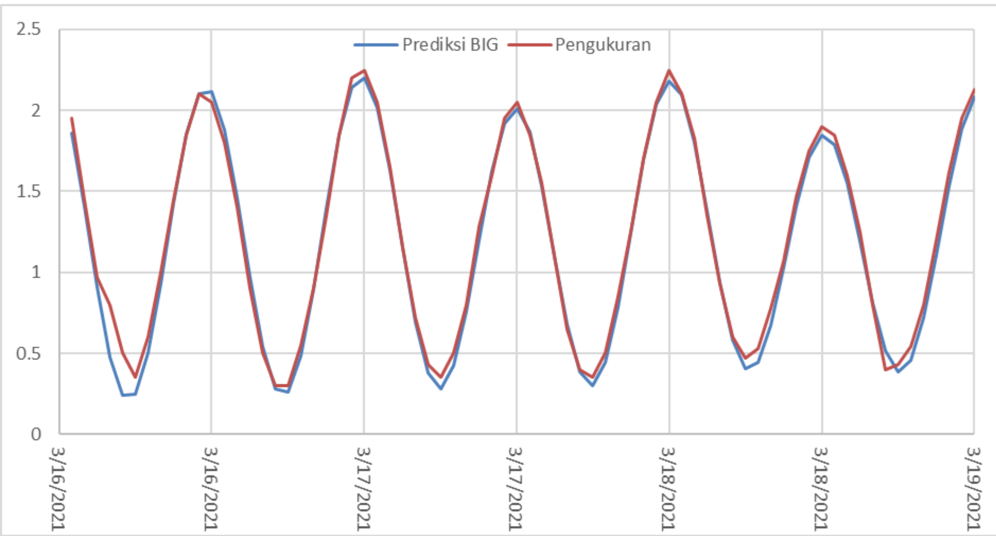

Fig 1. Graph The tide measurement compared with the BIG tide prediction

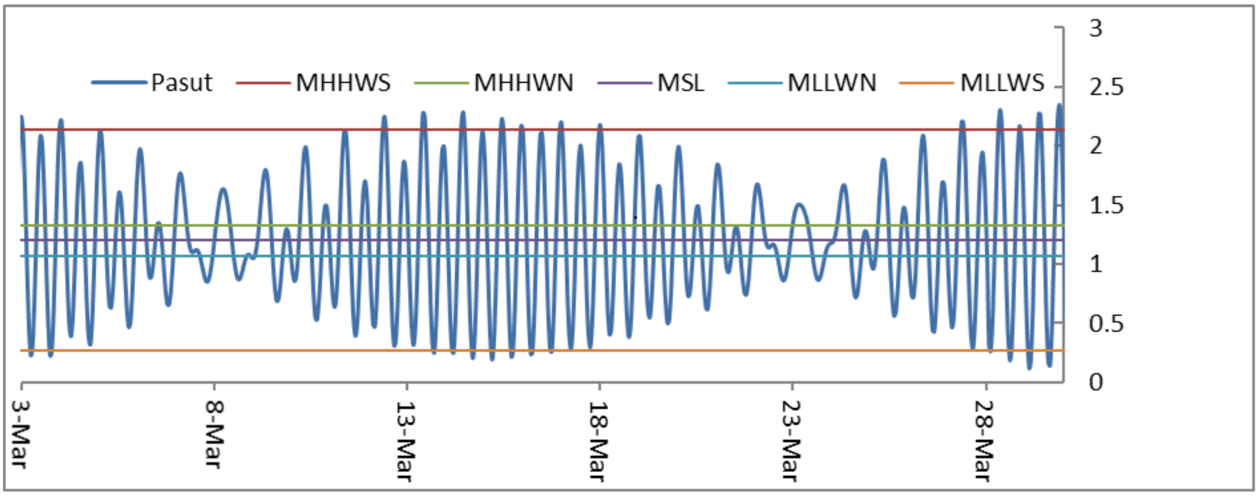

Fig 2. Graph of Prediction water level plan for Watusampu Waters in March 2021

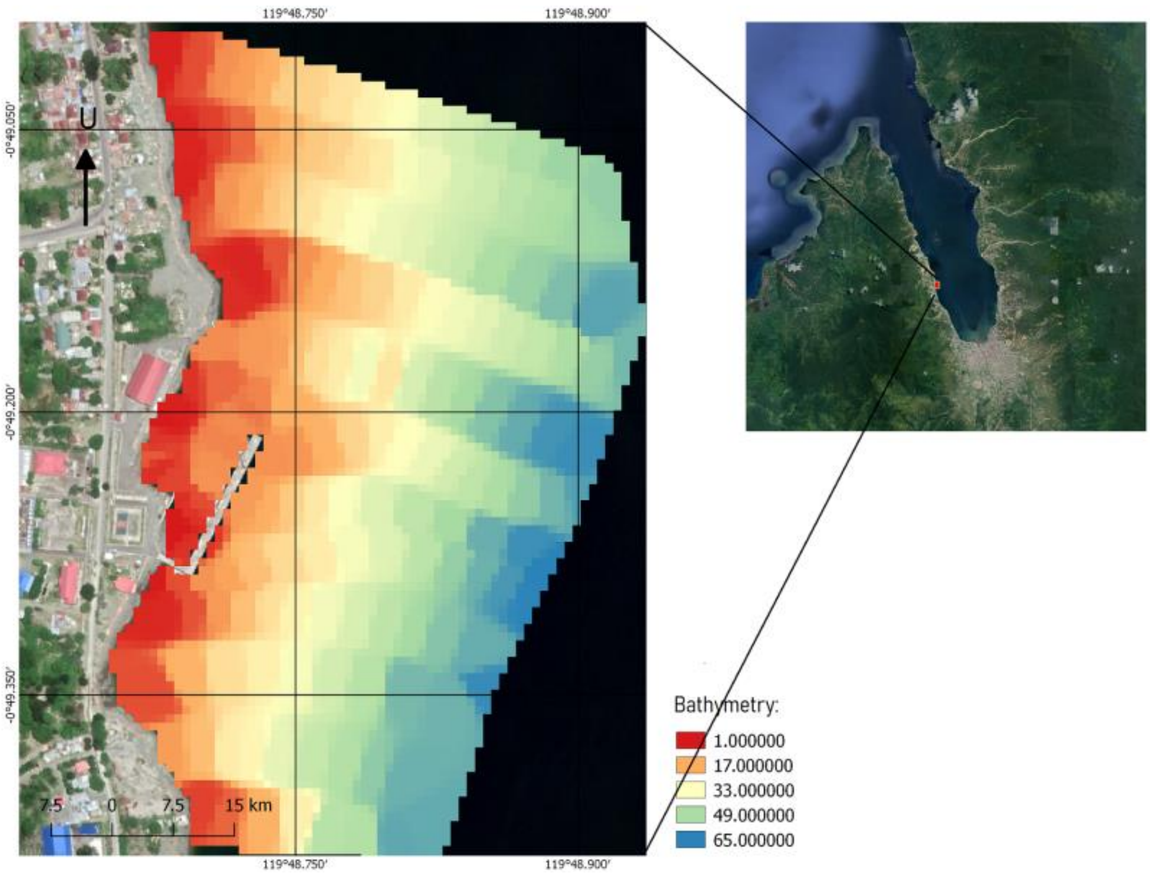

Fig 3. Watusampu Water Bathymetry Map Measurement Results

CONCLUSION

The depth of bathymetry Watusampu waters ranges from 66.5 meters with an increasing slope towards the south. The type of tide in Watusampu waters is a mixed tidal mix tilt daily with the dominant components, respectively, M2 and S2 with amplitudes of 0.5336 m and 0.4025 m. Tide Amplitude during Neap tide and spring tides are 0.2622 and 1.8722 m, respectively.

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