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Tsunami Threats Modelling Triggered by Earthquakes in Ujung Loe District, Bulukumba Regency

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Abstract: Ujung Loe is famous area in the mangrove tourism sector in Bulukumba Regency, but also prone to natural disasters, especially earthquakes and tsunamis from the Flores Back Arc Thrust. The purpose of this study is tsunami threats modelling that are affected the Ujung Loe coastal as a mitigation effort in minimizing losses and victims due to disasters. The modelling uses ComMIT with the worst tsunami scenario, generated from M 8.4 Flores Back Arc Thrust. And the mapping is processed using GIS. The data required for modelling include SRTM topographic data and bathymetry data from ETOPO1 and land cover data from the Open Street Map for futher analysis. From this study, it was found that the arrival time of the tsunami scenario due to Flores Back Arc Thrust at 44 minutes after earthqauke. The status of the tsunami threat on the Ujung Loe on shore was in the advisory category with the highest estimated run-up of around 160 cm in Manyampa Village and the estimated inundation depth up to 4 Km2 with with a maximum distance of 250 meters from the coastline. A representative temporary evacuation site (TES) based on satellite imagery, resulted in a safe area with an elevation above 10 meters from the mean sea levels.

Keywords: Tsunami, ComMIT, Arrival Time, Run Up, Inundation.

Introduction

Ujung Loe is famous area in the mangrove tourism sector in Bulukumba Regency. This area is 144.3 km^2 where 5 of the 13 villages are coastal areas. This district has a fairly long coastline, the fisheries sector is a generator of the community's economy (BPS, 2016). However, bad weather or coastal disasters, including tsunamis, can reduce the economic productivity of this region.The coastal area is directly opposite the Flores Sea which is tectonically very active with earthquakes and tsunamis. Based on the source of the tsunami generator, it is known that 90% of the tsunamis were caused by tectonic earthquake activity, 9% due to volcanic activity and 1% purely caused by landslides (Latief, et al, 2000). The impact of damage that occurs in a tsunami-affected area is very dependent on the type of construction and the height of the tsunami as well as the flow depth (Yeh et al, 2009).

Bulukumba Regency is classified as high risk based on the BNPB Tsunami Hazard Rating (BNPB, 2015). There is historical and geological evidence of tsunamis reaching Ujung Bulu coastal, and so the possibility of future events impacting low-lying populations and infrastructure in the Ujung Bulu cannot be dismissed. It is recorded in history in the Bataviashe Courant dated April 28, 1821, that on December 29, 1820, a large tsunami occurred due to an earthquake in the Flores Sea. The tsunami wave hit as far as Bulukumba, and damaged several villages in western Bantaeng to eastern Bulukumba, including the villages of Terang-Terang and Nipa-Nipa (Ngoc Nguyen et al., 2015).

Regional tectonics have revealed evidence from Marine geophysical surveys of two major back-arc thrusts: the 450 km long Flores Back Arc Thrust

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north of Sumbawa and western Flores, and the 350 km long Wetar Thrust north of Timor (Silver et al., 1983). From that movements, many earthquakes happen along Flores Sea.

Ujung Loe District has the potential to be affected by local and regional tsunamis. One way that can be done is by modeling tsunamis as a mitigation effort to minimize casualties due to the tsunami disaster. Tsunami modeling typically uses mathematical formulas that describe the characteristic physical conditions of a tsunami, called a tsunami model, to evaluate and predict the evolution of tsunami waves and their coastal impacts. For tsunami-prone areas, it is very necessary to design a tsunami evacuation scenario that is following the surrounding conditions and also tsunami forecasts from historical earthquake information that has occurred (Normile, 2007).

This study aims to determine the potential threat of a tsunami due to an earthquake and the impact of the run-up and inundation of the tsunami on the coast of Ujung Loe District from scenario M 8.4 of the Flores Back Arc Thrust. The results of this study are expected to be a reference in determining safe places for evacuation and increasing public awareness of the risk of tsunami in these coastal areas.

Materials and Methods

Study area

Study area along Ujung Loe coastal, Bulukumba Regency with the data used in this study are historical data from the tsunami-generating earthquake on December 29th,1820 with magnitude 8.4. Because there is no focal parameter data for the earthquake in 1820, the author assumes that this is the same fault as the Magnitude 6.4 earthquake on August 17th, 2018, with an epicenter that is almost the same as the 1820 earthquake (Table 1).

Table 1. Earthquake source parameter of generating a tsunami.

Fault	Mag (Mw)	Earthquake Source	Fault Parameter (°)			Fault Dimension		
			strike	dip	rake	Length (Km)	Width (Km)	Area/A (Km^2)
Flores Back Arc Thrust	8.4	120.0 °E 8.0 °S	90	81	84	420.8	116.6	33,282.9

This parameter data is downloaded from GFZ through the official website i.e: https://geofon.gfz-potsdam.de/old/eqinfo/form.php. Then the ETOPO1 bathymetry data (Amante and Eakins, 2009) was produced by the NOAA National Geophysical Data Center with an interval of 1 arc second and topographic data in the area around the research area in the form of Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data (Reuter et.al, 2007), all of which are already available at in the ComMIT application. The results of the ComMIT modeling produced logical data so that it was reliable (Titov et al., 2005; Wei et al., 2008; Titov, 2009 and Tang et al., 2009).

Procedures

The data processing method is based on the results of numerical tsunami modeling according to the worst-case scenario from the ComMIT application (Titov et.al., 2011) developed by NOAA (National Oceanic and Atmospheric Administration). First, make the initial modeling of the tsunami source obtainable by considering it as a seabed deformation with fault parameters. Based on Okada's elasticity theory (Okada, 1992), the tsunami source area is considered to follow the deformation plane of the earthquake fault on the seabed. This principle is used in the tsunami numerical model as an approximate value of tsunami wave propagation (JMA, 2007). The energy released by an earthquake source can be referred to as a seismic moment (Mo) which then results in the formation of area and slip from rupture (Madlazim, 2011). The input parameters needed for the design of the tsunami source (source modeling) in the form of fault dimensions (length and width) and slip were obtained based on empirical calculations using empirical equations from Scaling Law (Wells and Coppersmith, 1994), stated that there is a relationship between rupture length and magnitude. Fault dimension parameters are obtained from the scaling law equation :

$$M = 4{,}49 + 1{,}49 \times \log RLD \quad (1)$$
$$M = 4{,}37 + 1{,}95 \times \log RW \quad (2)$$
$$M = 4{,}43 + 0{,}90 \times \log RA \quad (3)$$

Remarks: M refer to Magnitude (Mw), RLD represent to subsurface rupture length (Km), RW represent to downdip rupture width (Km), and RA represent to rupture area (Km^2).

In the next stage, the authors created model run ComMIT by dividing the research area into 3 regions (Region A, B, and C) where the region is the boundary of the tsunami-affected area. The division of the region uses the nesting grid method. The author focuses on the nesting stage in the Ujung Loe district to produce high resolution in the affected area. Figure 1 is a division of the research area into three regions. Region A is the largest area (resolution 2 arcmin), Region B is the middle area (resolution 30 arcsec) and Region C is the smallest area (resolution 3 arcsec) with the most clearly visible affected areas as the focus of research. The smaller the region, the denser or detailed grid.

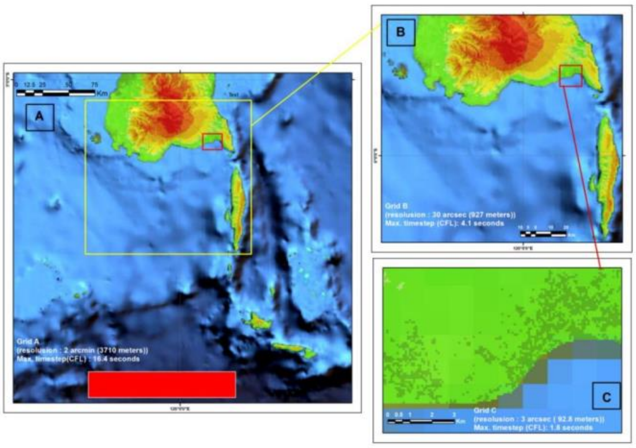

Figure 1. Fault modeling of the tsunami generating source and the grid of the research area. Beach ball and red block represent fault dimension of the scenario in Table 1. The black, yellow and red squares are nested grids for the earthquake-tsunami model. Region A is the largest area (the black square) , Region B is the middle area (the yellow square) and Region C is the smallest area as the focus of research (the red square)

Data analysis

After we have tsunami modelling result from ComMIT, then analyzing run-up models that have the potential to occur using GIS and accompanied by land cover data from the Open Street Map to identify the impact of inundation on land in the research location. We can calculate the size of the affected area using GIS and get the area that has the worst potential from the model and the area that is safe for evacuation.

Results and Discussion

The results of the tsunami modeling are in the form of wave height (run-up), and inundation (inundation depth) as well as the arrival time of the tsunami at the affected point. Furthermore, the final result is processed with a GIS application for analyzing run-up and inundation mapping which is overlaid with land cover.

Result-1

This tsunami potential analysis begins with studying the parameters of the earthquake that occurred in the Flores Back Arc Thrust. This parameter is then used to obtain changes in the shape of the seabed due to the earthquake that became the source of the tsunami and the propagation of the waves. In this study, tsunami modeling was carried out for 100 minutes. The modeling of the tsunami scenario due to the Flores Back Arc Fault is presented in Figure 2 and Table 2. Figure 2 describes the propagation of the tsunami waves to arrive at the tide gauge modeling points on the coast. The number of tide gauge modeling is 5 points, where the tsunami waves arrived at the coast around 44 minutes after the earthquake occurred. Tide gauge recorded maximum wave height/run-up in coastal affected this model around 90-160 cm. The maximum run-up at Manyampa Village reached 160 cm at 53 minutes after the earthquake occurred, in detail can be seen in table 2.

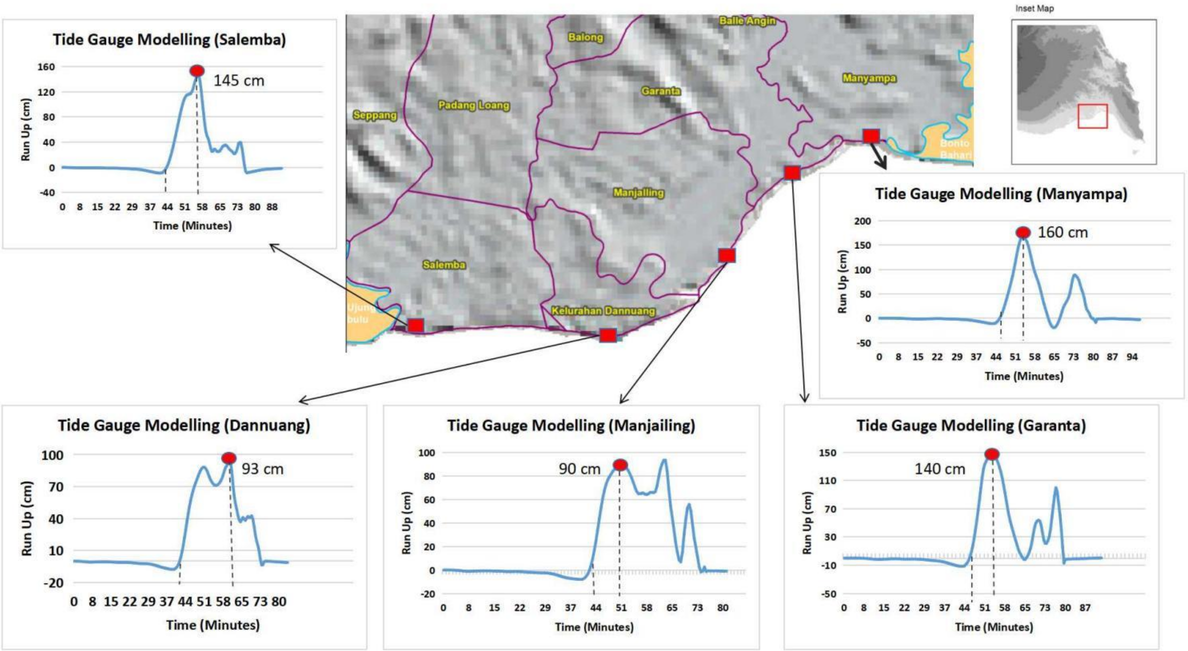

Figure 2. Arrival time of the tsunami scenario due to the Flores Back Arc Thrust from tide gauge modelling at 5 sites on Ujung Loe Coastal area (red point). The maximum run-up threats of tsunami wave at Manyampa Village about 160 cm.

Table 2. Earthquake source parameter of generating a tsunami.

Tide Gauge Point	**Arrival times (minutes after earthquake)**	**Max. Run up (cm)**	**Arrival times of Max. Run Up ((minutes after earthquake)**
Salemba	44	145	57
Dannuang	44	93	60
Manjailing	44	90	51
Garanta	44	140	54
Manyampa	44	160	53

Result-2

On the run-up map indicated in general, the threat of tsunami run-up is 70% at the advisory category (0.5 - 3 m), but some places are lower risk at 30% with the watch category (< 0.5 m). Maximum run up recorded in Manyampa Village is about 160 cm from Mean Sea Level (MSL).

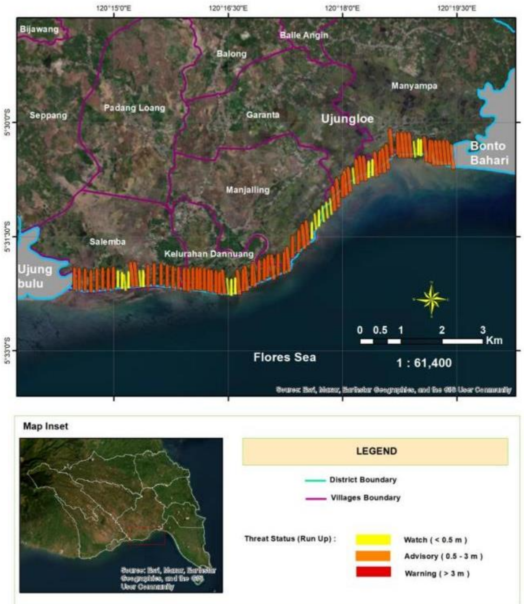

Figure 3. Threat status run up tsunami from Flores Back Arc Thrust earthquake scenario.

Result-3

The inundation of the tsunami waves that pass through the coast and coast is symbolized by a yellow cross as in Figure 4. This map is overlapped with land cover so that it can be seen how far the inundation occurred. The height of the location, the shape of the coast, and the height of the tsunami wave run-up are important factors for the distance of the tsunami wave inundation to the mainland. The estimated tsunami inundation in Ujung Loe District is 4 Km^2 with a tsunami-prone coast of 10 Km. The maximum inundation distance is 250 m from the coastal area, symbolized by the red dash line. The dominant land affected is the the pond area of 2.8 Km^2, while the mangrove area is 0.7 Km^2 , mix agricultural 0.2 Km^2, resident area 0.2 Km^2 and the affected river is 0.1 Km^2.

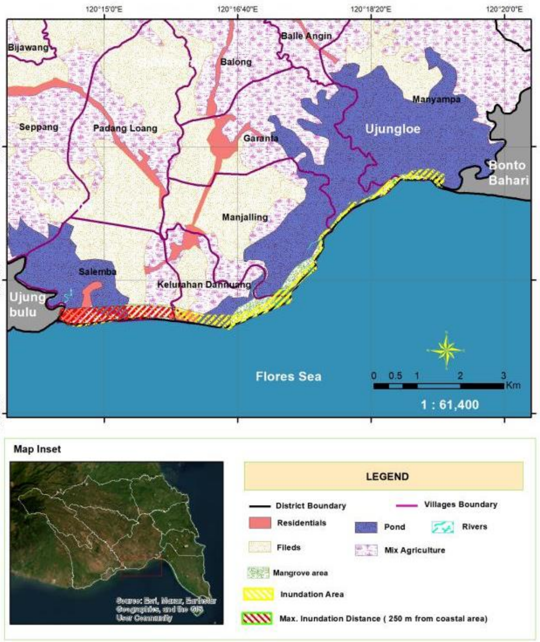

Figure 4. Maximum inundation/flow depth on Ujung Loe Coastal area.

Discussion

The earthquake and tsunami warning system (INA-TEWS BMKG), was issued within 5 minutes after the earthquake occurred. The community still has sufficient time, which is about 44 minutes for self-evacuation before the tsunami arrives. But of course, there is still a need for a tsunami evacuation map and routine training simulations from the community. This is because, at the time of the tsunami, panic will occur in the community, so the existence of an agreed tsunami evacuation route will minimize the risk of losses incurred. In addition, buildings located in the hazard zone must have a strong and sturdy building structure and have a vertical evacuation area with a minimum of three-story buildings.

Conclusions

Based on the data processing and analysis, several conclusions can be drawn, including:

- 1.The arrival time of the first wave is about 44 minutes after the earthquake.
- 2.Potential tsunami hazards in Ujung Loe District is advisory category, with an estimated run up about 160 cm.
- 3.Tsunami inundation up to 4 Km^2 with maximum distance is 250 m from coastal area.
- 4.The save area is 10 meters above Mean Sea Levels (MSL) can use to Temporary Evacuation Sites (TES)

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