Study of characteristic of tsunami base on the coastal morphology in north Donggala, Central Sulawesi

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Abstract. The northern arm of Sulawesi potentials to generate earthquake and Tsunami due to the existence of subduction zone in sulawesi sea. It makes the North Donggala as an area with active seismicity. One of the earthquake and Tsunami events occurred is the earthquake and tsunami of Toli-Toli 1996 (M 7.9) causing 9 people are killed and severe damage in Tonggolobibi, Siboang, and Balukang. This earthquake induced tsunami runup of 3.4 m and inundated as far as 400 meters. The aims of this study is to predict runup and inundation area using numerical model and to find out the characteristics of Tsunami wave on straight, bay and cape shape coastal morphology and slopes of coastal. The data in this research consist of are the Etopo2 bathymetry data in data obtained from NOAA (National Oceanic and Atmospheric Administration) , Toli-toli’s main earthquakes focal mechanism data 1st January1996 from GCMT (Global Centroid Moment Tensor) , the data gained from the SRTM (Shuttle Radar Topography Mission) data 30 m and land cover data in 1996 from Ministry of environment and forestry . Single fault model is used to predict the high of tsunami run-up and to inundation area along Donggala coastal area. Its reviewed by morphology of coastal area that higher run up shows occurs at coastline type like bay have higher run up compare to area with cape and straight coastline. The result shows that the slopes have negative or contras correlation with Tsunami runup and its inundation area.

1. Introduction
The coastal area is susceptible to inundation of natural disasters like tsunami, storm surges, etc. The propagation of tsunami is related to the morphological bathymetry. There are parameters for coastal morphology such as bays, Capes, straight shoreline, curved shoreline, gentle, stib coastal, etc.

The north arm is a region with highest seismicity especially northern coast, south and eastern part of the norh arm. There were occurred earthquakes and tsunami in 1968 and 1996 along north arm which is an area of seismic prone with highest activity. All phenomena of the shallow earthquakes generated by the motion of Palu-koro fault, pool of north arm Sulawesi and Spreading canter north Makassar strait [1]. In Toli-toli (1996) happened earthquake and tsunami (M 7.9), which suffered 9 victims, and physical defect in Tonggolobibi, Siboang, and Balukang [2]. The earthquake also generated tsunami with 3.4 meters level and inundation 400 meters [3]. When 1996 tsunami in toli-toli
is caused by subduction zone in Sulawesi Sea based on previous study. The earthquake is caused by palu-koro fault but it’s not true because palu-koro fault is moving horizontally.

Therefore, this research focus on numerical modelling of tsunami in west coast north Donggala, that generated by tectonic earthquakes in which can be mapping by considering the coastal morphological impact due to tsunami. This research is mean to the mitigation of tsunami in the coastal area because from the previous research because there were only view research about the correlation of tsunami due to coastal morphology and inundation area in Toli-toli’s tsunami 1996. Finally this research trying to developed the previous research with to make runup and inundation using numerical modelling and characterize tsunami due to the coastal morphology, bay, cape, straight, slope, etc.

2. Method
This research located in -0.350 S-0.7040 N to 119.760-119.990 E, west coast northern part of Donggala. The data in this research consist of are the Etopo2 bathymetry data in data obtained from NOAA (National Oceanic and Atmospheric Administration), Toli-toli’s main earthquakes focal mechanism data 1st January1996 from GCMT (Global Centroid Moment Tensor), the data gained from the SRTM (Shuttle Radar Topography Mission) data 30 m and land cover data in 1996 from Ministry of environment and forestry. There are three step in this research as follows:

2.1. Runup simulation using single fault method
In this step, the runup simulation calculation of fault dimension will be done by observe the distribution of main shock, foreshock, and aftershock [4]. Empirically, the fault dimension can be known by Papazachos et al, (2004) equation [5], as follows:

\[
\log L_0 = 0.55M_w - 2.19
\]

\[
\log W_0 = 0.31M_w - 0.63
\]

The calculation of Wide field fault using this equation below :

\[
A = L_0 \times W_0
\]

Where \(L_0\) is fault length (m), \(W_0\) is width of fault (m), and \(A\) is wide field fault (m²).

Seismic moment is the amount of energy that released in earthquakes event and it can be determine using equation below [6] :

\[
\log M_0 = (6.08 + M_w) * 3/2
\]

Dislocation of water body define using equation below [9]

\[
S = \frac{M_0}{\mu A}
\]

Where \(M_0\) is seismic moment (Nm), \(\mu\) is Rigidity (stiffness object, the harder the object is the energy required to move it greater, meaning greater seismic moment) (N/m²), \(S\) is Dislocation (m) and \(M_w\) is moment magnitude (Mw).

This calculation result inputted to L-2008 software by Mamoru Nakamura to illustrate vertical displacement and runup tsunami.
2.2. Simulation of tsunami Inundation. The simulation of tsunami using Arcgis 10.1 software with the Raster calculator functions. Hills, J. G. & Mader, C. L. 1997 [7], formulated an equation to calculated the runup tsunami as follows:

\[ X_{\text{max}} = (H_s)^{1.33} \cdot n^{-2} \cdot k \cos S \]  

(6)

Where \( X_{\text{max}} \) is maximum Inundasi (m), \( H_s \) is maximum tsunami run-up (m), \( k \) is constants corresponding to 0.06 for many tsunamis, \( n \) is Manning coefficient of land covers and \( S \) is slope of land.

3. Result and explanation

3.1 Runup simulation using single fault method

The calculation result from of the empirical approach (table 1) inputted in L-2008 software. Output of that process is visualization of vertical displacement.

| Mw  | L (km) | W (km) | A(km²) | A (m²) | Mo (Nm) | \( \mu \) (N/m²) | S(m) |
|-----|--------|--------|--------|--------|---------|-----------------|------|
| 7.9 | 142.8894 | 65.91739 | 9.42E+03 | 9.42E+09 | 9.33254E+20 | 3.00E+10 | 3.30E+00 |

Table 1. Empirical approaches with Scaling law.

In this study an earthquake with a large 7.9 Mw, source modeling of tsunami Toli-Toli use single fault model with fault parameter obtained by Donald L. Well & Kevin J. Coppersmith, 1994 scaling law. We get fault dimension with length 142.8894 km, width 65.91739 km, and 3.3 m for maximum displacement of Toli-Toli tsunami 1996.

Figure 1. Vertical displacement of tsunami modelling.

Results from the model design (source modeling) of vertical displacement, which shows deformation occurring on the sea bottom. Variation of vertical displacement value for this event describes the variation of the value of the maximum vertical displacement for this event is 1.14 meters and the minimum vertical displacement value is -1.14 meters from maximum vertical displacement value (+) show the rising of bottom sea. In the other hand, the minimum vertical displacement values (-) show the dropping in of sea floor (figure 1) [8]. Strike related to the fault direction. When the strike lead to the area with shallow morphology cause higher level of tsunami. In the other hand, if strike direction lead to the area with deep of bottom sea morphology cause lower level of tsunami [9]. This is understandable, because the vertical movement of the sea bottom can cause changes in the mass of water over the sea bottom in motion. If the upper oceans rise (uplift) or descend rapidly in response to an earthquake, it will rise and fall sea water on a large scale, from sea bottom to surface. The value of strike has a relationship with the direction of the fault. When this Strike leads to a more morphological area shallow the tsunami run-up is higher whereas if the direction of this strike leads to the morphological area of the seafloor in the small tsunami height.
Figure 2. Tsunami propagation model.

In tsunami propagation model figure 2) until Maximum time that chosen is during 3600 second, this parameter useful to define the maximum time that used to see propagation time of the tsunami. The model output can describe tsunami propagation during maximum time which we chosen before. Its data can be saved in propagation wave form every minutes, so that we can know when tsunami wave arrived to continent [3].

Table 2. Runup distribution result in few point from tsunami source modelling.

| Longitude   | Latitude     | H  | Point               |
|-------------|--------------|----|---------------------|
| 120.2374    | 0.895056     | 1.98| Simuntu             |
| 120.2449    | 0.820917     | 2.77| Dongko              |
| 120.2044    | 0.773473     | 2.1 | Soni                |
| 120.0367    | 0.585327     | 2.7 | Balukang            |
| 120.0494    | 0.520936     | 2.1 | Siwalempu           |
| 120.0354    | 0.502564     | 3.52| Siboang             |
| 120.0032    | 0.482956     | 2.39| Taipah 3            |
| 119.9978    | 0.48295      | 3.31| Taipah 2            |
| 119.9976    | 0.482281     | 3.24| Taipah 1            |
| 119.9917    | 0.481658     | 2.71| Taipah (river Mouth)|
| 119.9781    | 0.480986     | 3.51| Tonggolobibi 3      |
| 119.9759    | 0.475939     | 3.21| Tonggolobibi 2      |
| 119.9578    | 0.475631     | 2.74| Tonggolobibi 1      |
| 119.9478    | 0.474539     | 2.78| Limbosu             |
| 119.9311    | 0.479928     | 2.72| Pangalaseang 2      |
| 119.9071    | 0.480939     | 2.39| Pangalaseang 1      |
| 119.8851    | 0.423511     | 2.32787| Tonggoloibi 4      |
| 119.8869    | 0.390006     | 2.09888| Tonggoloibi 5      |
| 119.8636    | 0.368844     | 2.09402| lembe Mukti 1       |
| 119.8452    | 0.342183     | 2.25418| lembe Mukti 2       |

Runup value in the map of impact area above show in table tsunami affected areas map above (table 2).
Figure 3. Map of run up tsunami distribution in for each village.

The simulated track record (figure 3). The simulation results show that if an area is near to the tsunami source, the region will experience a tsunami in the first wave, this is because the distance is less than 46 km so it can be categorized as near field or local a tsunami that is a tsunami occurring where the distance between the source and the tsunami generated by the coast is very near. It is likely that the area around the earthquake felt or even damaged the building, based on tsunami data of the area that had severe damage ie the villages of Tongolobibi, Balukang and Siboang. These areas are areas near to fault summers, so it is important to conduct disaster mitigation efforts in this area if a tsunami is likely to occur at any time in the region. The results show that the area of the bay-shaped coastline, based on the wave theory, states that the wave region will converge or overcome the tsunami or maturity of the bay due to a resonance process in which the incoming wave meets the reflected wave causing the area the bay becomes strong, the ocean waves reflect each other and each other or a large wave in a straight line with a straight coastline and a headland. This research also shows the highest run-up is located at the end of the bay around it there is a river mouth like the village Tonggolobibi.
To measure the validity of model, the correlation coefficient calculated in matlab. From calculation show the correlation coefficient value between measurement and model about 0.78 (figure 4).

3.2 Inundation Simulation
Research for simulation of extents inundation Toli-toli’s for tsunami have not been there before. Application of geographic information system to create tsunami inundation area of Toli-toli 1996 by utilizing. When tsunami arrive in land, it propagation determine by slopes of coastal morphology, where in the steep coastal, the effect of tsunami will not too far reach the land because it stuck and reflect back the coastal cliff, while in the sloping coastal, effect of tsunami can be reach few kilometres to the land. Simulation result show that inundation area affected by land topography, higher land topography it cause lower inundation area and otherwise. The simulation show inundation area with runup value about 3.52 is 598 Ha (figure 5) and Inundation simulation analysis results show that tsunami inundation will travel far to the more gentle and will turn if it encounters high topography and low inundation area on terrestrial vegetation in the form of forest both primary forest, secondary forest and mangrove forest and the greater the extent of inundation if passing land with fine vegetation in this area including vacant land or dry land, water bodies and ponds.

4. Conclusion
Based on this research can be concluded that tsunami runup with 7.9 Mw will produce highest runup about 3.52 meters and inundation area about 286300 m². From simulation, describe the shoreline with bay shape have runup higher than straight and cape shape. Also, more sloping an area then the tsunami will higher, this case, have opposite relation with runup and inundation area or negative correlation with coastal characteristic.
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References
[1] Baeda Y A 2011 Seismic and Tsunami Hazard Potential in Sulawesi Island, Indonesia *Journal of International Development and Coorporation* vol 17 No. 1, pp 17-30
[2] Pelinovsky E, Yuliadi, D, Prasetya G, and H Rahman 1997 The January 1, 1996 Sulawesi Island Tsunami *Natural Hazards* B16
[3] S. Aswad, et al. 2013 Numerical Simulation Of The 1996 Toli-Toli Tsunami And The 2000 Peleng Tsunami Central Of Celebes With Single Fault Model, *Proceedings of the 7th International Conference on Asian and Pacific Coasts* (APAC 2013) Bali, Indonesia, September 24-26
[4] Suparto, Eka T P and Surono 2006 *Katalog gempabumi merusak di Indonesia tahun 1629-2006* No.3
[5] Papazachos B C, Scordilis E M, Panagiotopoulos D G, Papazachos CB, and Karakaisis G F 2004 Global Relations between Seismic Fault Parameters and Moment Magnitude of Earthquakes Bull. Geol. Soc. Greece, Vol. XXXVI. *Proceedings of the 10 International Congress*, Thessaloniki, April 2004th
[6] Hanks, Thomas and Kanamori H 1979 Moment magnitude scale *Journal of Geophysical Research*, 84 (B5): 2348–2350. Retrieved 2007-10-06
[7] Hills J G & Mader C L 1997 Tsunami produced by the impacts of the small asteroids. *Annals of the New York Accademy of Sciences* 822
[8] Nakamura M 2006 Source fault model of the 1771 Yaeyama tsunami- Southern Ryukyu island Japan inferred from numerical simulation, *Pure Appl Geophys* no 163
[9] Setyonegoro W 2011 Tsunami Numerical Simulation Applied To Tsunami Early Warning System Along Sumatra Region *Jurnal Meteorologi dan Geofisika* Vol. 12, No. 1Smid, Op.cit., pp 3