Predicting of Tsunami Inundation Area based on Propagation and Runup Numerical Model in Pacitan City

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Abstract. Pacitan city represents one of the regions residing in South East Java Province Indonesia about which on direct with Indian Ocean. In this area there is a meeting of plate of Indo-Australia with plate of Eurasia which is if colliding head-on potency can generate tsunami. Seeing this existing condition, it is needed a study to know how susceptible level of South East Java Province regional to get disaster of tsunami. Based on the tsunami was occurred in Aceh Indonesia on December 26, 2004 was killed more than 200.000 peoples, the tsunami disaster management become very important to study. One of the studies is how to predict the tsunami runup along shoreline of southern beach of East Java Province Indonesia. According to the geological data, area of east Java Ocean has high potential of earthquake. The history shows that there are many time tsunami occurred in East Java. Based on the initial study, one of the areas predicted as dangerous area for the tsunami is Pacitan city. To minimize the effect of tsunami hazard, prediction of inundation area base on the numerical model simulation of tsunami runup was done for Pacitan city. In this research predicting of inundation area caused by tsunami was studied. GIS was used as tool to predict the inundation area. From this research it can be shown that numerical model of tsunami can be used to predict the runup. Base on runup elevation, inundation area can be predicted well by using GIS.
Keywords: Tsunami, Inundation area, Numerical model, GIS.

Introduction

The biggest tsunami on the world was occurred on December 26, 2004, in *Banda Aceh*, Indonesia. More than 200.000 peoples were killed by this tsunami. To prevent this disaster in the others areas which are dangerous with the tsunami hazard, it is necessary to analyze how to mitigate the peoples if tsunami occurs (Atu, 2000). The purposes of this study are to minimize the tsunami victim and properties damage if the tsunami occur.
East Java Province is located in dynamic area, because there are three plates get together in Java Island. Those three plates are Eurasian, Indian Ocean, and Australian plates. Consequently, the earthquake often occurs in Java Island included East Java Province area (*Kabupaten Banyuwangi*, 2005). Tsunami will be occurred if there is earthquake in the sea area. Therefore, the potential of tsunami occurrences in southern beach of East Java Province is high. To prevent the tsunami disaster hazard, the research of tsunami disaster mitigation management for East Java Province based on the local characteristics of shoreline was done.

Sea bottom motion (rupture) or landslides can be used as tsunami source but in practical purpose, final form of the rupture can be used as initial condition of water level. The geometry of rupture can be estimated by using Okada's (1985) formulae. For understanding the local characteristics of bottom motion, the research was done by supporting the earthquake history data and GIS. The earthquake history data is used to analyze the initial wave of tsunami and GIS is used to simulate the inundation area due to the run-up elevation. The purposes of this research are to analyze the area inundated by tsunami. The inundation area is simulated based on the run-up elevation analyzed by numerical model. The distribution of maximum tsunami height is largely different depending on the locations of the seismic fault, though the maximum height is a few meters at the most. Tsunami height arrives the coast within several ten minutes after the occurrence of earthquake. These features mean that the most community residents along coast area are potentially under the vulnerability against tsunami disasters. The second feature means that a quick transmission system of the refuge alarm against tsunami attack is indispensable for community residents to ensure their safety, because it is difficult to construct a tsunami breakwater along the local coast due to an economic reason. In this study, the vulnerability against tsunami disasters along Pacitan city coastline is evaluated based on tsunami runup and its arrival time.

A numerical simulation of tsunami propagation based on a nonlinear long wave theory to estimate tsunami height and its arrival time along the coastline is conducted. Tsunamis are long waves of small steepness generated by impulsive geophysical events of the seafloor and of the coastline, such as earthquake and submarine or aerial landslides. Modeling of tsunami then usually used shallow water equations as governing equations. However, the dispersive effects play a role for trans-oceanic tsunami propagation (Imamura and Shuto, 1989). Hence dispersive wave model will be used here as model equations for better prediction of tsunami propagation.

Based on the 2007 research, Pacitan city located in south west of east Java Province, Indonesia is selected as research area (Agus and Fadly, 2007). To generate tsunami numerical simulation topographic, bathymetry, and earthquake data are needed.

Materials and Methods

Topographic, bathymetry, and earthquake data collection

Geographically, Pacitan city is located between 111°5’ East Longitude and 8°13’ South Latitude. The map of the Pacitan city is shown in Figure 1. This research was done using several materials relating to the parameters need in the analysis process. In summarize the materials used in this research can be shown as follows.

1. Topographic map in scale 1:25,000 and 1:5,000
2. Quick Bird satellite imagery
3. Land use detail planning map in scale 1:5,000
4. Bathymetry map

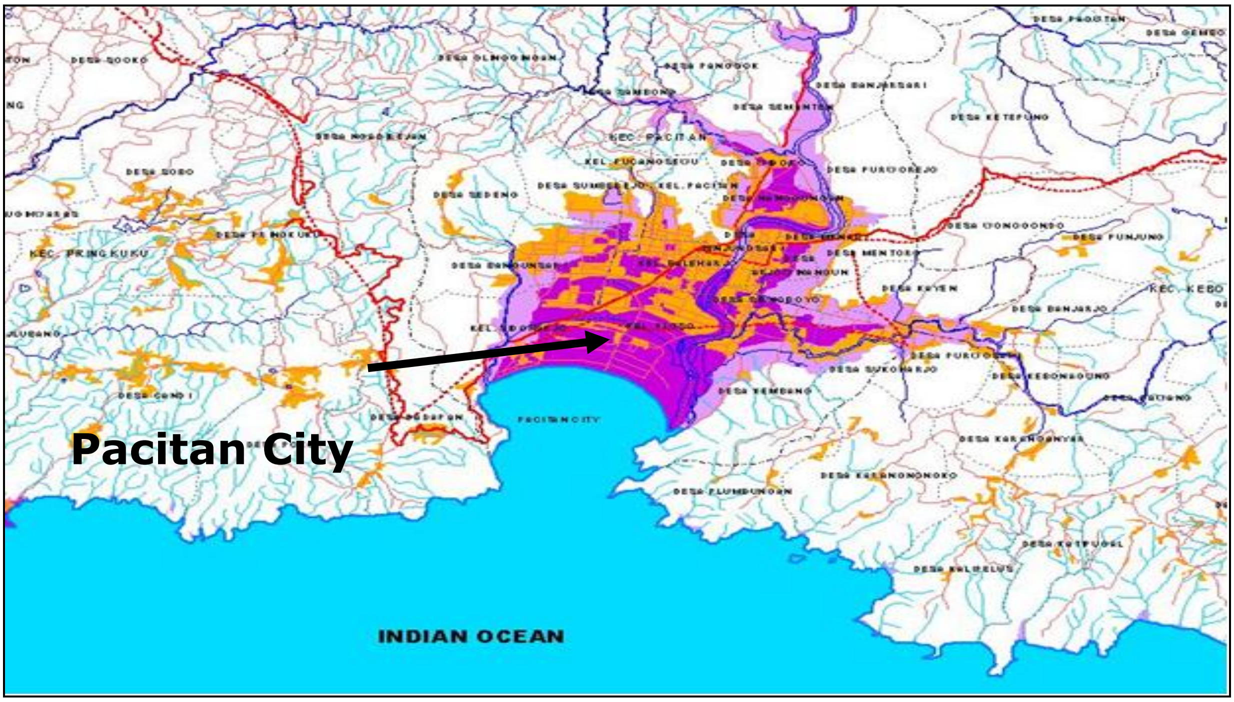


Figure 1. The map of Pacitan City.

The run-up elevation can be simulated using numerical method base on the initial wave generated by earthquake location and magnitude (Xiaoming, et.al., 2008). In this paper, numerical analysis to find the run-up elevation is not discussed. The run-up elevation were assumed base on the appropriate run-up elevation when the tsunami occurred. The other paper will be discussed how to analyze the run-up elevation using numerical simulation. Base on 5 m and 10 m run-up elevation, the inundated area of Pacitan city will be simulated. Base on the population number living, road network, road geometry, housing construction quality located along road in inundated area the evacuation road and location of shelter will be predicted. The location of evacuation area will be analyzed based on the topographic map and road network map.

In order to reduce the computer's memory and simulation time, domain of simulation are divided into three layers with different resolution. Due this condition, the bathymetry data was generated from three resources. For the first layer, bathymetry data was generated from etopo1 database, second layer from SRTM data, and third layer from Hydro-Oceanographic Bureau, Indonesian Marine force. The total simulation time is 60 minutes with time increment is 2 minute. Spatial increment which is in spherical coordinate, first layers is 1 minutes, second layer is 0,25 minute, and third layer is 0,05 minute.

GIS was applied to analyze the location of inundation area. People living in the area predicted inundating by tsunami should be knows well how to evacuate when tsunami occurred. Inundated area was predicted and plotted to the topographic map base on runup elevation analyzed using numerical model. Contour line is used to predict the inundation area. Using population density data (BPS, 2009), the number of people predicted inundating by tsunami can be analyzed. By using high resolution satellite remote sensing data, the housing distribution and road network can be drawn. After this analyzing process, the inundation area map can be drawn. Base on the GIS analyses requirements, the layer will be generated can be summarized as follows.

a. Contour line layer
   This layer is generated from topographic map published by BAKOSURTANAL in scale 1 : 25,000. The original contour interval is 12,5 m. The ground survey is needed to increase contour interval become 1 m. The attribute of the layer is contour elevation
b. Inundation area layer
   Inundation area decided base on the contour elevation. Base on the numerical model analysis result, tsunami runup elevation can be drawn in the topographic map. The attribute of this layer is area of inundated location.
c. Land use layer
   Land use layer was generated from high resolution satellite imagery. The Quick Bird satellite imagery is used in this research. After geometric correcting, the building located 100 m of both side road center lines is digitized. This work was done for all road network layers.
d. Road network layer
   This layer was generated from topographic map form BAKOSURTANAL (National Survey and Mapping Coordination Bureau) combined with data from Quick Bird. All roads located in inundation area and connected to the evacuation area are digitized. The attribute of this layer are road width, pavement type and condition, road alignment, and number of bridges cross the road.
e. Residential layer
   This layer is similar with the land use layer. But here only houses located in the research area are digitized.

The Universal Transverse Mercator (UTM) with zone number 49 is used for mapping the research area. After the all layers is ready as input data the inundation area can be predicted using overlapping analyses method in GIS. The polygon of inundation area is predicted base on the tsunami runup elevation. From this process, the inundation area can be predicted.

Tsunami propagation and runup numerical simulation

The tsunami propagation and runup numerical model was developed base on Cornel Multi-grid Coupled Tsunami Model (COMCOT). The numerical solution was done with assumed (1) full explicit scheme is used, (2) Leap-Frog scheme calculates free surface elevation at point, (3) Upwind scheme is applied for Non-linear convection terms.

Extended weakly non-linear Boussinesq-type equations in which time-dependent of water depth (bottom) term is included to the models based on derivation of Lynett and Liu (2002) are used as governing equations. Additional terms to accommodate bottom friction and energy dissipation caused by breaking waves are also included into the momentum equation.

In order to eliminate the error terms to the same form of dispersive terms, fourth-order accuracy of numerical scheme for time stepping and first-order numerical scheme for first order spatial derivative terms are used (Wei and Kirby, 1995). High order predictor-corrector scheme is used for time stepping, employing third order time explicit Adam-Bashforth scheme as predictor and fourth order Adam-Moulton implicit scheme as corrector step. The corrector step must be iterated until a convergence criterion is satisfied. The system equations are written in a form that makes convenient for application high-order time stepping procedure (Wei and Kirby, 1995).

Results and Discussion

After all research material ready to analyze, the contour line, inundation area, land use, road network, and houses layers can be developed. The first step analysis is predicting the runup elevation based on the numerical analysis. In this paper the simulation was done until second layer. The simulation was done with scenario described as follows.

1. Earthquake epicenter located in 109^0E, -9^0S for first simulation and 111^0E, -9^0S for second simulation.
2. Tsunami source parameters are length 100 km, width 50 km, dip 25^0, rake 90^0, strike 299^0, slip amount 10 m, depth 10 km, resultant moment magnitude 8,2.
3. The total simulation time is 60 minutes with time increment is 2 minute. Spatial increment which is in spherical coordinate, first layers is 1 minutes, second layer is 0,25 minute, and third layer is 0,05 minute.
4. First layer domain is 118^0E, -7,5^0S – 114^0E, -11,5^0S
5. Second layer domain is 110,75^0E, -8,25^0S – 111,5^0E, -8,75^0S

After simulating process, the runup elevation of tsunami can be found. The simulation result can be shown in Figure 2. From this figure in can be shown that the runup with elevation 9 – 10 m will be arrived in Pacitan city coast area. By tracing the area in Pacitan city with elevation less than 10 m, the inundation area can be predicted. This tracing process was done on the contour layer. The boundary of predicted inundation area call inundation layer. By overlapping the inundation, landuse, houses, and road network layers the inundation map can be drawn. The inundation map shown in Figure 3. From this figure it can be shown the area, housing, and infrastructure matter inundated by tsunami. Furthermore, the number of houses, length of road, public facilities, and others land uses can be analyzed. This analysis will be continued in this research until the tsunami mitigation map can be drawn.

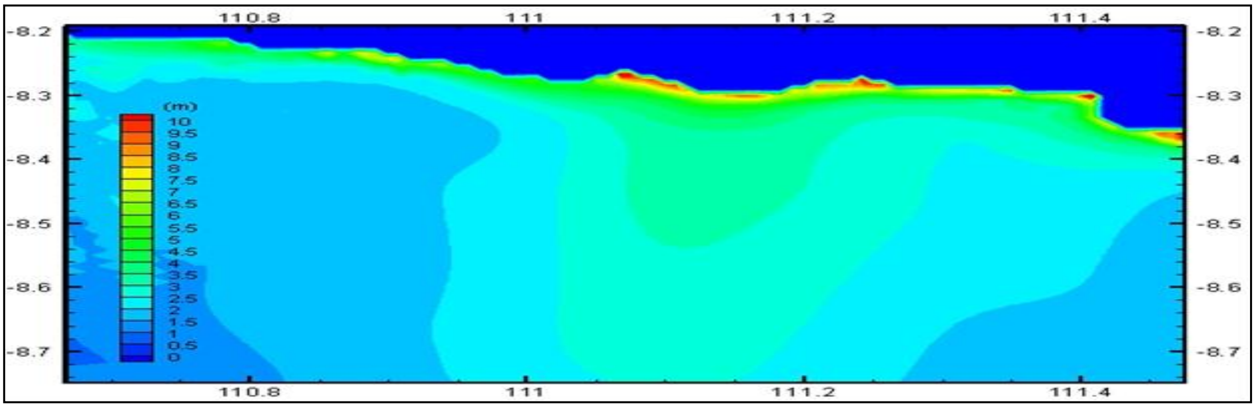
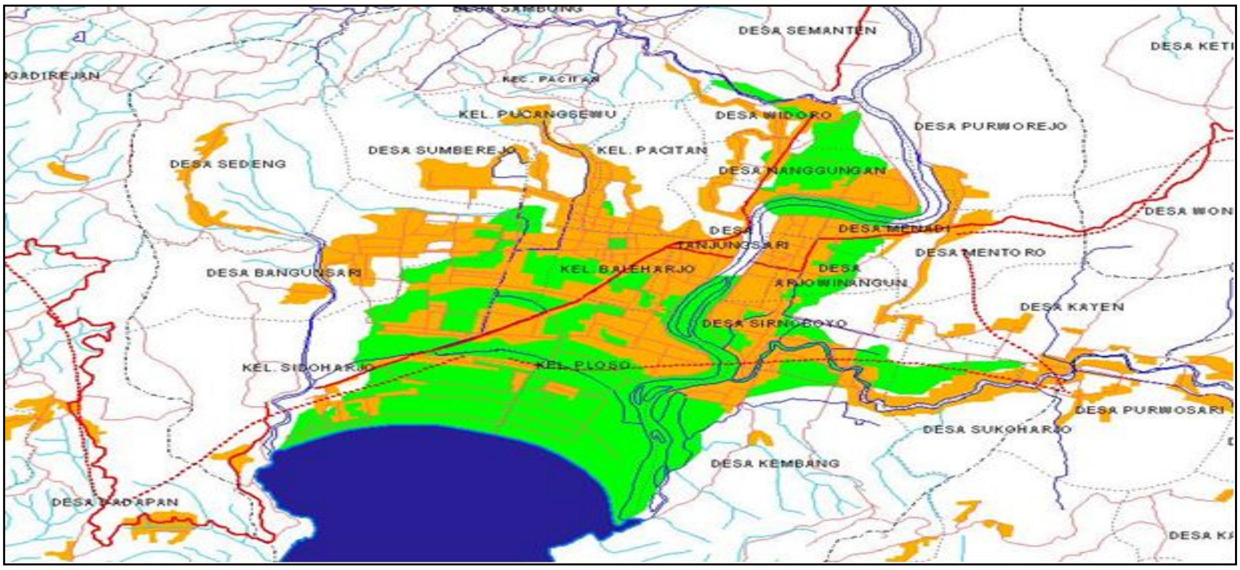


Figure 2. Runup elevation from Numerical Simulation.



■	Residential area	■	10 m runup	■	Indian Ocean
—	Road Network	—	River		

Figure 3. Inundated Area of Pacitan City Affected by Tsunami Runup.

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