NUMERICAL SIMULATION FOR THE ASSESSMENT OF TSUNAMI SCENARIOS IN SOUTHERN YOGYAKARTA, CENTRAL JAVA ISLAND, INDONESIA

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ABSTRACT

The study aims to assess the possible tsunami impact on Yogyakarta, the central coast of Java Island, Indonesia. Seven tsunami scenarios with different parameters estimated by referring the seismic gap and tectonics have been applied to calculate the tsunami propagation, inundation, maximum height and travel time, which are important indices for the assessment. Tsunami numerical modeling was performed by using TUNAMI-N2 with GEBCO bathymetry data. 38 tide gauge stations are selected as output points along Yogyakarta coastal area.

Tsunami simulations with two sources of different depths of 0 km and 10 km using similar sources parameters demonstrated that the depth of source affects the tsunami propagation, maximum tsunami height and inundation area. Through carrying out other simulations with the different parameters such as length and location, we also confirmed that the location and the length of tsunami source caused big difference for the tsunami propagation and tsunami height and inundation area. On the other hand, the catastrophic case (M_w 8.8) adopted from Okal and Synolakis (2007) showed the maximum tsunami height and the widest inundation area compared to the other tsunami sources. Tsunamis could reach the most of coastal area in Yogyakarta in less than 20 min to 50 min after the earthquakes according to the seismic gap.

Keywords: Tsunami scenario, Numerical simulation, Java, Tsunami assessment.

1. INTRODUCTION

Yogyakarta is one of tsunami prone areas in Indonesia, located in south of Java Island, face to face with subduction area. The Java subduction zone, is characterized by an absence of great interplate thrust earthquake (Okal and Synolakis, 2007). From historical earthquakes which occurred in south of Java Island, it is shown that there is a "Seismic Gap". Since 1900, despite historical reports, tsunami in south of Yogyakarta is unclear. NEIC (National Earthquake Information Center)/USGS catalogue lists (http://neic.usgs.gov/neis/epic/epic.html) show six earthquakes with magnitude larger than seven, in 1903, 1921, 1937, 1977, 1994 and 2006. Hence, in regard to the potential of seismic source, the coastal area of Yogyakarta might be the most prone area of tsunami.

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2. DATA AND METHOD OF COMPUTATION

2.1. Bathymetry and Topography Data

The bathymetry topography data are important in tsunami simulations. We used 30 arc second grids size of bathymetry data from GEBCO (General Bathymetric Chart of the Ocean) (https://www.bodc.ac.uk/data/online_delivery/gebco/). Finer spatial grid sizes were applied for four regions. The grid sizes used for regions R1, R2, R3 and R4 are 30, 10, 3.33 and 1.11 arc second respectively. Figure 1 shows the coverage area of computation. We combined topography data from SRTM (Shuttle Radar Topography Mission) (http://www2.jpl.nasa.gov/srtm/dataprod.htm) with GEBCO data for computation area (R4) of inundation.

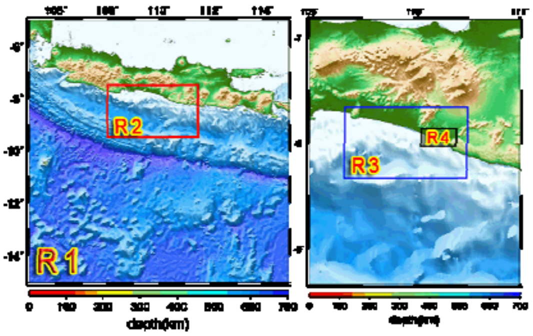


Figure 1. Computation area for numerical model in R1, R2 (left) and R3, R4 (right).

2.2. Tsunami Sources

A tsunami source plays an important role in tsunami simulation. For this study, seven scenarios have been applied to perform tsunami simulations according to the seismic gap at south of Java Island. A rectangular fault model tsunami sources are applied. Dip angle is assumed to be 10^0 for all scenarios. Strike angles are based upon pre-assumed trench alignment. Some scenarios are changed by depth, position and length. For catastrophic case, tsunami source are adopted similarly from Okal and Synolakis (2007). All the fault parameters used in this study are shown in Table 1.

Table 1 Parameter of tsunami sources for scenario earthquakes.

Scenario	Mag	Rigidity μ	Length L	Width W	Depth h	Strike φ	Dip δ	Rake λ	Slip u	Longitude	Latitude
No.	Mw	N	(km)	(km)	(km)	$(^0)$	$(^0)$	$(^0)$	(m)	$(^0)$	$(^0)$
1a	8.3	3.00E+10	355	135	10	289	10	102	2.5	111.6888	-11.300
1b	8.3	3.00E+10	355	135	0	289	10	102	2.5	111.6888	-11.300
2	7.7	3.00E+10	200	29	10	289	10	90	2.5	111.6888	-11.300
3	7.7	3.00E+10	200	29	10	289	10	90	2.5	110.0000	-11.000
4a	8.1	3.00E+10	300	75	3	280	10	90	2.5	109.5000	-9.900
4b	8.2	3.00E+10	450	75	3	280	10	90	2.5	109.5000	-9.900
5	8.8	3.00E+10	500	150	10	290	10	90	10	112.5000	-10.400

2.3. Tsunami Simulation

We used TUNAMI-N2 (Tohoku University Numerical Analysis Method for Inundation), developed by Disaster Control Research Center (DCRC), Tohoku University of Japan (Imamura et al., 2006) for modeling propagation and inundation of tsunami in coastal area of Yogyakarta. In this modeling code non linear shallow water equations with bottom friction terms are discretized by the leap-frog finite difference scheme. This model is widely used to simulate tsunami propagation and inundation on dry land (Koshimura et al., 2006).

Tsunami waveforms were calculated at 38 tide gauge stations along Yogyakarta coast as target points to obtain tsunami heights and arrival times. All stations are assumed at the front face of sea. Some stations are determined because of the high population in that areas. In this study the time step (Δ t) was set to 0.5 s to satisfy the stability condition. The number of time steps for computation is 21,600 (three hours).

3. RESULT AND DISCUSSION

3.1. Tsunami Wave Propagation into the coast

Figure 2 shows that the snapshots of tsunami propagations in R3 from Scenario 1a (top) and Scenario 1b (bottom) are slightly different. Tsunami wave length in Scenario 1a is longer than that in Scenario 1b. The wave propagation in Scenario 1a is also wider than Scenario 1a. The first positive tsunami could reach the coast more than 30 min after the earthquake.

Figure 3 shows that the snapshots tsunami propagation from Scenario 2 (top) and Scenario 3 (bottom) are similar. Before tsunami waves reach the coastal area, some disturbances occur. The disturbance in Scenario 3 is stronger than Scenario 2. In contrast with Scenario 3 which focused on the west part of Java Island, the area affected by tsunami in Scenario 2 is mostly concentrated at the east part. Yogyakarta coastal area will be more affected by tsunami in Scenario 3 compared to Scenario 2.

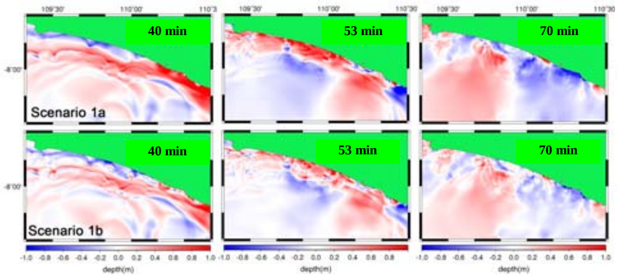


Figure 2. Snapshots of tsunami propagation in R3 at 40, 53 and 70 min after the earthquakes for Scenario 1a (top) and Scenario 1b (bottom).

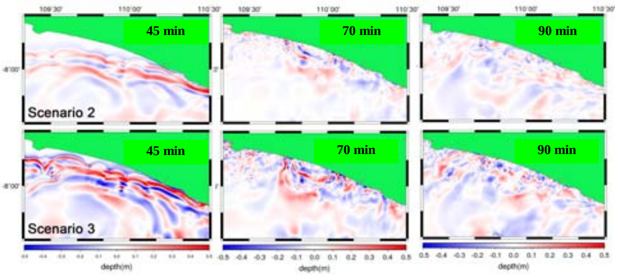


Figure 3. Snapshots of tsunami propagation in R3 at 45, 70 and 90 min after the earthquakes for Scenario 2 (top) and Scenario 3 (bottom).

Multi-faults cases were applied in Scenario 4. Scenario 4a consists of two faults as the tsunami source, in which the length of the each fault is 150 km. Scenario 4b consists of three faults. Because the time of deformation for each fault is quite short, it can be assumed that the initial condition for deformation of sea floor occurs at the same time. Figure 4 shows the propagation of tsunami wave in R3 at 25, 41, and 55 min after the earthquake. Even though the propagation is similar, the Scenario 4b produces wider and higher tsunami. The positive part of tsunami might reach the Yogyakarta coast in less than 30 min after the earthquake.

We applied the tsunami source for the most catastrophic case (M_w 8.8) which has been adopted from Okal and Synolakis (2007). Scenario 5 refers the full rupture of Java segment of the subduction zone. Figure 5 shows the tsunami propagation in R3 at 10, 20, 30, 60, 120 and 180 min after the earthquake.

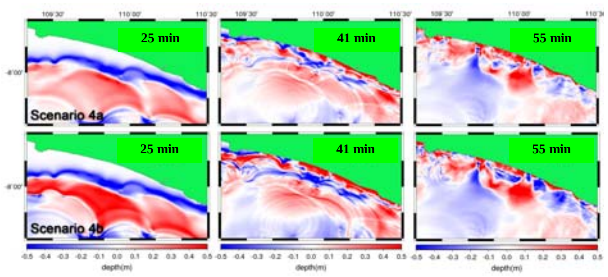


Figure 4. Snapshot of tsunami propagation in R3 at 25, 41 and 55 min after the earthquake for Scenario 4a (top) and Scenario 4b (bottom).

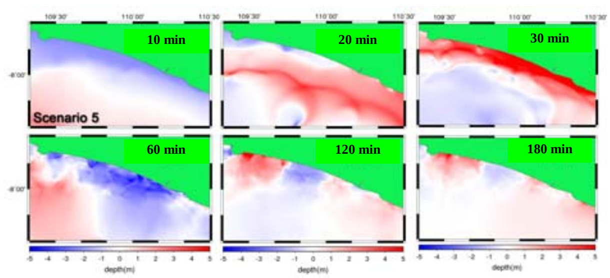
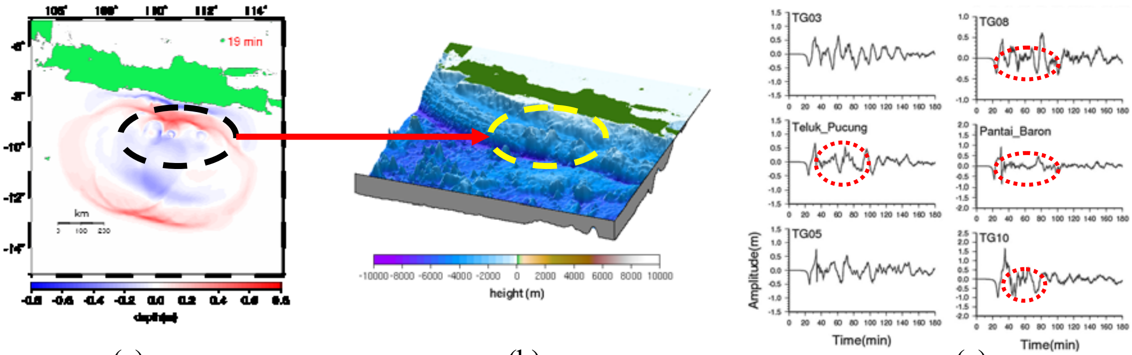


Figure 5. Snapshot of tsunami propagation in R3 at 10, 20, 30, 60, 120 and 180 min after the earthquake for Scenario 5.

From all scenarios we found that there are some disturbances of tsunami propagation which occur before it reaches Yogyakarta coast. The disturbances are caused by some “small sea mountains” at sea floors which changes bathymetry. Those disturbances will be shown in tsunami waveform with increasing high frequency signal at each target point. Figure 6 shows the disturbance of tsunami (a), the small sea mountains (b) and high frequency waveforms (c).



(a) (b) (c)

Figure 6. Snapshot from Scenario 1a at 19 min after the earthquake (a), small sea mountains at bathymetry (b), and high frequency signal shown in tsunami waveforms (c).

3.2. Maximum tsunami heights along the shore

Maximum tsunami height is one of the components obtained from tsunami simulation. The maximum tsunami height in Scenario 1a reached 3.0 m, near the Parang Tritis area. The maximum tsunami height higher than 2 m occurred at 10 tide gauge stations, mean while in Scenario 1b only at 3 tide gauge stations. Maximum tsunami height between 1.0 and 2.0 m occurred in Scenario 1a and 1b are: 13 and 15 tide gauge stations respectively. In Scenario 1b, the highest tsunami was calculated at TG18, which located not so far from highly populated Banaran area.

In Scenario 2 and 3, only at one tide gauge station tsunami maximum height Scenario 2 more than in 1 m. In contrast with Scenario 2, according to the waveform data, the maximum tsunami height in Scenario 3 is higher than 2 m at 3 tide gauge stations. The highest tsunami of 2.2 m is found at TG20. Another tsunami occurs at height less than 1 m in most areas of the east part of Java Island. The position of seismic source in Scenario 3 is located in the direction almost perpendicular to Yogyakarta coast and might affect the maximum height of tsunami.

Figure 7 shows the maximum tsunami heights for all stations all scenarios. In Scenario 4a compared with 4b, maximum tsunami will be affected by the length of tsunami sources. Tsunami higher than 2 m can occur at 2 tide gauge stations in Scenario 4b, but the maximum tsunami height is not exceeding 2 m in Scenario 4a. However, maximum tsunami height between 1 and 2 m are still dominant for both scenarios. The east part of Yogyakarta still obtains maximum tsunami height less than 1 m.

The maximum tsunami heights in Scenario 5 exceed 4 m at all tide gauge stations. The maximum height of 11.2 m occurs at Teluk Pucung tide gauge station. According to the other four Scenarios before, at the east part of Yogyakarta coast, tsunami wave is smaller than at the west part. However in Scenario 5, the highest tsunami wave occurs at the east part.

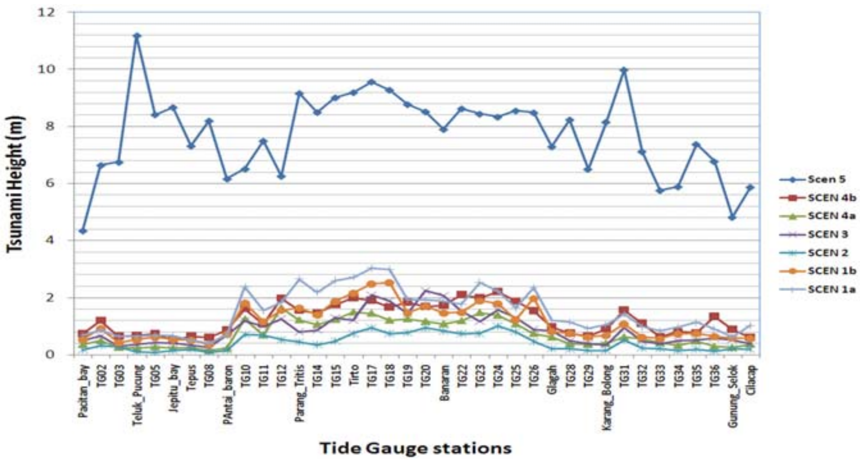


Figure 7. Maximum tsunami heights for all scenarios.

3.3. Inundation Area around Yogyakarta

Figure 8 show the inundation area for all scenarios. First column shows the inundated area in Scenario 1a and 1b are less than 1 km. The shape of inundation area is similar only limited of area, but the maximum inundation height is higher in Scenario 1a compared to Scenario 1b. The inundated area in the west part of Opak River is wider than in the east part.

Scenarios 2 and 3 illustrated at the second column in Figure 8 show that the inundation area Scenario 2 is smaller than in Scenario 3. The inundated area exceeds only a few hundred meters, making small inundated area. The shape of inundated area in Scenario 3 is similar to the two Scenarios of Scenario 1a and 1b, but the area smaller and steeper. The maximum inundation high in Scenario 3 is higher than in Scenario 2, but lowers than Scenarios 1a and 1b.

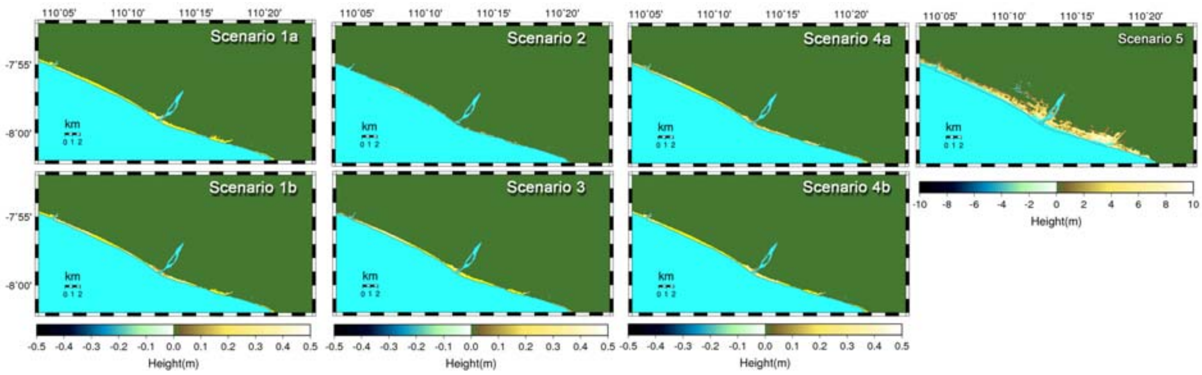


Figure 8. Inundation areas for all scenarios.

Since the source length used in Scenario 4b is longer than Scenario 4a, the maximum inundation height in Scenario 4b is higher than that in Scenario 4a. Figure 8 at the third column illustrated Scenario 4a and 4b. In Scenario 5 which is tsunami will reach more than 2 km inland with maximum height of more than ten meters. All coastal areas will be affected by the tsunami.

All scenarios show that some areas are always inundated compared to the other areas. It consists of three regions, namely, the southern of Plered ($7^0$56'S, $105^0$07'E), near the mouth of Opak River ($8^0$00'S, $110^0$16'E) and Parang Tritis area ($8^0$01'S, $110^0$19'E).

3.4. Tsunami Travel Time of tsunami to the Shore

Figure 9 shows the tsunami travel times for all scenarios. In Scenarios 1a and 1b, the tsunami reaches the coastal area in less than 30 min after the earthquakes. In Scenarios 2 and 3, tsunami travel times obtained at all tide gauge stations are more than 30 min after the earthquakes. Scenarios 4a and 4b are similar with Scenarios 1a and 1b, the tsunamis arrived in less than 30 min after the earthquakes at Pacitan Bay and propagated to the west gradually. As for Scenario 5 the tsunami travel time was less than 30 min after the earthquake. Tsunami travel time recorded at the Pacitan Bay showed a significant difference with the station located next to it.

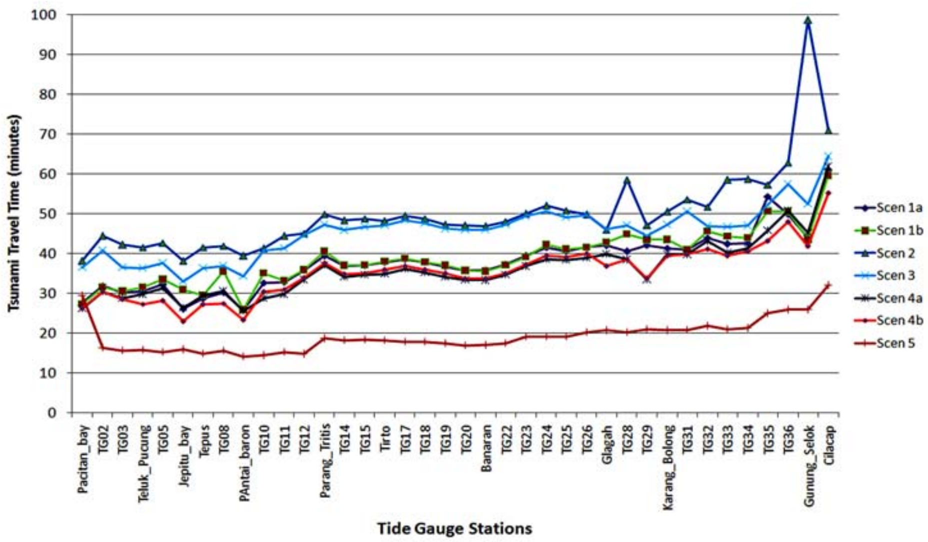


Figure 9. Maximum tsunami heights for all scenarios.

4. CONCLUSIONS

The maximum heights, travel times and inundation areas of tsunamis are derived from the tsunami simulations. The depth of tsunami source will affect the height, inundation area and travel time of tsunami. Also, the shape of the coastal area plays an important role in increasing the tsunami height. We found that the different positions of sources have affected the different propagation and height of tsunami. Although the fault parameters used are same, the source located almost perpendicular to the coast of Yogyakarta might be more dangerous for coast.

Based on the tsunami simulation result, we conclude that tsunamis could reach the coast of Yogyakarta in around 20 to 40 min after the earthquakes on the seismic gap at south of Java island. Tsunami heights would exceed up to 3 m and the inundated area could cover more than 500 m on land. In the catastrophic case, tsunami height could reach more than 10 m and the inundated area could cover 2 km on land.

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