Potential Tsunami Hazard on the Coast of the Indonesia’s New Capital Candidate

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Abstract. On the 26th of August 2019, the Indonesian government announced the location of the new nation’s capital city. The plan to move the capital city raises various pros, cons, and several challenges, including those from natural disaster aspects. East Kalimantan’s coastal area faces the Makassar Strait waters which have the potential for tsunamis, either originating from landslides or from the megathrust. The megathrust earthquake that has the potential to cause a tsunami in the area is the megathrust of North Sulawesi. In 1997, an earthquake measuring 7.9 Mw originating from the megathrust caused a catastrophic tsunami. According to Peta Gempa (Pusgen, 2017), the North Sulawesi Megathrust has the worst potential for an earthquake of magnitude 8.5. In this research, the tsunami wave height and the estimated time of arrival will be simulated using the TUNAMI numerical model. In addition, analyses from the simulation results are also made for coastal areas with high activity and large population (Palu, Toli-toli, Donggala, Mamuju, Samarinda, Berau, Kutai, and Bontang). The simulation results of this model show that the maximum height of the tsunami waves on the coast of East Kalimantan is 0.83 meters and the arrival time is around 1.6 to 2 hours.

1. Introduction

On the 26th of August 2019, Indonesia’s President, Mr. Joko Widodo officially announced the relocation of Indonesia’s capital city from Jakarta to East Kalimantan, one of provinces in Borneo Island [1]. This project should be planned conscientiously and be examined from its positive effects and its risks. One of the aspects that should be considered is the natural hazard. Indonesia is a country surrounded by subductions and megathrusts potential due to its complicated plate-convergences. According to data from 1600 to 1999, Indonesia has been hit by tsunami 105 times and 90% of them caused by earthquake that originated from megathrust [2]. During the time from 1965 to 2006, there were 14 tsunami events recorded in Indonesia [3] and in 2018, there were 2 tsunami events at the Sunda Strait and Palu due to flank-collapse and landslide respectively [4,5].

The coast of East Kalimantan, as the new capital city candidate, is facing Makassar Strait that had the preeminent frequency of historical tsunami in Indonesia [6]. The closest megathrust that potentially generates tsunami for East Kalimantan is North Sulawesi Megathrust which has the highest magnitude potential of M8.5 [7] and is a very active region. Historically, there have been 10 earthquake events greater than M7 originated from North Sulawesi (Table 1). In the Makassar Strait, the tsunami earthquake event has occurred 4 times since 1927 [8]. The maximum magnitude appeared from
earthquake that followed by tsunami in Sulawesi in 1996 was M 7.6, its epicentre is located in North Sulawesi (Lat 0.74 Lon 119.93) [8]. The tsunami wave height was 2 to 4 m [9].

Table 1. Historical earthquake event (>M7) at North Sulawesi [10]

| Time (UTC+7)     | Latitude | Longitude | Depth (km) | Magnitude (Mw) |
|------------------|----------|-----------|------------|---------------|
| 16/11/2008 17:02:32 | 1.271    | 122.091   | 30          | 7.4           |
| 25/11/1997 12:14:33 | 1.241    | 122.536   | 24          | 7             |
| 22/07/1996 14:19:35 | 1        | 120.45    | 33          | 7             |
| 01/01/1996 08:05:10 | 0.729    | 119.931   | 24          | 7.9           |
| 20/06/1991 05:18:52 | 1.196    | 122.787   | 31.4        | 7.5           |
| 19/05/1991 00:58:01 | 1.156    | 122.957   | 33          | 7             |
| 18/04/1990 13:39:19 | 1.186    | 122.857   | 25.7        | 7.8           |
| 14/08/1968 22:14:23 | 0.157    | 119.802   | 20          | 7.2           |
| 28/03/1964 11:30:09 | 0.542    | 122.139   | 130         | 7.4           |
| 08/11/1941 23:37:28 | 0.742    | 122.791   | 35          | 7.4           |

Not only Indonesia’s new capital city candidate region that will be affected, but also districts and cities along Makassar Strait (Figure 1). There are several areas with high population and activity, which would raise the risks if tsunami occurred. Those areas including Palu, Toli-toli, Samarinda, Bontang, and Mamuju. In 2018, Palu City has population of 385.619 people [11], while Toli-toli has the population of 233.409 people [12]. There are 872.768 people in Samarinda [13], 181.183 in Bontang [14], and 279.393 in Mamuju [15]. At Indonesia’s new capital candidate itself, there are 786.122 people in Kutai Kartanegara [16] and 160.910 in North Penajam Paser [17].

In this study, the tsunami simulation originated from worst case scenario in North Sulawesi Megathrust (M8.5) will be conducted to assess the tsunami wave height and the tsunami arrival time at the East Kalimantan’s coast as well as the other districts and cities in the region with the highest activity and population (Toli-toli, Palu, Mamuju, Samarinda, and Bontang) (Figure 1).

![Figure 1. High Populated Region that might be affected by North Sulawesi Megathrust tsunami [19]](image-url)

2. Data and Methods

The tsunami simulation is performed with the use of TUNAMI N3 which was developed by Tohuku University and modified by BTIPDP BPPT. The governing fundamental equations for this model are presented in the equation below [18]. The first equation is the law of mass conservation (1) while the other two are momentum conservation equations (2 and 3).

\[ \frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial t} + \frac{\partial N}{\partial y} = 0 \]  (1)
\[
\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left( \frac{MN}{D} \right) + gD \frac{\partial \eta}{\partial x} + \frac{g n^2}{D^{7/3}} M \sqrt{M^2 + N^2} = 0 \quad (2)
\]

\[
\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left( \frac{MN}{D} \right) + \frac{\partial}{\partial y} \left( \frac{N^2}{D} \right) + gD \frac{\partial \eta}{\partial y} + \frac{g n^2}{D^{7/3}} N \sqrt{M^2 + N^2} = 0 \quad (3)
\]

where x and y from the equations are horizontal axes, z is the vertical axis, t is the time (s), h is the still water depth (m), \( \eta \) is the vertical displacement of water surface above the still water surface (m), g is gravitational acceleration (m/s^2), M and N are the water discharge at x axis and y axis respectively (m^2/s), D is the total water depth (h+\( \eta \)) (m), and n for the Manning roughness.

2.1 Tsunami source and the data used for model simulation

Potentially worst earthquake magnitude that might generate tsunami from the North Sulawesi Megathrust (M8.5) [7] was applied for this tsunami simulation. The earthquake parameters (epicentre, magnitude, depth, focal mechanism, dimension, and dislocation) were used to generate the initial tsunami source, as presented in Table 2 [20, 21, 22]. The tsunami source consist of two faults with the highest elevation at the tsunami source is 2.4 meter (Figure 2). The tsunami source is one of the necessary inputs for the tsunami model simulation.

Table 2. Earthquake parameters for the tsunami source (North Sulawesi Megathrust, magnitude M8.5)

| Thrust Name | Faults | Epicentre Lon. (Mw) | Lat. | Mag. | Depth (km) | Focal Mechanism | Dimension L(km) | W(km) | Dislocation (m) |
|-------------|--------|---------------------|------|------|------------|-----------------|-----------------|-------|-----------------|
| North       | 1      | 120.39             | 1.5304 | 8.5  | 30         | 85              | 90              | 145   | 110             | 6    |
| Sulawesi    | 2      | 121.74             | 1.5387 |      | 30         | 95              | 90              | 145   | 110             | 6    |

Figure 2. The elevation of tsunami source (the North Sulawesi Megathrust M8.5)

2.2 The domain of study, the topography and the bathymetry data

There are two domains, namely domain D and domain E, that will be used for the tsunami simulation. The smaller domain E focuses on the Indonesia’s New Capital Candidate region (Figure 3). The topography and bathymetry for both domains are obtained from DEMNAS with 0.26 arc-second resolution [23], BATNAS with resolution of 6 arc-second [24], and GEBCO with the data resolution of 30 arc-second [25]. The differences of model setting for the domains are shown in Table 3. In this simulation, the threshold for tsunami elevation is 0.01 meter, therefore if the water elevation lies below 0.01 meter, it will not be identified as tsunami. The simulation time for this model is 14400 second (4 hours).
3. Result and Discussion

The sea surface height and the tsunami estimated time of arrival are shown in Figure 4 for domain D (left) and domain E (right). The colour in Figure 4 shows the sea surface height while the contour shows the estimated arrival time. It is seen that within domain D, the maximum water elevation is 9 m near the tsunami source. At domain E, the highest tsunami elevation is 3.3 meter and the fastest arrival time is 15 minutes located at the northeast part of the domain (north of Palu). The tsunami height and its time of arrival for 6 coastal locations in the region will be analysed.

Table 3. Earthquake parameters for the tsunami source (North Sulawesi Megathrust M8.5)

| Domain  | Domain size | Grid resolution | Threshold | Simulation time |
|---------|-------------|-----------------|-----------|-----------------|
| Domain D | 783 x 894   | 1851 m          | 1 cm      | 14400 sec       |
| Domain E | 801 x 776   | 617 m           |           | (4 hours)       |

3.1 The coast of Indonesia’s New Capital Candidate

There are 120 points along the coast of Indonesia’s New Capital Candidate used as observation points (Figure 5). Regarding to its potential hazard, the highlight of this study is the highest tsunami elevation and the fastest estimated time of arrival. The maximum tsunami wave elevation in the East Kalimantan region is 83 cm, located at points 90 to 103 (Kabupaten Kutai, Kecamatan Kamboja). The fastest estimated tsunami arrival time is 99.3 minutes, which occurs at the same locations with maximum elevation (Figure 6 and Table 4). The average of arrival time along the 120 observation points is approximately 2 hours, with an average elevation of about 40 cm.
3.2. The coast of Samarinda

Both the maximum tsunami wave height and the fastest time of arrival occur at the same points at Samarinda (point 62-82) (Figure 7). It is located in Kecamatan Marangkayu, with the highest tsunami elevation of 1.27 meter and the minimum estimated time of arrival at 56 minutes (Table 5). There are some points in Figure 8 that have no values for the tsunami wave height or the arrival time, which occurs since the tsunami elevation is below the threshold (1 cm). In Samarinda, the mean tsunami elevation is 57 cm while the estimated time of arrival is 101 minutes (Table 5).
Figure 7. The sea surface height and estimated time of arrival at the coast of Samarinda

Figure 8. The graphs of tsunami wave height and estimated arrival time at Samarinda

Table 5. The maximum and the average of tsunami wave height and tsunami estimated time of arrival

| Sea surface height (m) | ETA (min) |
|------------------------|-----------|
| Max 1.27               | Min 56.18 |
| Mean 0.57             | Mean 101.22 |

3.3. The coast of Bontang
At the coast of Bontang, the area that has the highest tsunami elevation and the lowest estimated time of arrival is Kecamatan Bontang Utara (Figure 9). The maximum elevation at Bontang is 1.68 meter and the fastest time arrival is 55.34 minutes. The average of estimated time of arrival in this region is 70 minutes and the tsunami elevation is 85 cm (Table 6). There is no tsunami recorded at the point 45 to point 56 (Figure 10).

Figure 9. The sea surface height and estimated time of arrival at the coast of Bontang
Figure 10. The graphs of tsunami wave height and estimated time of arrival at Bontang

Table 6. The maximum and the average of tsunami wave height and tsunami estimated time of arrival

| Sea surface height (m) | ETA (min) |
|------------------------|-----------|
| Max 1.68               | Min 55.34 |
| Mean 0.85              | Mean 70.73 |

3.4. The coast of Mamuju

The minimum estimated arrival time at the coast of Mamuju is 55.93 minutes (Figure 12) which occurs at Kecamatan Mamuju (Figure 11), shown in the grey dashes. The maximum elevation is presented in the red dashes, occurs at Kecamatan Kaluku with the tsunami elevation of about 0.5 meters (Figure 11 and 12). The average tsunami wave height in this area is 26 cm and the estimated tsunami time of arrival is approximately one hour (Table 7).

Figure 11. The sea surface height and estimated time of arrival at the coast of Mamuju
Figure 12. The graphs of tsunami wave height and estimated time of arrival at Mamuju

Table 7. The maximum and the average of tsunami wave height and tsunami estimated time of arrival

| Sea surface height (m) | ETA (min) |
|------------------------|-----------|
| Max 0.54               | Min 55.93 |
| Mean 0.26              | Mean 57.87 |

3.5. The coast of Tolitoli
Compared to the other regions, the tsunami elevation at the coast of Tolitoli is the highest (3.47 meter), with the smallest estimated time of arrival (7.19 minutes), due to its location which is close to the tsunami source. The fastest tsunami wave arrives at Kecamatan Utara Tolitoli, while Kecamatan Baolan is hit by the highest tsunami wave. Compared to the other 5 coastal locations, this area suffers not only the highest average tsunami elevation, but also the smallest average time of arrival, as shown in Table 8, where the tsunami elevation is 1.6 meter and the estimated time of arrival is 16 minutes, while the other coasts have the average of approximately one hour.

Figure 13. The sea surface height and estimated time of arrival at the coast of Tolitoli
Figure 14. The graphs of tsunami wave height and estimated time of arrival at Tolitoli.

Table 8. The maximum and the average of tsunami wave height and tsunami estimated time of arrival.

| Sea surface height (m) | ETA (min) |
|------------------------|-----------|
| Max 3.47               | Min 7.19  |
| Mean 1.62              | Mean 16.08|

3.6. The coast of Palu

Figure 15 shows that at the coast of Palu, Kecamatan Palu Barat (red dashes) is hit by the maximum tsunami elevation at about 1.36 meter, while the fastest tsunami wave arrives at Kecamatan Banawa in 36 minutes (grey dashes) after the earthquake. In this region, the average tsunami elevation is 54 cm and the average of estimated time of arrival is approximately 45 minutes.

Figure 15. The sea surface height and estimated time of arrival at the coast of Palu.
Figure 16. The graphs of tsunami wave height and estimated time of arrival at Palu

Table 9. The maximum and average of tsunami wave height and estimated arrival time

| Sea surface height (m) | ETA (min) |
|------------------------|-----------|
| Max                    | 1.36      | Min      | 36.45    |
| Mean                   | 0.54      | Mean     | 44.52    |

3.7 The comparison of tsunami elevation and estimated time of arrival along the coasts

Figure 17 shows the tsunami elevation (shown by the colours) and the propagation time (the contour isolines) in domain D. Table 10 shows the maximum tsunami elevation and the minimum estimated time of arrival at 6 regions including the coast of Indonesia’s new capital candidate. It is clear that the tsunami estimated arrival time along the coasts is more than 30 minutes, except Tolitoli that needs only 7 minutes since the initial tsunami source. For the coast of East Kalimantan, the location of Indonesia’s new capital candidate, the estimated time of arrival of tsunami is 1 hour 30 minutes with an elevation of 0.83 meter. The average sea surface height for all the observation points in the event of tsunami caused by North Sulawesi Megathrust is less than 1 meter, but for Tolitoli the tsunami height is 3.4 meter.

Figure 17. Sea surface height and estimated time of arrival at the domain
**Table 10.** Maximum sea surface height and min estimated time of arrival

| Location                  | Max SSH (meter) | Min ETA (minutes) |
|---------------------------|-----------------|-------------------|
| IKN (Kec. Kamboja)        | 0.83            | 99.34             |
| Samarinda (Kec. Marangkayu)| 1.27            | 56.18             |
| Bontang (Kec. Bontang Utara)| 1.68            | 55.34             |
| Mamuju (Kec. Kaluku)      | 0.54            | 55.93             |
| Palu (Kec. Palu Barat)    | 1.36            | 36.45             |
| Toli-toli (Kec. Baolan)   | 3.47            | 7.19              |

**Table 11.** Mean sea surface height and estimated time of arrival

| Location   | Mean SSH (meter) | Mean ETA (minutes) |
|------------|------------------|--------------------|
| IKN        | 0.42             | 124.09             |
| Samarinda  | 0.57             | 101.22             |
| Bontang    | 0.85             | 70.73              |
| Mamuju     | 0.26             | 57.87              |
| Palu       | 0.54             | 44.52              |
| Toli-toli  | 1.62             | 16.08              |

4. Conclusion
The nearest megathrust that potentially generates tsunami at the coast of Indonesia’s new capital candidate area is the North Sulawesi Megathrust. Tsunami simulation was conducted using TUNAMI N3 program and the potential tsunami source scenario used in this study is M8.5. The tsunami wave height and estimated time of arrival at the coast of East Kalimantan and other 5 districts with highest activity and population have been analysed.

At the coast of Indonesia’s New Capital Candidate, the highest tsunami elevation is estimated to be 0.83 m with arrival time of as fast as 100 minutes (at Kecamatan Kamboja). The highest tsunami elevation in the Makassar Strait region occurs in Toli-toli (3.4 m) which arrives in 7.19 minutes, followed by Bontang (1.6 m, 55 min), Palu (1.3 m, 36 min), Samarinda (1.3 m, 56 min), East Kalimantan (0.8, 100 min), and finally Mamuju (0.5 m, 56 min).

Suggestions for future study of the tsunami related to North Sulawesi Megathrust may include the use of more accurate spatial data with higher resolutions either from satellite or field survey. In addition, it is also necessary to assess potential tsunami hazard in this region due to landslide, since in Makassar Strait region, the threat is not only originated from earthquake, but also from submarine landslide which might generate more hazardous tsunami than those caused by earthquakes.

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