Probabilistic Analysis of Tsunami Caused by The Java Megathrust Active Fault: A Case Study of Jakarta, Indonesia

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Abstract. Indonesia is located on 3 main plates of the world, so it is known as the ring of fire area because of the potential for volcanic eruptions and earthquakes. This study aims to determine the analysis of the probability of the occurrence of tsunami waves generated on the coast of the Jakarta area. The research process was carried out by simulating tsunami waves using the Cornel Multigrid Coupled Tsunami (COMCOT) program and numerical modeling Shallow Water Equation (SWE). The results of this study are the probability obtained based on PTHA calculations with the largest percentage at the 7th location point for the 2000 years return period, namely 42.01% and 1.55% for the possibility of occurring with 0.5 meters and 3 meters, potential height The tsunami that reached the Jakarta area was 1.24 meters in the Muara Angke area. This uneven distribution was continued to create 7 points near the coast of Jakarta which have strategic areas with the results of location point 1 until 7, namely 1, 04 m; 1.12 m; 1.12 m; 1.19 m; 1.31 m; 1.48 m; and 1.78 m and the furthest distance reached by the tsunami was 32.4 meters in the Muara Angke area.

Keywords: Ring of fire, Tsunami, COMCOT, Shallow water equation, Re-period

1 Introduction

Indonesia is located on 3 major plates of the world namely the Eurasian, Indo-Australian and Pacific Plates. This makes Indonesia known as a ring of fire region because the potential for natural disasters of volcanic eruptions and earthquakes is very large [1]. Based on this, the capital city of Jakarta as the center of the country's economy should be wary of natural disasters that can cause tsunami. Although most of the seismicity is concentrated in the southern region of Java Island because it is located on the Indo-Australian Plate. According to data from Magma Indonesia, Java Island has 34 active volcanoes [2]. One of the active volcanoes is Mount Anak Krakatau which once erupted in 1883 and caused a tsunami wave height that reached 36 m in Merak, Banten [3]. In addition, earthquake activity in the Java Island area was also very powerful which occurred in Tasikmalaya Regency on September 2,2009 with a magnitude of 7.0 Mw. The earthquake was caused by a collision between the Indo-Australian Plate and the Eurasian Plate [4].

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Historically, the most significant earthquake event in the 17th century that hit Java Island occurred on January 5, 1699, when Batavia (Jakarta) experienced such a severe earthquake [5]. The losses suffered from the earthquake in the Jakarta area such as, the destruction of 21 houses, 29 wheat mills and at least 28 lives were lost, however, the factors that caused the earthquake are not known for sure and there is no early warning for the community [6]. From these problems, researchers will examine the capital city of Jakarta, especially the Java Megathrust zone, which can potentially cause an earthquake of 8.1 MW. With the aim of knowing how dangerous the risk of a tsunami is if there is a re-earthquake in the future.

This study uses the Probabilistic Tsunami Hazard Assessment (PTHA) method to measure the potential danger of tsunami propagation in the Jakarta area caused by earthquakes [7]. This PTHA method using the Cornell Multi-grid Coupled Tsunami (COMCOT) software tsunami modeling built by Prof. L -F Liu from Cornell University. This COMCOT serves to simulate the passage of a tsunami from the source of tsunami generation to the coastal area [8]. The simulation results of this study are in the form of the height of the tsunami wave that penetrates and the potential for the farthest distance of the wave in the land area of the area conducted by the study [8]. This purpose can be used as a reference parameter for the Government to make appropriate mitigation planning steps in the location under study, namely the Jakarta area, especially the coastline.

2 Research Materials and Methods

A. Numerical Modeling

Numerical simulation of tsunami waves was carried out in this study with the help of the Cornell Multi-grid Coupled Tsunami (COMCOT) program built and developed by Prof. L-F Liu from Cornell University [8]. In the application of the COMCOT program using Shallow Water Equations (SWE) which is to simulate tsunami propagation from sources that cause tsunamis to coastal areas. This simulation also adopts a finite different method with the leap-frog scheme used in solving linear and non-linear SWE equations. This leap-frog scheme is used to calculate the elevation of the water level at different time conditions. In fact, this scheme fragments the time and space of the calculation area into several areas – small areas commonly called grids (criticized). The basis of the equation governing the COMCOT and Shallow Water Equation programs is the equation of momentum and conservation of mass. The results of the study using the COMCOT program are in the form of tsunami height and tsunami arrival time which is used to determine the location points affected in the research area, namely the capital city of Jakarta, Indonesia. In its use, the COMCOT program has been used against tsunami events such as the Indian Ocean tsunami that occurred in 2004 [9]. For the equation of momentum and conservation of mass as follows:

Momentum equation:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \eta}{\partial x} + \frac{\tau_x}{P} = 0 \qquad (1)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \eta}{\partial x} + \frac{\tau_y}{P} = 0 \quad (2)$$

Equation of conservation of mass:

$$\frac{\partial \eta}{\partial t} + \frac{\partial[u(h+\eta)}{\partial x} + \frac{\partial[v(h+\eta)}{\partial y} = 0 \quad (3)$$

Research with the Shallow Water Equation can be linear and non-linear in spherical and cartesian coordinates. As for when the tsunami spreads in the deep sea, SWE is linearly applied in spherical coordinates with the following written:

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\varphi} + \left\{\frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi}(\cos\varphi Q\right\} = -\frac{\partial h}{\partial t} \quad (4)$$

$$\frac{\partial P}{\partial t} + \frac{gh}{R\cos\varphi}\frac{\partial \eta}{\partial \psi} - fQ = 0 \quad (5)$$

$$\frac{\partial Q}{\partial t} + \frac{gh}{R}\frac{\partial \eta}{\partial \varphi} + fP = 0 \quad (6)$$

If a tsunami propagates in shallow water, then with the equations above, non-linear components and surface friction are included. The equation is as follows:

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\varphi} + \left\{\frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi}(\cos\varphi Q)\right\} = -\frac{\partial h}{\partial t} \quad (7)$$

$$\frac{\partial P}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left\{\frac{P^2}{H}\right\} + \frac{1}{R}\frac{\partial}{\partial \varphi}\left\{\frac{PQ}{H}\right\} + \frac{gH}{R\cos\varphi}\frac{\partial \eta}{\partial \psi} - fQ + Fx = 0 \quad (8)$$

$$\frac{\partial Q}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left\{\frac{PQ}{H}\right\} + \frac{1}{R}\frac{\partial}{\partial \varphi}\left\{\frac{Q^2}{H}\right\} + \frac{gH}{R}\frac{\partial \eta}{\partial \psi} + fP + Fy = 0 \quad (9)$$

In simulations in relatively small areas, the effect of the earth's rotation is not very noticeable, using cartesian coordinates. As for the linear and non-linear equations in cartesian coordinates as follows:

a) Linear Shallow Water Equations in cartesian coordinates

$$\frac{\partial \eta}{\partial t} + \left\{\frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y}\right\} = \frac{\partial h}{\partial t} \quad (10)$$

$$\frac{\partial P}{\partial t} + gh\frac{\partial \eta}{\partial x} - fQ = 0 \quad (11)$$

$$\frac{\partial Q}{\partial t} + gh\frac{\partial \eta}{\partial y} - fp = 0 \quad (12)$$

b) Non-linear shallow water equation in cartesian coordinates

$$\frac{\partial \eta}{\partial t} + \left\{\frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y}\right\} = -\frac{\partial h}{\partial t} \tag{13}$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left\{\frac{\rho^2}{H}\right\} + \frac{\partial}{\partial y}\left\{\frac{\rho Q}{H}\right\} + gH\frac{\partial \eta}{\partial x} + Fx = 0 \tag{14}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left\{\frac{PQ}{H}\right\} + \frac{\partial}{\partial y}\left\{\frac{Q^2}{H}\right\} + +gH\frac{\partial \eta}{\partial y} + Fy = 0 \tag{15}$$

Where:

g	: Acceleration of gravity [m/s2]
P	: Flux discharge in the -x (West-East) direction [m2/s]
Q	: Flux discharge in the -y direction (South-North) [m2/s]
f	: Coriolis force coefficient [-]
φ, ψ	: Latitude and Longitude of the earth's sphere [°]
R	: Earth radius [m]
h	: Depth of circulation [m]
η	: Elevation of the water level [m]
H	: Total water depth [m]
Fx	: Friction of the base surface in the -x direction
Fy	: Friction of the base surface in the -y direction
$\tau_{(x,y)}$	: Shear strees in the x or y direction
Ω	: the rate of rotation of the earth
n	: Manning roughness coefficient [s/m1/3]
u	: the speed of the current in the -x direction [m/s]
v	: current velocity in the -y direction [m/s]

B. Stochastic Modeling

This stochastic modeling was developed by Mai and Beroza in 2002 with a method approach aimed at characterizing the slip complex of an earthquake. The characterization represented is from a spatial random field whose movement is different (anisotropic) according to the von Karman correlation function. The parameters of the von Karman correlation function such as the length of the correlation along the strike and dip as well as the Hurst exponent are determined using empirical formulas for the length and width of the fault. This is done because the creation of earthquakes based on landslides at the fault point cannot be definitively defined by the slip. The results of this simulation with stochastic modeling are several different sample counts in each event.

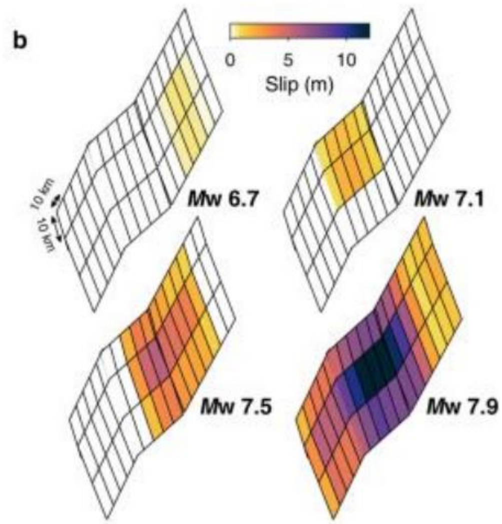

Fig. 1. Stochastic sample of slip distribution

C. Probabilistic Tsunami Hazard Assessment

Tsunami hazard probability analysis is a method used to determine the risk of tsunami hazard based on the probability of occurrence in an area where the probability is like the maximum amplitude exceeded. In tsunami modeling using PTHA, tsunami hazards are commonly expressed as "hazard metrics" that provide a quantity of tsunami impacts. This PTHA method was developed to be able to develop a re-period tsunami hazard that stretches from hundreds to thousands of years, beyond the limited historical record [7]. A study that uses the tsunami hazard probability (PTHA) analysis method, the parameters used in the scenario are megathrusts / earthquake fault [10] where the basic results of the study using this method are in the form of a hazard curve. The equations of the Probabilistic Tsunami Hazard Assessment can be seen as follows. For segmentation of megathrusts in every archipelago in Indonesia can be seen in the **Figure. 2**

$$F_M(m) = \frac{1-10^{-b(m-m_{min})}}{1-10^{-b(m_{max}-m_{min})}} \quad (16)$$

$$P(Mi = mj) = Fm(mj + 0.5\Delta m) - Fm(mj - 0.5\Delta m) \quad (17)$$

$$P(H > h \setminus mj) = 1 - \theta \left\{\frac{\ln(h) - \ln(H)}{\beta}\right\} \quad (18)$$

$$\lambda(H \geq h) = P(H \geq h \setminus mj)P(mi = mj) \quad (19)$$

$$P = 100\% x(1 - exp^{\lambda . t}) \quad (20)$$

Information:

Fm	: Cumulative Distribution
$P\ (Mi = mj)$	: Probability function based on unrelated magnitude
(Mw) $P(H > h\backslash mj)$	: Probability function based on tsunami height (0-15 meters)
P anniversary period	: Percentage of probability of occurrence in the x year
Mj interval)	: The magnitude of the earthquake used (j only indicates the
a values	: Seismicity level in an area
b values	: frequency of earthquake events

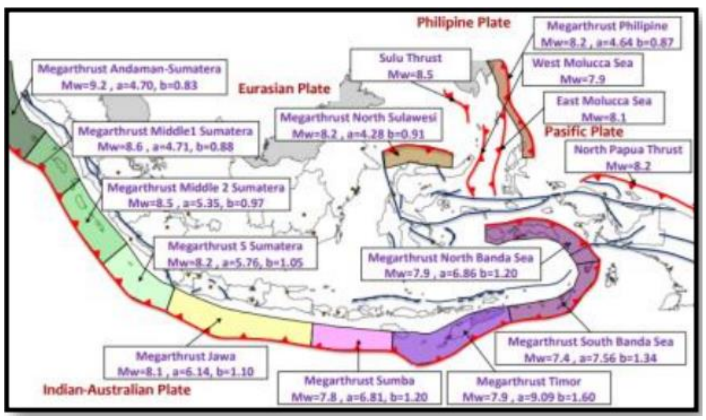

Fig. 2. Slip distributin Megathrust Segmentatior

Source: 2010 National Earthquake Map

D. Bathymetric and Topography Data

Bathymetric data is obtained through National Bathymetry (BATNAS). Bathymetric data provides information about the direction in which the waves move and the shape of a silting process that occurs when a tsunami hits an area. Topographic data is obtained through the Digital Elevation National Model (DEMNAS). Topographic data provides information about the shape of the slope of a contour. In the depiction, topographic data and bathymetric data are interconnected where the greater the degree of slope of the resulting slope will make the depiction of land contours on the bathymetric map also greater.

E. Earthquake Fault Source Data

In this study, earthquake fault source data came from modeling with the stochastic slip method developed by Mai and Beroza in 2002. This method is used to determine the initial condition of the location of the earthquake source. The location of the earthquake source used is based on research conducted by [11] as in Table I. However, of the 4 earthquake sources, only 2 were used, namely the Sunda Strait segment and the West Java segment. The selection of these 2 segments is because they have a location adjacent to the research area and will affect the results of the journey obtained. After determining the source of the earthquake, the next step is to divide the 2 earthquake sources into sub-faults – small sub-faults with dimensions of 10 km x 10 km. The sub-fault is used as a source of tsunami earthquakes. The magnitude of the earthquake used in this study was 8.5 Mw to 9.0 Mw with a range of 0.1. The selection is based on the fact that the magnitude of the earthquake is logarithmic and not linear so that the range of 8.5 Mw to 9.0 Mw is too far away.

To obtain slip values based on the earthquake segments of Sunda and West Java using the slipreal program. The data that entered into the slipreal program are Length (L), Width (W), sf size, mean dip, maximum depth and maximum earthquake magnitude.

Table 1. Fault Source Parameters

L (km)	W (km)	Sf Size (km)	Mean dip (°)	Max Depth (km)	Max Magnitude (Mw)
800	180	10	14	30	9

Table 2. The Input Codes on Slipreal Programs

Earthquake Parameters	Sundanese Stait Segment	West-central java Segment	East Java Seqment	Bali Segment
Mw	8,7	8,7	8,7	8,7
Depth (km)	34	20,188	15,467	28,556
Length (km)	340	460	400	600
Width (Km)	180	160	190,5	192,5
Max.Disp (m)	15,926	21,678	18,798	28,426
Strike (°)	297	296,753	275,798	271,119
Dip (°)	18	9,962	9,098	18,524

Slip (m)	8	6,5	6,5	2
Rake (º)	104	104	90	90
Latitude (º)	-7,239	-8,92	-9,834	-10,196
longitude (º)	104,435	107,88	111,974	116,519

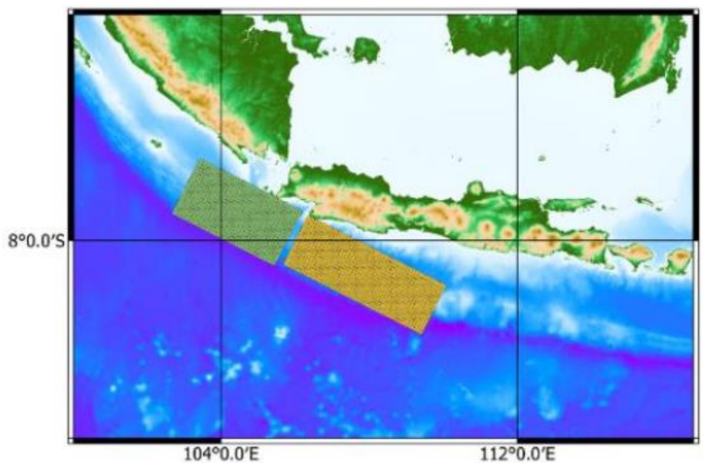

Fig. 3. *Sub-Fault* Epicenter Locations of 2 Earthquake

F. Simulation Parameter Data

In this study, the simulation used multilayers consisting of layers 1 to 5. In making layers 1 to 5, it aims to simulate tsunami waves with a detailed grid resolution at the location of the study. The images of layers 1 to 5 are as follows:

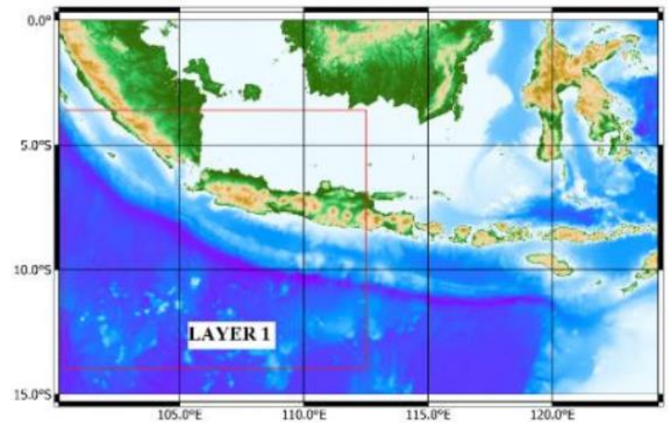

Fig. 4. Layer 1 simulation parameters

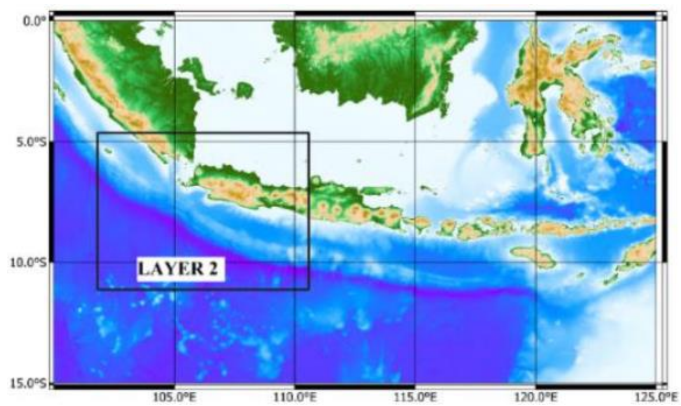

Fig. 5. Layer 2 simulation parameters

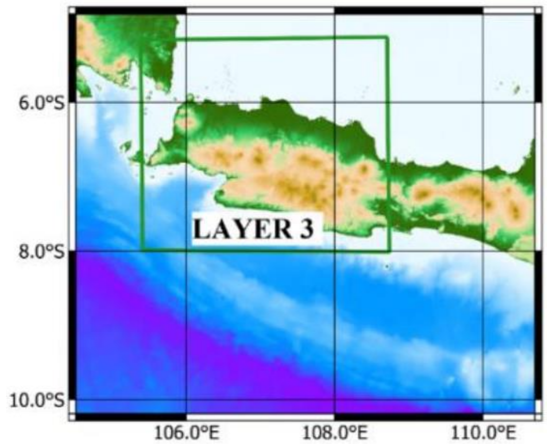

Fig. 6. Layer 3 simulation parameters

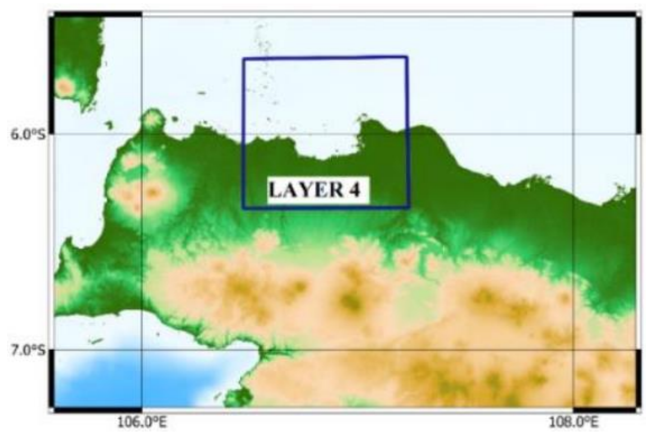

Fig. 7. Layer 4 simulation parameters

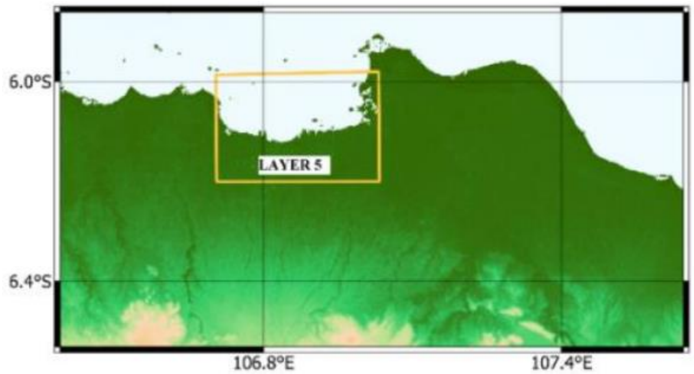

Fig. 8. Layer 5 simulation parameters

Based on the images from layers 1 to 5, in making it must be appropriate and cover the area that is a simulated tsunami wave in Jakarta. The simulation parameter data can be seen in Table 3

Table 3. Simulation Parameter Data

Layer	1	2	3	4	5 (Jakarta)
Lingkup Longitude (°)	100.32E – 112.50027E	101.817E – 110.5816E	105.4114E – 108.71E	106,4702E – 107.22678E	106,706E – 107.03E
Lingkup latitude (°)	13.95S – 3.6016S	11.12S – 4.6424S	7.9888S – 5,126S	6.34454S – 5,6423497S	6,201S – 5.983S
Ukuran *grid* (m)	1885.0	628.3	209.4	52.4	10
Jumlah *grid*	731 x 621	1678 x 1166	1781 x 1546	1634 x 1517	3499 x 2354
Parent grid	*None*	*Layer* 1	*Layer* 2	*Layer* 3	*Layer* 4
Ratio to parent grid	*None*	3	3	4	5

Coord System	*Spherical*	*Spherical*	*Spherical*	*Spherical*	*Cartesian*
SWE type	*Linear*	*Linear*	*Linear*	*Linear*	*Nonlinear*

3 Results and Discussion

A. Initial Condition

Initial condition is a condition used to determine the beginning of tsunami generation from the source location. Initial condition data from tsunami generation was obtained using a slipreal program by adopting stochastic slip modeling. With this modeling, the magnitude of the earthquake used for simulation is between 8.5 Mw to reach 9.0 Mw. In each earthquake magnitude 5 scenarios will be carried out because each scenario has a different slip value, so the total scenario used is 30. Therefore, the initial condition will be displayed from each earthquake magnitude and scenario where more details are found in the appendix.

In the 8.5 Mw earthquake, it was known that the height of the initial conditions of tsunami generation had a difference between scenarios 1 and 5. This happens because the resulting slip value has a variety of values. As for scenario 1 where the area with a red color indicates a tsunami wave with a height of up to 4 meters occurs in the sea. In fact, the spread of slips looks different in both faults. For areas with a blue color indicates the receding seawater on the coastline up to -4 meters. Meanwhile, scenario 5 the height of the tsunami wave also reaches up to 4 meters but with an even magnification of the slip in both faults. The area with the blue color in scenario 5 shows the receding seawater on the coastline up to -4 meters. Those initial conditions can be seen in the **Figure. 9**

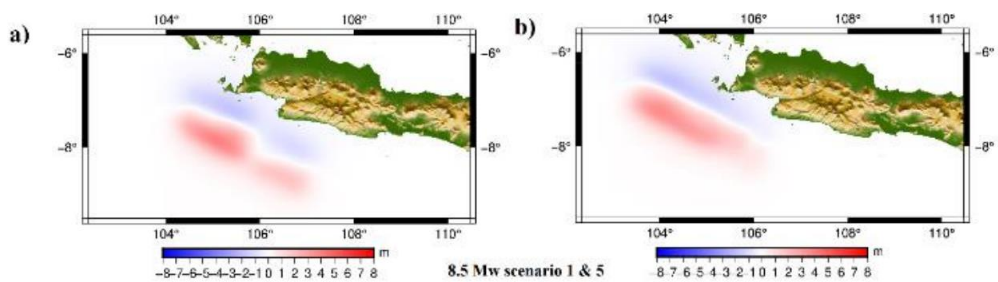

Fig. 9. Initial conditions of 8.5 Mw for scenario: a) 1 and b) 5

In the 8.6 Mw earthquake, it is known that the height of the initial conditions of tsunami generation has a difference between scenarios 1 and 5 This happens because the resulting slip values have varying values. As for scenario 1, where the area marked in red indicates a tsunami wave with a height of up to 6 meters occurred in the sea. However, the spread of the slip appears to be only in the 2nd fault. For areas with blue in scenario 1, it shows the receding seawater on the coastline up to -6 meters. Meanwhile, scenario 5 the height of the tsunami wave only reaches up to 4 meters with a slip distribution in both faultsthat are wider in area. The area marked in blue in scenario 5 shows the receding seawater on the coastline up to -4 meters. Those initial conditions can be seen in the **Figure. 10**

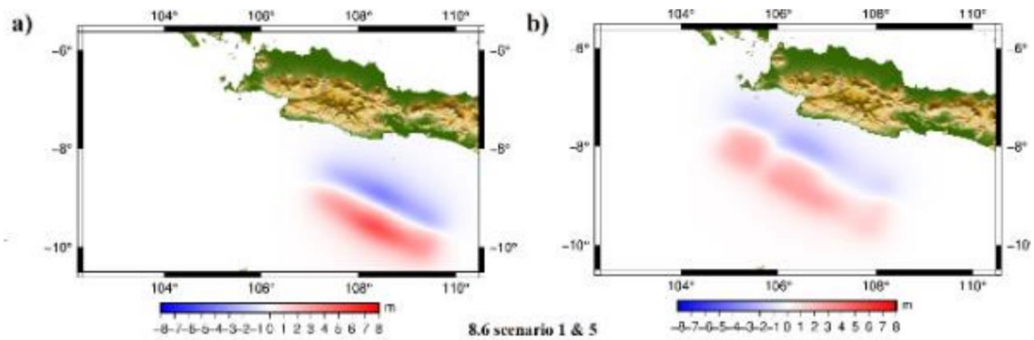

Fig. 10. Initial conditions of 8.6 Mw for scenario: a) 1 and b) 5

In the 8.7 Mw earthquake, it was known that the height of the initial conditions of the tsunami generation had a difference between scenarios 1 and 5. This happens because the resulting slip value has a variety of values. As for scenario 1, where the area marked in red indicates a tsunami wave with a height of up to 6 meters occurred in the sea. Although the slip distribution was seen to be only in the 2nd fault, the area was wider than the 8.6 Mw earthquake. Meanwhile, scenario 5 the height of the tsunami wave reaches up to 7 meters but with the slip spread it is only in the 2nd fault as well. The area marked in blue in scenario 5 indicates the receding seawater on the coastline up to -6 meters. Those initial conditions can be seen in the **Figure. 11**

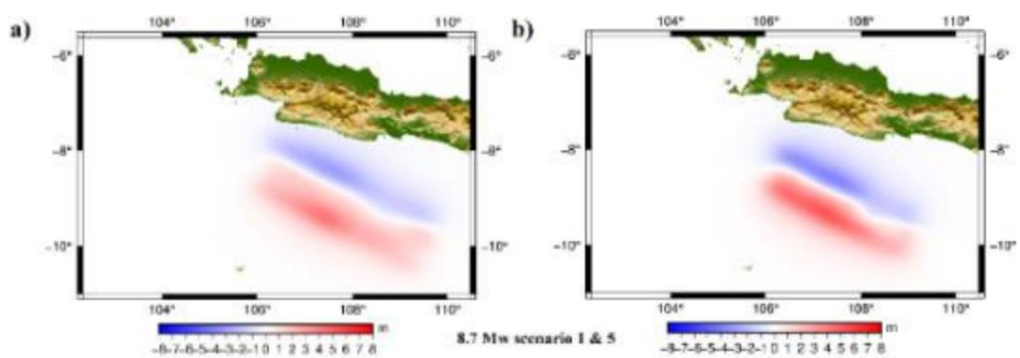

Fig. 11. Initial conditions of 8.7 Mw for scenario: a) 1 and b) 5

In the 8.8 Mw earthquake, it is known that the height of the initial conditions of the tsunami generation has a difference between scenarios 1 and 5 This happens because the resulting slip values have various values. As for scenario 1 where the area marked in red indicates a tsunami wave with a height of only up to 5 meters occurring in the sea. However, the distribution of slips appears to be wider in both faults. For areas with a blue color indicates the receding seawater on the coastline up to -5 meters. Meanwhile, scenario 5 the height of the tsunami wave only reaches up to 5 meters but the slip distribution looks wider in both faults. The area marked in blue in scenario 5 indicates the receding seawater on the coastline up to -5 meters. Those initial conditions can be seen in the **Figure. 12**

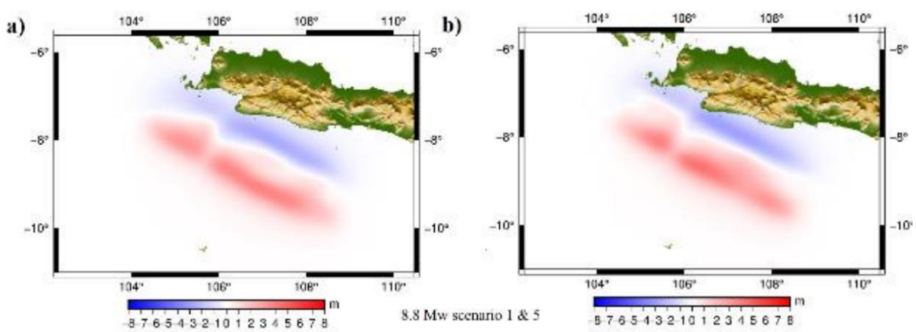

Fig. 12. Initial conditions of 8.8 Mw for scenario: a) 1 and b) 5

In the 8.9 Mw earthquake, it was known that the height of the initial conditions of tsunami generation had a difference between scenarios 1 and 5. This happens because the resulting slip value has a variety of values. As for scenario 1, where the area marked in red indicates a tsunami wave with a height of up to 7 meters occurred in the sea. However, the spread of slips is dominated by a height of less than 7 meters. For areas marked in blue indicates the ebb of seawater on the coastline up to -6 meters. Meanwhile, scenario 5 wave height reaches up to 8 meters. Even a height of 8 meters dominates the territory of the two faults. The area marked in blue in scenario 5 indicates the receding seawater on the coastline up to -7 meters. Those initial conditions can be seen in the **Figure. 13**

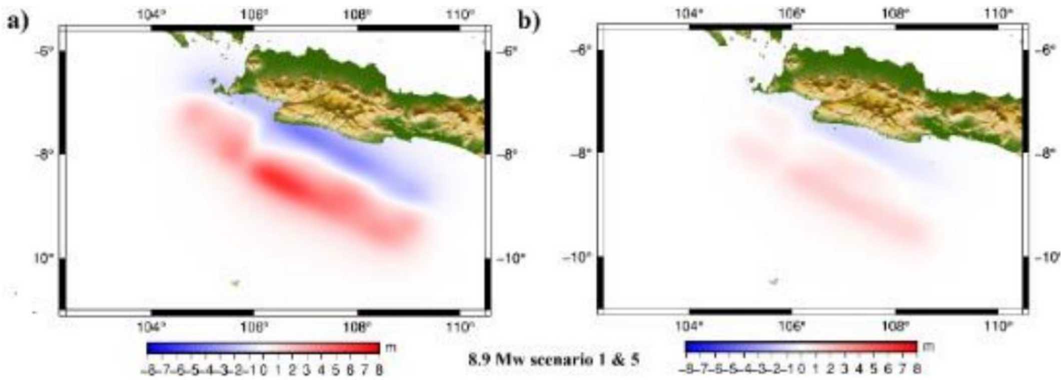

Fig. 13. Initial conditions of 8.9 Mw for scenario: a) 1 and b) 5

In the 9.0 Mw earthquake, it was known that the height of the initial conditions of tsunami generation had a difference between scenarios 1 and 5. This happens because the resulting slip value has a variety of values. As for scenario 1 where the area marked in red shows a tsunami wave with up to 8 meters occurring in the sea. In fact, the distribution of slips tends to be evenly distributed. For areas with a blue color indicates the receding sea water on the coastline up to -8 meters. While scenario 5 wave height reaches up to 8 meters. Even a height of 8 meters dominates the territory of the two faults. The area marked in blue in scenario 5 shows the receding seawater on the coastline up to -8 meters. Those initial conditions can be seen in the **Figure. 14**.

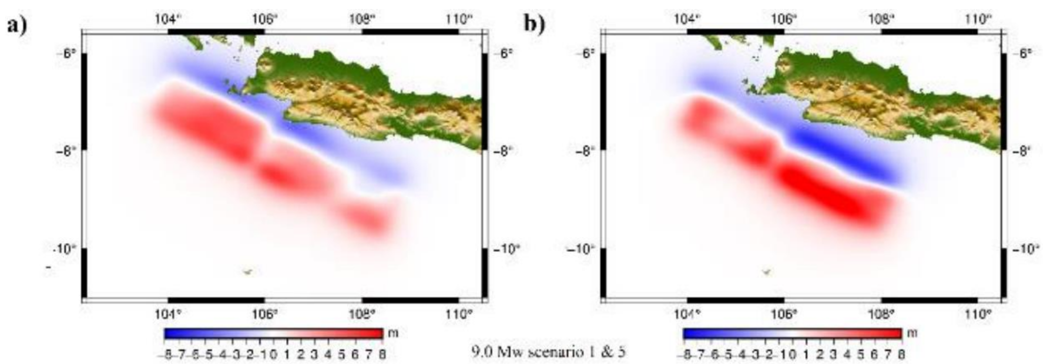

Fig. 14. Initial conditions of 9.0 Mw for scenario: a) 1 and b) 5

B. Tracing Process

The tracing process is a condition where after simulating 2 tsunami sources using comcot, layers 1 to 5 at a magnitude of 9.0 Mw scenario 1 are simulated. The use of scenario 1 with a magnitude of 9.0 Mw is based on the slip results in the initial condition which has the largest wave height at the fault source. The simulation of the journey was carried out to determine the height of the tsunami wave and the receding sea due to the earthquake produced from the source. This simulation was carried out for 21600 seconds where the reading of the data results was every 720 seconds. The selection of layer 2 and layer 5 used in this sub-chapter is because it includes the area of occurrence of altitude at the fault source and research location. However, in this exploration process using scenario 1 because it has a greater result of the height produced in the bay of Jakarta. This is because each scenario has a different slip value.

At 0 minutes it is known that the height of the tsunami wave at the source of the earthquake reached 4 meters. Meanwhile, the coastal area around the source of the earthquake receded to a depth of -4 meters. For walking within 24 minutes, the wave height reaches 4 meters in the coastal area of Pelabuhan Ratu in West Java to SMPN Satap1 which is on the coast of Lampung. The journey can be seen in the **Figure. 15**

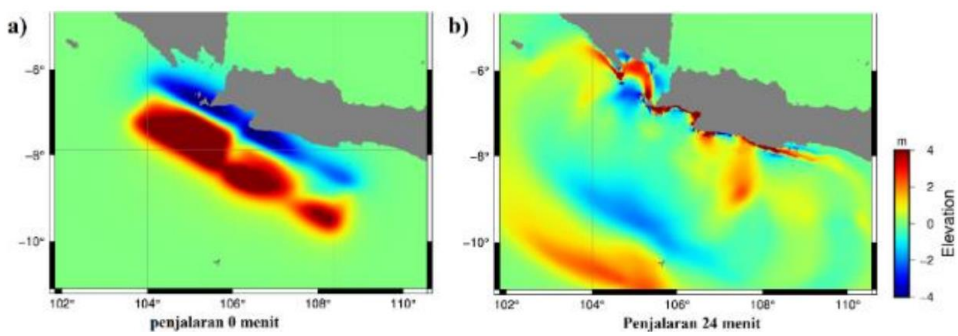

Fig. 15. Tsunami Tracing Process for: a) t=0 minutes and b) t=24 minutes

Within 48 minutes, it was discovered that the height of the tsunami wave reached 4 meters in the Pandeglang regency, Banten. In fact, it also spreads on the coast of Kota Agung District, Lampung which has many schools and offices. Meanwhile, the tsunami wave receded to a depth of -4 meters in the coastal area of Pelabuhan Ratu, West Java. For climbing within 72 minutes, the wave height reaches 4 meters in the coastal areas of Bakaheuni District, Lampung and carita coastline, Banten. The journey can be seen in the **Figure. 16**

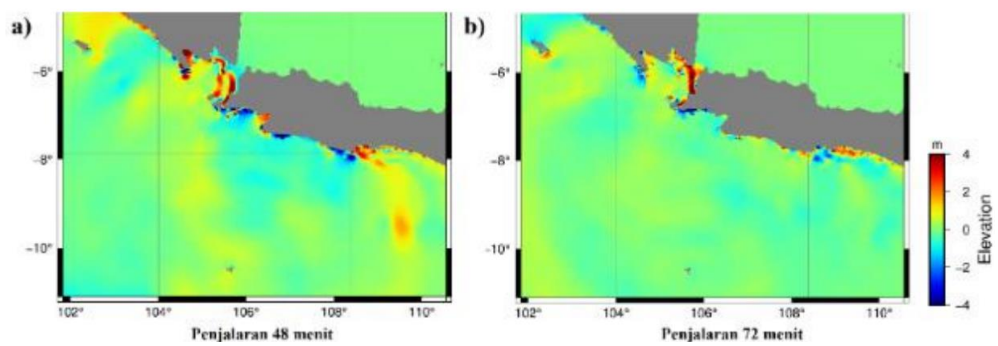

Fig. 16. Tsunami Tracing Process for: a) t=48 minutes and b) t=72 minutes

Within 96 minutes, it was discovered that the height of the tsunami wave reached 4 meters in the coastal area of Cilegon, Banten. In fact, it began to spread also in the coastal area of Bandar Lampung. Meanwhile, the tsunami wave began to recede to a depth of -2 meters in the coastal area of Pandeglang Regency, West Java. For a 120-minute hike, the wave height is only 2 meters in the Serang Regency, Banten and begins to decline by 2 meters in the coastal area of Bandar Lampung. Also, the receding of tsunami waves in the coastal area of Pandeglang Regency, West Java experienced an increase in depth of up to -4 meters. The passage can be seen in the **Figure. 17**

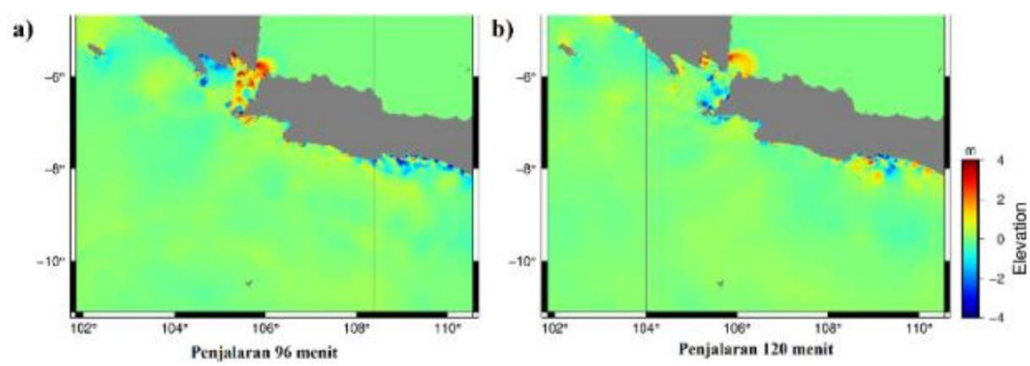

Fig. 17. Tsunami Tracing Process for: a) t=96 minutes and b) t=120 minutes

At 144 minutes the height of the tsunami wave, which was previously only 2 meters in Serang Regency, became 4 meters. In fact, the journey widened to the coastal area of South Lampung. Meanwhile, the tsunami wave began to recede to a depth of -2 meters in the coastal area of Cilegon, Banten. For a journey in 168 minutes, the wave height reaches 3 meters on the coast of the Lontar area in Serang City, Banten and propagates to the coastal area of South Lampung. And also, the receding tsunami waves in the coastal area of Bandar Lampung. The passage can be seen in the **Figure. 18**

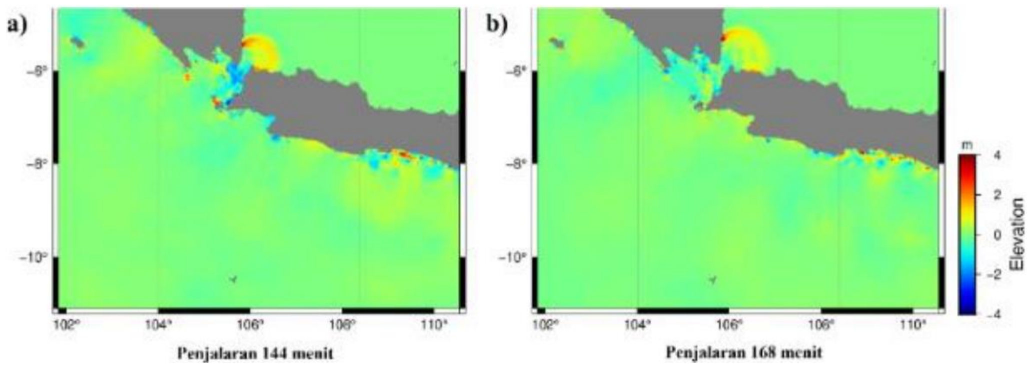

Fig. 18. Tsunami Tracing Process for: a) t=144 minutes and b) t=168 minutes

Within 192 minutes the tsunami wave entered the Jakarta Bay area with a height of up to 1-2 meters. The coastal area close to the wave is Pantai Indah Kapuk. For a 216-minute journey, the wave height reaches 2 meters near the coast of the Marunda area, North Jakarta and still propagates to the coastal area of South Lampung. The journey can be seen in the **Figure. 19**

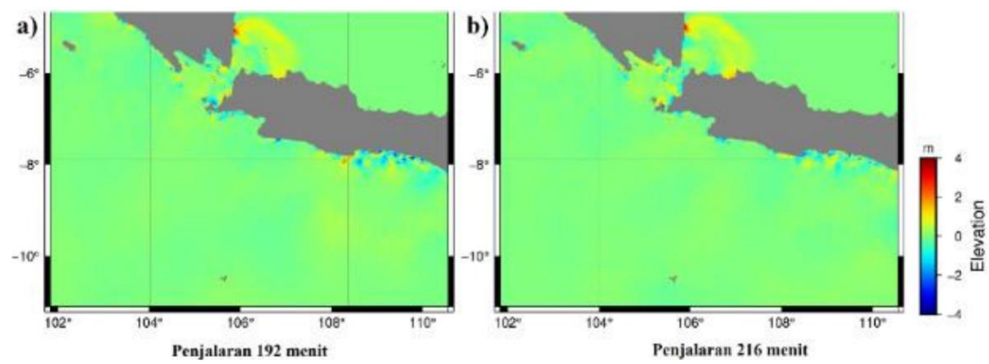

Fig. 19. Tsunami Tracing Process for: a) t=192 minutes and b) t=216 minutes

Within 240 minutes the tsunami wave in the Jakarta Bay area was less than 1 meter in the Marunda area, North Jakarta. And also, starting to enter the Muara Beach area, Bekasi. For the journey at the time of 264 tsunami waves left the Jakarta bay area and still spread near the coastal area of Muara Beach, Bekasi. The passage can be seen in the **Figure. 20**

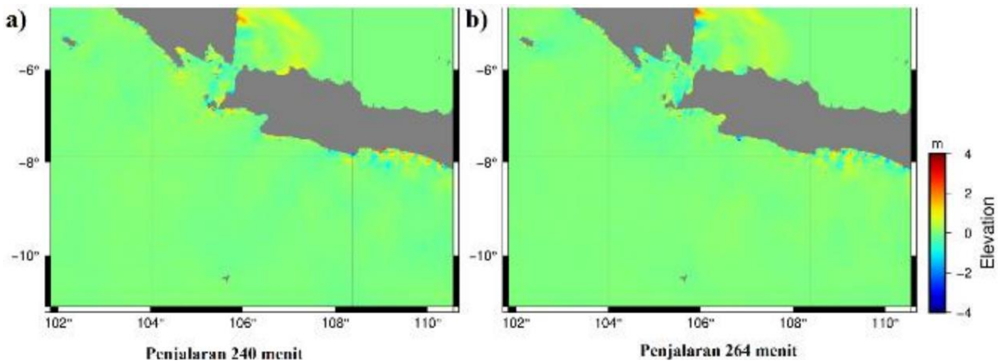

Fig. 20. Tsunami Tracing Process for: a) t=240 minutes and b) t=264 minutes

The time of 0 minutes is known that the sea water has a normal elevation by indicating a height of 0 meters. Meanwhile, on the journey in 36 minutes, it is known that the water level starts to rise even though it is still less than 1 meter. This is indicated by the color change in layer 5 where it starts to yellow. The passage can be seen in the **Figure. 21**

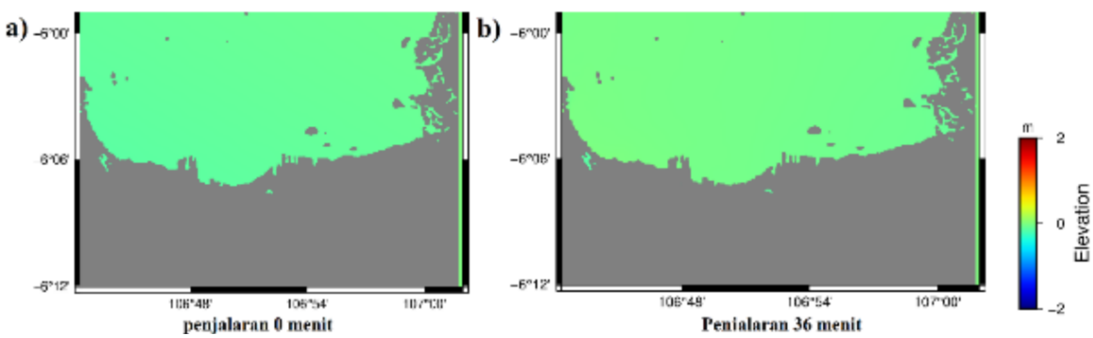

Fig. 21. Tsunami Tracing Process for: a) t=0 minutes and b) t=36 minutes

On the 72-minute journey, it is known that the image on layer 5 has a deeper yellow color but has not touched an elevation of less than 1 meter. Meanwhile, on the journey in 108 minutes, it is known that layer 5 is green where the height begins to decrease near normal. This is what the people of Jakarta are wary of due to water shrinkage. The passage can be seen in the **Figure. 22**

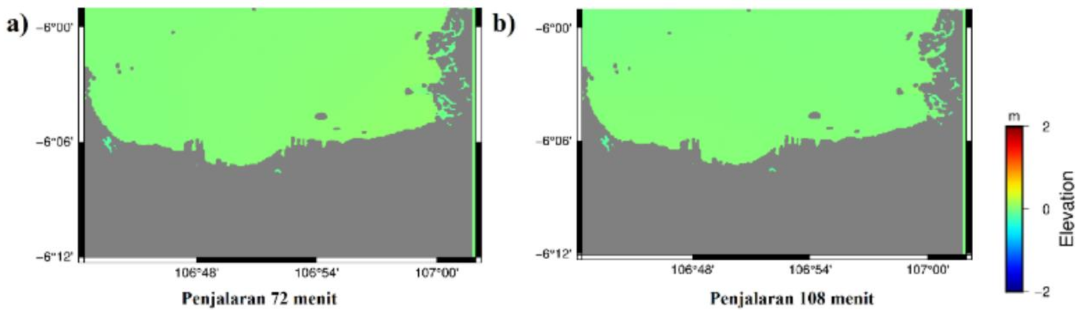

Fig. 22. Tsunami Tracing Process for: a) t=72 minutes and b) t=108 minutes

On the 144-minute journey, it is known that the image on layer 5 has a bluish-green color with a depth of almost -1 meter, a sign that the tsunami will soon enter the Jakarta Bay area. Meanwhile, on the journey in 180 minutes, it was known that at layer 5 the tsunami began to enter the Jakarta Bay area through the Pantai Indah Kapuk area with a height exceeding 1 meter. The journey can be seen in the **Figure. 23**

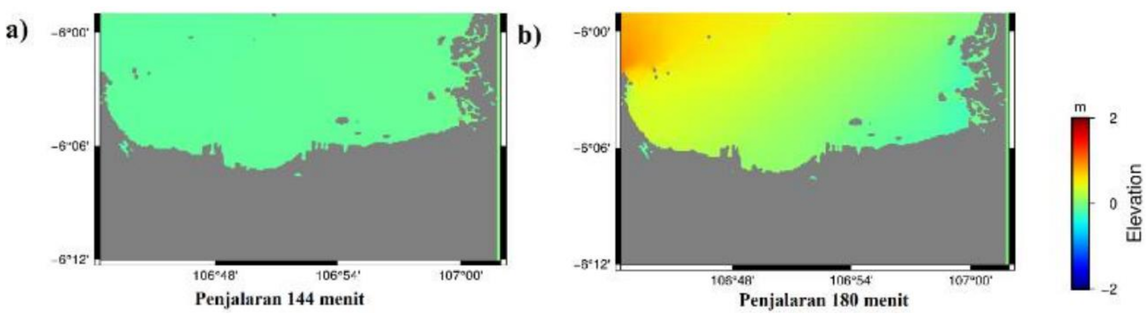

Fig. 23. Tsunami Tracing Process for: a) t=144 minutes and b) t=180 minutes

On the 216-minute journey, it is known that the image on layer 5 has a red color where the tsunami spreads in jakarta bay with a height of up to 2 meters. The areas close to the height of the tsunami wave in Jakarta bay are Pantai Indah Kapuk, Ancol and Marunda. Although the height of the tsunami does not touch the Jakarta area, it is worth being vigilant because Jakarta experiences land subsidence every year. Meanwhile, on the 252-minute journey, it is known that layer 5 is yellow where the height of the tsunami begins to decrease towards normal. The passage can be seen in **Figure. 24**

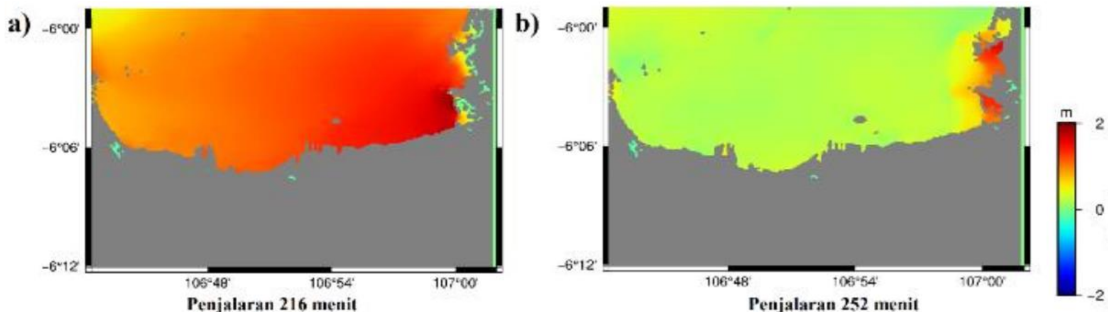

Fig. 24. Tsunami Tracing Process for: a) t=216 minutes and b) t=252 minutes

On the 288-minute journey, it is known that the image on layer 5 has blue, the color indicates the ebb and flow of the wave height in the bay area of Jakarta. As for the depth until it reaches -2 meters. Although the tsunami has receded, there is a potential for the height of aftershocks in the Jakarta Bay area. This happened on the journey in 324 minutes known at layer 5 in yellow where the aftershock tsunami wave headed towards Jakarta Bay with a height of up to 1 meter. The passage can be seen in the **Figure. 25**

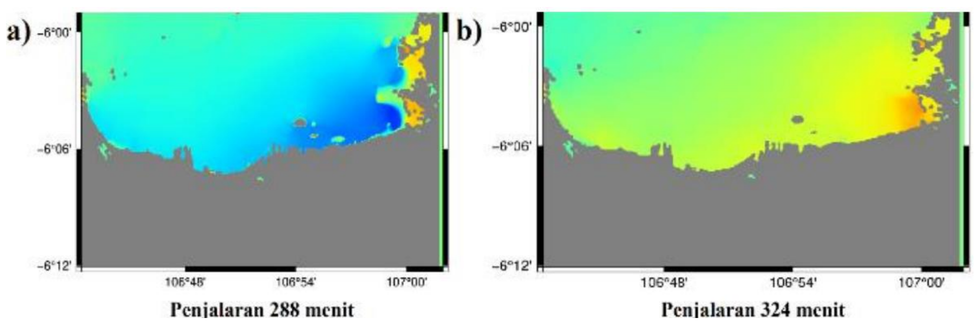

Fig. 25. Tsunami Tracing Process for: a) t=288 minutes and b) t=324 minutes

C. Tsunami Heights

Based on the results of the tsunami climb with an earthquake of 9.0 Mw, the capital city of Jakarta was affected by the height of the tsunami wave where the Mauara Angke tsunami area spread with an inundation of 32.4 meters and had a height of 1.24 meters. Although it only spreads 32.4 meters long, the area is warehousing and densely populated. The tsunami crossing was unevenly exposed to the entire Jakarta area because most of the tsunami waves heading to Jakarta had already hit other areas such as Pelabuhan Ratu, Pandeglang, Bakaheuni to Lampung. Furthermore, it is necessary to process layer 5 by creating 7 points in the area around the coastline that have important buildings in the capital city of Jakarta through the help of Qgis and ms.excel because the distribution is uneven. The purpose of the processing is to find out in more detail about the height of the tsunami wave near the coastal area of the capital city of Jakarta. The affected location points can be seen in the **Figure. 26**

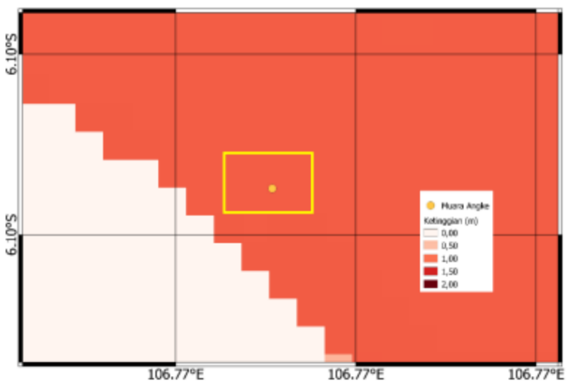

Fig. 26. Locations affected by the tsunami

At point 1, the area that was analyzed was Pantai Indah Kapuk because it is a densely populated area and has many buildings and destinations for the people of Jakarta. The height of the tsunami wave approaching the coast of Pantai Indah Kapuk reached 1.04 meters. At the 2nd point, the area analyzed was Pantai Indah Kapuk 2 because it has many important buildings such as shophouses (warehousing), hospitals, malls, and housing. The height of the tsunami wave approaching the coastline of Pantai Indah Kapuk 2 reached 1.12 meters. At the 3rd point, the area analyzed was the Pluit area because there was an Angke estuary port, Ruko (culinary destination), and aparterment which was densely populated. The height of the tsunami wave approaching the coast of the Pluit area reached 1.12 meters. At the 4th point, an analysis was carried out on the Ancol area because there is one of the historical museums, the Jakarta International Stadium as well as dufan and carnival beaches as recreational places for the people of Jakarta. The height of the tsunami wave approaching the Ancol coast reached 1.19 meters. At the 5th point, the area analyzed was Tanjung Priok because of the center of the Port in Indonesia and the large number of Pertamina oil tanks. The height of the tsunami wave approaching the coast of the Tanjung Priok area reached 1.31 meters. At the 6th point, the area analyzed was Marunda because this area is a logistics warehousing area in North Jakarta. The height of the tsunami wave approaching the coast of the Marunda area reached 1.48 meters. At the 7th point, the area analyzed was the Marunda area bordering Bekasi, West Java because there was a Shell LOBP factory and a factory center area. The existing height in this area reaches 1.78 meters. The picture of the distribution of the 7 tsunami height points can be seen in the **Figure. 27** for the comparison chart, an average calculation of the magnitude of the earthquake and the scenario at 7 location points can be seen in the **Figure. 28**

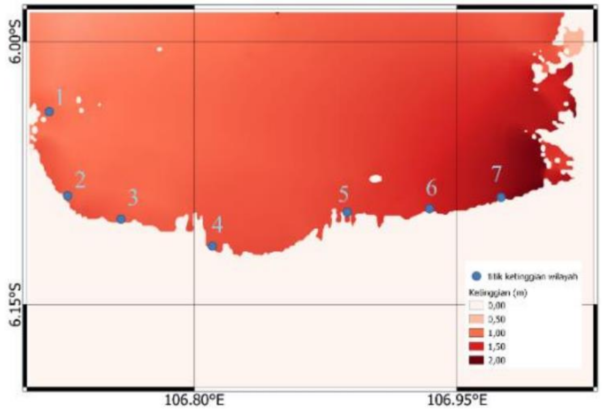

Fig. 27. Region 7 tsunami elevation points

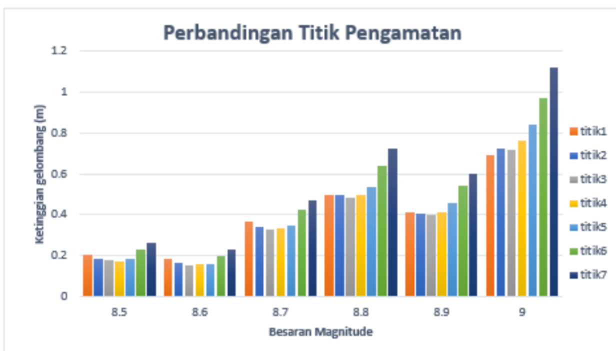

Fig. 28. comparison of wave heights of each earthquake & scenario

D. Hazard Curve

Tsunami modeling analysis using the Probabilistic Tsunami Hazard Assessment will produce a hazard curve regarding tsunamis in 7 points of the study conducted. The curve was used in this study to determine the probability of a tsunami that could occur in Jakarta in a span of hundreds to thousands of years beyond the historical record but in this analysis use 2000 years. In fact, this curve also provides information about the height of the tsunami wave at that time. The results of the plot analysis carried out at location point 1, namely Pantai Indah Kapuk with a re-period of 2000 years, it is known that the height of the tsunami was 0.176 meters. Meanwhile, location point 2, namely Pantai Indah Kapuk 2 with a period of 2000 years, is known to have a tsunami height of 0.162 meters. The height value is obtained through interpolation carried out against the height with an annual reperiod. As for the re-period at locations 1 and 2 can be seen in **Figure. 29**

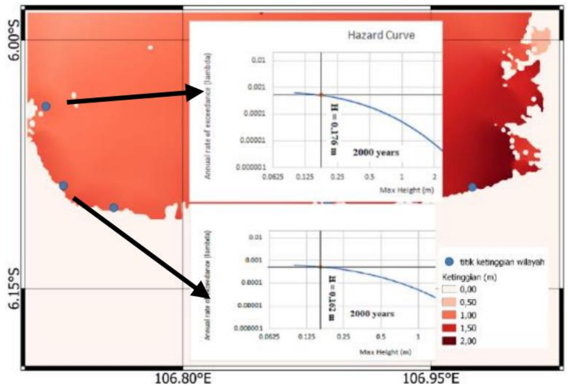

Fig. 29. Wave geights of 2000 years at location points 1 and 2

The results of the plot analysis carried out at location point 3, namely Pluit with a re-period of 2000 years, found that the height of the tsunami was 0.154 meters. Meanwhile, location point 4, namely Tanjung Priok with a re-period of 2000 years, is known to have a tsunami height of 0.156 meters. The height value is obtained through interpolation carried out against the height with an annual re-period. As for the re-period at locations 3 and 4 can be seen in **Figure. 30**

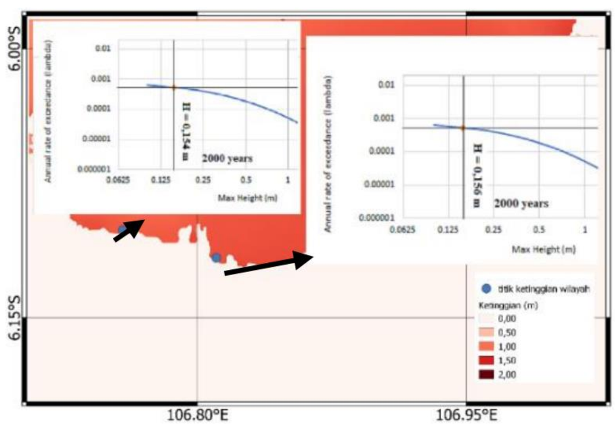

Fig. 30. Wave heights of 2000 years at location points 3 and 4

The results of the analysis of the plot carried out at location point 5 with a re-period of 2000 years found that the height of the tsunami was 0.161 meters. Meanwhile, location point 6 with a re-period of 2000 years is known to have a tsunami height of 0.205 meters. The height value is obtained through interpolation carried out against the height with an annual re-period. As for the re-periods at locations 5 and 6 can be seen in **Figure. 31**

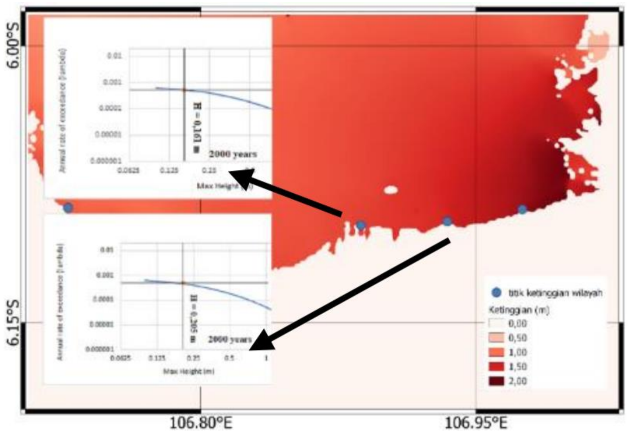

Fig. 31. 2000-year wave height at location points 5 and 6

The results of the analysis of the plot carried out at location point 7 with a re-period of 2000 years found that the height of the tsunami was 0.233 meters. The height value is obtained through interpolation carried out against the height with an annual re-period. As for the re-period at location 7 can be seen in the **Figure. 32**

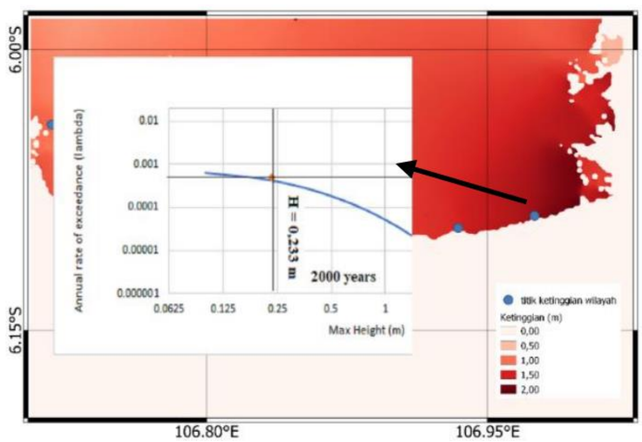

Fig. 32. Wave heights 2000 years at location points 7

From the results of the analysis carried out on 7 research location points, it is known that with a re-period of 2000 years the height of the tsunami only ranged from 0.1 to 0.2 meters. Thus it is necessary to calculate the percentage against a height of 0.5 meters and 3 meters. For an altitude of 0.5 meters on the coast, it is the threshold for tsunami hazard warnings while, a height of 3 meters is a warning of a large tsunami hazard. Based on calculations at location point 7, the probability percentage of tsunami height of 0.5 meters and 3 meters with a 2000-year re-period is 42.01% and

1.55%. The selection is only the 7th point at the study site because it is the result of the largest percentage of probability.

4 Conclusion

Based on research that has been carried out with the title "Probabilistic Analysis of Tsunami Disasters Caused by the Java Megathrust Active Fault: A Case Study of Jakarta, Indonesia" produced several conclusions, namely:

1) The probability value obtained based on PTHA calculations based on the largest percentage at the 7th location point is 42.01% for the probability of occurring with a ≥ of 0.5 meters for a 2000-year re-period, while 1.55% for a probability of occurring with a ≥ of 3 meters.
2) The results of the analysis of the potential height of the tsunami that reached the Jakarta area were 1.24 meters in the Muara Angke area. This uneven distribution made the researchers make 7 points near the coast of Jakarta which have strategic areas with the results of location point 1, location point 2, location point 3, location point 4, location point 5, location point 6 and location titk 7 which is 1.04 m; 1.12 m; 1.12 m; 1.19 m; 1.31 m; 1.48 m; and 1.78 m.
3) The results of the analysis of the farthest distance reached by the tsunami were 32.4 meters in the Muara Angke area.

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