Tsunami Inundation Modelling and Mapping Based on Megathrust Predictions along the Kalianda Coast of Lampung Province Using Delft3D

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Abstract

Tsunami Inundation Modelling and Mapping Based on Megathrust Predictions along the Kalianda Coast of Lampung Province Using Delft3D. Indonesia is situated along active subduction zones such as the Sunda Strait, making the country particularly Lampung Province highly vulnerable to megathrust-induced tsunami events. According to data compiled by the National Center for Earthquake Studies (2017), the Sunda Strait has the potential to experience a major earthquake with a magnitude of Mw 8.7–8.8. One notable historical event was the 2018 Kalianda tsunami, which caused fatalities and infrastructure damage. This study aims to model and map tsunami inundation in the Kalianda coastal area based on potential megathrust earthquake scenarios. Simulations were carried out using Delft3D and GIS software and validated against 2018 tsunami data using the Mean Absolute Error (MAE) and correlation coefficient (R), resulting in an error of 23.57% and a correlation of 0.543. Three tsunami scenarios were modeled, showing varying wave heights, arrival times, and inundation distances, contributing to improved tsunami mitigation strategies in coastal areas.

Keywords: Delft3D, Inundation, Tsunami, Megathrust, Kalianda.

INTRODUCTION

Indonesia is located between three major tectonic plates: the Indo-Australian Plate, the Pacific Plate, and the Eurasian Plate. The movement and interaction of these plates often generate undersea earthquakes that can trigger tsunamis. In addition, Indonesia lies within the Pacific Ring of Fire an area surrounding the Pacific Ocean characterized by high seismic and volcanic activity, further increasing the country's tsunami risk (Isham & Firmansyah, 2023). The vulnerable regions is Lampung Province, especially South Lampung Regency, which is geographically adjacent to the sea and active volcanoes (Urrohmah, 2022).

Tsunamis are large waves caused by natural events such as earthquakes, volcanic eruptions, or submarine landslides. While they may be nearly undetectable in deep waters, their height and destructive potential increase significantly as they approach shorelines. Subduction-zone earthquakes with magnitudes ≥7.0 are particularly capable of generating tsunamis (Lessy et al., 2021). The vertical displacement of tectonic plates can disturb ocean stability and trigger significant wave generation (NOAA, 2023). When these waves reach the coast, they can cause widespread destruction and loss of life.

One of the most significant tsunami threats in Indonesia is the potential for megathrust earthquakes. These zones, including the Sunda Strait Subduction Zone, are capable of generating high-magnitude events. According to national disaster risk projections, the Sunda Strait could experience earthquakes of moment magnitude (Mw) 8,7–8,8. For instance, during the 2018 tsunami that struck the coastal areas of Lampung, including Kalianda District, waves reportedly reached heights of 5–5.5 meters, overtopping 3.5-meterbhigh revetments built along the coast (Susanti Sundari, 2023). The affected regions extend across both the Lampung and Banten coastlines, which are classified as medium-risk zones based on Indonesia’s National Disaster Risk Index.

The coastal area of Kalianda, South Lampung, is particularly vulnerable due to its dynamic shoreline conditions and lack of evacuation infrastructure. In tsunami-prone areas, especially where the waves arrive rapidly and from multiple directions, inundation mapping is crucial for disaster preparedness and impact mitigation. Tsunami wave propagation modelling especially for potential megathrust scenarios can help visualize the extent, height, and speed of tsunami waves. Such models, when validated using historical data, provide valuable inputs for planning evacuation routes and early warning systems. The 2018 tsunami in Kalianda provides a significant dataset for validating future scenario-based simulations.

Understanding and knowledge of tidal patterns can provide various scientific and practical insights. However, in this study, tidal effects were not considered (Mardika & Pratama, 2021). Based on data and existing literature, (Mardika, Mashuri, & Safaraz, 2024) modelled tsunami wave propagation at Tanjung Setia Beach in Lampung by incorporating wind speed variations as a key factor. However, the study did not address earthquake-induced tsunami generation nor validate its model against real tsunami events. This reveals a methodological gap, particularly in incorporating seismic parameters such as historical magnitudes or megathrust scenarios into Delft3D modelling, supported by validation with observed tsunami data. To address this research gap, the present study models tsunami inundation in Kalianda, South Lampung, based on megathrust earthquake scenarios along the Sunda Strait Subduction Zone using Delft3D and GIS tools (Tsa et al., 2024). The model is validated using the 2018 tsunami data, with accuracy evaluated through Mean Absolute Error (MAE) and correlation coefficient (R) methods (Ali et al., 2022). Three scenarios are analyzed based on wave arrival times, maximum inundation distances, and wave heights under different seismic conditions.

This study aims to enhance the accuracy of tsunami hazard prediction by incorporating real earthquake magnitudes and historical data into Delft3D simulation. The findings are expected to support local disaster risk management by providing scientifically validated inundation maps. These maps can inform the development of effective evacuation plans and coastal mitigation strategies, contributing to increased community resilience in the face of potential megathrust-induced tsunamis.

METHODS

This research is conducted in Kalianda District, South Lampung Regency, Lampung Province. The study focuses on megathrust tsunami modelling based on historical tsunami wave height data related to the tsunami event that occurred in South Lampung Regency, Lampung Province, in 2018, using four coordinate points as references:

1. Way Panas Beach, Kalianda District, South Lampung Regency, Lampung Province. The coordinates are 5.746° S and 105.587° E, with an elevation of 9 meters above mean sea level.
2. Bom Kalianda Pier, Kalianda District, South Lampung Regency, Lampung Province. The coordinates are 5.742° S and 105.589° E, with an elevation of 7 meters above mean sea level.
3. Sanggar Beach, Kalianda District, South Lampung Regency, Lampung Province. The coordinates are 5.727° S and 105.586° E, with an elevation of 14 meters above mean sea level.
4. Maja Village Office, Kalianda District, South Lampung Regency, Lampung Province. The coordinates are 5.755° S and 105.586° E, with an elevation of 11 meters above mean sea level.

This final project employed a quantitative method with a case study approach and numerical analysis. This method is a numerical data analysis approach designed to obtain objective results on a specific phenomenon from data collection (Mardika, Mashuri, & Dandi Rahman Hakim, 2024). This study employes a numerical modelling approach to simulate tsunami wave propagation and inundation in the coastal area of Kalianda, South Lampung, using Delft3D software developed by Deltares (Pipit Muliyah, Dyah Aminatun, Sukma Septian Nasution, Tommy Hastomo, Setiana Sri Wahyuni Sitepu, 2020. The modelling aims to analyze tsunami wave distribution, wave height, and arrival time at the coastline. In the data collection process, two data type are used: primary and secondary. The explanation of the research data used is presented below.

The primary data used in this study:
1. Wave propagation distance coordinates refer to the positions indicating how far the tsunami waves have traveled in the (x, y) spatial domain. In this study (Oktaviani et al., 2012), 4 observation points were selected as the basis for validating the historical tsunami event, which is further used to predict a potential future megathrust tsunami.

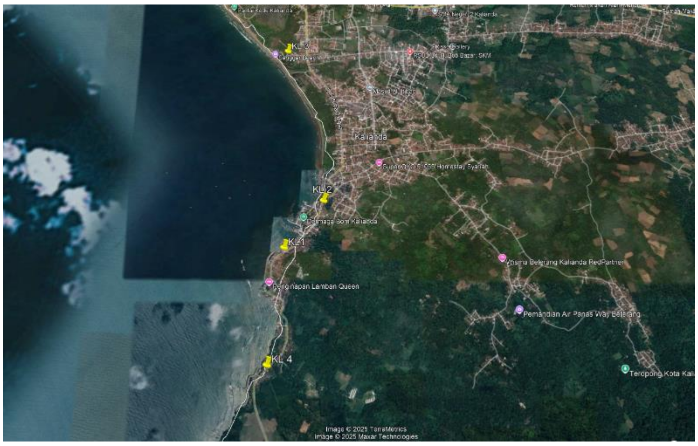

Figure 1. Observation Location of the Study (Google Earth, 2025)

The secondary data used in this study:

1. Bathymetry and topography

   Badan Informasi Geospasial (BIG) released the Seamless Digital Elevation Model of Indonesia (DEMNAS) in 2018. DEMNAS comprises two types of elevation models. The first is DEMNAS for terrestrial areas with a spatial resolution of 0.27 arc-seconds (approximately 8 meters), and the second is DEMNAS for marine areas, also known as the National Bathymetry Dataset (BATNAS), with a spatial resolution of 6 arc-seconds (approximately 180 meters) (Alfath et al., 2025).

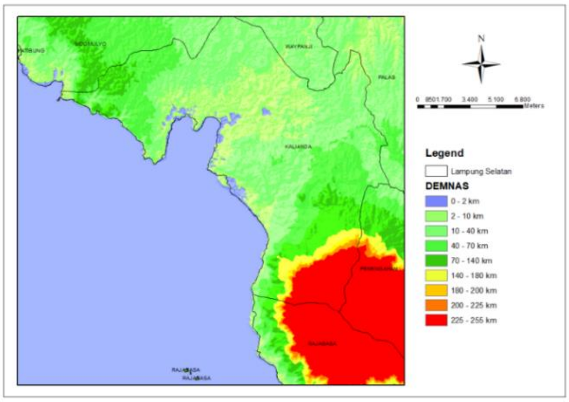

Figure 2. DEMNAS map of the Kalianda region (Badan Informasi Geospasial, 2025)

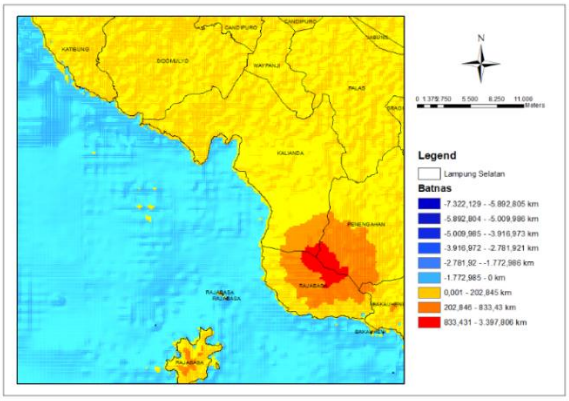

Figure 3. BATNAS map of the Kalianda coastal area (Badan Informasi Geospasial, 2025)

2. Historical Tsunami Data

   Lampung Province has several regions with a high risk of tsunami threats. This is due to its location along the Indian Ocean, which is prone to high wave activity. On December 22, 2018, a landslide from Mount Anak Krakatau triggered a tsunami, with wave heights reported by the Badan Nasional Penanggulangan Bencana (BNPB) to range between 3 and 5 meters.

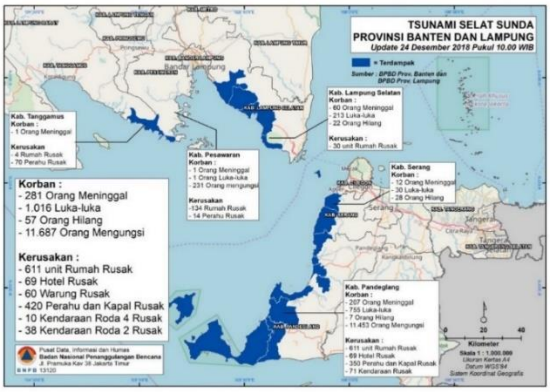

Figure 4. Tsunami Distribution Map of the 2018 Sunda Strait (BNPB, 2018)

The Delft3D simulation modeled seawater dynamics in coastal and open ocean areas to analyze tsunami wave generation, propagation, and inland inundation, using bathymetric data, coastal geometry, and open boundary conditions as inputs (Arafat et al., 2025). Initial calibration and validation are performed with 2018 Sunda Strait tsunami data, and model accuracy is assessed using Mean Absolute Error (MAE) and the correlation coefficient (R). After validation, the same configuration is applied to simulate a potential Mw 8,8 megathrust scenario from BMKG data, producing outputs such as wave height distribution, propagation distance, arrival time, and inundation extent.

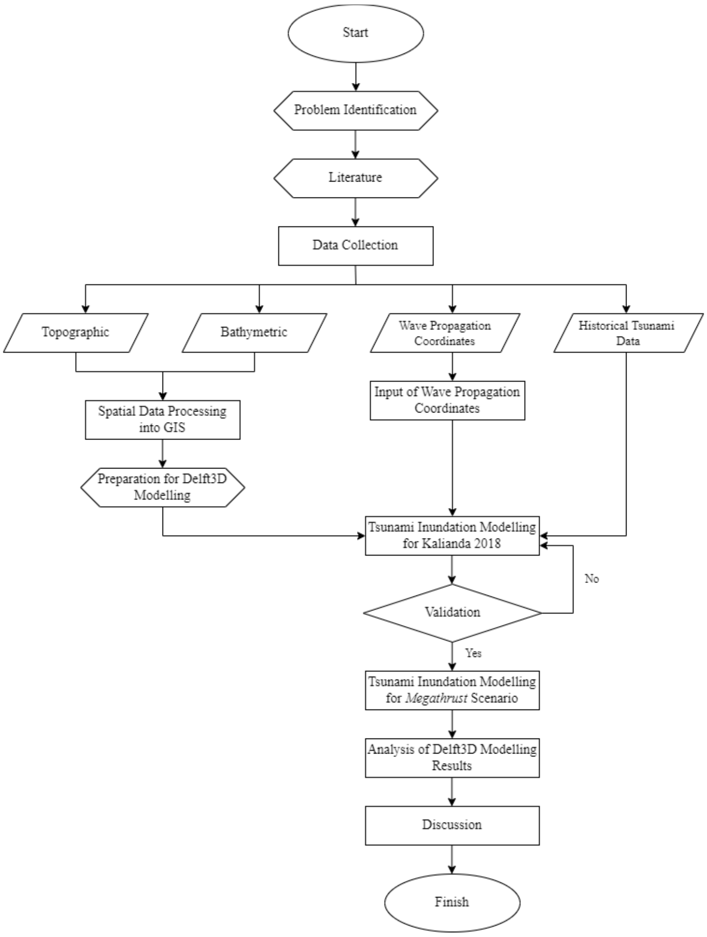

Figure 5. Flowchart of the Research Methodology

RESULTS AND DISCUSSION

Results

1. Delft3D Modelling Analysis Based on the 2018 Historical Tsunami

In the modelling phase, the earthquake magnitude parameter is input into Delft Dashboard to generate wave heights consistent with the 22 December 2018 tsunami. This event is caused by a sector collapse of Anak Krakatau. Based on BNPB estimates of wave heights between 2,0 and 5,0 meters, the calculation followed the empirical equation on Teknik Pantai by (Triatmodjo, 1999).

a. Lower limit (2 meter)
m = 2,26 M – 14,18
1 = 2,26 M – 14,18
M = 6,71 SR

b. Upper limit (5 meter)
m = 2,26 M – 14,18
2 = 2,26 M – 14,18
M = 7,15 SR

The calculation results indicate that the range of earthquake magnitudes used in the simulation falls between Mw 6,71 and 7,15. These values were then tested incrementally in Delft3D software to assess their impact on tsunami wave propagation distance.

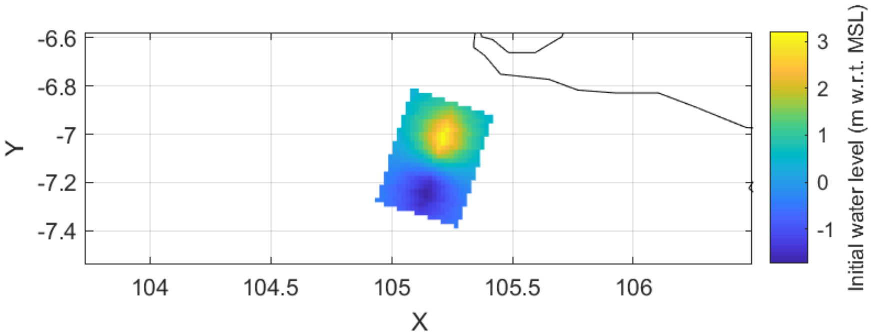

Figure 6. Initial Water Surface Elevation Historical Tsunami

2. Validation of the Historical Tsunami Modelling Results

The validation assessed the model’s ability to replicate tsunami wave response to bathymetry and coastal geometry using MAE for three earthquake sources: Mw 6.71 producing waves of 2–3 m, Mw 7.0 producing 3–4 m, and Mw 7,15 producing 4–6 m, in line with Triatmodjo, 1999 empirical relation linking fault deformation to initial wave height. Once satisfactory accuracy is achieved, the same validated configuration is applied to simulate a potential Mw 8.8 megathrust scenario for tsunami hazard assessment.

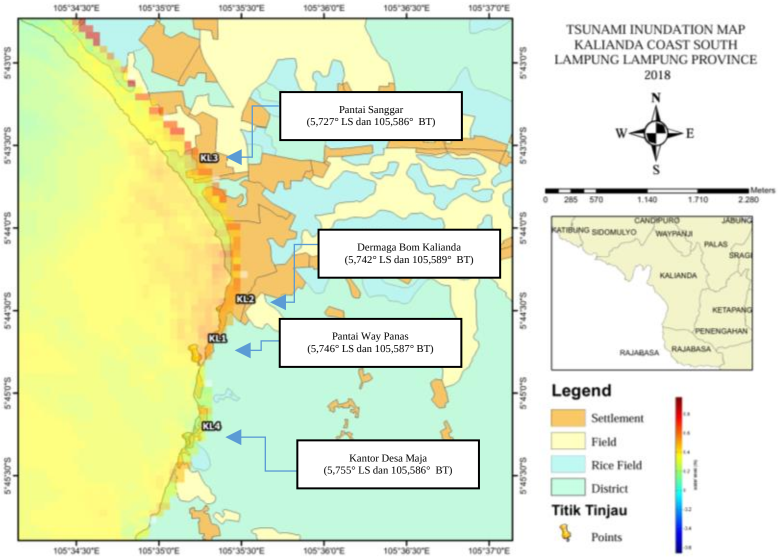

Figure 7. Tsunami Inundation Map of Kalianda 2018

Table 1. Observed Wave Propagation Distance in the Field (Real Conditions)

No.	Observation Point	Wave Propagation Distance (meters)
1.	KL 1	84,45
2.	KL 2	95,24
3.	KL 3	113,89
4.	KL 4	87,39

a. Magnitude of 6,71 Mw (2–3 meters)

Table 2. Wave Propagation Distance in the 6,71 Mw Simulation

No.	Observation Point	Wave Propagation Distance (meters)
1.	KL 1	155,07
2.	KL 2	115,53
3.	KL 3	79,03
4.	KL 4	71,06

b. Magnitude of 7,01 Mw (3–4 meters)

Table 3. Wave Propagation Distance in the 7,01 Mw Simulation

No.	Observation Point	Wave Propagation Distance (meters)
1.	KL 1	105,57
2.	KL 2	65,49
3.	KL 3	138,55
4.	KL 4	101,76

c. Magnitude of 7,15 Mw (4–6 meters)

Table 4. Wave Propagation Distance in the 7,15 Mw Simulation

No.	Observation Point	Wave Propagation Distance (meters)
1.	KL 1	200,1
2.	KL 2	140,93
3.	KL 3	167,02
4.	KL 4	101,09

3. Delft3D Modelling Analysis Based on Megathrust Earthquake Prediction

This study used three Delft3D grid-based tsunami modeling scenarios to simulate wave propagation from a predicted Mw 8.8 megathrust earthquake in the southwest Sunda Strait. The scenarios differed in fault orientation angles relative to the coastline, aiming to determine which direction would most likely cause inundation in Kalianda, Lampung.

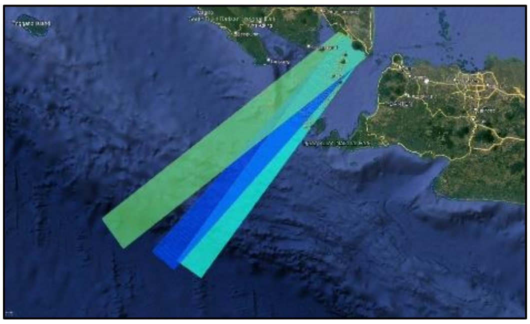

Figure 8. Three Scenarios of Wave Propagation Direction

The selection of the angle for each scenario takes into account the geographic limitations of the surrounding area. If the fault is oriented too far north, wave propagation could potentially impact the Tanggamus region, which is outside the study's focus area. Conversely, if the fault is oriented too far south, the impact would be greater on the west coast of Banten Province.

a. Scenario 1 (wave approach angle of 45º)

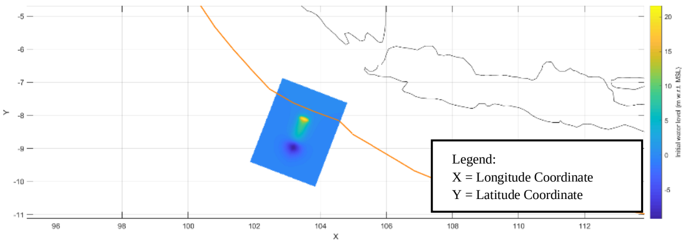

Figure 9. Initial Water Surface Elevation Scenario 1

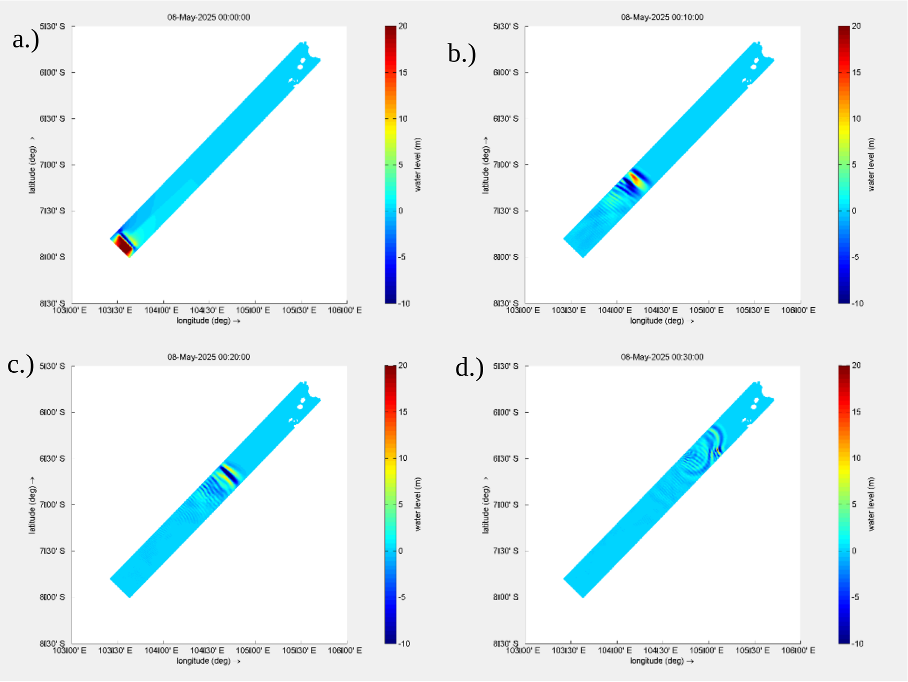

Figure 10. Sea Surface Elevation from 0 to 30 Minutes

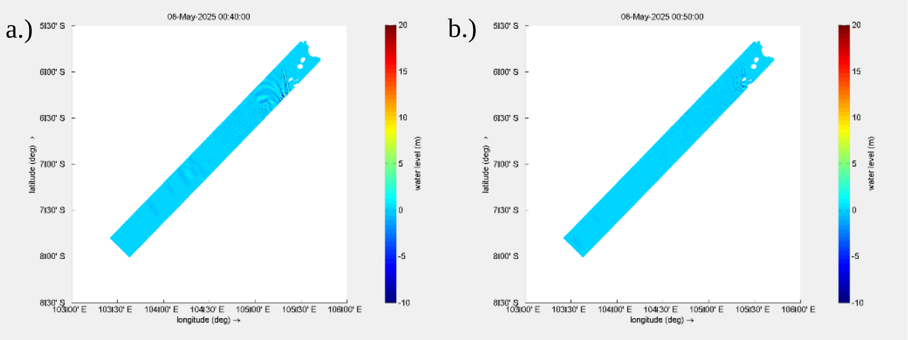

Figure 11. Sea Surface Elevation from 40 to 50 Minutes

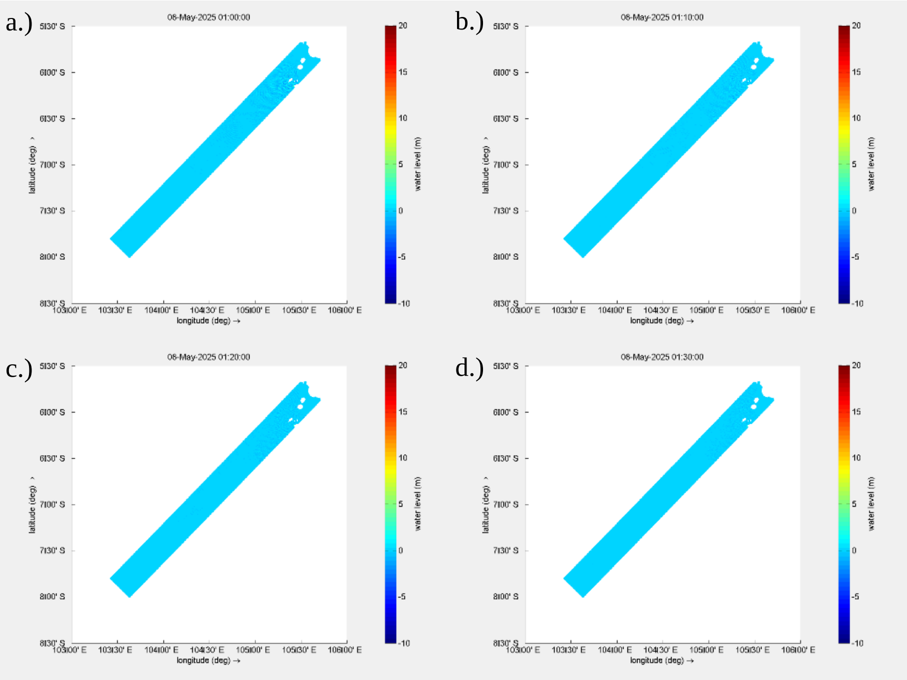

Figure 12. Sea Surface Elevation from 60 to 90 Minutes

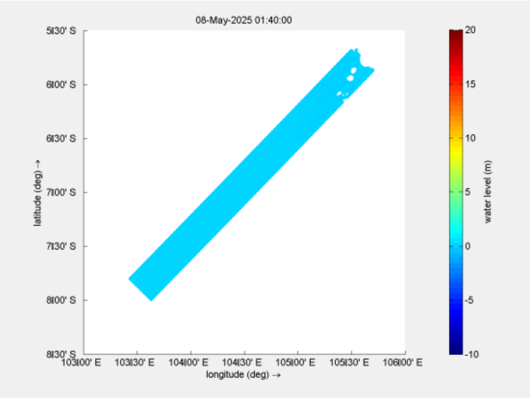

Figure 13. Sea Surface Elevation at 100 Minutes

b. Scenario 2 (wave approach angle of 51°)

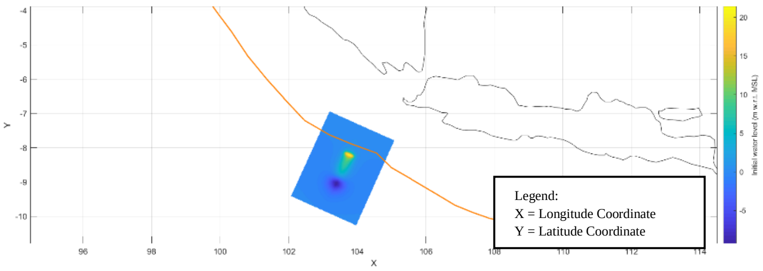

Figure 14. Initial Water Surface Elevation Scenario 2

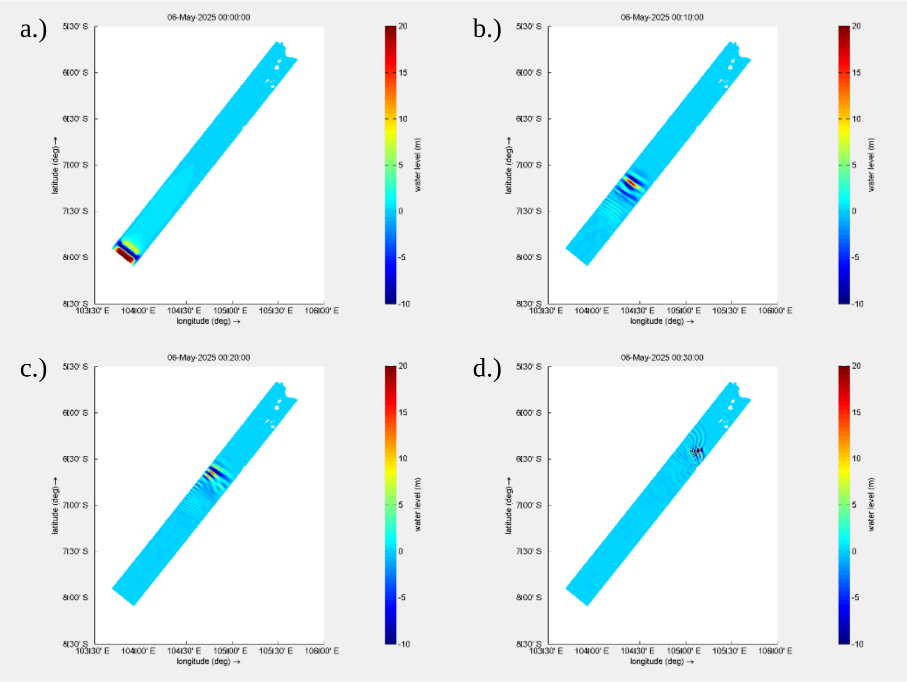

Figure 15. Sea Surface Elevation from 0 to 30 Minutes

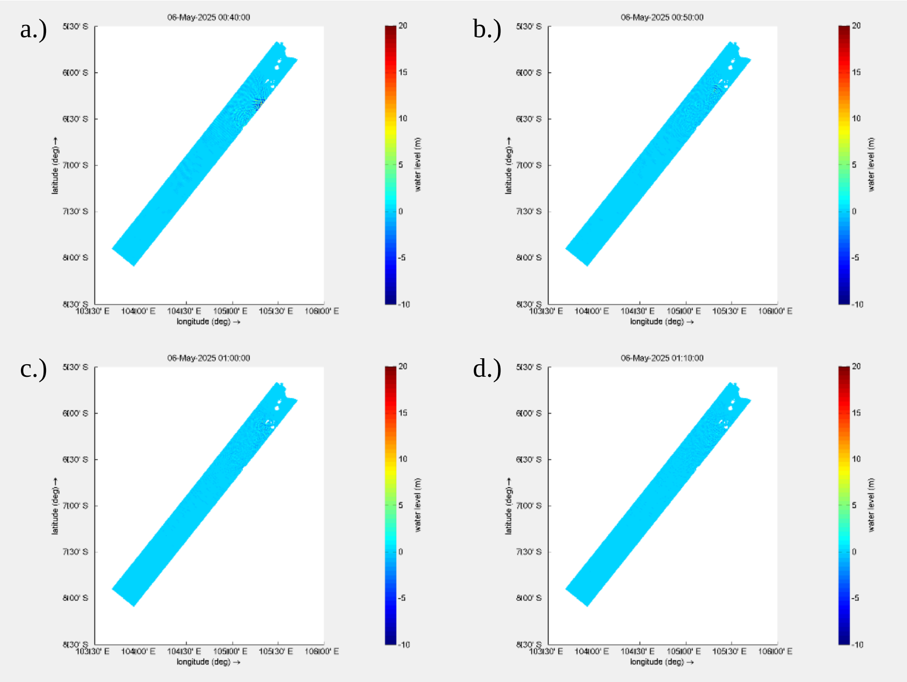

Figure 16. Sea Surface Elevation from 40 to 70 Minutes

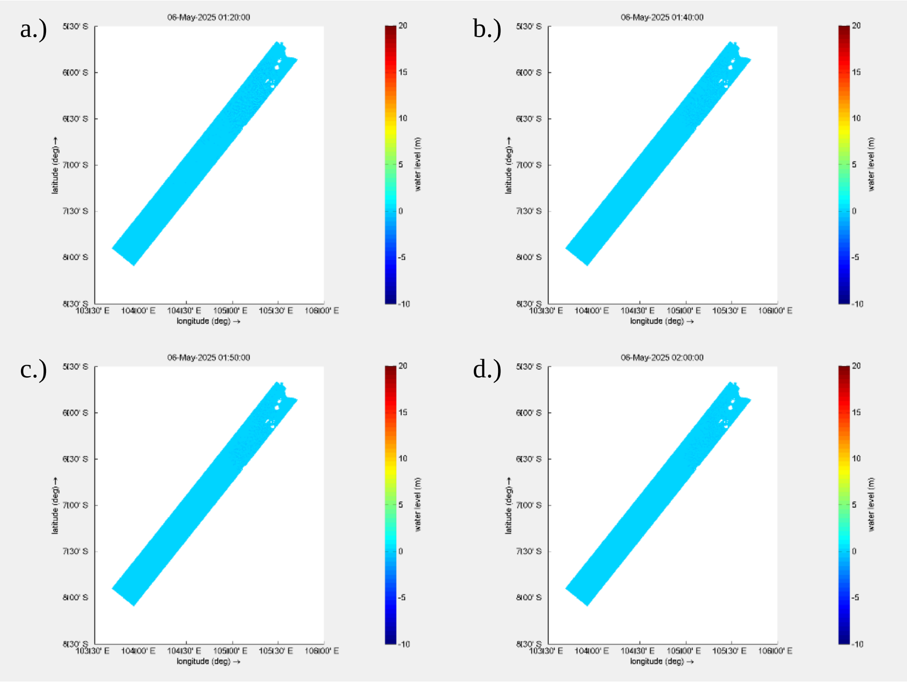

Figure 17. Sea Surface Elevation from 80 to 110 Minutes

c. Scenario 3 (wave approach angle of 36º)

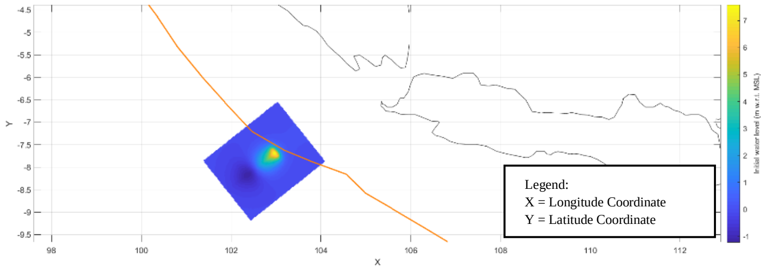

Figure 18. Initial Water Surface Elevation Scenario 3

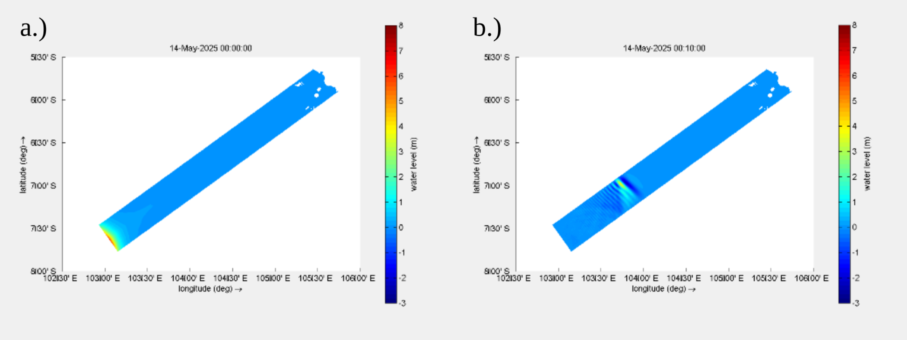

Figure 19. Sea Surface Elevation from 0 to 10 Minutes

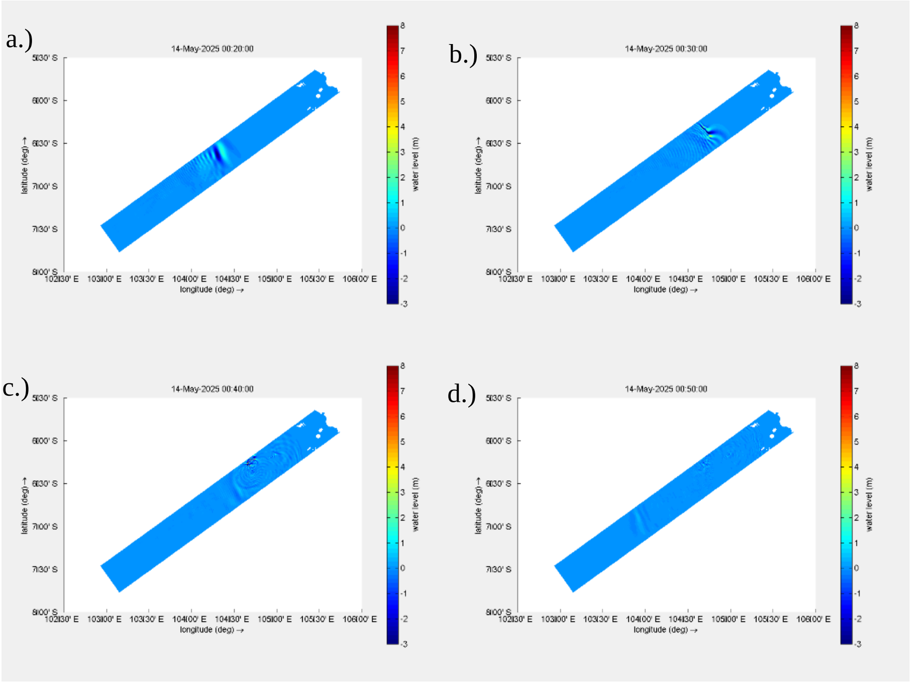

Figure 20. Sea Surface Elevation from 20 to 50 Minutes

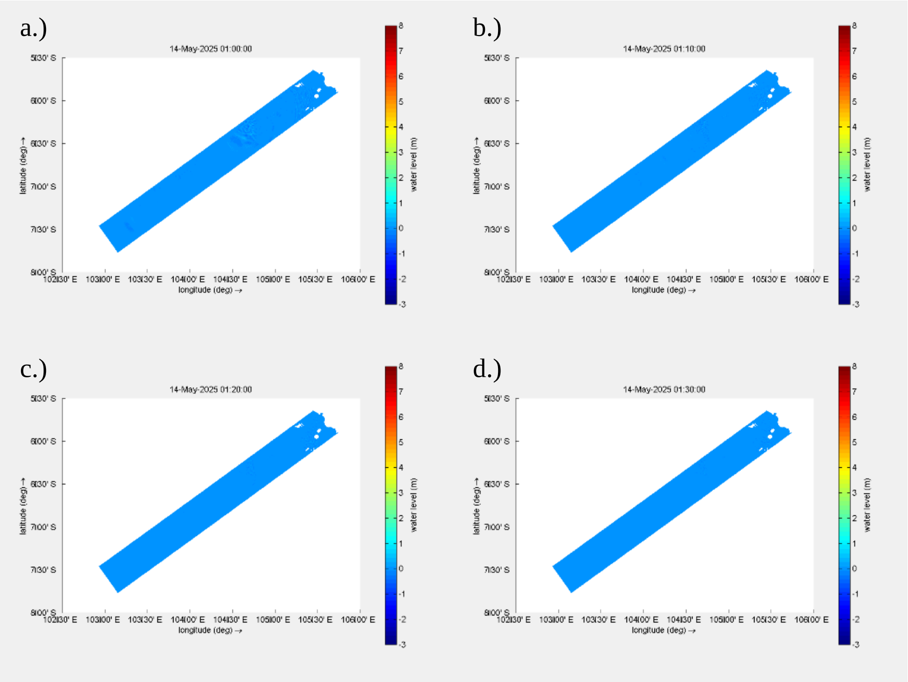

Figure 21. Sea Surface Elevation from 60 to 90 Minutes

Discussion

From the three validation results using historical data, it is observed that the earthquake magnitude of 7,01 Mw yielded the smallest error, approximately 23,57%, and the highest correlation coefficient interpretation, at 0,543. These findings indicate that the validation most closely matching the historical earthquake magnitude is 7,01 Mw, characterized by the lowest error and the highest field interpretation accuracy. This suggests that the 7,01 Mw magnitude provides the most reliable representation for simulating the historical tsunami event.

Table 5. Recapitulation of Historical Data Modeling Validation

Historical Tsunami Modelling	Mean Absolute Error (MAE)	Correlation Coefficient (R)
6,71 Mw (2–3 meters)	26,80%	0,495
7,01 Mw (3 – 4 meter)	23,57%	0,543
7,15 Mw (4 – 6 meter)	59,88%	0,096

After the validation process, three megathrust tsunami scenarios were simulated, each incorporating parameters such as wave arrival time, maximum tsunami height at the shoreline, and the maximum inland inundation distance from the shoreline. These scenarios were designed to represent varying levels of potential impact, enabling a comprehensive assessment of coastal vulnerability and hazard mitigation planning.

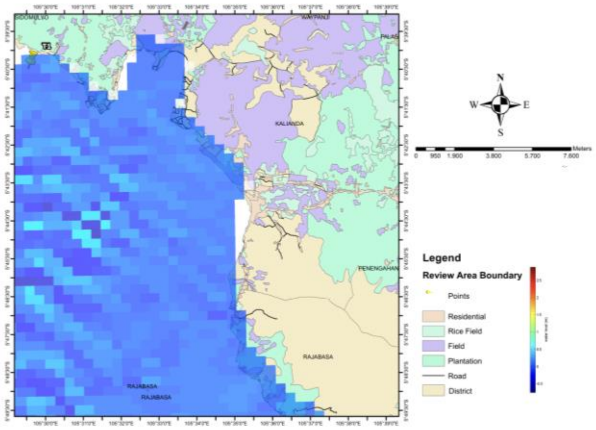

Figure 22. Predicted Megathrust Tsunami Inundation Map Scenario 1

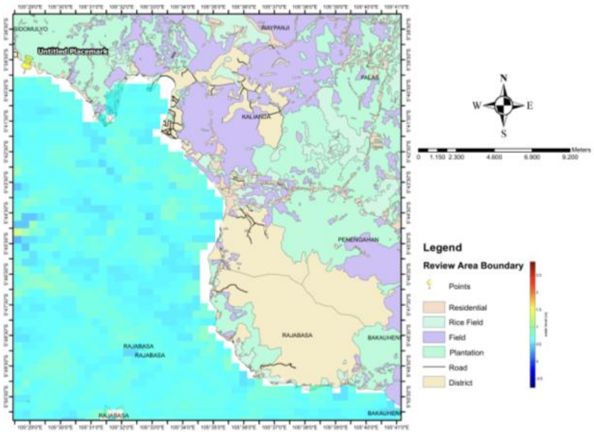

Figure 23. Predicted Megathrust Tsunami Inundation Map Scenario 2

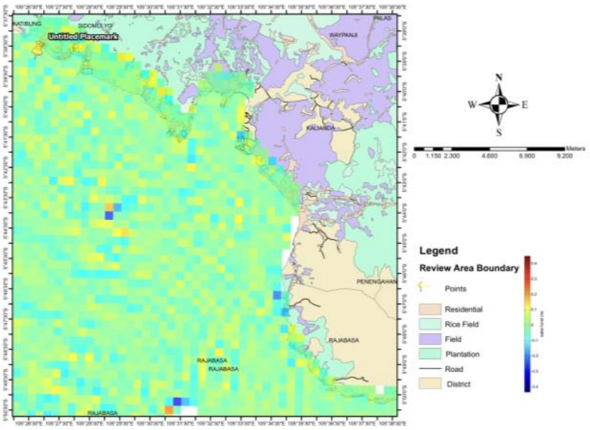

Figure 24. Predicted Megathrust Tsunami Inundation Map Scenario 3

Table 6. Recapitulation of Predicted Megathrust Modelling

Scenario	Arrival Time (min)	Maximum Height (m)	Maximum Inland Distance (m)	Description
Scenario 1	100	1,0	446,32	Tsunami reaches shoreline in 100 min, height 1 m, inland 446,32 m.
Scenario 2	-	-	-	The tsunami wave does not reach the shoreline.
Scenario 3	90	0,4	1016	Tsunami reaches shoreline in 90 min, height 0,4 m, inland 1016 m.

CONCLUSION

1. Observations of the 2018 Kalianda Tsunami were conducted at four locations namely Way Panas Beach, Kalianda Bom Pier, Sanggar Beach and Maja Village Office. Based on tsunami modeling using historical data the maximum inland wave propagation distances measured from the shoreline to the furthest inundation point were 84,45 m, 95,24 m, 113,89 m and 87,39 m.
2. The best validation result derived from the Mean Absolute Error (MAE) equation is 0,2357 or 23,57 % which falls within the low error range of 0,00 to 0,299 and the correlation coefficient (R) is 0,543 which falls within the medium interpretation category of 0,50 to 0,69.
3. Tsunami prediction modeling from a megathrust earthquake used three scenarios, with scenario 1 as the most extreme where waves reached the shoreline in 100 minutes, 1 meter high, and inundated 446,32 meters inland. In scenario 2 waves did not reach the shoreline. In scenario 3 waves arrived in 90 minutes, 0,4 meter high, and inundated 1016 meters inland.

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