# The Modeling of Tsunami Based on Existing Land Cover in Padang City

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**Abstract,** The west coast of Sumatra Island is highly susceptible to earthquakes that can trigger tsunamis, with Padang City being particularly vulnerable. As the largest city on the west coast of Sumatra Island and the capital of West Sumatra Province, Padang is located in close proximity to the megathrust fault. This study aimed to assess the effectiveness of the current land cover in Padang City in reducing the impact of tsunami waves. The tsunami modeling in this study was based on a projected sea level rise of 11 meters along the coastline. The analysis involved calculating the decrease in water level blocked by different land cover types in Padang City. To determine the affected area, a Cost-Distance analysis was conducted. The results of the modeling revealed that a total area of 3.231 hectares in Padang City would be affected by the tsunami. This encompasses eight out of the total 11 sub-districts in Padang. Among these sub-districts, Koto Tangah has the highest potential impact, covering an area of 1.393 hectares. The land cover type most prone to being affected is the settlement area, with a total area of 1.577 hectares and approximately 39.204 buildings at risk. These findings highlight the importance of considering land cover conditions and their role in mitigating the impact of tsunamis, particularly in vulnerable areas like Padang City.

**Keywords**: Modeling, Tsunami, Land Cover

## 1 Introduction

Indonesia, situated in Southeast Asia and straddling the equator, is known as an archipelago nation. One notable feature of Indonesia is its abundance of volcanic mountains spanning from the west to the east, earning it the moniker "the ring of fire" country. As a consequence of this geological characteristic, Indonesia experiences frequent earthquakes and volcanic eruptions [1].

The geographical positioning of Indonesia reveals its proximity to three active tectonic plates. These include the Indo-Australian Plate to the south, the Pacific Plate to the east, and the Eurasia Plate to the north [2]. The region of West Sumatra poses a particular hazard due to its location on the western coast of Sumatra Island (Fig. 1), where the Indo-Australian Plate converges [3].

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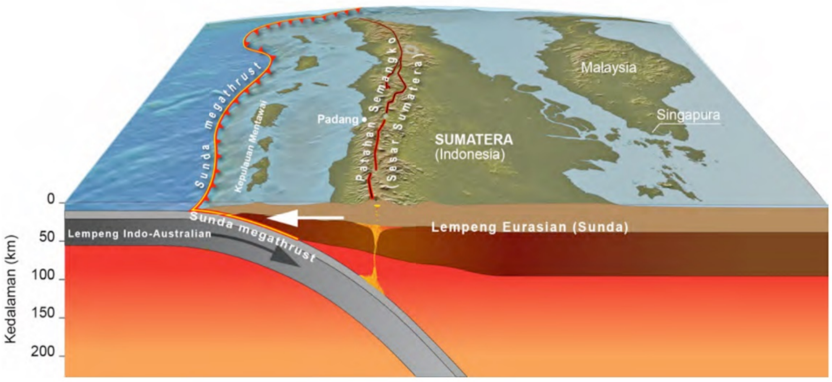


**Fig. 1.** The Sunda Megathrust fault caused an earthquake and tsunami in Padang City, West Sumatra [4]

The province of West Sumatra has witnessed multiple tsunamis throughout its history. One notable event took place in 1797 when an underwater landslide, triggered by a preceding earthquake, resulted in a devastating tsunami. The wave's height was estimated to be between 5 and 11 meters, reaching approximately 1 kilometer inland. Another significant occurrence transpired in 1833 when a rupture along the Sumatran trench, spanning 1.000 kilometers, generated a tsunami. The accompanying earthquake was estimated to have a magnitude of 8.8 to 9.3 Mw [5]. This repetitive cycle of earthquakes is attributed to the continuous movement of tectonic plates over several centuries [4]. Considering these circumstances and the geographical location of the city of Padang, it falls under the dangerous category and faces a high level of vulnerability to tsunami hazards [6] [7] and [8].

The land cover conditions in coastal areas play a crucial role in determining the extent of tsunami inundation. This is due to the fact that different types of land cover have varying capacities to reduce water levels and diminish the force of tsunami waves[9] [10]. It should be noted that each land cover possesses a distinct attenuation capacity. The inadequate ability to anticipate disasters is evident in suboptimal spatial planning and development initiatives that fail to consider the risks posed by natural calamities [11]. Conducting risk assessments becomes imperative in the realm of disaster risk reduction [12] [13].

Modeling the tsunami disaster is very important to be carried out and studied more deeply because it can provide information on disaster mitigation and land cover management. Based on the above conditions, this study aims to see how much capacity the current land cover condition of Padang City has in reducing tsunami waves; this model can simulate and predict the level of damage and losses caused by the tsunami disaster. This research is very much needed as a reference by the government in making spatial planning and disaster mitigation policies.

## 2. Materials and method

### 2.1 The research location and research times

The research was carried out between July and August 2022 in the administrative region of Padang City, located in the province of West Sumatra. The extensive area affected by the study was divided into sections based on a projection of an 11-meter increase in water level along the shoreline, derived from a study conducted by BNPB (Badan Nasional Penanggulangan Bencana) on the maximum tsunami height risk in the Padang City area [14].

## 2.2 Tsunami inundation model

The $H_{loss}$ model was applied to Padang beach for the tsunami inundation analysis [15]. This model requires three primary inputs: wave height on the shoreline, surface roughness (as outlined in Table 1), and slope. The wave height on the coastline was determined based on data provided by BNPB, indicating water levels reaching 11 meters on Padang beach [14]. The surface roughness values were derived from a land use map generated by BIG (Badan Informasi Geospasial) and high-resolution imagery interpretation. Additionally, the DEMNAS (Digital Elevation Model Nasional) obtained from the Government (BIG) was used for the analysis.

The data processing involved several steps. Firstly, the $H_{loss}$ model was utilized to calculate the decrease in sea levels. Secondly, a cost-distance analysis was conducted to determine the extent of seawater inundation or the affected areas of the tsunami. Finally, all the calculated indicators for each variable were compiled in a table or statistical data format, providing an overview of the affected areas.

**Table 1**. Type and the source data

| No | Data | Source |
|---|---|---|
| 1 | DEM | DEMNAS from Ina-Geoportal BIG (https://tanahair.indonesia.go.id)) |
| 2 | Landuse Map | Ina-Geoportal BIG and hight resolution imagery interpretation |
| 3 | Administration Map | BIG (https://tanahair.indonesia.go.id) |

In the Tsunami Risk Assessment book, which is based on the regulatory chief of the National Disaster Management Authority (issued as no 4/2012), it is stated that the increased water level for tsunami events in Padang is 11 meters. This reference serves as the basis for wave height on the coastline used in the current study.

## 2.3 Data processing techniques

The decrease in water level formula for tsunami inundation can be represented as follows:

$$Hloss = \left( \frac{167n^2}{H_0^{\ 1/3}} \right) + 5 \sin S$$

$H_{loss}$ : the decline of water height per meter from the inundation
n : the surface roughness coefficient
$H_0$ : the sea water height in the shoreline
S : slope (degree)

In this formula, $H_{loss}$ represents the amount of wave height lost per meter of distance traveled by the tsunami. $H_0$, the initial wave height on the shoreline, is not explicitly included in this formula as it is already accounted for in the Hloss value. The surface roughness coefficient is a measure of the ability of different types of land cover to impede the progress of tsunami waves. Each land cover category has a different surface roughness coefficient, reflecting its capacity to resist wave propagation. In the context of Padang, where there is no jungle along the shoreline, settlements are likely to have a higher surface roughness coefficient compared to other land cover types. It's important to note that this formula provides a simplified representation of the complex dynamics of tsunami inundation and factors influencing water level decrease. The actual behavior of tsunamis can be influenced by various additional factors and considerations.

**Table 2**. The surface roughness coefficient value

| No | Type of the used areas | The Surface Roughness Coefficient Value |
|---|---|---|
| 1 | Waterbody | 0,007 |
| 2 | Bush | 0,040 |
| 3 | Forest | 0,070 |
| 4 | Farms | 0,035 |
| 5 | Agriculture | 0,025 |
| 6 | Empty land | 0,015 |
| 7 | Buildings | 0,045 |
| 8 | Mangrove | 0,025 |
| 9 | Fishpond | 0,010 |

The output of the decrease in water level equation can be used as an input for determining the inundation area using the cost-distance function. The cost-distance function calculates the cumulative cost or distance required to travel across a cost surface. In this case, the cost surface is represented by a grid of cells that depict the loss of wave height ($H_{loss}$) [16]. By applying the cost-distance function to the grid representing the sea shoreline, the algorithm determines the lowest cumulative cost (or distance) needed to traverse the cells based on the assigned cost values ($H_{loss}$). This process helps identify the areas that are more likely to be affected by the tsunami inundation, as the cells with higher cumulative costs indicate a greater reduction in wave height and thus potentially lower water levels. By utilizing the cost-distance function and the loss of wave height grid, it becomes possible to estimate and visualize the extent of the inundation area resulting from a tsunami event.

## 3 Results and Discussion

The city of Padang is administratively divided into 11 sub-districts. Among these, eight sub-districts, comprising 30 villages, are located directly on the coastline and are susceptible to being directly affected by tsunamis. However, there are three sub-districts, namely Kuranji, Pauh, and Lubuk Kilangan, which are not directly affected by tsunamis. The reason for their relative safety is twofold: first, these sub-districts are situated at a considerable distance from the coastline, and second, they have a relatively higher elevation compared to the coastal areas. These factors contribute to a lower risk of tsunami impact in Kuranji, Pauh, and Lubuk Kilangan sub-districts.

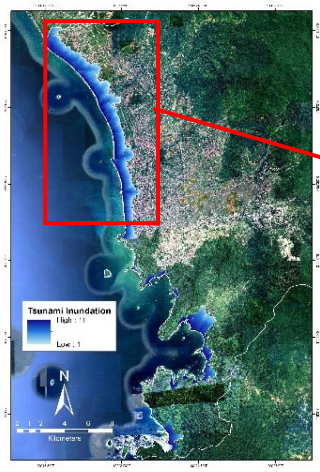


**Fig. 2a.** Inundation Tsunami Map of 11 meters hight

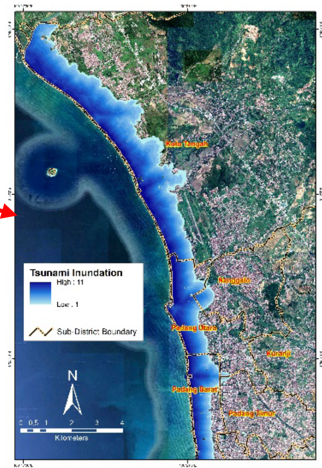


**Fig. 2b.** Inundation Tsunami Map on Padang Sub-District

Figures 2a and 2b illustrate the results of the tsunami inundation modeling, based on a run-up scenario of 11 meters on the coastline. The total area affected by the tsunami inundation is 3.231 hectares. The most severely impacted area is characterized by a gentle slope and is predominantly occupied by built-up land and buildings. This area experiences high levels of activity, particularly during the day, as it serves not only as a residential zone but also hosts government offices and agencies. The concentration of government activities further contributes to the significance of this area.

**Table 3.** Area of Inundation For Each Sub-District

| No | Sub-District | Affected Area (ha) |
|---|---|---|
| 1 | Koto Tangah | 1.393 |
| 2 | Padang Utara | 392 |
| 3 | Padang Barat | 407 |
| 4 | Padang Timur | 8,7 |
| 5 | Padang Selatan | 102 |
| 6 | Nanggalo | 51,5 |
| 7 | Lubuk Begalung | 54,7 |
| 8 | Bungus Teluk Kabung | 822 |

Among the sub-districts in Padang City, the Koto Tangah sub-district has the highest potential to be affected by the tsunami, considering the 11-meter increase in water level. This sub-district has an affected area of approximately 1.393 hectares, which corresponds to around 6.2% of the total area. The impact is predominantly observed in the built-up areas, indicating the vulnerability of densely populated and urbanized regions to tsunami events.

On the other hand, the Padang Timur sub-district has the smallest affected area, estimated to be around 8,7 hectares. This sub-district experiences a relatively lower impact compared to others, potentially due to its geographical location and elevation. These findings provide valuable insights into the distribution and extent of the potential impact in different sub-districts of Padang City, helping authorities and decision-makers prioritize resources and develop appropriate mitigation strategies to minimize the impact of tsunamis.

**Table 4.** Inundation Affected Area by Landuse Type

| No | Type of Landuse | Affected Area (ha) |
|---|---|---|
| 1 | Building | 1.577 |
| 2 | Agriculture | 545 |
| 3 | Farms | 275 |
| 4 | Others | 834 |

Based on Table 4, the built-up land or buildings are identified as one of the areas with the highest potential hazard in the event of a giant tsunami. This land cover type encompasses an area of approximately 1.577 hectares, indicating its vulnerability to the impact of tsunamis. Furthermore, there are a total of 39.204 buildings within this area (as shown in Fig. 3), emphasizing the significant potential for damage and loss in densely populated urban areas.

In addition to built-up land, agricultural areas cover a significant extent of 545 hectares, making them another land cover type prone to being affected by tsunamis. Similarly, plantations, spanning approximately 275 hectares, are also identified as areas with potential hazards.

Understanding the distribution and vulnerability of different land cover types provides crucial insights for disaster preparedness and mitigation efforts. By prioritizing areas of higher risk, authorities can develop strategies and allocate resources to minimize the impact and enhance the resilience of these areas in the face of giant tsunamis.

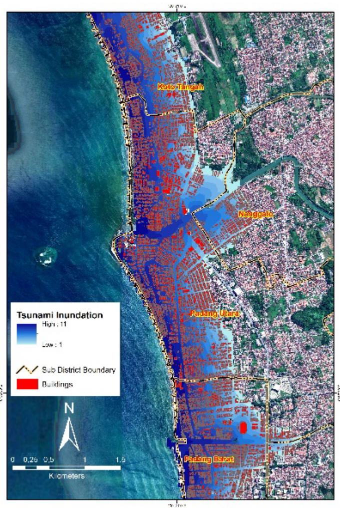


**Fig. 3.** Buildings affected by the tsunami modeling

Indeed, the situation is concerning, particularly because the built-up area primarily consists of residential buildings. If a tsunami disaster were to occur during the day, when community activities are in full swing, the potential for a higher number of victims would be even more significant. This is because offices, schools, markets, and tourist areas, which are often bustling during working hours, would also be within the affected tsunami zone.

The observation highlights the lack of consideration for the potential tsunami disaster in the spatial pattern plan, which serves as the foundation for spatial management. It emphasizes the importance of integrating disaster risk assessments and mitigation strategies into spatial planning processes. By incorporating the potential hazards and risks associated with tsunamis, authorities can develop more resilient spatial plans that prioritize the safety and well-being of the community. This includes appropriate zoning regulations, land use restrictions, and the establishment of evacuation routes and safe areas to minimize the impact of future tsunami events.

# 4 Conclusion

Based on the findings of this research study, several key conclusions can be drawn. Firstly, the modeling of an 11-meter increase in water level on the coastline revealed extensive tsunami inundation. Among the sub-districts in Padang City, Koto Tangah sub-district experienced the most significant impact from the inundation. Additionally, the land cover type that was most affected by the modeling was the built-up land or building areas.

The modeling of tsunami inundation conducted in this study takes into account important factors such as wave height, surface roughness (represented by land use types), and elevation of the area. This comprehensive modeling approach enables the government to better predict the level of risk associated with tsunamis. Consequently, it facilitates the estimation of potential damage and losses, as well as the identification of appropriate mitigation strategies.

By utilizing such modeling techniques, the government can enhance its preparedness and response measures, enabling more effective planning and resource allocation to minimize the impacts of tsunamis in vulnerable areas like Padang City.

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