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Analysis Of Tsunami Hazard Potential on The Coast of Bitung City, North Sulawesi

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Abstract

This thesis aims to study the tsunami hazards in the Maluku Sea region, particularly in the coastal area of Bitung, Indonesia. The research focuses on modeling and analyzing the potential tsunamis triggered by earthquake events in that region. The data used includes bathymetry, topography, coastline, and river data obtained from the Geospatial Information Agency (Badan Informasi Geospatial-BIG). The tsunami modeling process utilizes the software COMCOT (Cornell Multi-grid Coupled Tsunami). The earthquake source parameters (PusGen) used in the modeling, such as magnitude, focal depth, length of the fault plane, the width of the fault plane, dislocation of the fault plane, strike, dip, slip/rake, and modeling area, were obtained from worst-case scenarios based on PusGen's research results. The research consists of two main stages: the pre-verification stage, where data processing and tsunami modeling are conducted, and the verification stage, where field surveys are carried out to determine the coordinates for Temporary Evacuation Sites (TEP) and Final Evacuation Sites (FEP). Various equipment, such as GPS, altimeters, stopwatches, cameras, and drones, are used during the field verification. The research procedures include a literature review, data collection of topography, bathymetry, earthquake parameters, and fault mechanism. Subsequently, tsunami modeling is conducted, and hazard analysis is performed based on the model results. Tsunami hazard maps are generated to highlight high-risk areas in the coastal region of Bitung, and evacuation routes are identified to prepare the coastal community of Bitung to face potential tsunami threats. The research offers important information to assist in the development of warning systems and efficient evacuation strategies to protect the coastal community of Bitung from tsunamis' devastating impacts.

Keywords: Tsunami; Bitung; coastal area; earthquake; PusGen

INTRODUCTION

Sulawesi Island, an Indonesian territory, stands amidst regions characterized by intense seismicity, setting it apart with its remarkable susceptibility to seismic events compared to its counterparts. This is notably exemplified by the most recent significant earthquake recorded in the northern segment of this area in 1996, reaching a magnitude of M 7.9 (Kertapati, 2006). Anchored by its geological attributes, the region is subject to diverse tectonic interactions, including the North Sulawesi Trench subduction, the Maluku collision, the Philippine Sea Plate subduction, and various active faults within northern Sulawesi. Consequently, this geographical expanse emerges as a veritable hotspot for tectonic earthquakes and the associated hazards they entail (S. Harmsen, 2007).

Turning our attention to the Maluku Sea, renowned for its heightened seismic activity, a profound investigation comes to light. According to data sourced from the United States Geological Survey (USGS) spanning from 1900 to 2022, the Maluku Sea has experienced no less than 15 earthquakes with magnitudes surpassing 7.0. Additionally, Sriyanto et al. (2019) emphasize that the prevailing fault motion in this zone is characterized by vertical displacement – a trait aligned with the criteria for generating potentially destructive tsunamis, a notion previously endorsed by the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) in 2012.

Recent years have borne witness to a series of seismic events that have yielded tsunamis, including occurrences in November 2014, July 2019, and November 2019, marked by shared features in magnitude and vertical fault motion. The 2014 tsunami event, precipitated by a Mw 7.2 earthquake, finds its epicenter ensconced within the heart of the Maluku Sea. This seismic episode resonated across Sulawesi Utara and Maluku Utara, with tide gauges recording height fluctuations of 9 cm, 1 cm, and 3 cm respectively at Jailolo, Tobelo, and Manado. The 2014 earthquake rupture zone encompasses approximately 100 km, stretching southwest to northeast, where the primary seismic mechanism manifests as an oblique fault dominated by vertical motion, characterized by a strike of 192° and a dip of 55°.

The broader impact of seismic events extends beyond structural devastation and encompasses disruptions in infrastructure, loss of life, and a cessation of socio-economic activities. A pronounced and swift consequence of earthquakes is the potential for triggering tsunamis, resulting in the rapid inundation of coastal localities.

Within this context, the focus narrows to Bitung, a city marked by accelerated development. The inauguration of a toll road and the city's distinction as a special economic zone epitomize the government's steadfast commitment to comprehensive growth. The port facilities, fostering both domestic and international connectivity, position Bitung as a pivotal trading conduit within the Asia-Pacific realm.

However, this strategic economic prosperity coexists with an underlying apprehension, wrought by the region's geological adjacency to the converging Pacific Plate, Eurasian Plate, and Philippine Sea Plate. The Mayu-Talaud zone within the Maluku Sea exhibits heightened seismicity, notably characterized by vertical fault displacements.

Considering these coexisting realities, this study assumes a critical role, delving into the potential disaster risk stemming from seismic activity – particularly the cataclysmic potential of tsunamis – within Bitung's coastal expanse. With the aim of fortifying prevention and mitigation measures, the research embarks on the meticulous creation of a comprehensive tsunami modeling scenario. It builds upon precedent studies, highlighting the pivotal influence of the coefficient of roughness (Manning coefficient) on tsunami wave propagation and emphasizing the interplay between coastal topography and land cover. To achieve this, the research employs the COMCOT (Cornell Multi-grid Coupled Tsunami Model) software, renowned for its precision and expedited computational capabilities, facilitating an exhaustive assessment of tsunami inundation.

Against the backdrop of these scientific considerations, the research strives to augment the comprehension of the immediate ramifications of tsunamis in Bitung. Its multifaceted objectives span the acquisition of data concerning tsunami height and arrival times, the cartographic delineation of tsunami hazard zones along Bitung's coastline, and the formulation of temporary and definitive evacuation routes. Beyond these tangible contributions, the research endeavors to evolve into a reference point for disaster vulnerability mapping, especially regarding tsunamis, offering profound insights for knowledge enhancement and broader mitigation strategies to benefit society.

RESEARCH METHODOLOGY

This study focuses on the tsunami modeling in the Maluku Sea region, with the defined fault plane coordinates ranging from 0.5920° N to 1.9510° N and 124.9730° E to 125.7400° E, as depicted in Figure 1.

The parameters of the earthquake source for the worst-case scenario in tsunami modeling are outlined in Table 1.

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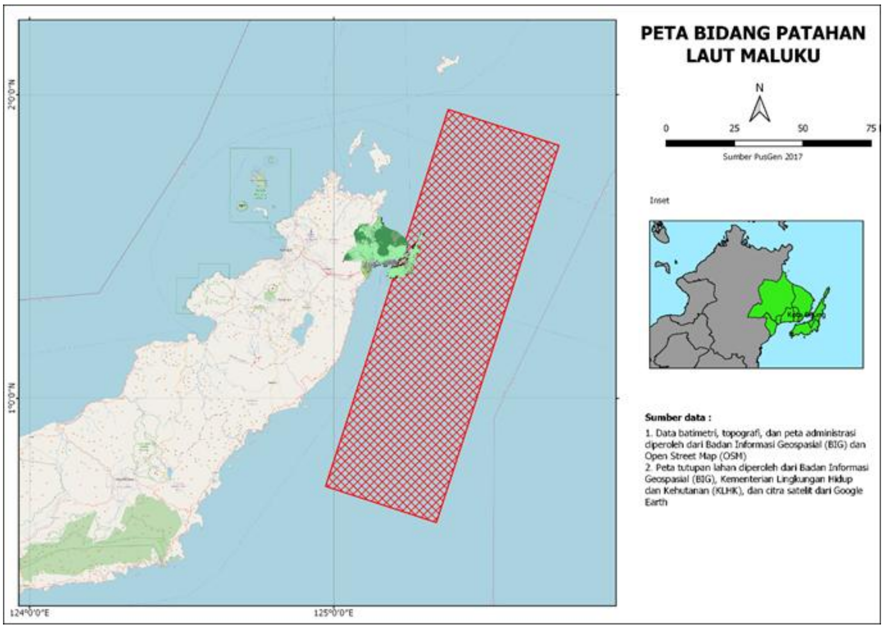

Gambar 1. Peta Lokasi Penelitian.

Table 1. Parameters of the earthquake

No	Parameters	Values
1	Region	Sangihe Subduction
2	Epicenter	1,272°N – 125,356° E
3	Depth	10 km
4	Magnitude	Mw 7,9
5	Length of Fault	145,2 km
6	Width of Fault	42,6 km
7	Slip	6,7
8	Strike	198°
9	Dip	45°
10	Rake Angle	90°

The modeling area is divided into 8 coastal districts of Bitung City, namely Aertembaga, Ranowulu, Girian, Lembeh Selatan, Lembeh Utara, Maesa, Matuari, and Madidir. All these districts have the potential to be impacted by tsunami waves. However, the results presented in this paper will only focus on Maesa and Matuari due to the impact on the community caused by the tsunami, considering that these two districts have the highest population in Bitung.

The data employed in this research consists of historical earthquake epicenter data and parameters of fault planes within the Indonesian region. Historical earthquake epicenter data from the Maluku Sea area were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) and the United States Geological Survey (USGS). Parameters related to fault planes were sourced from the National Earthquake Study Center (PusGen) in 2017.

The process of tsunami modeling begins by determining the parameters of the generating earthquake, which encompass magnitude, focal depth, length of fault plane, width of the fault plane, fault dislocation, strike, dip, slip/rake, and the modeling area. Bathymetric and elevation data, along with land cover data, are also vital components of this process.

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The COMCOT software (Cornell Multi-grid Coupled Tsunami Model) is utilized for conducting tsunami modeling. COMCOT employs a nonlinear equation and explicit leap-frog finite method, incorporating the nested grid technique for numerical computations. This computational approach results in output that closely approximates real-world situations.

The outcomes of the COMCOT modeling encompass tsunami propagation animations, the distribution of maximum wave heights, depth of flow, and maximum wave velocities. Moreover, this model enables the creation of graphs depicting changes in sea level at specific points, referred to as virtual tide gauge stations. The modeling analysis predominantly emphasizes the tsunami inundation distribution at the district level, inclusive of contour lines depicting wave arrival times. These modeling results contribute to the determination of recommendations for temporary and final evacuation sites.

Land cover data is obtained from the National Geospatial Information Agency (BIG), the Ministry of Environment and Forestry (KLHK), and Google Earth. Land cover maps are utilized as references for field verification.

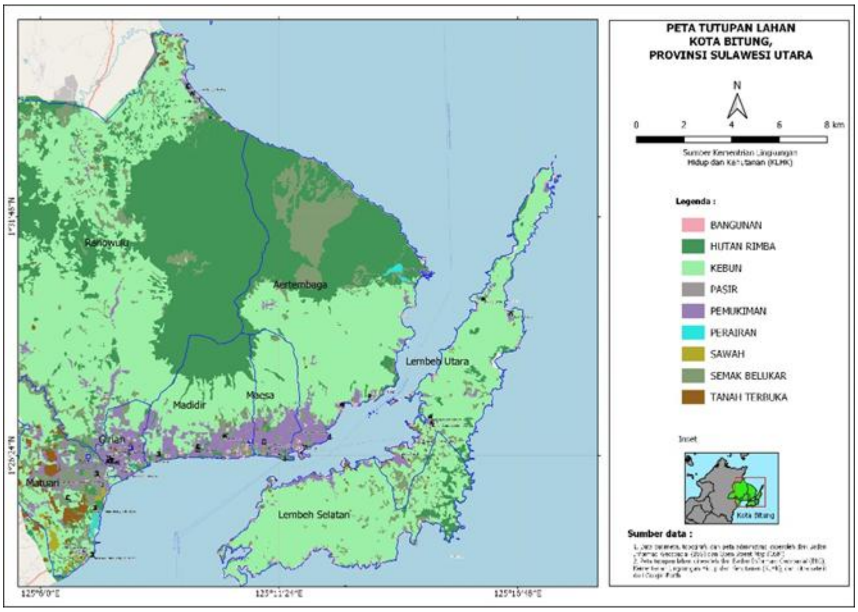

Figure 1. Map of land cover in Bitung

During the field verification survey, several materials and tools are necessary, including tsunami hazard maps, GPS devices, altimeters, stopwatches, cameras, drones, paper forms/checklists, and writing tools.

The research procedure involves a literature review, and the collection of topographic, bathymetric, earthquake parameter, and earthquake source mechanism data. Subsequently, modeling is executed using COMCOT to derive data on wave arrival times, wave heights, and inundation levels. The analysis of tsunami hazard is conducted based on the modeling outcomes, and a tsunami hazard map is produced. The field verification phase entails survey and data validation. The final tsunami hazard map and evacuation route map are compiled after the verification process.

RESULTS AND DISCUSSIONS

Based on the simulation results shown in Figure 3, Maesa District has the potential for tsunami inundation along its coastal area, with estimated heights ranging from 0.5 to 7 meters above normal sea level. The tsunami waves are predicted to cause inundation reaching distances between 400 meters and 1.2 km from the shoreline towards inland. The field survey results that have been verified indicate recommendations for establishing 4 Final Evacuation Points (FEPs) and 7 Temporary Evacuation Points (TEPs) in the Maesa District area.

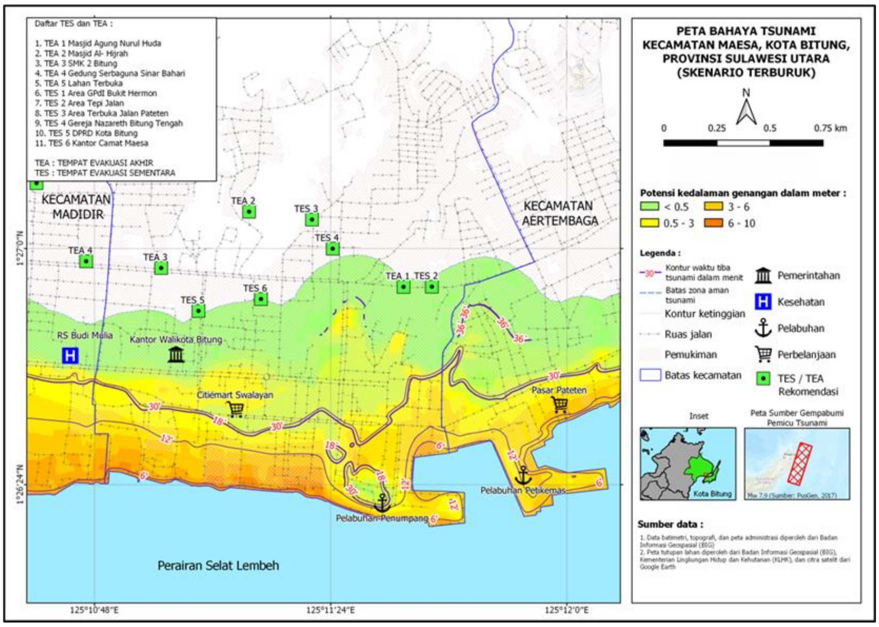

Figure 2. Tsunami Hazard Map of Maesa District

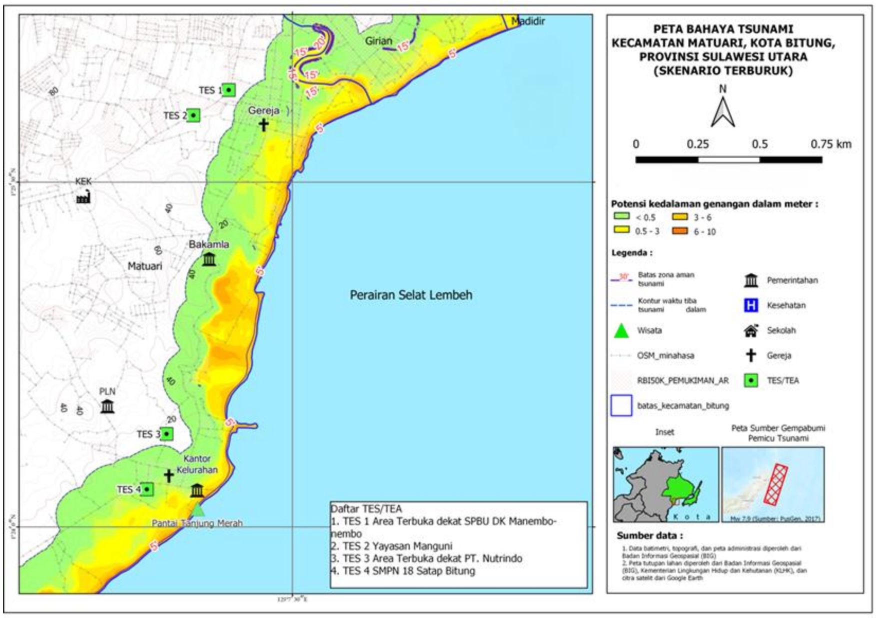

Figure 3. Tsunami Hazard Map of Matuari District

Based on the simulation results depicted in Figure 4, Matuari District has the potential for tsunami inundation along its coastal area, with estimated heights ranging from 0.5 to 8 meters above normal sea level. The tsunami waves are estimated to cause inundation reaching distances of up to 90 to 800 meters from the shoreline towards inland.

The field survey results that have been verified indicate recommendations for establishing 4 Temporary Evacuation Points (TEPs) in the Matuari District area.

Once the modeling process was completed, recommendations for evacuation points (Temporary and Final Evacuation Points) were determined. These points are characterized as open

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and relatively spacious gathering areas. The determination was based on the modeling results, specifically identifying open and expansive areas that lay beyond the inundation buffer/lowest zone (indicated in green). In addition to these modeling-based selections, evacuation point locations were also directly identified in the field using the method of path traversing.

Path traversing involves calculating the time it takes to travel from the coastline to the evacuation point on foot. The walking speed assumed for path traversing is at a leisurely pace and not hurried. This approach aims to ensure that the path traversing time is relatively inclusive for individuals who might be sick or elderly. The following table provides a compilation of recommendations for both Temporary and Final Evacuation Points:

Table *2*. List of Temporary and Final Evacuation Sites in Maesa Subdistrict

No	Locations	Coordinates		Altitude (masl)	Position	Total time	Tsunami's ETA
		Latitudes	Longitudes				
1	Area GPdI Bukit Hermon (TEP)	1.442339206 1.447665654	125.1946448 125.1954373	6.0 18.0	Start Finish	12'	6'
2	Area Tepi Jalan (TEP)	1.439045873 1.44838348	125.1925952 125.1942869	- -	Start Finish	20'	6'
3	Masjid Agung Nurul Huda (FEP)	No Path Transversing					6'
4	Area Terbuka Jalan Pateten (TEP)						6'
5	Gereja Nazareth Bitung Tengah (TEP)						6'
6	DPRD Kota Bitung (TEP)	1.440225625 1.447357703	125.1833266 125.1844043	- -	Start Finish	18'	6'
7	Kantor Camat Maesa (TEP)	No Path Transversing					6'
8	Masjid Al- Hijrah (FEP)						6'
9	SMK 2 Bitung (FEP)						6'
10	Gedung Serbaguna Sinar Bahari (FEP)						6'
11	Lahan Terbuka (FEP)						6'

Table *3*. List of Temporary and Final Evacuation Sites in Matuari Subdistrict

No	Locations	Coordinates		Altitude (masl)	Positions	Total time	Tsunami's ETA
		Latitudes	Longitudes				
1	Lahan Kosong (TEP 1)	1.428300 1.429730	125.125884 125.119817	0 19	Start Finish	09'	5'
2	Yayasan Manguni (TEP 2)	No Path Transversing					5'
3	Lahan Kosong (TEP 3)						5'
4	SDN INPRES 7/83 (TEP 1)	1.402656 1.405258	125.119610 125.112117	0 15	Start Finish	12'	5'

CONCLUSION

In conclusion, the coastal city of Bitung, with its urban center predominantly situated near the coastline, is exposed to potential tsunamis with a worst-case scenario corresponding to an M 7.9 earthquake in the Maluku Sea. The estimated fastest arrival time of the tsunami along the coastal area is approximately 3 minutes, with the estimated tsunami height reaching around 20 meters above mean sea level (masl). The findings from the field verification of evacuation paths indicate that the evacuation times in Bitung are generally longer than the estimated fastest tsunami arrival time on the coast. Based on

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the results obtained from the tsunami hazard modeling, field verification surveys, and evacuation path assessments in the coastal area of Bitung, several recommendations can be put forth:

1. Regular awareness campaigns should be conducted to continually enhance and maintain the public's awareness about the significant tsunami potential in Bitung.
2. It is recommended to construct Vertical Evacuation Facilities (VEFs) in potential tsunami inundation zones, as the simulation results of evacuation paths indicate longer evacuation times than the estimated fastest tsunami arrival time on the coast. The implementation of VEFs would ideally provide the local population with additional time for independent evacuation before the tsunami waves arrive.
3. The establishment of a mangrove tree planting program is essential to mitigate the height of tsunami waves, delay the arrival of tsunami waves, and diminish the extent of their inland reach.

By following these recommendations, the city of Bitung can enhance its preparedness and resilience in facing potential tsunami hazards, ultimately safeguarding its population and urban infrastructure.

REFERENCES

[1] M. Asrurifak, M. Irsyam, B. Budiono, W. Triyoso, and Hendriyawan, "Development of Spectral Hazard Map for Indonesia with a Return Period of 2500 Years Using Probabilistic Method," *Journal Civil Engineering Dimension*, vol. 12, no. 1, 2010.

[2] BMKG, "Pedoman pelayanan peringatan dini tsunami," Jakarta: BMKG, 2012.

[3] BMKG, "Informasi gempabumi berpotensi tsunami," BMKG. [Online]. Available: http://inatews.bmkg.go.id/?act=tsuevents. [Accessed: Nov. 25, 2022].

[4] E. Bryant, Tsunami: The Underrated Hazard (3rd edition). Chicester: Praxis, 2014.

[5] Dewan Nasional Kawasan Ekonomi Khusus Republik Indonesia, kek.go.id. [Accessed: Nov. 24, 2022].

[6] C. Goto, Y. Ogawa, N. Shuto, and F. Imamura, "Numerical Method of Tsunami Simulation with The Leap-Frog Scheme (IUGG/IOC Time Project)," IOC Manual, UNESCO, No. 35, 1997.

[7] A. R. Gusman, A. D. Nugraha, and H. A. Shiddiqia, "Hypocenter relocations and Tsunami simulation for the 15 November 2014 Northern Molucca Sea earthquake in Indonesia," Jurnal Geofisika, vol. 15, no. 1, pp. 1-9, 2017.

[8] Hamilton, "Tectonics of Indonesia Region," Washington: U.S Govt Print Off, 1979.

[9] S. Harmsen, "USGS Software for Probabilistic Seismic Hazard Analysis (PSHA) Draft Document," USGS, 2007.

[10] F. Imamura, Tsunami Modelling Manual. Disaster Control Research Center, Tohoku University, Senday, Japan, 2006.

[11] A. Joseph, Tsunamis Detection, Monitoring, and Early Warning Technologies. USA: Academic Press, 2011.

[12] E. K. Kertapati, Aktivitas Gempabumi di Indonesia. Bandung: Pusat Suvei Geologi, 2006.

[13] D. Mardiatno, "A proposal for tsunami mitigation by using coastal vegetation: some findings from the southern coastal area of Central Java, Indonesia," Journal of Natural Resources and Development, vol. 3, 2013.

[14] R. McCaffrey, E. A. Silver, and R. W. Raitt, "Crustal structure of the Molluca Sea collision zone, Indonesia," in The tectonic and geologic evolution of Southeast Asian seas and islands, 1980, pp. 161-177.

[15] H. Mutmainah, D. W. Christiana, G. Kusumah, "Tsunami Mentawai 25 Oktober 2010 Dan Dampaknya Kini

Terhadap Pantai Barat Mentawai," Jurnal Kelautan, vol. 9, no. 2.
[16] National Centers for Environmental Information (NOAA), "Global Historical Tsunami Event and Runups," [Online]. Available: https://www.ngdc.noaa.gov/hazard/tsu.shtml. [Accessed: Nov. 1, 2022].
[17] Pusat Studi Gempa Nasional (PusGen), "Peta sumber dan bahaya gempa Indonesia tahun 2017," Bandung: Pusat Penelitian dan Pengembangan Perumahan dan Permukiman Badan Penelitian dan Pengembangan Kementrian Pekerjaan Umum dan Perumahan Rakyat, 2017.
[18] H. Satake, "Tsunami and Earthquake," Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, IISEE (International Institute of Seismology and Earthquake Engineering), Tsukuba, 2006.
[19] P. M. Shearer, Introduction to Seismology (2nd edition). Cambridge University Press, New York, 2009.
[20] A. Socquet et al., "Microblock stations and fault coupling in SE Asia triple junction (Sulawesi, Indonesia) from GPS and earthquake slip vector data," Journal of Geophysical Research, vol. 111, 2006.
[21] S. P. D. Sriyanto, et al., "Pemodelan inundasi dan waktu tiba Tsunami di Kota Bitung, Sulawesi Utara berdasarkan skenario gempabumi Laut Maluku," Geomatika, vol. 26, no. 1, pp. 47-54, 2019.
[22] S. P. D. Sriyanto, "Modifikasi Sistem Peringatan Dini Tsunami Sebagai Upaya Pengurangan Dampak Tsunami Di Wilayah Pesisir Kota Bitung, Sulawesi Utara," Tesis. Fakultas Perikanan dan Ilmu Kelautan. Ilmu Perairan. Universitas Samratulangi. Manado, 2021.
[23] H. Tatehata, "Perspectives on Tsunami Hazard Reduction," edited by G. Hebenstreit. Vol.9. Kluwer Academic Publishers, Netherlands, 1997.
[24] USGS, "Earthquake catalog," US Geological Survey, 2022. [Online]. Available: https://earthquake.usgs.gov. [Accessed: Nov. 2, 2022].
[25] S. Widada, I. M. Darda, and A. Satriadi, "Identifikasi Wilayah Terdampak Tsunami berdasarkan Peta Ancaman Tsunami di Kabupaten Lumajang, Jawa Timur," Buletin Oseanografi Marina, 2022.
[26] X. Wang and W. Power, "COMCOT: a Tsunami Generation Propagation and Run-up Model," GNS Science Report, 2011/43, pp. 203-222.
[27] C. Widiwijayanti, C. Tiberi, C. Deplus, M. Diament, V. Mikhailov, and R. Louat, "Geodynamic evolution of the northern Molucca Sea area (eastern Indonesia) constrained by 3-D gravity field inversion," Tectonophysics.
[28] S. Yudhicara, R. Robiana, and I. C. Priambodo, "The influence of coastal conditions on tsunami inundation of Bima Bay, West Nusa Tenggara," Bulletin of the Marine Geology, vol. 29, no. 1, pp. 29-42, 2014.

http://ejournal.unsrat.ac.id/index.php/platax 10.35800/jip.v10i2.60969