Propagation and Characteristic of Tsunami Wave in Lembeh Strait, North Sulawesi, Due to the Earthquake in the Molucca Sea

by Gerald Tamuntuan 18

PAPER • OPEN ACCESS

Propagation and Characteristic of Tsunami Wave in Lembeh Strait, North Sulawesi, Due to the Earthquake in the Molucca Sea

To cite this article: G H Tamuntuan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1115** 012090

Propagation and Characteristic of Tsunami Wave in Lembeh Strait, North Sulawesi, Due to the Earthquake in the Molucca Sea

G H Tamuntuan*[1], B B Mambu[1], G Pasau[1], A T Mandagi[2], D P Pandara[1], and Ferdy[1]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences, Sam Ratulangi University, Jl. Kampus Unsrat, Manado – Indonesia
[2]Department of Civil Engineering, Faculty of Engineering, Sam Ratulangi University, Indonesia

*Corresponding author: gtamuntuan@gmail.com

Abstract. Modeling the propagation of a tsunami triggered by an earthquake with a hypocenter in the double subduction of the Maluku Sea using the TUNAMI-N2 program has been carried out. The objectives of this research are to find out the model of tsunami propagation towards Bitung City, how the effect of Lembeh Island on tsunami waves, and the characteristics of the waves that occur in the Lembeh Strait. The modeling uses two earthquake scenarios with different magnitudes which are 7.5 *Mw* (scenario A) and 8.0 *Mw* (scenario B). The results show that the wave propagation model towards Bitung City in the two scenarios is relatively the same, but has a different arrival time and wave height depending on the earthquake energy of the tsunami generator. The arrival time of the tsunami waves in Lembeh strait area, the strait between Bitung City and Lembeh Island, was relatively slower indicating that Lembeh Island could serve as a tsunami barrier for Bitung City. The characteristics of the tsunami waves in Lembeh Strait are also different from the areas outside the strait. This is due to the effects of diffraction and wave superposition that occur in the strait area. The characteristics of the waves that occur inside and outside the Lembeh Strait are important things to know in order to determine a more optimal tsunami disaster mitigation strategy in Bitung City.

1. Introduction

North Sulawesi is one of the disaster-prone areas in Indonesia. The Molucca Sea, which is located in the eastern part of this region, is a tectonically complex place and has high earthquake intensity [1]. Seismic activity in the Molucca Sea occurs due to the double subduction of the Molucca Sea plate, where to the west of this plate is sub ducted under the Sangihe plate and to the east under the Halmahera plate [2]. Until 2000, this region was the host of 12.6% of destructive earthquakes and about 30% of tsunami cases that have occurred in Indonesia [1]. This makes the area around the Molucca Sea as a zone that is very potential to be affected by the tsunami disaster, so that various mitigation efforts need to be done.

The city of Bitung, the largest port city in North Sulawesi, is located on the east coast of the northern peninsula of Sulawesi Island, facing the Molucca Sea. The uniqueness of this city is the presence of Lembeh Island between the city and the Molucca Sea. The interesting thing is that Bitung City and Lembeh Island are only bordered by the relatively narrow Lembeh Strait. Although the shape, size and distance of the island from the coast in relation to the characteristics of tsunami waves have been studied [3, 4], the study of the effects of the existence of islands which are relatively close to the coast and the characteristics of the interference of tsunami waves that occur in relatively narrow is very rare.

One way of studying the propagation pattern and characteristics of a tsunami wave is through modeling. TUNAMI-N2 is a model and software developed by the Disaster Control Research Center, Tohoku University, Japan [5]. This model has been widely used for the tsunami simulation process in various places in the world [6, 7, 8]. In this study, a tsunami propagation model triggered by an earthquake in the Molucca Sea was carried out using TUNAMI-N2. Further analysis has been carried out on a number of tide gauges or imaginary points in Bitung City to determine the characteristics of the tsunami waves that occur in the open area (facing directly to the Molucca Sea) and along the Lembeh Strait, an area obstructed by Lembeh Island.

2. Material and Methods

Tsunami wave modeling and propagation simulations are carried out using the TUNAMI-N2 software. The data input is based on two earthquake scenarios, each with a magnitude of 7.5 *Mw* and 8.0 *Mw*. The epicenter of the earthquake is assumed to be in the Molucca Sea and opposite the City of Bitung, which is at coordinates 1.239 ° N and 126,213 ° East. The earthquake is assumed to occur at a depth of 10 km and form a fault with a strike equal to 208 °, dip equal to 53 °, slip angle equal to 106 °. The fault parameter data used in the study were calculated based on earthquake magnitude and supported by marine bathymetry data around Sulawesi Island obtained from GEBCO (General Bathymetric Chart of the Ocean) and topographic data of Bitung City from SRTM (Shuttle Radar Topograhy Mission). Subsequent modeling was carried out on four different layers as shown in Figure 1.

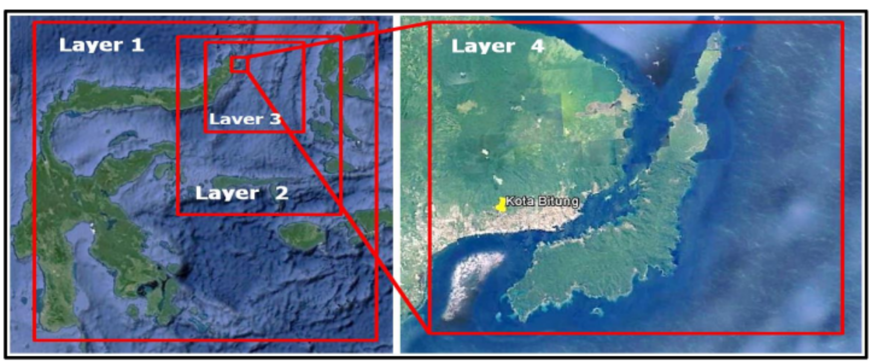

Figure 1. Modeling layers for analysis of tsunami propagation in Bitung City. Layer four shows Bitung City with Lembeh Island in front.

To obtain the height and arrival time of the tsunami waves in the Bitung area, ten tsunami wave observation points or tide gauges have been added as illustrated in Figure 2. These ten points cover several villages on the coast of Bitung City which are inhabited by many residents, namely Girian Bawah (TG1), Wangurer Barat (TG2), Wangurer Timur (TG2), Paceda (TG3), Madidir Unet (TG3), Madidir Ure (TG4)), Madidir Weru (TG5), Pakadoodan (TG6), Bitung Barat One (TG6), Kadoodan (TG6), Bitung Timur I (TG7), Bitung Timur (TG8), Winenet Dua (TG9), Aertembaga I (TG10) and

IOP Conf. Series: Materials Science and Engineering 1115 (2021) 012090 doi:10.1088/1757-899X/1115/1/012090

Aertembaga II (TG10). TG1 to TG6 are outside the Lembeh Strait, while TG7 to TG10 are inside the strait.

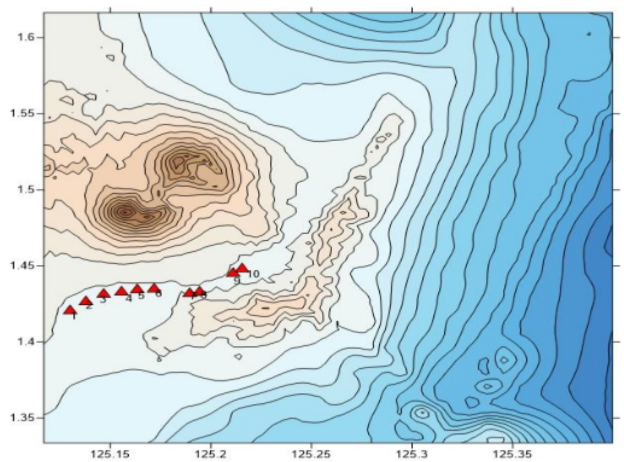

Figure 2. Tide Gauge at 10 points in Bitung City.

3. Results and Discussion

The simulation process begins by calculating the fault parameters using the empirical equation of Wells and Coppersmith (1994) [9]. Although there are quite a number of regression equations between magnitude and fault parameters [10], the Wells and Coppersmith equations are more commonly used in previous studies [11]. The fault parameters based on the two earthquake magnitude scenarios developed in this research are presented in Table 1. The simulation results with TUNAMI-N2 show that the tsunami propagation pattern is relatively the same. The difference is that the greater the magnitude of the earthquake that triggers the tsunami, the greater the speed of propagation of the waves. Figure 3 illustrates the wave propagation pattern based on Scenario B at four layers at different times. In the example presented, it can be seen that until the 17th minute (1,020 s) the part of Bitung City which is in the inner area of the Lembeh Strait has not been relatively affected by the tsunami waves, while the part of the city which is outside the strait has been attacked by the tsunami tidal waves. This indicates that the existence of Lembeh Island is very effective in reducing the arrival time of tidal waves, especially in the city of Bitung which is in the Lembeh Strait.

Table 1. Earthquake scenario and fault parameters

Scenario / Magnitude (*Mw*)	Fault Parameter*		
	Length (km)	**Width (km)**	**Slip (m)**
A / 7.5	73.28	29.17	7.35
B / 8.0	151.36	46.77	14.50

*** calculated based on the Wells and Coppersmith equation (1994)**

IOP Conf. Series: Materials Science and Engineering 1115 (2021) 012090 doi:10.1088/1757-899X/1115/1/012090

In Scenario A, the maximum recorded tsunami wave height (H_{max}) detected on the entire tide gauge varies between 0.78 m (tide gauge 10) to 3.56 m (tide gauge 6), while the wave arrival time varies between 900 s on tide gauge 1 and the longest. which is 1,810 s on the tide gauge 9. In TG1 - TG6, the peak of the first wave arrived at the 1,200 to 1,290 second, while in the TG7 - TG10 it arrived at the 1,460 to 2,050 second.

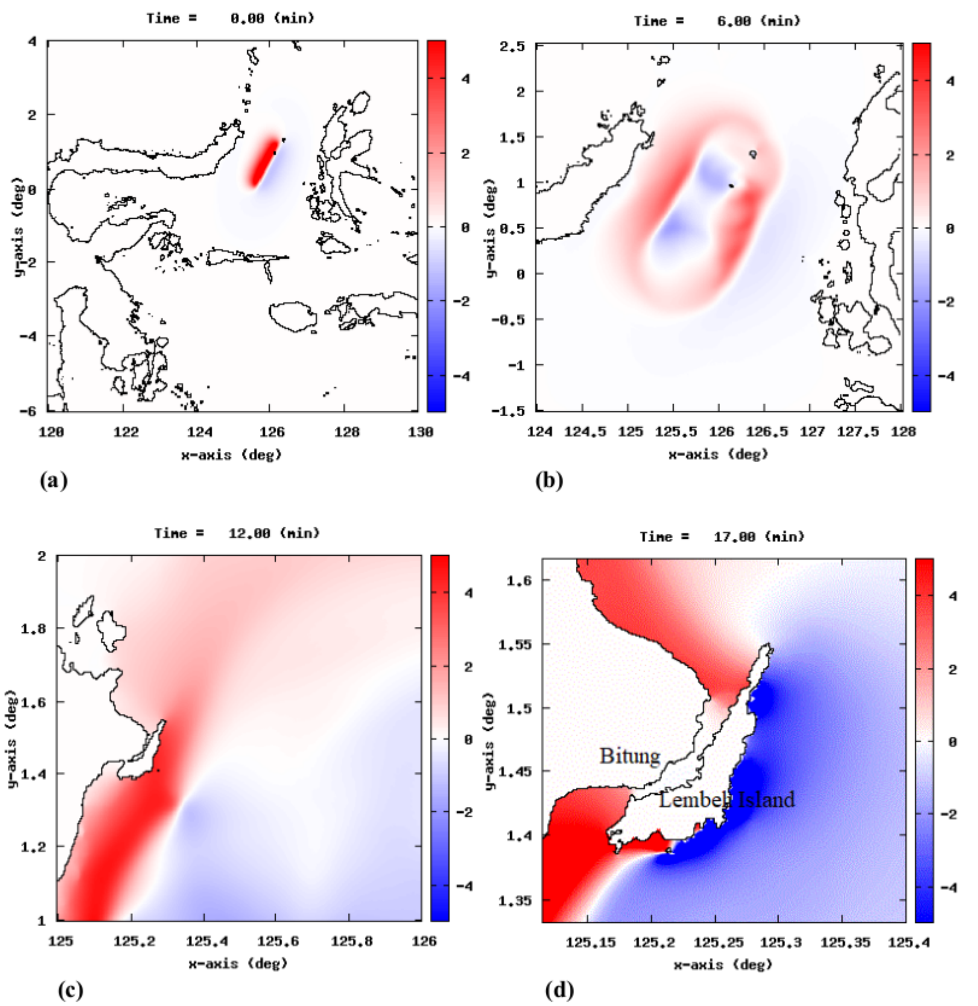

Figure 3. (a) Tsunami onset at 0 minutes, (b) Tsunami propagation at 6 minutes, (c) Tsunami propagation at 12th minute and (d) Tsunami reaches Bitung City at 17th minute

In Scenario B, the H_{max} varies between 3.66m (on tide gauge 9) to 14.98m (on tide gauge 6). The arrival time of the wave on tide gauge 1 occurs at 710 seconds and on tide gauge 10 at 1.590 seconds. The variation of the arrival time of the first wave peaks at TG1 - TG6 is 1180 s to 1,260 s. The arrival time of the first wave peaks at TG7 and TG8 is around 1,470 s, while in TG9 and TG10 it is around 1,920 s. The difference in earthquake energy in the two scenarios causes H_{max} in Scenario B to be 4.2

IOP Conf. Series: Materials Science and Engineering 1115 (2021) 012090 doi:10.1088/1757-899X/1115/1/012090

times higher than in Scenario A. In general, both scenarios show three tsunami waves occurring over a period of 80 minutes. However, in contrast to scenario A, the waves recorded in TG1 - TG8 in scenario B are relatively in the same phase, except that in TG9 and TG10 they have a phase difference of about 180 ° to the waves in TG1 - TG8.

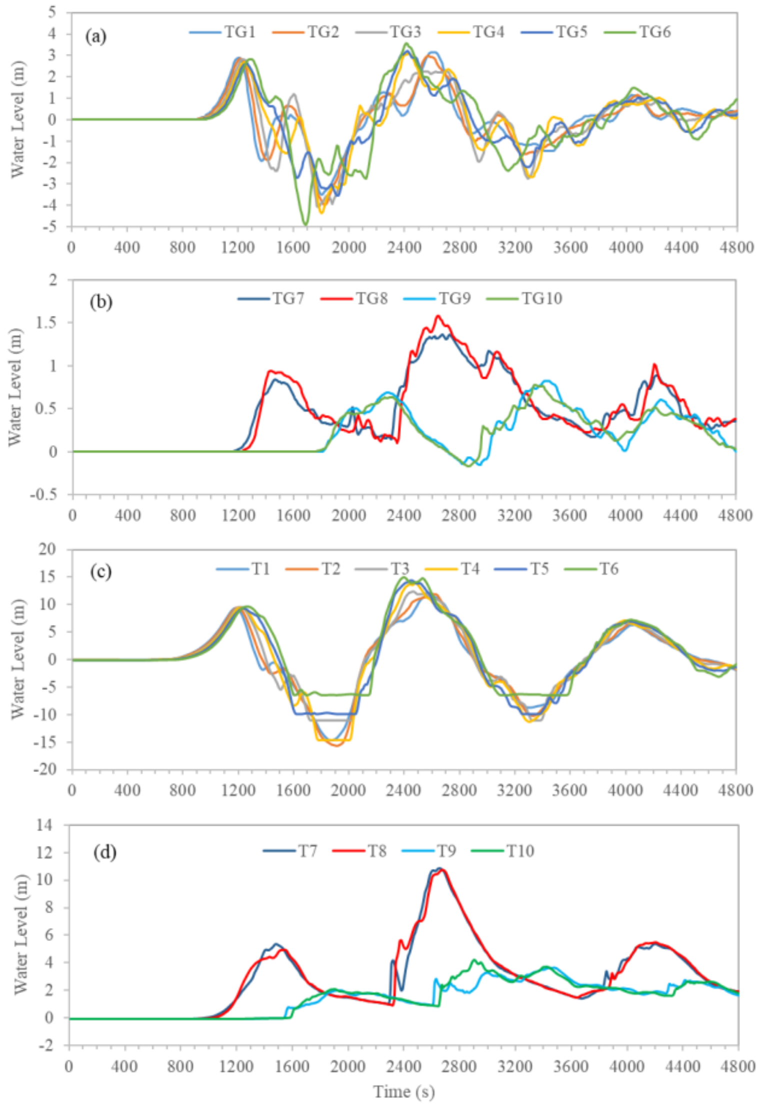

Figure 4. Water level fluctuations recorded in the tide gauge (a) TG1 - TG6 in Scenario A, (b) TG7 - TG10 in Scenario A, (c) TG1 - TG6 in Scenario B, and (d) TG7 - TG10 in Scenario B.

Waves passing through the island will experience diffraction. The case in this study shows that the direction of the tsunami wave propagation is relatively perpendicular to Lembeh Island so that it experiences diffraction on both sides of the island. Figure 3d shows the diffraction wave moving in from the northeast to the southwest and vice versa. The water level fluctuation pattern on an imaginary 10 tide gauge is shown in Figure 4. The water level fluctuation due to the tsunami waves at the 6 tide gauge outside the Lembeh Strait, namely TG1 - TG6, shows the cycle of the tide and low tide levels which oscillate against the still water level. In Scenario A, the arrival times of the tsunami waves peaks at the tide gauges are relatively different (Figure 4a). The stronger the earthquake that triggered the tsunami, the more uniform the water level fluctuation pattern due to the tsunami on the tide gauge 1 - 6 and the smaller the difference in the arrival time of the wave crests (Figure 4c).

Figures 4b and 4d are the patterns of water level fluctuation due to the tsunami waves on the tide gauge 7 - 10 which is located relative to the Lembeh Strait. Unlike the 1 - 6 tide gauge, the sea level on the 7 - 10 tide gauge fluctuates above the SWL. This occurs because the masses of water entering from both sides of the strait are relatively confined within a certain period of time and experience interference. The wave crests are caused by constructive interference, while the troughs are caused by destructive interference. The water level above the SWL over a longer period of time indicates that the part of Bitung City which is in the middle of the Lembeh Strait will experience longer inundation.

The existence of offshore islands that are relatively far from the coast in several studies can amplify the height of the tsunami waves due to the interference effect that occurs behind the island [12]. Due to the Lembeh Strait, it is relatively narrow (the distance between the coast of Bitung City is relatively close to Lembeh Island) so that the tsunami waves that form in the strait have unique characteristics. The characteristics of the tsunami waves that occur in this section, in particular for tide gauges 9 and 10, are different compared to other tide gauges. On tide gauges 9 and 10, the tsunami wavelength is relatively smaller and has a tsunami wave H_{max} of only about 20 - 40% of the H_{max} recorded on other tide gauges. The uniqueness of the characteristics of the tsunami waves in the central part of the Lembeh Strait is closely related to the energy reduction and diffraction effects of the tsunami waves due to the existence of Lembeh Island.

4. Conclusions

TUNAMI-N2 modeling based on earthquake data and position as discussed in this study indicate that the arrival time of tsunami waves in Bitung City is around 900 s for a 7.5 *Mw* earthquake and 710 s for an 8.0 *Mw* earthquake. In the worst case scenario, the height of the tsunami waves in Bitung City, especially on the coast outside the Lembeh Strait can reach 14.98 m. There are differences in the characteristics of the tsunami waves on the coast outside and inside the Lembeh Strait. The arrival time of the tsunami waves on the coast that is in the Lembeh Strait takes longer than the coast of Bitung City which is outside the Lembeh Strait, while the maximum wave height that occurs is only around 20 - 40%. This indicates that Lembeh Island can slow down the arrival time and reduce the tsunami wave height. However, the fluctuation of the water level in the interior of the strait is relatively above the SWL so that the impact on standing water in the zone has a much longer duration. The difference in characteristics between waves that occur inside and outside the Lembeh Strait is an important thing that needs to be studied further to determine a more optimal tsunami disaster mitigation strategy in Bitung City.

Acknowledgments

This research was fully funded by Ministry of Research and Technology through Penelitian Strategis Nasional Institusi Research Grant (2018) to GP & GT.

References

[1] Hamzah L, Puspito N T and Imamura F 2000 Tsunami catalog and zones in Indonesia *Journal of Natural Disaster Science* **22** (1) 25-43

[2] Widiwijayanti C, Tiberi C, Deplus C, Diament M, Mikhailov V and Louat R 2004 Geodynamic evolution of the northern Molucca Sea area (Eastern Indonesia) constrained by 3-D gravity field inversion *Tectonophysics* **386** (3-4) 203-222

[3] Fu D, Liu B, Wang G, Zheng J and Zeng Y 2020 An analytical study of long wave propagation around two circular islands *Ocean Engineering* **211** 107617

[4] Stefanakis T S, Contal E, Vayatis N, Dias F and Synolakis C E 2014 Can small islands protect nearby coasts from tsunamis? An active experimental design approach *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* **470** (2172) 20140575

[5] Imamura F, Yalciner A C and Ozyurt G 2006 *Tsunami Modelling Manual (TUNAMI model)* Japan: Tohoku University

[6] Pasau G, Tamuntuan G and Tanauma A 2019 Numerical modelling for tsunami wave propagation (case study: Manado bays) *IOP Conference Series: Materials Science and Engineering* **567** (1) 012005

[7] Ha D M, Tkalich P, Soon C E and Megawati K 2009 Tsunami propagation scenarios in the South China Sea *Journal of Asian Earth Sciences* **36** (1) 67-73

[8] Tinti S, Armigliato A, Manucci A, Pagnoni G, Zaniboni F, Yalciner A C and Altinok Y 2006 The generating mechanisms of the August 17, 1999 Izmit bay (Turkey) tsunami: regional (tectonic) and local (mass instabilities) causes *Marine Geology* **225** (1-4) 311-330

[9] Wells D L and Coppersmith K J 1994 New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement *Bulletin of the seismological Society of America* **84** (4) 974-1002

[10] Stirling M, Goded T, Berryman K and Litchfield N 2013 Seismic hazard of the Canterbury region, New Zealand: New earthquake source model and methodol- ogy *Bull. New Zeal. Natl. Soc. Earthquake Eng.* **41** 51–65

[11] Asim K M, Javed F, Hainsl S and Iqbal T 2019 Fault Parameters-Based Earthquake Magnitude Estimation Using Artificial Neural Networks *Seismological Research Letters* **90** (4) 1544-1551

[12] Kornei K 2017 Offshore islands might not shield coastlines from tsunami waves *Eos* **98** 1-11

Propagation and Characteristic of Tsunami Wave in Lembeh Strait, North Sulawesi, Due to the Earthquake in the Molucca Sea

ORIGINALITY REPORT

18%	15%	17%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	repo-dosen.ulm.ac.id Internet Source	5%
2	repository.up.ac.za Internet Source	2%
3	www.sciencegate.app Internet Source	1%
4	repository.untar.ac.id Internet Source	1%
5	fmipa.unsrat.ac.id Internet Source	1%
6	I Purwanto, H Y Fauziah, M Subali, M Andriansyah, D Saptono, A I Sukowati, H Hanifah. "Android-Based Intangible Cultural Heritage Expert System In Banten Province Using Backward Chaining Method", IOP Conference Series: Materials Science and Engineering, 2021 Publication	1%

7	Gazali Rachman, Bagus Jaya Santosa, Andri Dian Nugraha, Supriyanto Rohadi et al. "Seismic Structure Beneath the Molucca Sea Collision Zone from Travel Time Tomography Based on Local and Regional BMKG Networks", Applied Sciences, 2022 Publication	1 %
8	Submitted to The University of Manchester Student Paper	1 %
9	G Pasau, G H Tamuntuan, A Tanauma. "Numerical modelling for tsunami wave propagation (case study: Manado bays)", IOP Conference Series: Materials Science and Engineering, 2019 Publication	1 %
10	"Tsunami Science Four Years after the 2004 Indian Ocean Tsunami", Springer Science and Business Media LLC, 2009 Publication	1 %
11	Guangsheng Zhao, Xiaojing Niu. "Local amplification of tsunami waves along the west coast of Negros Island and Panay Island", Applied Ocean Research, 2022 Publication	<1 %
12	E D P Putra, H S Wahyuni, T Hertiana, Nasri, M Muhammad, D Satria. "Antibacterial Activity of Silver Nanoparticles Poguntano Herb	<1 %

Extract (Picria fel-terrae Lour) against Staphylococcus epidermidis", IOP Conference Series: Earth and Environmental Science, 2023
Publication

13	Jinghua Wang, Philip L.-F. Liu. "Interactions between Dongsha Atoll and Mw 9 Tsunamis and their Impacts in South China Sea Region", Journal of Earthquake and Tsunami, 2022 Publication	<1%
14	etheses.whiterose.ac.uk Internet Source	<1%
15	pertambangan.fst.uinjkt.ac.id Internet Source	<1%
16	www.preventionweb.net Internet Source	<1%
17	Zhisong Li, Chao An, Hua Liu. "Evaluation of different earthquake scaling relations on the generation of tsunamis and hazard assessment", Ocean Engineering, 2020 Publication	<1%
18	media.neliti.com Internet Source	<1%
19	N. H. Mardi, M. A. Malek, M. S. Liew. "Tsunami simulation due to seaquake at Manila Trench and Sulu Trench", Natural Hazards, 2016 Publication	<1%

20	W Kongko, S Karima, Daryono. "The Tsunami Model of Mount Anak Krakatau Landslide in 2018 and Its Future Potential Hazard to the Coastal Infrastructures in Sunda Strait", Journal of Physics: Conference Series, 2020 Publication	<1 %
21	"Global Tsunami Science: Past and Future, Volume I", Springer Nature, 2017 Publication	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		