doi: 10.37905/jgeosrev.v6i1.22561 ejurnal.ung.ac.id/index.php/jgeosrev

Vol. 6, No. 1, January 2024: 29-36

Jambura Geoscience Review

p-ISSN 2623-0682 | e-ISSN 2656-0380

Department of Earth Science and Technology, Universitas Negeri Gorontalo

Tsunami Modeling Study in Geological Disaster Mitigation in the Kwandang Region

Tirsya Aygina Jaenet Mooduto[1], Fadhil Abdillah Ahmad[1], Mohamad Ashar Fitrayadi Ramdan S. Kodung[1], Ni Luh Ananda Pusvita Sari[1], Taufik Hidayansya[1], Aang Panji Permana[1*]

[1] *Geology Engineering Department, Gorontalo State University, Moutong, 96554, Gorontalo, Indonesia*

ARTICLE INFO

Article history:
Received: 25 October 2023
Accepted: 28 January 2024
Published: 30 January 2024

Keywords:
Geological Disaster Mitigation; Kwandang; Tsunami Modeling;

Corresponding author:
Aang Panji Permana
Email: aang@ung.ac.id

ABSTRACT

The northern coast of the northern arm of Sulawesi is the meeting place of 3 plates that collided with each other during the Neogene period. This condition makes the northern part of Gorontalo, especially Kwandang sub-district, very prone to earthquakes with magnitudes above 6 on the Richter scale (SR), which is one of the triggers for tsunamis. In the period from 1990 - 2008, there were 4 major earthquakes recorded in Gorontalo, namely 1990 (7.3 SR), 1991 (7.1 SR), 1997 (7.0 SR) and 2008 (7.7 SR). Therefore, further research is needed on the return period of the earthquake and the tsunami model that occurs and the sign of tsunami occurrence in the past. This research aims to determine the return period of the earthquake that caused the tsunami and the tsunami model as well as the sedimentology analysis of paleotsunami deposits. The calculation of the earthquake return period uses the Guttenberg-Richter method. Modeling calculations were carried out using the COMCOT numerical model. This model performs calculations by solving shallow water equations in the form of both linear and non-linear equations. Paleotsunami deposits were analyzed using the sedimentology method. The results of the calculation at a magnitude of 6.0 SR show that within 100 years, the study area has a chance of a potentially destructive earthquake of 1.14024978. The results of modeling the tsunami-prone zone, obtained an area of 165.598389 ha. And obtained paleotsunami deposits containing foraminifera with a sediment thickness of 14 cm.

How to cite: Mooduto, T, A, J., Ahmad, F, A., Kodung, M, A, F, R, S., Sari, N, L, A, P., Hidayansya., & Permana, A, P. (2024). Tsunami Modeling Study in Geological Disaster Mitigation in the Kwandang Region. *Jambura Geoscience Review, 6(1)*, 29-36. https://doi: 10.37905/jgeosrev.v6i1.22561

1. INTRODUCTION

An earthquake is a tremor (seismic wave) that will spread in all directions within the earth as a result of faults/faults, plate collisions, and volcanic activity (Hidayah, 2022). Earthquakes are among the deadliest natural disasters in the world. Many lives have been lost as a result of this natural disaster. Most recently, on February 6, 2023, Turkey was rocked by a devastating earthquake with a magnitude of 7.8. And reportedly the death toll reached 46 thousand people and is expected to continue to grow. It does not stop there, the main earthquake that occurs on the seabed can cause another natural disaster that is no less dangerous, namely a tsunami. Earthquakes greater than magnitude 6.5 and with an earthquake depth of less than 100 km above sea level are characteristics that trigger tsunami disasters (Alfaris, 2020).

Gorontalo itself with a complex tectonic order cannot be separated from the potential danger of earthquakes that trigger tsunamis, especially the northern area of Gorontalo which is the place of the meeting of 3 plates that collided with each other during the Neogene period (Pasau, Tanauma, 2011). Of course, the result of the meeting of the 3 plates will lead to the development of all types of structures at all scales, and impact zones including subduction, faults, and thrust. The North Sulawesi Subsidence Column in the north and the Sangihe Tunjaman Column in the south of Gorontalo are the main sources of earthquakes in Gorontalo. Ironically, the majority of these lanes are on the seabed (Cipta, 2009).

History and geological facts provide knowledge about how natural disasters in the past could destroy human civilization. In earth sciences, the concept of the present is the key to the past is known and this also means that the past is the key to the present/future. What translates to understanding the threat of future disasters is that we must learn from natural disasters that have occurred in the past. According to the Intergovernmental Oceanographic Commission (2019), a paleotsunami is a tsunami that occurred before historical records or there were no written observations. In simple terms, paleotsunami can be interpreted as a tsunami that occurred in the past. Identification of paleotsunami can be done using paleotsunami proxies, namely various criteria used to identify deposits caused by the tsunami process. There are several paleotsunami proxies according to (Goff et al. 2011). Grain sizes range from lumpy (about 750 m3 or larger) to fine clay. Tsunamis will usually carry material of various sizes depending on the available sediment sources. Then the sediment with its general characteristics fines inwards and upwards within the deposit. Deposits generally rise in land height and can extend several kilometers inland and tens or hundreds of meters along the coast. Then the sedimentary units are different/contrast to the other layers due to different waves and there are laminated sub-units.

Based on the catalog of significant earthquakes published by the Meteorology, Climatology, and Geophysics Agency (BMKG), there were at least six damaging earthquakes. An earthquake and tsunami occurred in Gorontalo on November 17, 2008. The earthquake caused damage to buildings (Setiyono, 2018). One of the largest was the earthquake on April 18, 1990, with a magnitude of 7 which claimed 3 lives with 1,140 houses damaged in Gorontalo, Atingola, and Inobonto. This shows that earthquakes occur not only once and have the potential to repeat in the future. In addition, the available seismicity records span less than 100 years, so they are insufficient to describe the existing seismotectonic conditions. In addition, seismic levels could have caused large tsunamis in the past, but geological evidence of tsunami traces of how high and far the inundation was does not exist. Based on the foregoing, knowledge about the re-period of large magnitude earthquakes that trigger tsunamis is not widely known. Therefore, this study was conducted to examine the spatial and temporal patterns of earthquake events in the Sulawesi Sea using historical earthquake data and analyze the impact of tsunamis that have occurred in the past through geophysical modeling and geological surveys.

2. METHOD

Research is carried out online offline at the Geological Engineering Laboratory, Gorontalo State University and at Kwandang District, North Gorontalo Regency, Gorontalo Province.

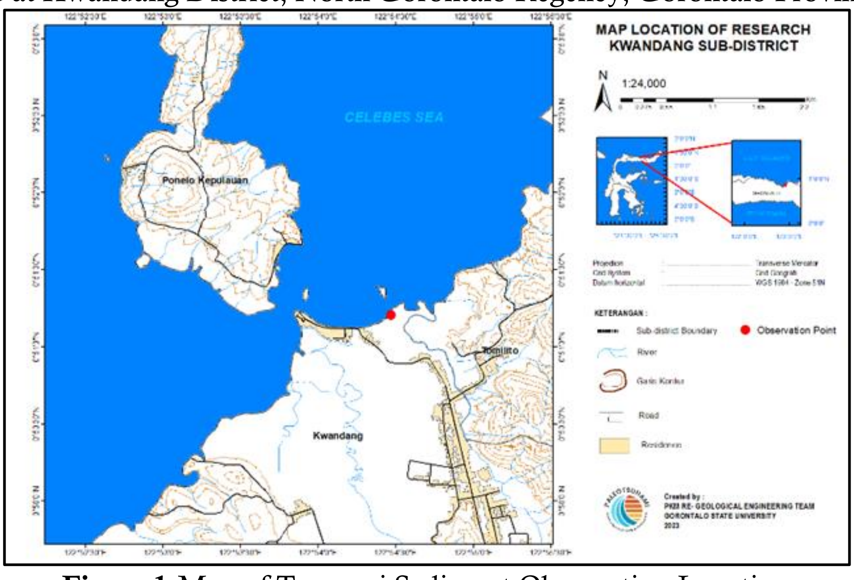

Figure 1. Map of Tsunami Sediment Observation Location

2.1. Research Procedures

2.1.1. Earthquake Probability and Return Period

We collected data from the International Seismological Center database (ISC) as well as correlation with the Meteorology, Climatology and Geophysics Agency database (BMKG) Gorontalo Province with magnitude parameters taken ranging from >6 to >8 and the time of occurrence starts from 1905 to 2023 so that the distribution of earthquakes will be obtained according to the history of destructive earthquakes in Gorontalo. The data obtained will be processed using calculations recurrence interval of earthquakes.

2.1.2. Tsunami Modeling Simulation

After finding data on the earthquake return period, the next step is a tsunami modeling simulation. This simulation is carried out using COMCOT 1.7 software (Wang and Liu, 2006). which uses the shallow method water equations. Measurable achievement indicators at this stage are results Tsunami numerical modeling.

2.1.3. Identify Tsunami Indication Areas

At this stage, we identify the tsunami modeling results using Arcgis and Global Mapper tools. The resulting modeling makes it possible to find out potential areas where tsunamis have occurred.

2.1.4. Observation of potential tsunami areas

At this stage, field observations will be carried out to look for traces Tsunami occurred in Kwandang District. Observations were carried out with carrying out excavations using a hoe and shovel, taking samples field, and identification of sediments in the research area. This stage is proof that Gorontalo Province, especially Kwandang District, has experienced a tsunami so there is a need for better mitigation efforts.

2.2. Data Analysis

2.2.1. Earthquake Return Period

From data obtained from the ISC and BMKG earthquake catalogues, statistical data is created that shows spatial and temporal patterns and notes. Empirical results from tsunami waves. Calculation of the earthquake return period is calculated using the equation:

$$\theta = 1\ N\ (\ M \geq M0) \quad (1)$$

2.2.2. Tsunami Modeling

From the results of tsunami modeling, the deposit area will be determined paleotsunami and potential tsunami areas. Then it will be done observations to prove the hypothesis regarding the tsunami incident in the Province Gorontalo.

2.2.3. How to Interpret and Summarize Research Results

The interpretation and conclusion of the results in this research is if the data Historically, strong earthquakes can produce earthquake return periods strength and tsunami models for paleotsunami sediment analysis.

3. RESULTS AND DISCUSSION

3.1. Probability and Period of Earthquake Recurrence

By using the Maximum Likelihood method and for the analysis of the earthquake period itself, this theory can be used because there is an equation of frequency and magnitude relationship described by Richter and Guttenberg. The analysis carried out is by statistical analysis of seismic level values and rock brittleness levels which are the relationship between frequency and magnitude by Gutenberg-Richter.

Two seismotectonic parameters that are often used in analyzing various things related to earthquakes are the seismicity index a which shows the intensity of earthquake events in a particular area and the b value which shows the susceptibility value of rocks. In the Guttenberg–Richter formulation, the values of a and b are constants in this case determined by the maximum likelihood method formulated by Utsu (1967), namely.

$$\hat{b} = \frac{\log e}{\overline{M} - \overline{M_0}}$$

Where e = 2.71828, M is the average magnitude and $M0$ is the minimum magnitude. The following is a description of the value of $\hat{b}$ with a magnitude of 6.0 SR:

Table 1. Value calculation $\hat{b}$

$\hat{b}=\frac{\log e}{\overline{M}-M_0}$	$\hat{b}=\frac{\log e}{\overline{M}-M_0}$
$\hat{b}=\frac{2{,}71828}{\overline{6}-\overline{6{,}0}}$	$\hat{b}=\frac{2{,}71828}{\overline{7}-\overline{7{,}0}}$
$\hat{b}=\frac{0{,}434}{\overline{6{,}1}-\overline{6{,}0}}$	$\hat{b}=\frac{0{,}434}{\overline{7{,}3}-\overline{7{,}0}}$
$\hat{b}=\frac{0{,}434}{0{,}1}$	$\hat{b}=\frac{0{,}434}{0{,}1}$
$\hat{b}=4{,}34$	$\hat{b}=1{,}446$

Next, calculate the seismicity index value α, determined using the following formula :

$$\alpha = \log N\,(M > M_0) + \log(\hat{b}\ln 10) + M_0\,\hat{b} \quad (2)$$

Table 2. Value calculation a

$a = Log\ N\ (M > M_0) + Log\ (\hat{b}\,In\ 10) + M_0\hat{b}$	$a = Log\ N\ (M > M_0) + Log\ (\hat{b}\ In\ 10) + M_0\hat{b}$
$a = Log$ 108 (6,1 > 6,0) + Log (4,33 In 10) + 6.0 x 4,33	$a = Log$ 5 (7,3 > 7,0) + Log (1,446 In 10) + 7.0 x 7,3
a = 2,033 (6,1 > 6,0) + Log (9,97) + 25,98 a = 2,033 (6,1 > 6,0) + 0,99 + 25,98 a = (6,1 > 6,0) 28,973 Calculation of the a value with a minimum magnitude of 6,0 and an average of 6,1	a = 0,69 (7,3 > 7,0) + Log (3,32) + 51,5 a = 0,69 (7,3 > 7,0) + 0,52 + 51,5 a = (7,3 > 7,0) 52,71 Calculation of the a value with a minimum magnitude of 7,0 and an average of 7,3

Table 3. Results of the seismicity index assessment of α and b values

Magnitudo	**α**	**b**
6,1>6,0	28,973	4,34
7,3>7,0	52,71	1,446

The seismicity index is the normalization of the number of earthquakes per year. Areas with a high seismicity index are prone to earthquakes. The probability of an earthquake and the duration of an earthquake for each intensity in the study area vary depending on the seismity index. To calculate the probability of an earthquake is taken period T = 10, 30 and 100 years. While the magnitude chosen is a minimum of 6.0 and a minimum of 7.0 SR assuming the earthquake has the potential to cause damage. Parameters calculated as seismicity indices will make it easier for us to know the possibility of at least one large earthquake (with large destructive power) in an area within a certain period of time.

The calculation of the re-period of the occurrence of damaging earthquakes is obtained using the formula:

$$N1 = (M > M_0) = 10^{(a - Log\ (\hat{b}\ In\ 10) + Log\ \ \Delta t) - bM_0} \quad (3)$$

Table 4. Probability of earthquake occurrence for period T (years) and average value of earthquake recurrence period at Magnitude

Magnitude	**Seismicity Index**	**b**	**T=10 Years**	**T=30 Years**	**T=100 Years**
6,1> 6,0 SR	28,973	4,34	0,11402497	0,34197944	1,14024978
7,3> 7,0 SR	52,71	1,446	0,85506677	0,25644840	0,85506671

A short repeat period indicates that earthquakes occur frequently in a region, while a long repeat period indicates that earthquakes are rare.

The calculation results at magnitude 6.0 SR show that within 100 years, the study area has a chance of a potentially damaging earthquake as much as 1.14024978. That is, there is a high probability of a potentially destructive earthquake within a hundred years. Based on the value of these opportunities, it can be concluded that the region has a significant potential risk of earthquakes.

3.2. Paleotsunami Sedimentological Analysis

The location of collection and observation is located in Katialada village, Kwandang District, North Gorontalo Regency. Adjacent to the yard of the local community with coordinates: 0.853392 LU – 122.907682 BT. The depth of the test well was 126 cm (Figure 2). In the cross-section of the observation hole / test well, there are 4 layers based on color differences. 1 layer of which is estimated to be a layer of tsunami deposits with a thickness of 14 cm.

The paleotsunami sediment test well found consists of 4 layers, namely.

1. The bottom layer or Layer 1 is 33 cm thick, in the form of mixed coarse sand, dark brown with white spots.
2. On top of layer 1, layer 2 with a layer thickness of 11 cm with a dark brown color of sand is deposited.
3. On top of layer 2, a layer of thought Paleotsunami deposits was deposited. This layer has a thickness of 14 cm with a light brown color and found several coral fragments with the granularity of sand silt. Some indications that this layer is the discovery of erosion field contact structures between layer 2 and layer three that characterize land tsunami deposits.

In layer 4 or the top layer of the test well, there is a layer of loose sand, brown in color, there are gravel fragments, and also found traces of roots from coconut trees.

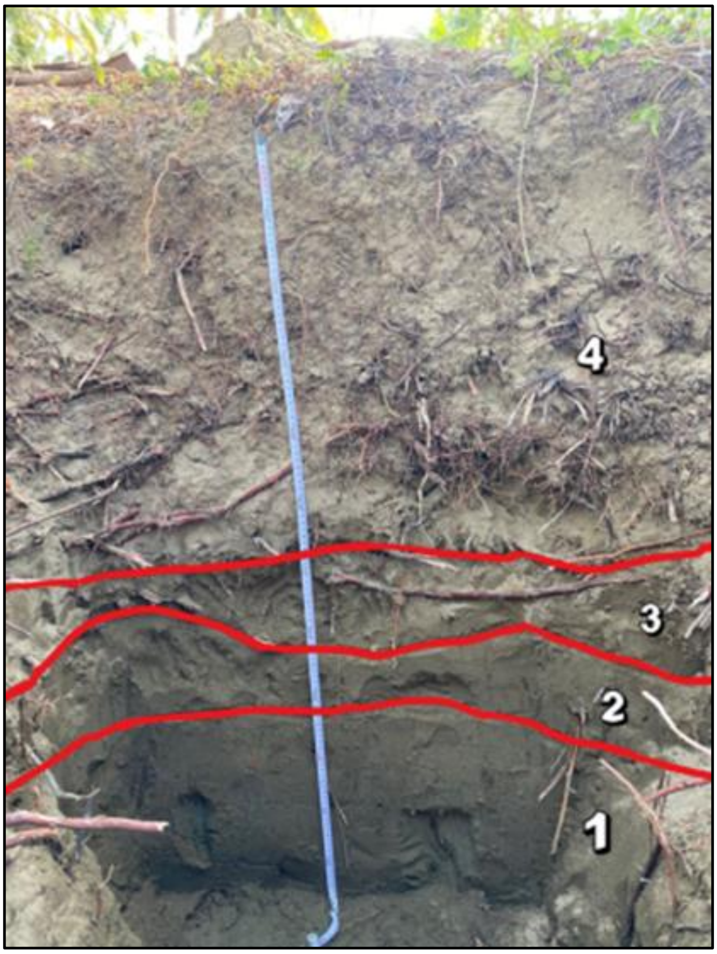

Figure 2. Paleotsunami sediment test well

3.3. Tsunami Modelling

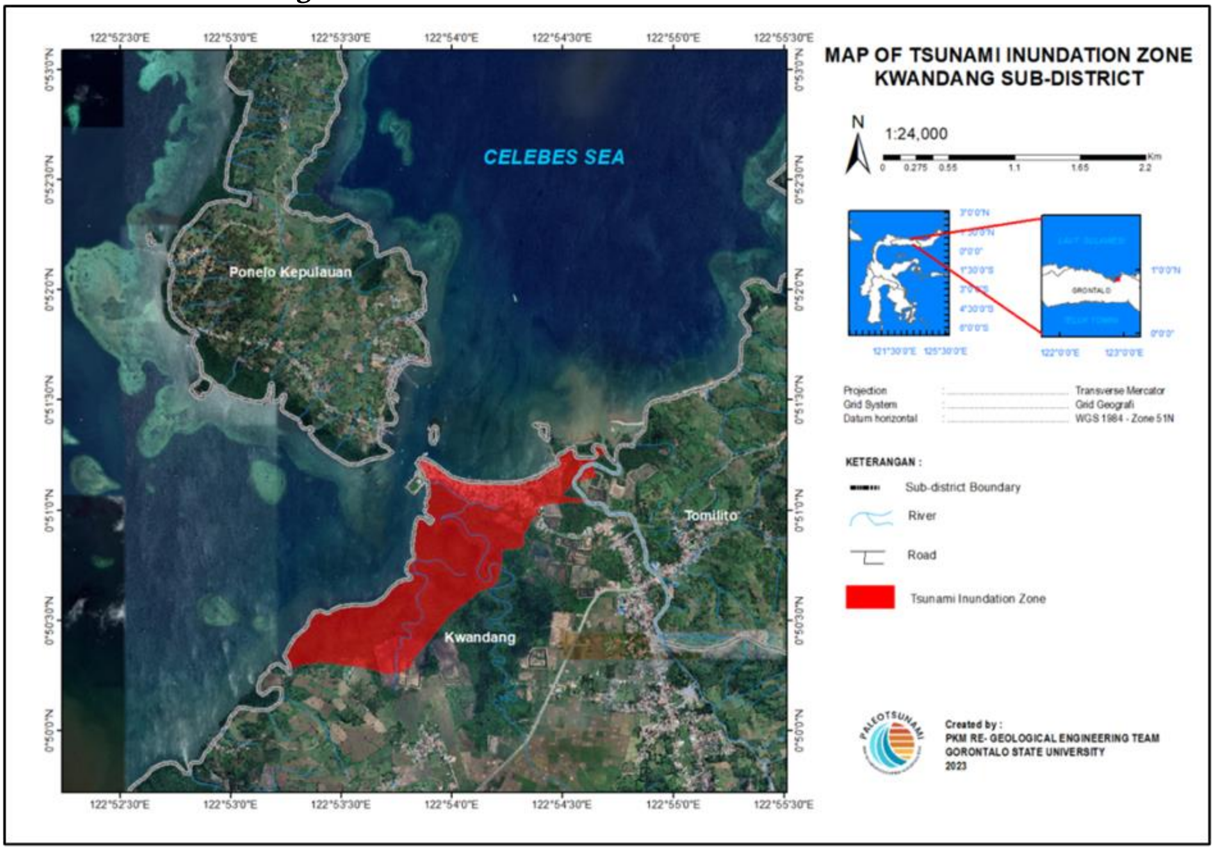

Figure 3. Tsunami inundation zone of the study area

Based on Figure 3, it can be indicated that the northern part of Kwandang District has a high potential tsunami hazard. The results of this study are supported by data from BMKG, which states that North Gorontalo Regency, precisely Kwandang District, is an area that has experienced a tsunami event.

Based on the results of tsunami modeling, in Kwandang District there are two villages included in the tsunami immersion zone. The results of the analysis showed that the total area of the tsunami immersion zone in Kwandang sub-district was 165.598389 ha. The village with the highest danger area in Kwandang District is Bulalo Village with a total area of 102.231029 ha. Then followed by the village that became the place of tsunami sedimentology observation, namely Katialada village with an area of tsunami immersion zone, namely, 61.630242 ha. The high area of danger in these two villages is caused by the slope that tends to be flat and the value of surface land cover which is relatively only community settlements. The low inundation barrier causes a widening of areas that may be affected by the tsunami event. This tsunami incident became an important lesson for the community and government. Increased mitigation efforts and reducing the impact of tsunami disaster risk in the Serang Regency area are needed considering that the Sunda Strait area has a very high tsunami potential.

4. CONCLUSIONS

Kwandang District is an area that has a high tsunami potential. The northern part of Kwandang District shows the potential tsunami hazard with the results of modeling the tsunami-prone zone, with a total area of 165.598389 ha.

Tsunami modeling with Geological Information Systems (GIS) can help the disaster mitigation process effectively and efficiently. The calculation results at magnitude 6.0 SR show that within 100 years, the study area has a chance of a potentially damaging earthquake as much as 1.14024978. That is, there is a high probability of a potentially destructive earthquake within a hundred years. Based on the value of these opportunities, it can be concluded that the region has a significant potential risk of earthquakes.

Based on the results of tsunami modeling, in Kwandang District there are two villages included in the tsunami immersion zone. The results of the analysis showed that the total area of the tsunami immersion zone in Kwandang sub-district was 165.598389 ha. namely the villages of Bulalo and Katialada. This tsunami hazard map obtained from the modeling results can be used as one of the information bases in disaster mitigation planning, such as installing tsunami alarms and determining safe areas from tsunami disasters.

5. ACKNOWLEDGMENTS

The autors would like to thank Directorate General of Higher Education (DITJEN DIKTI) for funding this research, as well as the Department of Geological Engineering, Major of Earth Science and Technology, Faculty of Mathematic and Natural Science, Gorontalo State University, for granting permission to use the facilities at Geological Engineering Laboratory during data processing. We would like to thank Head of Kwandang District and its staff, thanks to BPBD North Gorontalo Regency, thanks to the People of Posso Village and Katiladaa Village, Kwandang District. As well as thanks to the supervisors Mr. Dr. Aang Panji Permana, S.T, M.T and Mr. Hasan Arif Efendi S.T., M.Eng as well as the academic community of the Department of Earth Science and Technology, Universitas Negeri Gorontalo.

6. REFERENCES

Alfaris, L., Baswantara, A., & Suhernalis, S. (2020). Analisa Numerik Tsunami Pangandaran Dan Implikasinya Terhadap Mitigasi Bencana. MARLIN, Vol. 1(1), 39-45.

Aswan, A. and Rizal, Y. (2021). Identification Of Suspected Paleotsunami Deposits Study From Karapyak Beach, Pangandaran Area, West Jawa, Indonesia. Bulletin of the Marine Geology, Vol. 36(2), 381443.

BMKG. (2018). Jejak Tsunami Masa Lalu di Antara Pangandaran dan Cilapcap. Pusat Gempabumi dan Tsunami Kedeputian Bidang Geofisika Badan Meteorologi Klimatologi dan Geofisika, Jakarta Pusat.

Chagué-Goff, C., Schneider, J. L., Goff, J. R., Dominey-Howes, D., & Strotz, L. (2011). Expanding the proxy toolkit to help identify past events—lessons from the 2004 Indian Ocean Tsunami and the 2009 South Pacific Tsunami. Earth-Science Reviews, Vol. 107(1-2), 107-122.

Engel, M., Pilarczyk, J., May, S. M., Brill, D., & Garrett, E. (2020). Geological records of tsunamis and other extreme waves. Elsevier.

Ernandi, F. N. (2020). Analisis variasi a-value dan b-value dengan menggunakan software zmap v. 6 sebagai indikator potensi gempa bumi di wilayah Nusa Tenggara Barat. Jurnal Inovasi Fisika Indonesia (IFI), Vol. 9(3), 24-30.

Hidayah, R. S. (2022). Analisis Distribusi Waktu dan Luasan daerah Deformasi Gempabumi Susulan Studi Kasus Gempa Bumi di 10 Pasaman Barat 25 Februari 2022. Bachelor's thesis, Fakultas Sains dan Teknologi UIN Syarif Hidayatullah Jakarta.

Kurniawan, W., Bangun, E., & Prakoso, B. (2021). Estimasi Ancaman Tsunami di Zona Subduksi Sulawesi Bagian Utara Sebagai Upaya Mitigasi Bencana Tsunami. PENDIPA Journal of Science Education, Vol. 5(2), 204-209

Lopez, G. I. (2015). Tsunamigenic Sediment. Springer: enclyclopedia of Earth Scientific Dating Methods. vol. 3, 827-832.

Lumintang, V. G., Pasau, G., & Tongkukut, S. J. (2015). Analisis tingkat seismisitas dan tingkat kerapuhan batuan di Maluku Utara. Jurnal Ilmiah Sains, Vol. 15(2), 94–98. https://doi.org/10.35799/jis.15.2.2015.9224

Madlazim, M. (2013) Kajian awal tentang b value gempa bumi di Sumatra. Jurnal Penelitian Fisika dan Aplikasinya (JPFA), Vol. 3(1), 41–46. doi: 10.26740/jpfa.v3n1.p41-46.

Setiyono, Urip. (2018). Buku katalog gempabumi signifikan dan merusak 1821-2017. BMKG.

Sungkowo, A. (2016). Studi Kerentanan Sesimik dan Karakteristik Dinamik Tanah di Kota Yogyakarta dari Data Mikrotremor. Yogyakarta: Tesis, Universitas Islam Indonesia.

Suwandi, E, A., Sari, I, L., & Waslaluddin, W. (2017). Analisis Percepatan Tanah Maksimum, Intensitas Maksimum dan Periode Ulang Gempa Untuk Menentukan Tingkat Kerentanan Seismik di Jawa Barat (Periode Gempa Tahun 1974- 2016). Wahana Fisika, Vol. 2(2), 78-96. https://doi.org/10.17509/wafi.v2i2.9371.

Wahyuni, D., Intan, P. K., & Hendrastuti, N. (2020). Analisis seismotektonik dan periode ulang gempa bumi pada wilayah Jawa Timur menggunakan relasi Gutenberg–Richter. Jurnal Mahasiswa Matematika ALGEBRA, Vol.1(1), 22-32.

Zakaria, Z., & Sidarto, S. (2015). Aktifitas Tektonik di Sulawesi dan Sekitarnya Sejak Mesozoikum Hingga Kini Sebagai Akibat Interaksi Aktifitas Tektonik Lempeng Tektonik Utama di Sekitarnya. Jurnal Geologi dan Sumberdaya Mineral, Vol. 16(3), 115-12

Zera, T. (2014). Menentukan Peluang Dan Periode Ulang Gempa Dengan Magnitude Tertentu Berdasarkan Model Guttenberg-Ritcher. Spektra: Jurnal Fisika dan Aplikasinya, Vol. 15(1), 44-48.