JPPIPA 10(SpecialIssue) (2024)

Jurnal Penelitian Pendidikan IPA
Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Preliminary Study of *a-value* and *b-value* of Earthquake at Timor Leste Period 1975 – 2022

Jose da Costa[1*], Sukir Maryanto[1], Alamsyah Mohammad Juwono[1], Joanico Pires[2], Geovanio Pedro da Silva Almeida[2], Luis Teofilo da Costa[2]

[1]Physics Department, Brawijaya University, Malang, East Java, Indonesia.
[2]Instuto de Geociências de Timor-Leste (IGTL), Dili, Timor Leste

Received: June 19, 2024
Revised: August 17, 2024
Accepted: August 25, 2024
Published: August 31, 2024

Corresponding Author:
Jose da Costa
dacostajose432@gmail.com

DOI: 10.29303/jppipa.v10iSpecialIssue.8578

Abstract: Analysis of the seismicity parameter for earthquakes in Timor Leste has not focused on the level of seismicity activeness (a-value) and rock brittleness (b-value). A study on earthquake hazards needs to be conducted to minimize the impacts caused by the disaster. One kind of mitigation effort is the spatial mapping of the seismotectonic parameters of a-value and b-value. Determining the variations of changes in seismotectonic parameter values utilized the maximum likelihood statistical method. Analysis results of seismotectonic parameter values for Zone 1 showed that a-value variations ranged from 7-10, b-value ranged from 0.9-1.5, Zone 2, a-value variations ranged from 6-10, b-value ranged from 0.9-1.9, For Zone 3, a-value variations ranged from 8-17, b-value ranged from 1.3-1.9, This indicated high levels of rock brittleness and low levels of rock resistance toward stress; of these three zones, the zone with the highest seismicity level is Zone 3, followed by Zone 1 and Zone 2, while the regions with the greatest chance for an earthquake occurring with a large magnitude and repetition of earthquake occurrences within a short time interval is Zone 1 and Zone 2. Meanwhile, Zone 3 is the region with the smallest chance for earthquakes occurring with a large magnitude.

Keywords: a-value; b-value; Maximum Likelihood Method; Timor Leste.

Introduction

Geographically, the country of Timor Leste is located within 8° SL – 10° SL and 124° EL – 127° 30′ EL, and is bordered to the north by the Banda Strait, Wetar Island, and Alor Island in Indonesia; to the south by the Timor Strait and Australia; to the west by Kupang (East Nusa Tenggara); and to the east by the Leti Islands in Indonesia. Timor Leste is a part of the Banda Arc, which is the meeting zone of three different tectonic plates (Hamilton, 1973), which are the Indo–Australian Plate, the Pacific Plate, and the Eurasian Plate (Hamilton, 1973).

Timor Leste follows the curving subduction zone of the Banda Arc, and is not followed by the presence of active volcanism or a volcanic arc; this absence of a volcanic arc becomes the distinct characteristic of the Banda Arc, which makes the tectonic formation and phases in Timor Leste to be ones that are complex (Dinis *et al*., 2013). The occurrence of tectonic activity in Timor Leste is due to the movement of the Australian Plate in the south moving toward the north, which eventually results in a divergent boundary in the form of a collision with the Banda Arc archipelago.

This plate movement event that results in the divergent boundary began with a collision in the Central Timor region in the Late Miocene period, which was

How to Cite:
Costa, J. da, Maryanto, S., Juwono, A. M., Pires, J., Almeida, G. P. da S., & Costa, L. T. da. (2024). Preliminary Study of a-value and b-value of Earthquake at Timor Leste Period 1975 – 2022. *Jurnal Penelitian Pendidikan IPA*, *10*(SpecialIssue), 711–718. https://doi.org/10.29303/jppipa.v10iSpecialIssue.8578

then followed by a collision in the southwest of Timor Leste (R. A. Harris, 1991), The collisions that began from the Late Miocene to the Early Pliocene period are the youngest collisions in the world and thus result in the youngest metamorphic rocks in the world. Earthquakes are defined as soil tremors that are caused by a sudden release of energy in the crust of the earth (Elnashai and Sarno, 2008), as well as according to Lutgens (1982) in Hidayat & Santoso (1997).

Earthquakes have a serious impact on human life, especially for those who live in close to active faults both on land and subduction zones in coastal areas (Desifatma et al., 2022). Timor Leste is a country with a very high level of seismicity; this is caused by three earthquake faults, as the active fault system in Sawu Sea, the Wetar Upthrust, and the subduction system of the Australian Plate south of Timor Leste (Sunardi *et al*., 2017; Supendi *et al*., 2020; Yang *et al*., 2020).

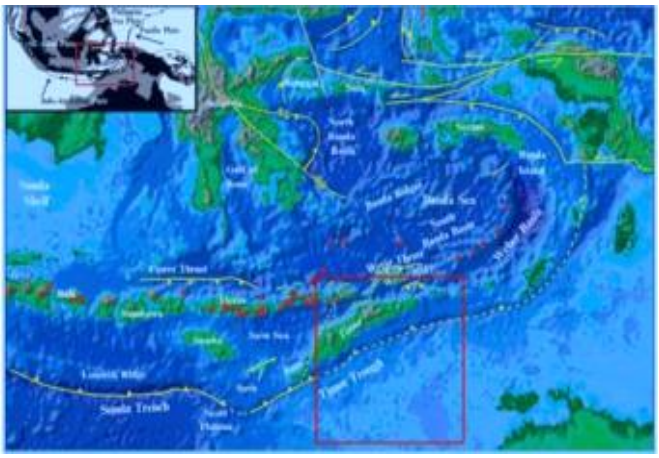

Figure 1. Research location as indicated by the red rectangle, modified from Harris (2019)

In Timor Leste, two damaging earthquakes have occurred; one of them occurred on August 27, 1977 with a magnitude of 6.8 Ms (with no tsunami) and the epicenter located at 58 km N (North) of Likisa at a depth of 25 km. The impact of the earthquake reached VII-VIII MMI on the maximum intensity scale, and the earthquake thus had potentially damaging power. The damaging earthquake caused 2 deaths and 25 injuries. The other occurred on May 14, 1995 with a magnitude of 6.9 Mw; this earthquake resulted in a tsunami with a maximum height of 4 m, with the epicenter being at 27 km NNW (North-Northwest) of Maubara at a depth of 11 km. The earthquake caused 11 deaths and 19 injuries; furthermore, several houses were severely damaged due to a local tsunami in the proximity of Dili, and landslides occurred near the epicenter (BMKG, 2018).

These two occurrences of damaging earthquakes clearly indicate that the Timor Leste region is a region with high seismic activity and vulnerability toward the hazard potential from earthquakes and tsunamis, even though this requires a long time, and which is caused by the Sawu Sea active fault, Wetar Up thrust, and Australian Plate subduction system. Where the East Nusa Tenggara region represents being along the subduction zone, namely the front arc area of the Australian plate moving northward (Thene, 2016) and has a structure of four rock types (Rahardiawan & Purwanto, 2016).

Therefore, the knowledge about the level of seismicity and the hazard potential for seismic disasters in the Timor Leste region is very much needed for disaster mitigation needs. Technically, the knowledge about the level of seismicity and rock brittleness in the Timor Leste region may be obtained through determining the a-value and b-value parameters by utilizing secondary data of earthquakes from the United States Geological Survey (USGS) catalog from 1975-2022 with the aid of the ZMAP6.0 application (Wiemer, 2001).

Method

Earthquake statistics in the form of frequency-magnitude distribution (FMD) can be used to find out the seismicity level of a region. Mathematically, FMD is written out as the Gutenberg-Richter Law 1944 in (Apriliani et al., 2021) and the following equation:

$$\log N(M) = a - bM \quad (1)$$

where N is the number of events in a region within a certain time period with strength of $M \geq Mc$ (magnitude of completeness) that is defined as the smallest magnitude value where the Gutenberg-Richter Law still applies, values a and b are the seismic parameters that are relevant to the hazard potential for seismic disasters and area vulnerability. Mathematically, the Gutenberg-Richter Law (1944) is an equation for a straight line, where log N is the vertical axis and M is the horizontal axis. In this case, the physical meaning of parameter a is the seismicity level of the region being observed, for which the value depends on the area of the region, length of observation period, and the largest observed magnitude (Han *et al*., 2015); (Amaro-Mellado and Bui, 2020).

Meanwhile, value b represents the ratio of small earthquakes to large earthquakes, which indicates the stress level of sub-surface rocks (Godano *et al*., 2014; Scholz, 2015; Amaro-Mellado *et al*., 2017). The application of Equation (1) depends on the estimation accuracy for Mc. If the estimate for Mc is too high, this will cause a decrease in the sample data for earthquakes. Conversely, if Mc is too low, the results for the seismic parameters a and b may become deviant (Mignan, 2012;

Mignan and Woessner 2012). In this context, the Maximum Likelihood method was employed for the study.

Maximum Likelihood Method

The maximum likelihood approach (Ernandi & Mudlazim, 2020) has the advantage of being able to calculate statistically the value of the parameter for earthquake activity in order to be able to minimize magnitude voids at certain intervals, thereby being able to provide stable final results. The maximum likelihood approach (Aki, 1965) is one of the statistical methods that is usually used to solve seismo-tectonic problems, for which estimation of a and b is performed according to maximal probability (Mignan and Woessner, 2012) with the estimation of b being carried out through the following equation:

$$b = \frac{1}{\overline{M} - M_0} \log e \quad (2)$$

where b is the parameter of the rock brittleness level, $\overline{M}$ is the mean magnitude of the earthquake data, M_0 is the minimum magnitude of the earthquake data, e is the Euler constant (2.71828), and log e = (0.4343). A value of $b \approx 1.0$ means that the geological sub-surface rocks possess high stress (Han *et al.*, 2015); (Amaro-Mellado and Bui, 2020). The spatial variation of b can be used as a precursor for major earthquakes (Nuannin *et al.*, 2012). Meanwhile, the estimation of a is determined by the following equation:

$$\hat{a} = \log N(M \geq M_0) + \log(b \ln 10) + M_0 \hat{b} \quad (3)$$

where $\hat{a}$ is the parameter of the seismicity level of a region, $\hat{b}$ is the estimation of rock brittleness level, log N (M ≥ M_0) is the mean value of the cumulative total of earthquakes, M_0 is the minimum magnitude of the earthquake data, M is the mean magnitude of the earthquake data, and N is the cumulative total of the utilized earthquake data.

Research Data, Data Collection Technique, and Data Processing

This research utilized secondary data comprising 1782 earthquake occurrences in Timor Leste and its surrounding regions within the years from 1975-2022 with magnitude variations of 3.2 ≥ Mw ≤ 7.5 and earthquake epicenter depth reaching 613 km that was obtained from the USGS earthquake catalog at http://earthquake.usgs.gov/earthquakes/.

The earthquake data has not undergone a filtering process that will remove data of foreshocks and aftershocks (Ngatmanto, 2009) that has the objective of increasing the level of accuracy of calculation results for Mc, b-value, and a-value in Timor Leste and the surrounding regions. In this case, the values for Mc, b-value, and a-value in Timor Leste and the surrounding regions are calculated by creating three seismic zones, which are (1) Zone 1 with regional boundaries of -12.544° SL – 124.651° EL and -7.841° SL – 123.759° EL and 777 earthquake events, (2) Zone 2 with regional boundaries of -12.544° SL – 127.304° EL and -7.841° SL – 124.651° EL and 714 earthquake events, and (3) Zone 3 with regional boundaries of -12.544° SL – 128.666° EL and -7.841° SL – 127.304° EL and 291 earthquake events. The division of these three zones were made according to the earthquake density as seen in Figure 2.

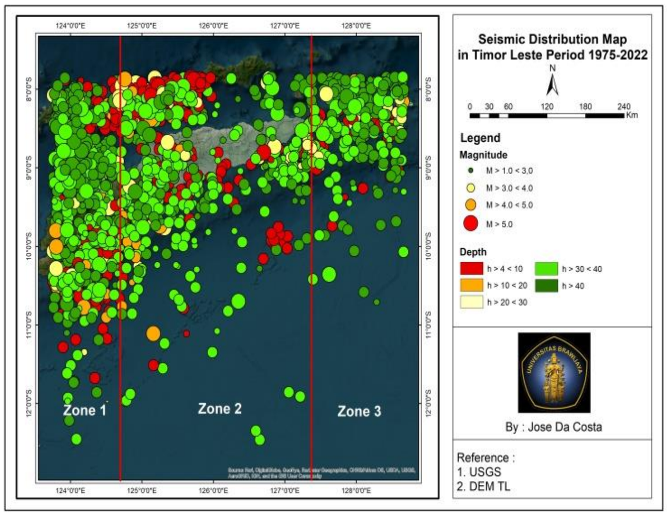

Figure 2. Map of the seismic zones of the research area: Zone 1, Zone 2, and Zone 3.

All the earthquake data that were included as the sample were downloaded from the USGS catalog in the csv file format. Then, the earthquake data were processed with the aid of a spreadsheet to convert the earthquake magnitude from moment magnitude to Mw according to a specific conversion technique (Dinis et al., 2013) and to adjust the entry format as determined by ZMAP6.0 by longitude, latitude, year, month, day, magnitude, depth, hour, and minute. After this adjustment, the data were stored in the format of file.dat as input for the ZMAP6.0 (Dinis et al., 2013) program with the aid of Matlab R2013a.

The filtering process involved the decluster using (Dinis et al., 2013) technique that was performed to eliminate foreshocks and aftershocks in order to purify the data for the main shocks. Next was the calculation of values for Mc, b-value, and a-value, for which the three seismic parameters were used to find out the potential of seismic disaster hazards for Timor Leste and the surrounding areas.

The data from the three zones were then processed again using ZMAP6.0 (Dinis et al., 2013) to obtain output in the form of histograms and FMD curves, Mc parameter estimation, b-value, a-value, b-value spatial variation, and source depth variation. The output from the three seismic zones were analyzed to obtain a comprehensive image of the seismicity level and vulnerability potential for Timor Leste and the surrounding areas. The research design can be seen in Figure 3.

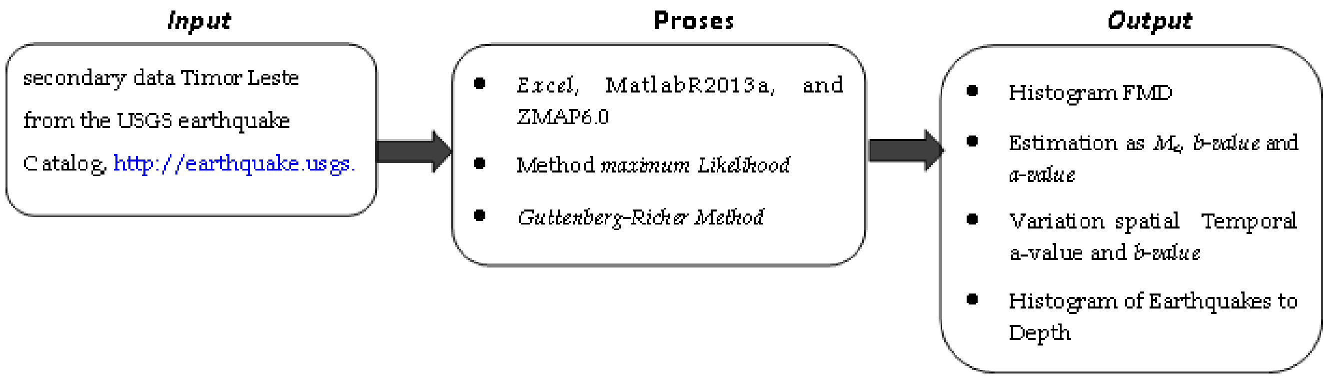

Figure 3. Schema for the research of seismicity and potential seismic hazards in Timor Leste and surrounding regions

Result and Discussion

The research results are discussed through the figures created with the aid of ZMAP6.0 and Matlab, as (1) histogram of earthquakes to magnitude, (2) FMD curves, (3) b-value spatial variation distribution, and (4) histogram of earthquakes to depth. The analysis was differentiated according to the seismic zones, as Zone 1, Zone 2, and Zone 3. Analysis of the histogram of earthquakes to magnitude and the FMD curves for all seismic zones can illustrate the levels of seismicity and stress of sub-surface rocks in Timor Leste and the surrounding areas. Analysis of b-value variability and the histogram of earthquakes to depth reflects the potential of tectonic earthquake disaster hazards in Timor Leste and the surrounding areas. Analysis of the histogram of earthquakes to depth shows the distribution of earthquake sources (the hypocenter locations).

Histogram of Earthquakes to Magnitude

Based on the plot of magnitude Mw against the number of events N for all seismic zones (Figure 4), the greatest earthquake frequency was in the class interval of $4.5 \geq Mw \leq 4.9$, which correlated to 777 events in Zone 1, 714 events in Zone 2, and 291 events in Zone 3. The largest magnitudes in the years from 1975-2022 were Mw 6.7 in Zone 1, Mw 7.5 in Zone 2, and Mw 6.2 in Zone 3. The histogram plots of magnitude distribution for all three seismic zones in Timor Leste and the surrounding areas have the same pattern, where all plots showed an exponential decrease in the cumulative frequency of earthquake events for the magnitude reach of $Mw \geq 5.0$, following the linear-log Gutenberg-Richter Law (1944) (Dinis et al., 2013).

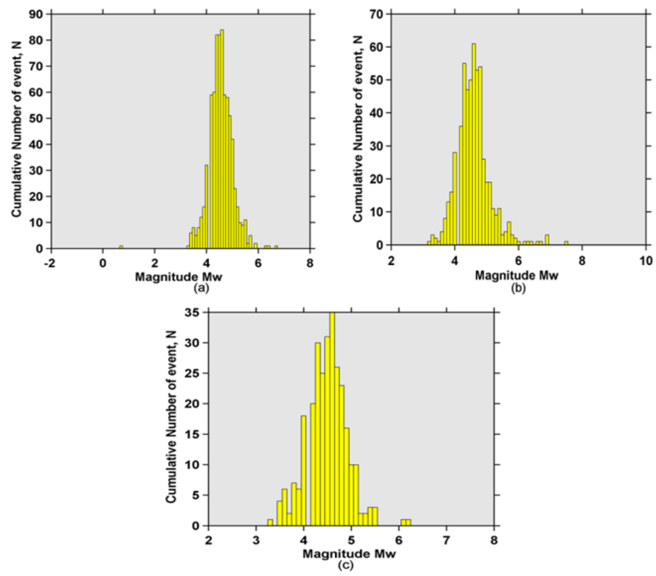

Figure 4. Plot of magnitude Mw against number of events N for (a) Zone 1, (b) Zone 2, and (c) Zone 3

Based on Figure 4, the median values of the magnitude class with the highest frequencies associated with Mc estimations were 4.5 for Zone 1, 4.5 for Zone 2, and 4.8 for Zone 3, which are categorized as moderate magnitudes. To ensure the accuracy of Mc estimation as well as b-value and a-value, it became necessary to make corrections to the Mc value (Dinis et al., 2013) (Wiemer, 2001; Woessner and Wiemer, 2005) in the form of FMD curves, for which the Mw plot was made against the cumulative number of events (N) and the logarithm of the number of events (log N) simultaneously.

Frequency Magnitude Distribution (FMD)

Figure 5 presents the FMD curves for all seismic zones as created by ZMAP6.0 (Dinis et al., 2013). FMD curves show the results of Mc and a-value calculations, which indicate the seismicity level (Dinis et al., 2013) and the b-value that represents the stress level of sub-surface rocks (Dinis et al., 2013). Additionally, FMD curves present the results of calculations for a (annual), which was used to explain the seismicity rate within the observation period from 1975-2022 or a range of 47 years.

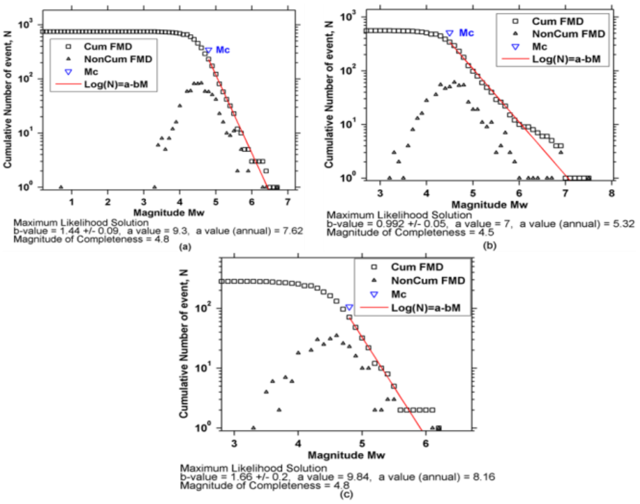

Figure 5. FMD curves with estimations of Mc, b-value, a-value, and a (annual) obtained from ZMAP6.0 for (a) Zone 1, (b) Zone 2, and (c) Zone 3.

b-value Spatial Variation Distribution

Analysis of b-value behavior and tectonic conditions for Timor Leste and the surrounding regions for the years from 1975-2022 was performed by mapping the spatial distribution of b-value. Examining spatial variations of b-value is one of two methods that can be used to examine the potential of major earthquakes occurring in a certain region. Mapping was conducted using ZMAP6.0 and Matlab R2013a (Dinis et al., 2013). To obtain an image with a high resolution, ZMAP6.0 required a minimum of 200 events (Dinis et al., 2013). Because the data requirement of at least 200 earthquake events for each seismic zone was fulfilled for this study, the spatial distribution map of b-value for the three seismic zones could be obtained with high resolution and could be trusted (Dinis et al., 2013).

Figure 6 shows the spatial distribution map of b-value for the Timor Leste region from 1975-2022. Variations of b-value on the map are illustrated through different colors, for which blue shows a relatively low b-value, while red shows a relatively high b-value. The three spatial variation plots for b-value indicated that epicenters of relatively strong earthquakes lie in a region with a low b-value. This finding is in line with the results of prior research (Dinis et al., 2013) where it was stated that areas with a high accumulation of seismic energy correlate with a low b-value.

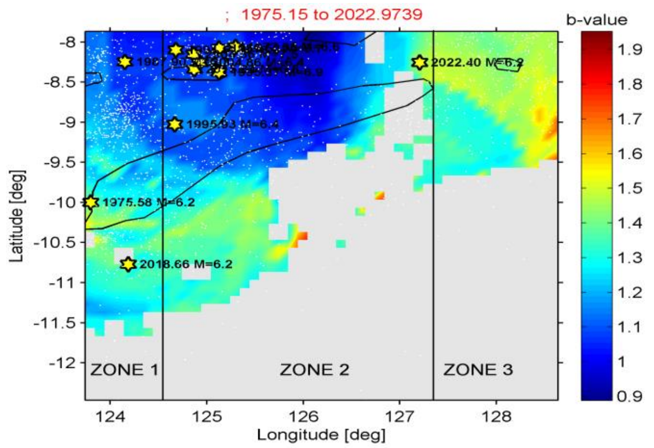

Figure 6. Distribution map of b-value spatial variations for the three zones in the Timor Leste region

Figure 6 shows the spatial variation of b-value in Zone 1, for which b-value was obtained with a range of 0.9-1.5. The high b-value indicates that the region has rocks with a low endurance toward stress, while the low b-value with a range of 0.9-1.2 as in the blue color above usually correlates with a high stress level. This means that the structure of sub-surface rocks in the region has a very high stress level (Dinis et al., 2013).

For Zone 2, the b-value was found to have a range of 0.9-1.9; the red color on the map indicates that the area has a high level of rock brittleness compared to others, and the high b-value indicates that the region has rocks with a low stress endurance, while the low b-value with a range of 0.9 – 1.2 as with the blue color indicates that the region has a characteristic of rocks possessing very high elasticity, and more dominantly compared to the low b-value in Zone 1.

In Zone 3, the b-value was obtained with a range of 1.3-1.9, where the red color on the map indicates that the region has rocks with a high level of brittleness compared to others, and the high b-value indicates that there are rocks with low endurance toward stress in the region, while the low b-value as indicated by the blue on the map shows that the region has a characteristic of rocks possessing very high elasticity. In other words, areas that have large heterogeneous rock characteristics are prone to cracking and relatively unable to withstand high stress accumulation (Linda et al., 2019). If the b-value is higher and the higher too of a-value, then it shows that the rock is getting more brittle in that area (Soehaimi, 2008).

Histogram of Earthquakes to Depth

A histogram plot of earthquakes to source depth needs to be created with the objective of mapping out the distribution of earthquake occurrences in Timor Leste and the surrounding regions with the aid of ZMAP6.0 (Dinis et al., 2013). The conducted analysis referred to the research by Hutchings and Mooney (2021), who classified earthquakes based on depth, as deep source earthquakes with hypocenters > 300 km, intermediate source earthquakes with hypocenters from 70-300 km, and shallow source earthquakes with hypocenters < 70 km. Several references (Dinis et al., 2013) stated that the reach of a shallow earthquake can be up to a depth of 100 km. Figure 7 illustrates the distribution of earthquakes to depth for all the seismic zones.

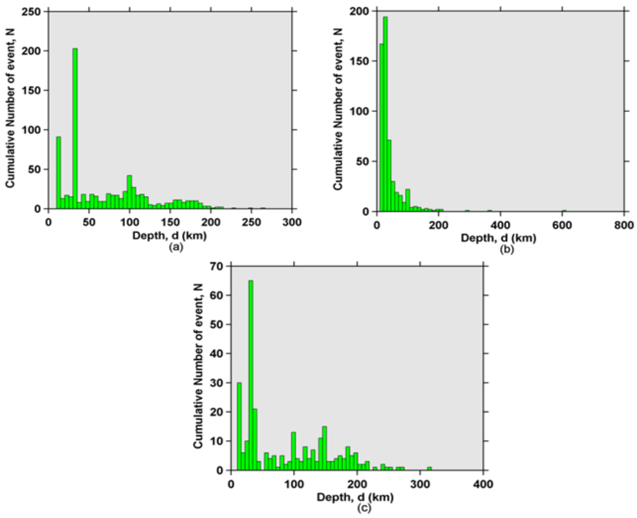

Figure 7. Plot of source depth d against number of events N for (a) Zone 1, (b) Zone 2, and (c) Zone 3

Figure 7 shows that the majority of earthquakes in all the seismic zones occurred at depths of less than 70 km (shallow sources); shallow earthquakes occurred relatively more frequently than earthquakes at intermediate depths (70 km < d < 300 km). As an example, Zone 1 was dominated by shallow earthquakes with 200 events at source depths of 10-35 km. Zone 2 was dominated by 197 shallow earthquakes with source depths of 10-40 km. Zone 3 was dominated by 66 shallow earthquakes with source depths of 10-50 km.

The seismic information that can be gained in relation to the seismic parameters of b, a, and a (annual) is that the region of Timor Leste and surrounding areas have seismicity levels and seismicity rates that are relatively high, with the majority of earthquakes being at shallow sources, in line with prior findings (Dinis et al., 2013). Additionally, Figure 7 provides confirmation that earthquakes with deep sources greater than 300 km very rarely occur in Timor Leste (Dinis et al., 2013); thus in general, the region of Timor Leste and surrounding areas are vulnerable to the potential of seismic disaster hazards (tectonic earthquakes and tsunamis), although the earthquake strengths are not too great.

Conclusion

The seismicity and vulnerability potential of the region of Timor Leste and surrounding areas toward the hazards of tectonic earthquakes and tsunami disasters are examined through analyses of the a-value and b-value parameters. These two parameters are calculated by the Gutenberg-Richter Law and the maximum likelihood approach for earthquake data from 1975-2022 with moment magnitudes of 3.2 ≤ Mw ≤ 7.5 and depths up to 613 km. Technically, the region of Timor Leste and surrounding areas can be divided into three zones. The results of FMD statistical calculations indicate that the mean value of a (annual) of 4.7 reflects a high level of seismicity and the b-value varies from 0.9-1.9, indicating that the majority of events are moderate events (4.5 ≤ Mw ≤ 7.5). Although major earthquakes rarely occur, the active fault in Sawu Sea, the Wetar Up thrust, and the Australian Plate subduction system can become tsunami triggers with shallow earthquakes dominating (average source depth of 10-40 km), and therefore the vulnerability of the region of Timor Leste and surrounding areas toward seismic disaster hazards needs to be observed.

Acknowledgements
The research team would like to thank the USGS for the availability of secondary earthquake data for this study that can be freely accessed through http://earthquake.usgs.gov/earthquakes/ as well as IGTL-IP who had granted permission for the author to carry out research for the Thesis.

Author Contributions
All authors contributed to writing this article. Conceptualization, J. d. C. and S. M.; Methodology, J. d. C. and S. M; Validation, S. M.; A. M. J.; J. P.; G. P. S. A.; and L. T. C.; formal analysis, S. M.; investigation, J. d. C.; resources, J. d. C.; data curation, J. d. C.: writing—original draft preparation, J. d. C. and S. M.; writing—review and editing, S. M. All authors have read and agreed to the published version of the manuscript.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

References

Aki, K. (1965). Maximum likelihood estimate of b in the formula log N = a - bM and its confidence limits. *Bulletin of the Earthquake Research Institute, the University of Tokyo*, 43(2), 237-239. https://Doi/10.4236/ojs.2016.61016

Apriliani, T., Prastowo, T., Fisika, P. S., Fisika, J., & Surabaya, U. N. (2021). Penentuan Parameter Seismik A -Value Dan B -Value untuk Analisis Potensi Gempa di Wilayah Maluku. *Jurnal Inovasi Fisika Indonesia (IFI), 10(1)*, 11–20. https://doi.org/10.26740/ifi.v10n1.p11-20

Amaro-Mellado, J. L., Morales-Esteban, A. & Martínez-Álvares, F. (2017). Mapping of seismic parameters of the Iberian Peninsula by means of a geographic information system. *Central European Journal of Operations Research*, 26(3), 739-758. https://Doi.org/10.1007/s10100-017-0506-7

Amaro-Mellado, J. L. & Bui, D. T. (2020). GIS-Based mapping of seismic parameters for the Pyrenees. *International Journal of Geo-Information*, *ISPRS Int. J. Geo-Inf*, *9*(7), 452. https://doi.org/10.3390/ijgi9070452

Badan Meteorologi Klimatologi dan Geofisika. (2018). *Katalog Gempa Signifikan dan Merusak 1874-2017*. 252.https://cdn.bmkg.go.id/Web/1821-2018.pdf

Desifatma, E., Kadir, I. R., Taufik, A., & Pratomo, P. M. (2022). Integrasi Early Warning System untuk Gempabumi. *Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat*, *19*(1), 22. http://dx.doi.org/10.20527/flux.v19i1.9509

Dinis, P. A., Tassinari, C., & Cabral Pinto, M. M. S. (2013). Geochemistry and detrital geochronology of stream sediments from East Timor: Implications for the origin of source units. *Australian Journal of Earth Sciences*, *60*(4), 509–519. https://doi.org/10.1080/08120099.2013.810664

Elnashai, S.A., & Sarno, D.L., (2008). *Fundamental of Earthquake Engineering*, Wiley, Hongkong. https://www.wiley.com/en-jp/9781118678923

Ernandi, F. N., & Mudlazim. (2020). Analisis Variasi a-*value* Dan b-*value* Dengan Menggunakan Software *ZMAP* V.6 Sebagai Indikator Potensi Gempa bumi Di Zona Nusa Tenggara Barat. *Jurnal Inovasi Fisika Indonesia,9(3)*. https://doi.org/10.26740/ifi.v9n3.p24-30

Godano, C., Lippiello, E. & de Arcangelis, L. (2014). Variability of the *b value* in the Gutenberg-Richter distribution. *Geophysical Journal International,* 199(3), 1765-1771. https://doi.org/10.1093/gji/ggu359

Gutenberg, B. & Richter, C. F. (1944). Frequency of earthquakes in California. *Bulletin of the Seismological Society of America*, 34(4), 185-188. https://doi.org/10.1785/BSSA0340040185

Hall, R., & Wilson, M. E. J. (2000). Neogene sutures in eastern Indonesia. *Journal of Asian Earth Sciences*, *18*(6), 781–808. https://doi.org/10.1016/S1367-9120(00)00040-7

Hamilton, W. (1973). Tectonics of the Indonesian Region. *Bulletin of the Geological Society of Malaysia*, *6*, 3–10. https://doi.org/10.7186/bgsm06197301

Han, Q., Wang, L., Xu, J., Carpinteri, A. & Lacidogna, G. (2015). A robust method to estimate the *b-value* of the magnitudo-frequency distribution of earthquakes. *Chaos, Solitons & Fractals*, 81(Part A), 103-110. https://doi.org/10.1016/j.chaos.2015.09.004

Harris, R. A. (1991). Temporal distribution of strain in the active Banda orogen: a reconciliation of rival hypotheses. *Journal of Southeast Asian Earth Sciences*, *6*(3–4), 373–386. https://doi.org/10.1016/0743-9547(91)90082-9

Harris, R. (2019). *The nature of the Banda arc-continent collision in the Timor region The Nature of the Banda Arc – Continent Collision in the Timor Region*. *February*. https://doi.org/10.1007/978

Hidayat, N., & Santoso, E. W. (1997). *Gempa bumi Dan Mekanismenya*. In Alami*: Jurnal Teknologi Reduksi Risiko Bencana*, 2, 50–52. https://media.neliti.com/media/publications/195598-ID-gempa-bumi-dan-mekanismenya.pdf

Hutchings, S. J. & Mooney, W. D.(2021). The seismicity of Indonesia and tectonic implications. *AGU Advancing Earth and Space Science*, 22(9), 1-42. https://doi.org/10.1029/2021GC009812

Kadirioglu, F. T. & Kartal, R. F. (2016). The new empirical magnitudo conversion relations using an improved earthquake catalogue for Turkey and its near vicinity (1900-2012). *Turkish Journal of Earth Sciences*, 25(4), 300-310. https://doi.org/10.3906/yer-1511-7

Kiser, E., Ishii, M., Langmuir, C. H., Shearer, P. M. & Hirose, H. (2011). Insights into the mechanism of intermediate-depth earthquakes from source properties as imaged by back projection of multiple seismic phases. *Journal of Geophysical Research*: *Solid Earth*, 116, B06310. https://doi.org/10.1029/2010JB007831

L, Ihsan, N., & Palloan, P. (2019). Analisis Distribusi Spasial Dan Temporal Seismotektonik Berdasarkan Nilai B-Value Dengan Analysis Of Spatial And Temporal Distribution Of Seismotectonics Based On B-Value Using The Likelihood Method On Java Pendahuluan Gempa Bumi Sering Melanda Indonesia, *Jurnal Sains dan Pendidikan Fisika (JSPF), 1(4), 16-31.* https://ojs.unm.ac.id/JSdPF/article/view/9403

Marzocchi, W., Sandri, L., Heuret, A. & Funiciello, F. (2016). Where giant earthquakes may come. *Journal of Geophysical Research: Solid Earth*, Vol. 121(10), 7322-7336. https://doi.org/10.1002/2016JB013054

Mignan, A. (2012). Functional shape of the earthquake frequency magnitudo distribution and completeness magnitudo. *Journal of Geophysical Research*, Vol. 117(B8), 8302. https://doi.org/10.1029/2012JB009347

Mignan, A. & Woessner, J. (2012). Understanding seismicity catalogs and their problems: Estimating the magnitudo of completeness for earthquake catalogs. *Community Online Resource for Statistical Seismicity Analysis* (CORSSA), 1(4), http://doi.org/10.5078/corssa-00180805.

Naylor, M., Orfanogiannaki, K. & Harte, D. (2010). Exploratory data analysis: magnitudo, space, and time. *Community Online Resource for Statistical seismicity Analysis* (CORSSA), pp. 1-42. http://www.corssa.org.

Ngatmanto, D. (2009). Penentuan Potensi Gempa bumi Merusak Berdasarkan Parameter Kegempaan Di Wilayah Busur Banda. *Jurnal Meteorologi dan Geofisika.* https://doi.org/ 10.14203/Widyariset.13.2.2010.125-132

Nuannin, P., Kulhánek, O. & Persson, L. (2012). Variations of b-*value*s preceding large earthquakes in the Andaman–Sumatra subduction zone. *Journal of Asian Earth Sciences*, 61, 237-242. https://doi.org/10.1016/j.jseaes.2012.10.013

Popandopoulus, G. A. & Chatziioannou, E. (2014). Gutenberg-Richter law parameters analysis using the Hellenic unified seismic network data through Fast-Bee technique. *Earth Science*, 3(5), 122131. https://doi.org/article/10.1134/S10693513120900 17

Rahardiawan, R., & Purwanto, C. (2016). Struktur Geologi Laut Flores, Nusa Tenggara Timur. *Jurnal Geologi Kelautan*, *12*(3), 153. http://dx.doi.org/10.32693/jgk.12.3.2014.256

Reasenberg, P. (1985). Second-order moment of Central California seismicity. *Journal of Geophysical Research*, 90(B7), 5479-5495. https://doi.org/10.1029/JB090iB07p05479

Scholz, C. H. (2015). On the stress dependence of the earthquake *b value*, *Geophysical Research Letter*, Vol. 42, pp. 1399-1402. http://ir.lib.ncu.edu.tw:88/thesis/view_etd.asp? URN=106622608&fileName=GC106622608.pdf

Soehaimi, A. (2008). Seismotektonik dan Potensi Kegempaan Wilayah Jawa. *Indonesian Journal on Geoscience*, *3*(4), 227–240. https://doi.org/10.17014/ijog.3.4.227-240

Sunardi, B., Istikomah, M. U., & Sulastri. (2017). Analisis seismotektonik dan periode ulang gempa bumi wilayah Nusa Tenggara Barat tahun 1973-2015. *Jurnal Riset Geofisika Indonesia*, 1(1). https://www.researchgate.net/publication/31692 1051

Supendi, P., Nugraha, A. D., Widiyantoro, S., Pesicek, J. D., Thurber, C. H., Abdullah, C. I., Daryono, D., Wiyono, S. H., Shiddiqi, H. A. & Rosalia, S. (2020). Relocated aftershocks and background seismicity in eastern Indonesia shed light on the 2018 Lombok and Palu earthquake sequences. *Geophysical Journal International*, 221(3), 1845-1855. https://doi.org/10.1093/gji/ggaa118

Thene, J. (2016). Mitigasi Bencana Gempa Bumi Berbasis Kearifan Lokal Masyarakat Rote Kabupaten Rote Ndao Provinsi Nusa Tenggara Timur. *Jurnal Teori Dan Praksis Pembelajaran IPS*, *1*(2), 102–106. http://dx.doi.org/10.17977/um022v1i22016p102

Tocheport, A., Rivera, L. & Chevrot, S. (2007). A systematic study of source time functions and moment tensors of intermediate and deep earthquakes. *Journal of Geophysical Research*, 112(B7), 311. https://doi.org/10.1029/2006JB004534

Wiemer, S. (2001). A software package to analyze seismicity: ZMAP. *Seismological Research Letters*, 72(3), 373-382. https://doi.org/ 10.4236/jssm.2009.23019

Woessner, J. & Wiemer, S. (2005). Assessing the quality of earthquake catalogues: estimating the magnitudo of completeness and its uncertainty. *Bulletin of Seismological Society of America*, 95(2), 684698. https://doi.org/10.1785/0120040007

Yang, X., Singh, S. C. & Tripathi, A. (2020). Did the Flores back-arc thrust rupture offshore during the 2018 Lombok earthquake sequence in Indonesia. *Geophysical Journal International*, 221(2), 758-768. https://doi.org/10.1093/gji/ggaa018