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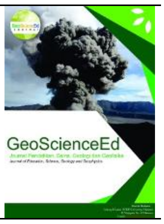

Analysis of Seismic Quiescence Precursors Before the M7.4 Earthquake of 28 September 2018 in Central Sulawesi Based on Seismotectonic Spatial Distribution and Earthquake Fracture Lengths

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Abstract: The aim of the study was to determine when the seismic quiescence occurred and seismic activity after the earthquake alongside fracture length. The method of analysis of seismic quiescence and fracture length is z-value and Wells and Coppersmith equation. Data processed with MATLAB and Zmap were 1478 events from 1983-2023. The study area is divided into several grids with sizes of 0.1°* 0.1°. The number of earthquakes included (N = 800, 700, 600, 500, 400, 300, and 200). The z-value was calculated for each grid based on the earthquake data organized in one grid and seismic activity after earthquake. The results of the analysis of the z-value calculation in each grid show of seismic quiescence before a significant earthquake. Based on the results of the spatial distribution of z-value in Central Sulawesi, the seismic quiescence preceded the 28 September 2018 earthquake event (M 7.4) by about 21 years beginning in 1990. When cut at 2019.6, there was a decrease in seismic activity again, which indicated that an earthquake would occur, so it was thought to be a trigger factor for future earthquake precursors. While the fracture length of the 7.4 Mw earthquake of 104,232 meters shows a positive correlation between magnitude and fracture length.

Keywords: Earthquake, Seismic Quiescence, Fracture Length, Z-value, Wells and Coppersmith

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Introduction

An earthquake is an event that releases a certain amount of energy in the earth's crustal rocks. One of these energies is wave energy called seismic waves. These waves are emitted from their source and travel in all directions, so they can be detected by seismic sensors (Gumawan & Subarjo, 2005). Sulawesi Island has a very complex geology and tectonic setting, it consists of a number of lithospheric sections that display a history or geological events of subduction or subduction processes (Cipta & Robiana, 2016). This process causes the existing and active structures to move at different speeds, causing the islands of Sulawesi to produce frequent earthquakes (PuSGeN, 2017).

Sulawesi Island, especially Central Sulawesi Province, has a main structure that is the source of earthquakes on land and at sea. The source of earthquakes at sea comes from the subduction zone in North Sulawesi, which is located next to the island of Sulawesi, while the source of earthquakes on land comes from several active faults on the mainland of Central Sulawesi, one of which is the Palu Fault. The Palu region has a high seismic potential due to the Palu Koro Fault (Bellier et al., 2001). History records that until now the Central Sulawesi region has experienced many destructive earthquakes and casualties. Central

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Sulawesi has experienced several significant and destructive earthquakes. Destructive earthquakes in the Central Sulawesi region that have occurred include the 1910 earthquake in Toli-Toli with a magnitude of M6.5, the Palu earthquake in 1939 with a magnitude of M7.0, the Tambu earthquake on 14 August 1968 with a magnitude of M7.5, the Poso earthquake in 1996 with a magnitude of M 6. 8, the Donggala earthquake in 2005 had a magnitude of M 6.2, the Palu earthquake in 2018 had a magnitude of M 7.4, the Sigi earthquake in 2020 had a magnitude of 6.2, the Parigi Moutung earthquake in 2021 had a magnitude of M 6.2, the earthquake in Toli-Toli in 2022 had a magnitude of M 6.1 and the Toli-Toli earthquake in 2023 had a magnitude of M 7.0. The real impact of the Palu Koro Fault is the earthquake that occurred on 28 September 2018 with Mw 7.4 at a depth of 10 km centered 26 km north of Donggala, Central Sulawesi (Simangunsong et al., 2019).

The high seismic activity in the Central Sulawesi region requires further research on the spatial distribution of seismotectonic and earthquake fracture length in analyzing seismic quiescence precursors in minimizing earthquake disaster events. Increased seismicity during a certain period before a strong event will be concentrated around the periphery of the rupture zone, while the rupture zone itself is relatively quiet. The purpose of this study is to determine the seismic quiescence phenomenon and the length of earthquake fractures in the earthquake that occurred in Central Sulawesi. Therefore, to understand seismotectonic processes and earthquake prediction research is to understand seismic patterns as a function of space and time. This research investigates seismic precursors before the occurrence of an earthquake (Papadimitriou, 2008).

The analysis of seismic activity often relies on the magnitude-frequency distribution relationship, which is characterized by seismotectonic parameters known as the a-value and b-value. The a-value, which varies with the area and time period studied, reflects the seismic productivity of a region. In contrast, the b-value indicates the relative distribution of earthquake sizes. This relationship is crucial for various seismic studies, including assessing seismicity, understanding seismotectonic features, evaluating seismic hazards, calculating recurrence intervals for different earthquake magnitudes, mapping subsurface magmatic activity, and examining induced seismicity (Syafriani & Yulkifli, 2018).

The a-value indicates of characteristics of a region, reflecting both the number of earthquakes and the size of the area studied (Huang et al., 2002). Conversely, the b-value provides insight into the tectonic conditions related to regional stress, a high b-value generally signifies lower rock stress conditions (Katsumata, 2011). Variations in b-values can signal medium- to short-term earthquake precursors, often interrupted by periods of seismic quietude. In areas like Central Sulawesi, which experience high seismic activity, monitoring seismic quiescence is crucial for detecting potential decreases in activity. Seismic quiescence refers to a marked reduction in seismic activity before a major earthquake. To mitigate the effects of large earthquakes, it's essential to track precursors in areas prone to significant seismic events. Analysis seismic quiescence helps identify signs that precede a major earthquake (Main et al., 1989).

The value of b is obtained from the magnitude-frequency relationship which can be seen in the on Equation 1 (Richter, 1942).

$$\text{Log } N = a - bM \qquad (1)$$

In this context, N represents the frequency of earthquakes, M denotes the magnitude of earthquakes, and a and b are constants. A high a-value signifies that the area experiences frequent seismic activity, while a low a-value indicates reduced seismic activity. The a-value reflects the seismic characteristics of a region, influenced by the number of seismic events. In contrast, the b-value represents the local tectonic stress conditions affecting the rocks in the area. Where N is the frequency of earthquakes and M is the magnitude of earthquakes, a and b are constants. A large a-value indicates the area has high seismic activity, while a smaller a-value indicates low seismic activity. The *a-value* of a represents the condition of the region and is influenced by the number of seismic events and the *b-value* of represents the local tectonic stress state of the rocks in an area.

Anomalies in seismicity patterns and variations in seismicity level anomalies are precursors on medium and short time scales before major earthquakes occur (Wyss & Sobolev, 2004). Analysis seismic quiescence precursors involve calculating the standard deviation of Z in a region to identify potential periods of unusually low seismic activity before a major earthquake occurs near the epicenters. A positive z-value indicates a reduction in seismic activity, whereas a negative z-value signifies an increase in activity. Typically, significant earthquakes are preceded by certain phenomena or seismic cycles. Seismic data can be utilized to detect these precursors and observe the emerging patterns.

This is because seismicity data is spread across all seismically active regions and is used to look at seismicity patterns prior to major shocks from different tectonics. It also provides information that will be needed to determine the level of early warning associated with seismic precursors. The seismicity data obtained occurred at the crustal depth where the main shock occurred. By using seismicity patterns, research on earthquake prediction becomes a good earthquake precursor to study at this time (Puangjaktha & Pailoplee). A noticeable decline in the average level of seismic activity in the years leading up to a major earthquake should be regarded as a potential indicator of seismic quiescence. The results of the calculation of z values in Central Sulawesi allow for the presence of earthquake precursors in the future. Earthquake fracture length is a parameter studied in seismology to determine the properties of subduction zones (Diansari & Subakti, 2015). In studying the relationship of magnitude to length, width and area of rupture statistically based on the source mechanism, namely strike slip, reverse, and normal (Wells & Coppersmith). The analysis of earthquake fracture length can be done using the Equation (7) which aims to predict the fracture length that occurred in the Donggala Regency earthquake, 28 September 2018 with a magnitude of 7.4.

Previous studies have only analyzed the phenomenon of seismic quiescence, so researchers want to analyzed statistically by knowing the precursors of earthquakes using the z-value method, then the possibility of strong earthquakes will occur in the future. In addition, finding the fracture length using the Equation (7) will help us understand the geological structure of the area where the earthquake occurred, identify other potential hazards and determine areas at high risk of damage and landslides.

The seismic quiescence phenomenon is closely related to the length of the earthquake rupture. The length of the rupture is the horizontal distance of rock displacement caused by an earthquake. The displacement occurs along the fault, which is a crack plane in the earth's crust. In areas with high complexity such as the meeting of several faults or subduction zones, the seismic quiescence phenomenon is more often observed before a major earthquake occurs. This is due to the interaction between various tectonic elements that can cause the possibility of seismic quiescence before the release of energy in the form of a major earthquake. From the calculation of the z-value in the Central Sulawesi region, the seismic quiescence phenomenon will be obtained that precedes a major earthquake. By knowing the precursors and length of the rupture, we can estimate the possibility of a major earthquake in the future.

Method

The earthquake data utilized in this study was obtained from the United States Geological Survey/National Earthquake Information Centre (NEIC/USGS) for the period from 1983-2023. The region of interest is defined by coordinates 3°30′N - 1°50′ N and 119°0′-124°20′ E. The dataset includes earthquake with magnitude of $7.4 \geq M \geq 3$ with a mb-type magnitude (magnitude body). The data was analyzed using the ZMAP version 6.0. The processing steps led to results including the z-value and the length of earthquake fractures, as illustrated in Figure 1.

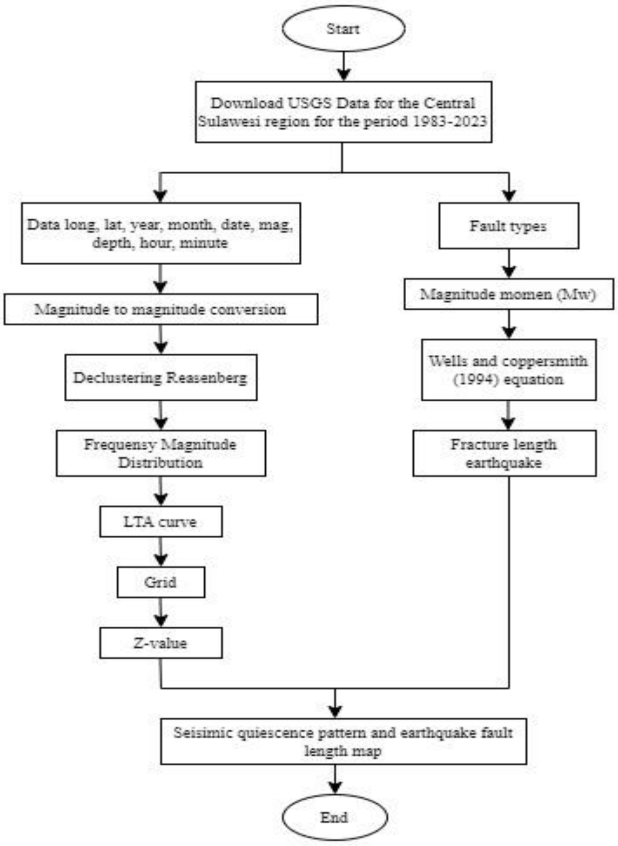


Figure 1. Data processing techniques for seismic quiescence and fracture length earthquake

Before processing the earthquake data, each earthquake's magnitude was converted due to the different magnitude types present in the dataset. Since the majority of the data was recorded with mb magnitudes, it was converted to body magnitude (Mb). Following the conversion, the data, including longitude, latitude, year, month, date, magnitude, depth, hour, and minute, was input into the ZMAP software. The next step is to separate the earthquake data to remove the effects of previous earthquakes and aftershocks. The ZMAP software then generated seismicity distribution maps for Central Sulawesi covering the period from 1983 to 2023. To obtain the a-values and b-values, the frequency distribution of magnitudes was analyzed using the z-tools menu in ZMAP. Additionally, the time series analysis menu in ZMAP was used to generate the LTA Curve (Wiener, 2001). The seismic quiescence phenomenon is analyzed using the spatial distribution z-value method (Wiemer & Wyss, 2001). Before conducting the calculation, the study area is divided into multiple grids, with each grid having a spacing of 0.1 x 0.1 units. The number of earthquake events per grid is set at 100. The Z-value is then calculated using Equation (2).

$$z(t) = \frac{(R_{bg} - R_w)}{\sqrt{\frac{S_{bg}}{n_{bg}} + \frac{S_w}{n_w}}} \tag{2}$$

Where Rbg is the average seismicity for the data outside of the selected time interval. Rw indicates the average seismicity of the selected data. Sbg is the variation over the whole period and Sw is the variation over the selected period nbg and nw are the number of events over the whole and selected periods (Ozturk & Bayrak, 2012).

The z-value calculation is performed based on the number of selected earthquakes in each node, denoted as $NZMAP$. The time period between $Tstart$ and $Tend$ is divided into $N\Delta t$ short time (ST) windows, where the width of each $N\Delta t$ is Δt. The background seismicity level is determined using Equation (3).

$$R_{bg} = \frac{1}{n_{bg}}\left(\sum_{i-1}^{N1} ni + \sum_{i=n2+1}^{N\Delta t} ni\right) \tag{3}$$

Where ni is the amount of earthquake data calculated in the ST time window and nbg in Equation (2) has the same value as $N1 + N\Delta t - N2$ is the last ST time window before entering the long-term (LT) time window, LT time window has a width Δt. The seismicity level Rw in the (LT) time window is calculated using the following Equation (4).

$$R_w = \frac{1}{nw}\sum_{i=N1+1}^{N2} ni \tag{4}$$

Where nw is defined as $\Delta T/\Delta t$, Rw is then compared to Rbg using the earlier Equation (1). The variations Sbg and Sw are calculated using Equation (5).

$$S_{bg} = \frac{1}{n_{bg}}\left\{\sum_{i=1}^{N1}\left(ni + R_{bg}\right)^2 + \sum_{i=N1+1}^{N\Delta t}\left(ni - R_{bg}\right)^2\right\} \tag{5}$$

And Equation (6).

$$S_w = \frac{1}{n_w}\left\{\sum_{i=N1+1}^{N2}(ni - R_w)^2\right\} \tag{6}$$

A positive z-value indicates a decrease in the average seismicity level during the selected interval compared to the overall average seismicity level. Conversely, a negative z-value signifies an increase in the average seismicity level within the selected interval. The larger the z-value, the more pronounced the observed difference.

The calculation to determine the length of the fault is to determine the type of fault first, then enter the earthquake magnitude data which has been converted into the Moment magnitude (Mw) using the Equation (7) [19].

$$Log\ L = (a * M_w + b) \tag{7}$$

And Equation (8).

$$L = 10^{(a*Mw+b)} \tag{8}$$

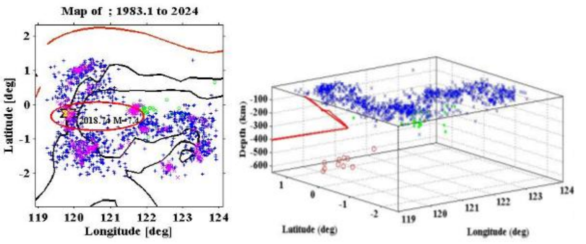
Where L is the fracture length (m), Mw is the earthquake magnitude, a and b are empirical constants that depend on the type of fault. The seismotectonic parameter b value is correlated with the length of the earthquake rupture, if the b value is low, it is associated with high stress and tends to store energy that can be released at any time in the form of a large earthquake so that it can result in an increasingly long earthquake rupture. As for the constant values of a and b, they can be determined on the type of fault in the earthquake according to the Table 1 (Woessner et al., 2011).

Table 1. Wells and Coppersmith's (1994) Constanta a and b

Fracture Parameters	**Fracture Type**	**Constanta' a**	**Constanta' b**
Fracture Length (L)	Strike Slip	0.62	-2.57
	Reverse	0.58	-2.42
	Normal	0.50	-1.88
	Oblique	0.59	-2.44

Result and Discussion

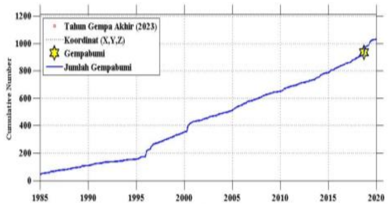
The number of earthquakes used was 1478 events from 1983 to 2023. The earthquake magnitude used is 7.4 ≥ M ≥ 3 SR with a depth of 10 ≤ D ≤ 600 km Figure 2 below illustrates the map of seismicity distribution in the Central Sulawesi region after declustering so that the number of earthquakes becomes 1156 events.



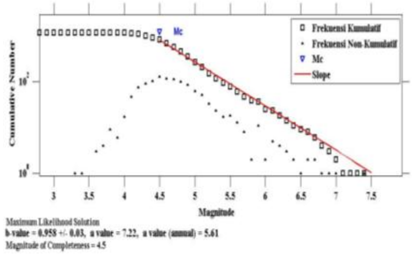
(a) (b)

Figure 2. Regional seismicity (a) seismic distribution map of central Sulawesi (b) three-dimensional variation of latitude and longitude with respect to depth

Based on Figure 2 it can be seen that the Central Sulawesi region has high seismic activity. This is indicated by the number of earthquake events scattered in the waters of Central Sulawesi and on the mainland of Central Sulawesi. Earthquakes marked in blue have a depth of D < 194.0 km, green with a depth of D < 388.1 km, and red with a depth of D < 646.8 km. Based on this figure, it can be seen that the earthquake with the largest magnitude is marked with a yellow star. Areas that have high seismic activity are seen at coordinates (0.2259° N and 119.85° E). Three-dimensional graph of latitude and longitude variations against the depth of the epicenter and hypocenter distribution map can be seen in Figure 2(b). Where it can be seen that the blue dots depict shallow earthquakes, the red dots depict deep earthquakes. Figure 2(b), illustrates that the Central Sulawesi region is dominated by shallow earthquakes. The number of earthquake occurrences in Central Sulawesi can also be illustrated using a cumulative curve, as shown in Figure 3(a). This curve represents the total number of earthquakes over time for the dataset used. The frequency-magnitude relationship shows the correlation between the magnitude and the number of earthquakes. The frequency-magnitude distribution curve for Central Sulawesi is presented in Figure 3(b).



(a)

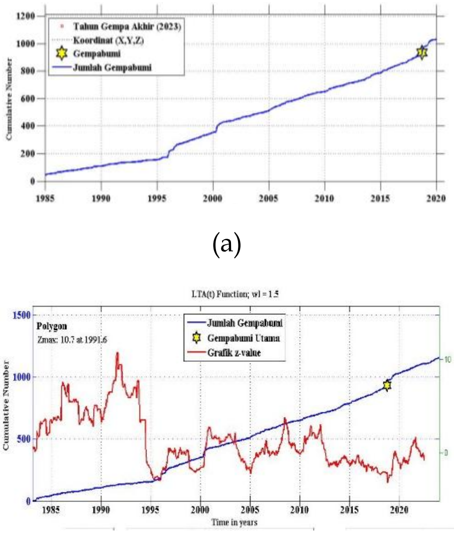


(b)

Figure 3. (a) Cumulative number curve (b) magnitude frequency distribution

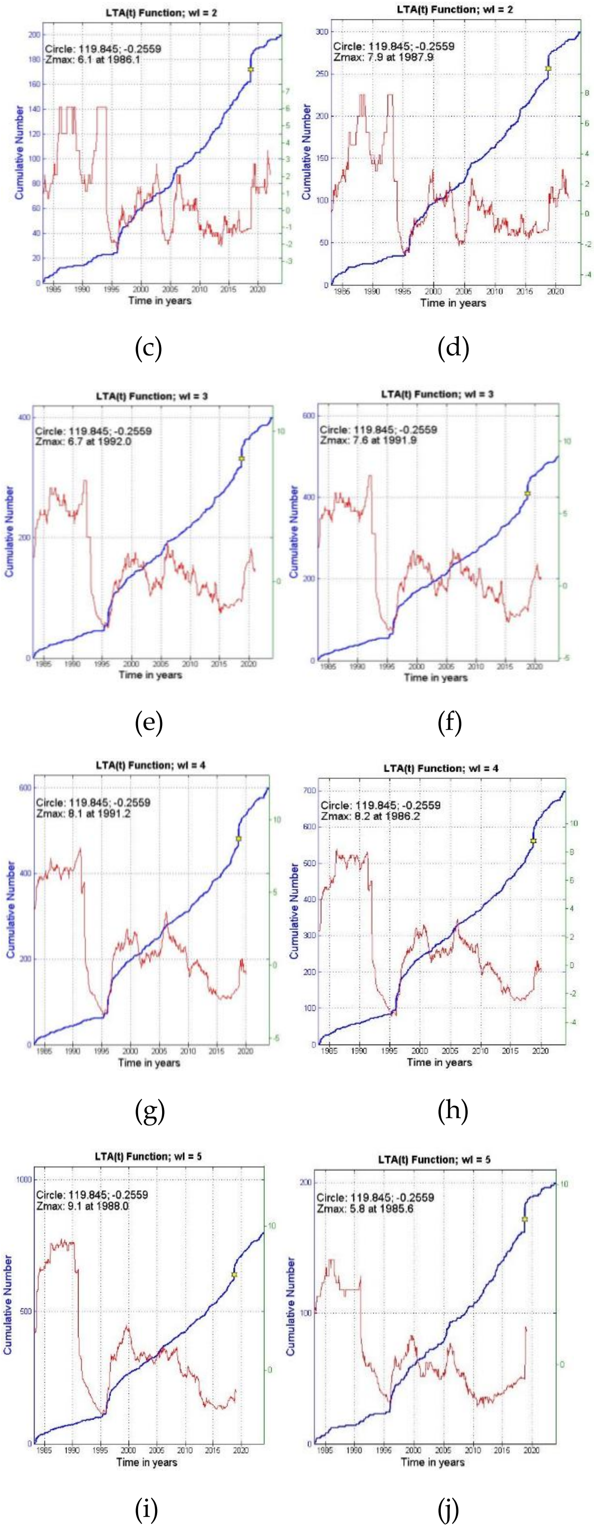
Based on the magnitude frequency distribution graph above, the greater the magnitude value, the less frequent the earthquake. The Mc value in the graph above is 4.5, which illustrates that when the magnitude is more than 4.5, the frequency of earthquake occurrence will decrease. Figure 3(b) shows a -b value of 0.958 ± -0.03, with a low b value this means that the research area has a high level of stress which means it has a high chance of large earthquakes. The value of a is 7.22, the value of an obtained shows that the Central Sulawesi region is an area with large seismic activity.

Cumulative sum curves can be used to display the total number of earthquakes over time, which gives an idea of seismic activity. To calculate the z-value, the study area is divided into several grids, each with a size of 0.1° x 0.1°. The number of earthquakes in each grid is determined (N = 800, 700, 600, 500, 400, 300 and 200) (Syaputri, 2021). The z-value was calculated on each grid based on the earthquake data included in one grid. The results of the z-value calculation on each grid can be seen in the LTA function curve to see how the change in seismic activity decreases as shown in the following Figure 4.



(a)

(b)



(c) (d)

(e) (f)

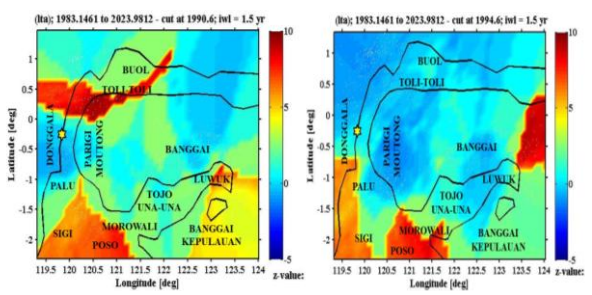
(g) (h)

(i) (j)

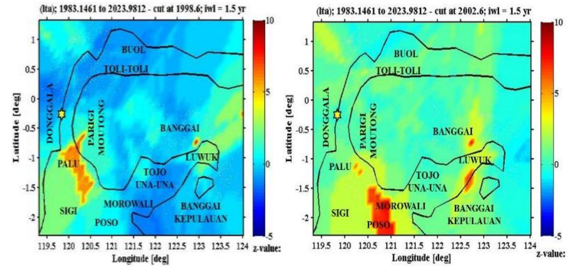
Figure 4. Cumulative number curve with z-value of LTA function for Central Sulawesi region 1983-2023. (a) Cumulative number curve against time, (b) N = 100, Tw = 1.5 years, (c) N = 200, Tw = 2 years, (d) N = 300, Tw = 2 years, (e) N = 400, Tw = 3 years, (f) N = 500, Tw = 3 years. (g) N = 600, Tw = 4 years, (h) N = 700, Tw = 4 years, (i) N = 800, Tw = 5 years, (j) N = 200, Tw = 5 years

Figure 4 illustrates the cumulative number of earthquakes in the Central Sulawesi region from 1983 to 2023. The blue line represents the cumulative earthquake count, while the yellow star marks the epicenter of a major earthquake. The figure indicates that there was no significant seismic change from 1983 to 2000, but from 2001 to 2021, there was a notable increase in seismic activity, including the significant earthquake on September 28, 2018, highlighted by the yellow star-shaped epicenter. This significant earthquake occurs due to the accumulation of energy that can trigger a significant earthquake. Figure 4(b-c) shows a plot of the cumulative number curve with the z-value of the LTA (t) function. The blue line is the cumulative number graph, the red line is the z-value graph. The maximum z-value of this function indicates the time when the seismic quiescence change starts. Based on the curve in Figure 4(b) the maximum z-value is 10.7 which occurred in 1991.6. This indicates that the time of the first significant change in seismic activity or the occurrence of the seismic quiescence phenomenon in this zone was 1991.6. The 28 September 2018 earthquake was preceded by a seismic quiescence phenomenon in 1990.6. In the research area, the seismic quiescence phenomenon occurred in 1987.3. In the earthquake on September 28, 2018 in Donggala, the seismic quiescence phenomenon occurred about 21 years earlier.

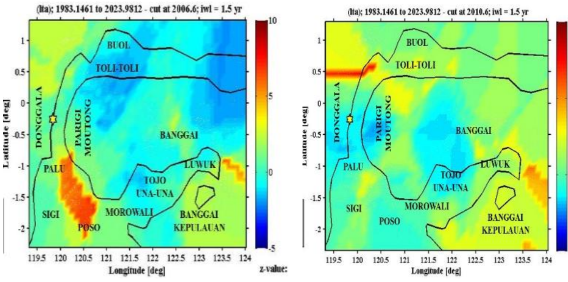
The spatial distribution of z-values in the Central Sulawesi region for the 28 September 2018 earthquake with magnitude M7.4 and after the 28 September 2018 earthquake can be seen in Figure 5.



(a) (b)



(c) (d)



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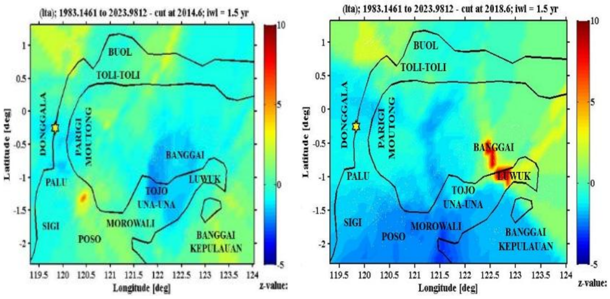
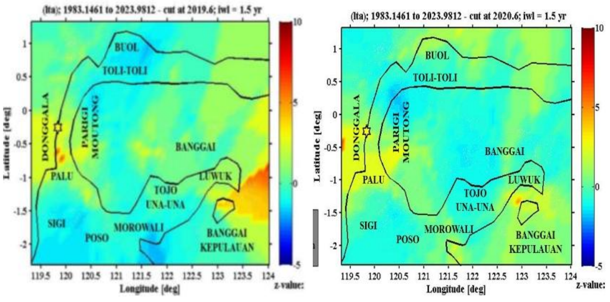
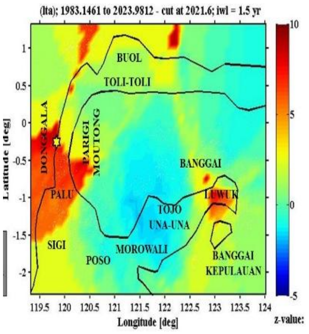


(g) (h)



(i) (j)



(k)

Figure 5. Spatial distribution of z-value with iwl= Tw 1.5 years (a) cut at 1990.6, (b) cut at 1994.6, (c) cut at 1998.6, (d) cut at 2002.6, (e) cut at 2006.6, (f) cut at 2010.6, (g) cut at 2014.6, (h) cut at 2018.6, (i) cut at 2019.6, (j) cut at 2020.6, (k) cut at 2021.6

Figure 5 shows the spatial distribution of z-value in the Central Sulawesi region before the significant earthquake event on 28 September 2018 with a magnitude of 7.4 and after the significant earthquake event on 28 September 2018. The spatial distribution of z-value is shown in several times, starting from cut at 1990.6, 1994.6, 1998.6, 2002.6, 2006.6, 2010.6, 2014.6, 2018.6, 2019.6, 2020.6, and 2021.6 with Tw iwl = 4 years before the 2018 earthquake and Tw iwl = 1 year after the 2018 earthquake. Positive z-values marked in red represent a decrease in seismic activity (seismic quiescence), while negative z-values marked in blue represent an increase in seismic activity. Based on Figure 5 which shows the spatial distribution of z-values in this research zone, the 28 September 2018 earthquake event with M7.4 was preceded by a seismic quiescence phenomenon. The beginning of the seismic quiescence phenomenon in this zone was seen when the cut at 1990.6. The 2018 earthquake event was preceded by a seismic quiescence phenomenon in 1990.6 about 21 years before the 2018 earthquake.

However, around the cut-off point of 2010.6, approximately 8 years prior to the 2018 earthquake, there was an increase in seismic activity near the mainshock due to the gradual release of energy on a smaller scale. This rise in activity peaked with the 28 September 2018 earthquake. Following this event, at the cut-off point of 2019.6, seismic activity declined once more. According to data from the United States Geological Survey (USGS), the magnitude of the main earthquake in Central Sulawesi on 28 September 2018 was 7.4, centered in Donggala Regency.

There are different types of faults, including horizontal and thrust faults. The earthquake in question occurred along the Palu-Koro Fault, which is classified as a strike-slip fault. This classification is based on the criteria established by Equation (7), as outlined in Table 1. the constant values a and b for the shear fault movement mechanism with a value of 0.62 while for the value of b is -2.57, so if entered into the Equation (7) the length of the earthquake fault is 104.232 meters from the main earthquake epicenter. So, the fracture length (L) value obtained is 104.232 meters from the epicenter of the earthquake in the Central Sulawesi region on September 28 2018, which is precisely in Donggala Regency based on Figure 6.

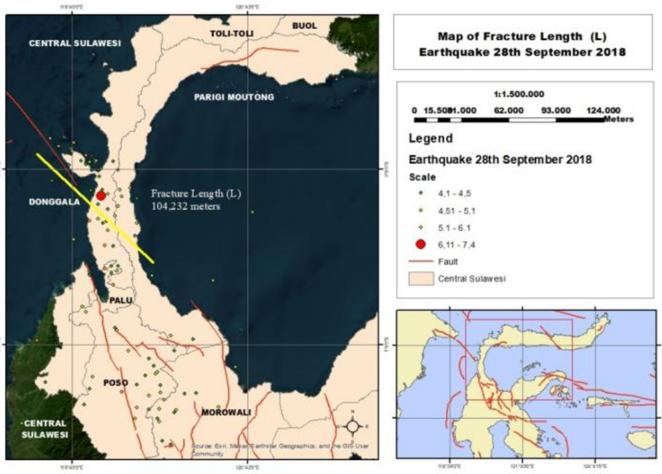


Figure 6. Map of fracture lengths for the September 28 2018 earthquake

Based on Figure 6 the Equation (7), the value of the length of the fault in the earthquake in Donggala Regency, Central Sulawesi on 28 September 2018 was 104.232 meters from the epicenter with a magnitude of 7.4. This indicates a positive correlation between earthquake magnitude and fracture length. The length of these fractures indicates significant movement along the Palu-Koro fault, the main fault in the region. The elongated fractures have the potential to cause extensive surface deformation and contribute to the secondary phenomena of liquefaction and tsunami. From the Figure 6 it is obtained that the greater the magnitude of the earthquake, the longer the crack or earthquake fault. This is in accordance with Equation (7), which states that fault magnitude and type are very influential in determining fault length and seafloor displacement based on known magnitude. In addition, this equation also states that the greater the potential maximum magnitude that will occur, the longer the time required for the earthquake to recur and the longer the resulting earthquake fractures will be. The length of these fractures can affect the precursor seismic quiescence before a major earthquake occurs. When there is a decrease in seismic activity, this indicates an accumulation of energy in the study area. Meanwhile, if there is an increase in seismic activity, this is due to the accumulation of energy that is released in the form of smaller earthquakes.

The study of fracture length using the Equation (7), which has global applicability with certain limitations, supports the findings of a previous analysis of the Central Sulawesi earthquake fracture length based on SAR and optical data. This earlier study, constrained by satellite coverage and the need for pre- and post-earthquake data, identified a maximum slip of approximately 6 meters near Palu City. It also found an average slip difference of about 1.9 meters between the unmapped northern segment and the known southern segment, which is 4.7 kilometers from the Palu-Koro Fault. Consequently, the seismic events indicate that the most significant seismic slip occurs along the southern sector of the Palu-Koro Fault south of Palu, while the northern segment has smaller values (Polcari et al.,2019).

Areas with decreased seismic activity are associated with a positive z-value, which signifies the accumulation of energy in the region. This positive z-value indicates that the stress in the rock has not yet reached the threshold to be released, leading to energy build-up. In contrast, areas with increased seismic activity are characterized by a negative z-value, reflecting energy release. This release occurs when the stress in the rock exceeds its capacity, causing a fault. As a result, the region experiences heightened seismic activity and a gradual release of energy. A complete rise in seismic activity suggests a sudden release of substantial energy, resulting in large-scale magnitudes.

So, this related to the area that experiences energy collection and cooling before the release of energy in a large earthquake. On longer faults, the process of energy accumulation and termination occurs over a wider area, so the possibility of seismic quiet in that area is greater. The spatial distribution of seismotectonic such as patterns, subduction zones and tectonic plate boundaries can influence the generation of seismic quiescence. In areas with the high tectonic complexity, such as the intersection of several faults or subduction zones, calm phenomena are more often observed before large earthquake occur. This matter caused by interactions between various tectonic elements which can cause energy to accumulate, thereby increasing the possibility of seismic quiescence before the release of energy in the form a large earthquake.

Earthquake events are usually by fracture length around the main earthquake area. There is a linear relationship between earthquake magnitude and fracture length. The relationship between fracture length and magnitude, where the greater the magnitude value, the longer the fracture in the earthquake. This is in accordance with the experts' statement that the greater the return period of an earthquake, the greater the magnitude of the earthquake that will occur as well as the fracture length of the earthquake. If depicted in a graph with the x-axis as fracture length (L), and the y-axis as magnitude (Mw), the empirical data on the length of the fracture and the magnitude of the earthquake will form a straight line with a slope determined by the constant value then the intersection point with the y-axis is determined by the constant a value.

Conclusion

Earthquakes in the Central Sulawesi region from 1983 to 2023 using the z-value method indicates high seismic activity, with numerous earthquake events both in the waters and on the land of Central Sulawesi. Research on seismic quiescence, based on the cumulative number curve, reveals that there was no significant change in seismic activity from 1983 to 2000. However, from 2001 to 2021, there was a notable increase in seismic activity. The maximum z-value in this study area was recorded in 1991.6, with a Zmax of 10.7. Prior to the 2018 earthquake, the z-value analysis using the LTA N = 800 Tw = 2 functions identified a seismic quiescence phenomenon in 1987.3, with a z-value of 8.1, approximately 21 years before the September 28, 2018 earthquake. The spatial distribution of z-values, cut at 2019.6, showed another significant decrease in seismic activity, which could indicate potential future earthquakes. In addition, the fracture length in the M7.4 earthquake in Central Sulawesi on 28 September 2018 showed a positive correlation between earthquake magnitude and fracture length.

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