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Comparison of Seismicity Between the Subduction Zone and Local Fault Zone in the Bali Island Region During the 1963–2023 Period Using the Likelihood Method

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Abstract: Research has been conducted on the comparison of seismicity between the subduction zone and the local fault zone in the Bali Island region during the 1963–2023 period. This research aims to compare the *b-value*, *a-value*, seismicity index, and earthquake recurrence period between the subduction zone and the local fault zone. The research was conducted within the observation boundaries of 114,4°–115,7° East Longitude and 11,4°–8,8° South Latitude. The research was carried out at the Center for Meteorology, Climatology, and Geophysics Region III Denpasar using the likelihood method for earthquakes with magnitude ≥ 3,3. The data used were obtained from the official websites of the USGS (United States Geological Survey) and BMKG, with depths ≤ 600 km for the subduction zone and depths ≤ 35 km for the local fault zone. The results show that the subduction zone has a *b-value* of 0,534 and an *a-value* of 4,599, while the local fault zone has a *b-value* of 0,829 and an *a-value* of 5,087. The seismicity index in the subduction zone ranges from 0,289–13,046 with an earthquake recurrence period of 0,077–3,459 years. Meanwhile, in the local fault zone, the seismicity index ranges from 0,126–8,366 with an earthquake recurrence period of 0,212–7,949 years. Earthquake distribution is dominated in the subduction zone at 82,63% compared to the local fault zone at 17,37%.

Keywords: seismicity; recurrence period; likelihood method; subduction zon;, local fault zone.

Introduction

Geographically, Indonesia is an archipelagic country located at the meeting point of three tectonic plates: the Eurasian plate moving eastward, the Pacific plate moving westward, and the Indo-Australian plate moving northward towards Indonesia (Sulistyo, 2021). The movement of these plates causes frequent natural disasters in Indonesia, particularly earthquakes ranging from small to large magnitudes (Cahyaningsih, L., 2021).

The sources of seismic activity in Bali originate from both the subduction zone and local fault zones. The subduction zone is an area where one tectonic plate is being forced beneath another, often resulting in large earthquakes due to the pressure and friction at the plate boundary. In addition, there are local fault zones, which include shallow and active fault lines on the Earth's crust. Movement along these faults can generate small to moderate earthquakes (Yuliana, 2022).

Historically, Bali has experienced a significant earthquake with a magnitude of 6,2 in 1976, known as the Seririt Earthquake. This event caused the destruction of more than 1.500 buildings, with around 573 people killed and thousands more injured or displaced. Furthermore, Bali has experienced other significant earthquakes, such as the Karangasem

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Earthquake in 2019, which caused minor damage; the Karangasem Earthquake in 2021, which killed 3 people and damaged dozens of buildings; and the Gianyar Earthquake in 2024, which resulted in minor damage but no fatalities (BMKG, 2023).

To minimize the hazards caused by earthquakes, mitigation efforts are necessary, one of which is estimating the recurrence period of earthquakes that have the potential to cause damage. One method that can be used to calculate earthquake activity parameters is the likelihood method. The likelihood method is used to calculate the seismic activity parameters statistically (Budiman, 2019). With this method, the level of earthquake activity can be determined quantitatively through the Gutenberg-Richter equation, seismicity index, and earthquake recurrence period for specific magnitudes in a region (Widyaningrum, A., 2020). The earthquake recurrence period is the estimated average time between occurrences of earthquakes with a certain magnitude in a given area. The value of the earthquake recurrence period can be used to estimate the frequency of earthquakes with a specific magnitude occurring within a certain period (Rohadi, 2021).

Method

This research was conducted at the Center for Meteorology, Climatology, and Geophysics Region III Denpasar. The data used in this study are earthquake data from the Bali Island region during the period 1963–2023. After the data was obtained, it was classified based on the earthquake source. For the subduction zone, earthquakes with magnitude (M) ≥ 3,3 and depth ≤ 600 km were considered, with geographical coordinates of 114,4° – 115,7° East Longitude and 11,4° – 8,8° South Latitude. For the local fault zone, earthquakes with magnitude (M) ≥ 3,3 and depth ≤ 35 km were used, with geographical coordinates of 114,4° – 115,7° East Longitude and 8,8° – 7,9° South Latitude. From this data, the *b-value* and *a-value* were calculated. The calculation begins by determining the *b-value* using Equation 1 (Septiani, 2021):

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

Subsequently, the *a-value* calculation was performed using Equation 2 (Septiani, 2021):

$$a = \log N + \log (b \ln 10) + M_0 b \quad (2)$$

After obtaining the *b-value* and *a-value*, the seismicity index calculation was then continued using Equations 3, 4, and 5 (Rahmatulloh, 2022):

$$a' = a - \log (b \ln 10) \quad (3)$$

$$a_1' = a' - \log T \quad (4)$$

$$N(M) = 10^{a_1' - bM} \quad (5)$$

Following this, the earthquake recurrence period was calculated using Equation 6 (Rohadi,2021):

$$\Theta = \frac{1}{N(M)} \quad (6)$$

Subsequently, the distribution percentage between the subduction zone and the local fault zone was calculated using Equations 7 and 8 (Hanel, 2019):

$$P_s = \frac{N_s}{N_t} \times 100\% \quad (7)$$

$$P_z = \frac{N_z}{N_t} \times 100\% \quad (8)$$

Results and Discussion

This study uses secondary data. The map of Bali Island was then classified into two regions based on the earthquake source, namely the subduction zone and the local fault zone. Figure 1 shows the distribution of earthquake events occurring in the subduction zone of Bali Island, with geographical coordinates of 114,4° – 115,7° East Longitude and 11,4° – 8,8° South Latitude. A total of 561 earthquake events were recorded during the period 1963–2023, with magnitudes M ≥ 3,3.

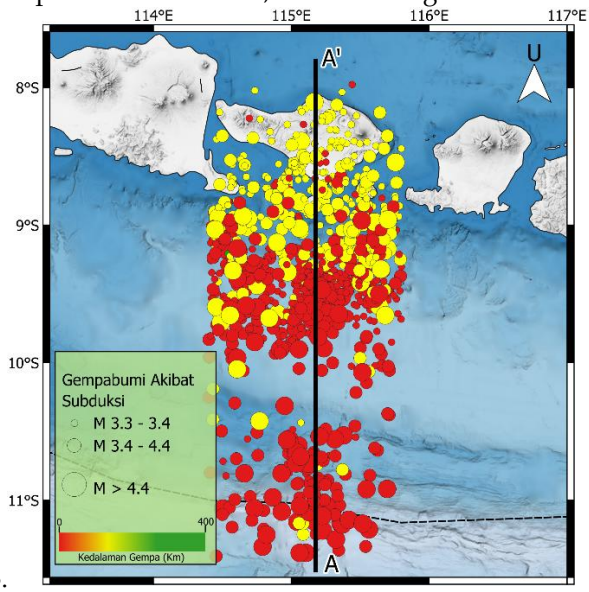

Figure 1. Map of the subduction zone.

Figure 2 shows the distribution of earthquake events occurring in the local fault zone of Bali Island, with geographical coordinates of 114,4° – 115,7° East Longitude and 8,8° – 7,9° South Latitude. A total of 118 earthquake events were recorded during the period 1963–2023, with magnitudes M ≥ 3,3.

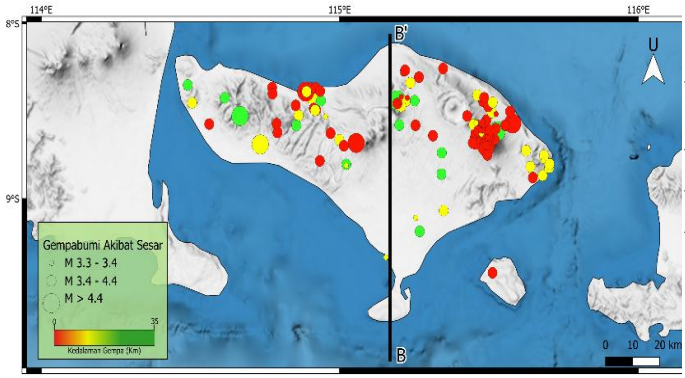

Figure 2. Map of the local fault zone

The results of the calculation of the *b-value*, *a-value*, seismicity index, and earthquake recurrence period using the likelihood method are presented in Table 1 and Table 2.

Table 1. Calculation results for the subduction zone

Subduction Zone					
M	*b*	*a*	(N(M))	(θ)	(%)
3,3			13,046	0,077	
3,4			11,538	0,087	
3,5			10,204	0,098	
3,6			9,024	0,111	
3,7			7,98	0,125	
3,8			7,057	0,142	
3,9			6,241	0,16	
4			5,519	0,181	
4,1			4,881	0,205	
4,2			4,317	0,232	
4,3			3,818	0,262	
4,4			3,376	0,296	
4,5			2,986	0,335	82,622
4,6	0,534	4,599	2,64	0,379	
4,7			2,335	0,428	
4,8			2,065	0,484	
4,9			1,826	0,548	
5			1,615	0,619	
5,1			1,428	0,7	
5,2			1,263	0,792	
5,3			1,117	0,895	
5,4			0,988	1,012	
5,6			0,773	1,294	
5,7			0,683	1,464	
5,9			0,534	1,871	
6			0,473	2,116	
6,1			0,418	2,393	
6,2			0,37	2,706	
6,4			0,289	3,459	

Table 2. Calculation results for the local fault zone

Local Fault Zone					
M	*b*	*a*	(N(M))	(θ)	(%)
3,3			4,72	0,212	
3,4			3,9	0,256	
3,5			3,223	0,31	
3,6			2,663	0,376	
3,7			2,201	0,454	
3,8			1,818	0,55	
3,9			1,503	0,666	
4	0,829	5,087	1,242	0,805	17,379
4,1			1,026	0,975	
4,2			0,848	1,18	
4,3			0,7	1,428	
4,4			0,579	1,728	
4,6			0,395	2,53	
4,7			0,327	3,062	
4,9			0,223	4,485	
5,2			0,126	7,949	

The b-value, a key parameter in the Gutenberg-Richter relationship, describes the relative proportion of small to large earthquakes and is closely related to the geological and tectonic conditions of a region. In this study, the b-value for the subduction zone is 0,534 indicating that the region is dominated by medium to large-magnitude earthquakes, with stronger rock structures and higher stress accumulation. In contrast, the local fault zone exhibits a b-value of 0,829 reflecting more frequent occurrences of small earthquakes due to more brittle rock formations. These findings are in line with the study by Handayani et al. (2020), which stated that subduction zones often generate stronger earthquakes due to prolonged tectonic stress buildup, while local fault zones tend to release energy more frequently but in smaller magnitudes.

The a-value, which reflects the overall seismic activity level, was found to be 4,599 in the subduction zone and 5,087 in the local fault zone. Although fewer earthquake events were recorded in the local fault zone, the higher a-value suggests a denser frequency of seismic events within that area, highlighting a more active but low-magnitude seismic environment. This is consistent with the findings of Sari et al. (2020), who reported that active local faults can generate swarms of small earthquakes due to unstable fracturing behavior.

The seismicity index and recurrence period were calculated to understand the yearly frequency of earthquakes of different magnitudes. The seismicity index in the subduction zone ranges from 0,289 to 13,046 whereas in the local fault zone, it ranges from 0,126 to 8,366. Meanwhile, the recurrence period in the subduction zone ranges from 0,077 to 3,459 years, and in the local fault zone, from 0,212 to 7,949 years. The shorter recurrence period and higher index in the subduction zone indicate that despite a lower b-value, earthquakes of significant magnitude occur more frequently. This relationship demonstrates the higher potential hazard posed by subduction zone activity. As Indri (2021) suggests, tectonic zones with higher seismic energy release tend to have shorter recurrence intervals, making them more critical in hazard assessments.

Lastly, the distribution percentage of seismic activity highlights the dominant role of the subduction zone in the overall seismicity of Bali Island. The subduction zone accounts for 82,622% of seismic activity, while the local fault zone contributes 17,379%. This supports the understanding that Bali's seismic hazard is primarily influenced by subduction-related tectonic processes. The convergence between the Indo-Australian and Eurasian plates, forming the Sunda Arc, plays a major role in generating intense seismic activity in this region (Priadi & Arifin, 2017).

Conclusion

Based on the results and discussion of the study, the following conclusions were drawn: 1) In the subduction zone, the *b-value* is 0,534, and in the local fault zone, it is 0,829, which indicates that in the subduction zone, the rocks tend to be strong and capable of storing energy for a long period, leading to earthquakes with moderate to large magnitudes. In contrast, the local fault zone shows that the rocks are more fragile and release energy more easily, resulting in earthquakes with smaller magnitudes but occurring more frequently. The *a-value* in the subduction zone is 4,599, and in the local fault zone, it is 5,087, indicating that the local fault zone has a higher level of seismic activity compared to the subduction zone. The seismicity index in the subduction zone ranges from 0,289 to 13,046, with earthquake recurrence periods ranging from 0,077 to 3,459 years. In the local fault zone, the seismicity index ranges from 0,126 to 8,366, with recurrence periods ranging from 0,12 to 7,949 years; 2) The calculation of the distribution percentage of seismic activity shows that 82,622% of the seismic activity occurs in the subduction zone, while 17,379% occurs in the local fault zone. This indicates that the subduction zone is the primary source of seismic activity in Bali Island.

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