Geosfera: Jurnal Penelitian Geografi (GeoJPG)
Vol. 4.No. 2 Desember 2025, Hal.532-542
DOI: https://doi.org/10.37905/geojpg.v4i2.36433

p - ISSN: 2962-5424
e - ISSN: 2962-5416

Correlation Between Seismicity Rates and Earthquake Return Periods in the Southern Offshore of West Java, Indonesia

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Diterima: 9-11-2025 **Disetujui: 11-12-2025** **Publish: 12-12-2025**

Abstract *The Indian Ocean region south of Java constitutes a highly active seismic zone dominated by the subduction of the Indo-Australian plate beneath the Eurasian plate. This study investigates the seismicity parameters (a-value and b-value) using the Gutenberg-Richter law and estimates the return periods of significant earthquakes. Analyzing earthquake catalog data covering a span of 53 years, we identified the Magnitude of Completeness (Mc) and calculated frequency-magnitude distributions. The results reveal a b-value of 1.17, indicating a region characterized by high material heterogeneity and complex stress release mechanisms. Furthermore, the probabilistic return period for a magnitude 6.5 earthquake is estimated to be approximately 19.24 years. These findings suggest that while the region exhibits frequent moderate-magnitude energy release, the potential for destructive tsunamigenic events remains significant, necessitating robust hazard mitigation strategies for the southern coast of Java.*

Keywords: *Seismicity; Gutenberg-Richter; Return Period; Indian Ocean; South Java; Seismic Hazard*

1. INTRODUCTION

Indonesia is situated at the dynamic intersection of three major global tectonic plates the Indo-Australian, Eurasian, and Pacific plates creating one of the most seismically complex and active regions globally. Within this archipelago, the southern region of Java Island is particularly critical due to its proximity to the Java Trench, a deep-sea trench that marks the convergent boundary where the oceanic Indo-Australian plate subducts beneath the continental Sunda Block (part of the Eurasian plate). This subduction occurs at a convergence velocity of approximately 6–7 cm/year (Koulali et al., 2016), driving a continuous and rapid build-up of tectonic stress. The mechanical coupling along this subduction interface is governed by friction; specific segments or asperities become locked, preventing aseismic slip and causing the accumulation of significant elastic strain over decades (PUSGEN, 2017). When the accumulated stress eventually exceeds the frictional strength of the fault plane, the locked sections rupture, releasing the stored energy as powerful earthquakes. Historically, this zone has demonstrated its capacity for destruction through events such as the 1994 Banyuwangi earthquake (*Mw* 7.8) and the 2006 Pangandaran earthquake (*Mw* 7.7). Crucially, these events were identified as tsunami earthquakes, characterized by slow rupture velocities that generate destructive tsunamis disproportionate to the felt ground shaking (Goro et al, 2024). This specific characteristic highlights the immense and often underestimated seismic hazard facing the densely populated and economically vital coastal areas of Southern Java (Firdaus et., al., 2023).

To effectively mitigate future risks and refine Probabilistic Seismic Hazard Assessment (PSHA) models, a robust understanding of the statistical properties governing seismicity is essential. Among the various statistical models, the temporal and spatial distribution of earthquakes is most universally described by the Gutenberg-Richter (G-R) power law. This relationship is mathematically expressed as $log10N = a - bM$, where N represents the cumulative number of seismic events with a magnitude greater than or equal to M (Gutenberg & Richter, 1944). In this equation, the constant a quantifies the seismic productivity or the overall rate of seismicity within the studied volume and time window. However, the slope of this relationship, known as the *b*-value, serves as the most critical physical parameter in seismotectonics. The *b*-value acts as a stress meter for the earth's crust, correlating inversely with differential stress levels (Scholz, 2019). Laboratory experiments and field observations suggest that variations in *b* are driven by the heterogeneity of the rock material and the applied shear stress (Shearer, 2019). A lower *b*-value (typically < 1.0) indicates high stress accumulation and increased material homogeneity, conditions often found in locked fault zones or major asperities capable of generating megathrust earthquakes (Rosalia et al, 2021). Conversely, a higher b-value (> 1.0) is frequently associated with regions of lower stress, high structural heterogeneity, or the presence of high pore fluid pressure. Consequently, mapping the spatial variation of *b*-values allows for the identification of creeping sections versus locked patches, providing vital clues about the nucleation potential of future large-scale ruptures (Wandono et al, 2023).

The Java subduction zone has been the subject of extensive geophysical investigations aimed at unraveling its complex seismotectonic behavior. Pioneering work by Chang et al. (2005) analyzed the spatial and temporal variations of *b*-values across the entire Sumatra-Java arc. Their findings revealed distinct segmentation along the trench, identifying specific zones of anomalously low *b*- values which were interpreted as indicators of high stress accumulation and potential asperities for future rupture. Building on this, Widiyantoro et al. (2020) utilized gap analysis combined with GPS data inversion to propose potential tsunamigenic scenarios for South Java. Their study highlighted a concerning deficit in seismic energy release, suggesting that a seismic gap exists off the coast of Java which could host a megathrust event of magnitude up to *Mw* 9.1, potentially generating tsunamis exceeding 20 meters in height. Complementing these hazard assessments focused on the structural geometry of the subduction zone by employing double-difference algorithms to relocate earthquake hypocenters (Alfaris, et.al., 2022). This relocation provided a sharper resolution of the dipping Indo- Australian slab, essential for distinguishing between interface megathrust events and deeper intraslab earthquakes (Prihatini, 2025). While these studies provide a robust scientific foundation, earthquake catalogs are inherently dynamic datasets. The seismic cycle evolves continuously, and the stress regime may shift following significant ruptures or aseismic slip events. Consequently, continuous updating of statistical analyses using the most recent data is imperative to capture the evolving state of the subduction interface and to refine return period estimates (Romli, 2022).

Most previous statistical analyses characterizing the Java subduction zone have relied on earthquake catalogs with temporal cutoffs around 2015 or 2018. While valuable, these studies offer a snapshot of the seismogenic state that may no longer accurately reflect the current tectonic conditions. The seismic cycle is inherently dynamic; recent moderate-to-strong seismic activity in the Indian Ocean south of Java suggests potential shifts in the local stress regime, possibly influenced by stress transfer mechanisms or post-seismic relaxation following ruptures in adjacent segments . This study distinguishes itself by utilizing a comprehensively updated earthquake catalog that extends the observational window up to 2024. By incorporating the most recent five years of seismic data, we capture crucial fluctuations in seismicity rates that older catalogs inevitably miss. This temporal extension allows for a more robust and current assessment of the seismicity parameters *a* and *b* values), effectively minimizing epistemic uncertainties associated with data completeness. Consequently, this research offers a significantly refined estimation of the probabilistic recurrence intervals for large-magnitude earthquakes. Such precision is critical for calibrating dynamic seismic hazard maps and ensuring that disaster risk reduction strategies are grounded in the most up-to-date geophysical evidence available (Siagian, 2023).

The primary objectives of this article are threefold, structured to provide a comprehensive and up- to-date assessment of the seismic hazard in this critical subduction zone. First, we aim to rigorously determine the Magnitude of Completeness (*Mc*) and the fundamental seismicity parameters specifically the *a*-value and *b*-value for the Indian Ocean sector south of Java (Marliyani, et al, 2016). By utilizing the most recent available data extending through 2024, this study ensures that the derived statistical models are robust, minimizing the epistemic uncertainties often introduced by catalog incompleteness or outdated temporal windows. Second, we seek to deeply analyze the tectonic implications of the calculated *b*-value in relation to the current stress state of the subduction interface. This involves interpreting the *b*-value not merely as a statistical constant, but as a physical proxy for crustal heterogeneity and differential stress, thereby allowing us to infer whether specific segments are accumulating strain (locked) or releasing energy aseismically creeping. Third, we intend to estimate the probabilistic return periods for moderate to large magnitude earthquakes (M ³ 6.0). This predictive component is crucial for translating statistical parameters into actionable temporal forecasts. Ultimately, the results derived from these objectives are intended to serve as a vital scientific reference for disaster mitigation strategies and infrastructure planning along the southern coast of Java, specifically contributing to the refinement of regional seismic hazard maps and the strengthening of building resilience standards.

2. METHODS

2.1. Study Area

The research focuses on the seismically active offshore region of the Indian Ocean, situated directly south of the Java Island coastline, which constitutes a critical and high-risk segment of the Sunda Arc subduction system. The geographical boundaries of the study area are strictly defined by coordinates 7.53 S to 9.23 S and 104.04 E - 109.07 E. These spatial limits were meticulously selected to comprehensively capture the full kinematic profile of the convergent margin, spanning from the undeformed oceanic lithosphere in the south to the coastal fore-arc region in the north. This domain encompasses a series of distinct morphological and tectonic features that control the regional seismogenesis. The most prominent feature is the Java Trench, reaching depths exceeding 6,000 meters, which marks the surficial trace of the subduction zone where the Indo-Australian plate begins its descent beneath the Eurasian plate. North of the trench lies the accretionary prism, a zone of intense deformation and sediment accumulation and the fore-arc basin, a sedimentary depression that separates the prism from the volcanic arc.

Collectively, these features represent the primary nucleation zones for interplate seismicity, where significant elastic strain is accumulated due to plate coupling. The chosen spatial extent facilitates a dual-purpose analysis: it allows for a detailed examination of the stress accumulation processes along the shallow megathrust boundary (responsible for tsunamigenic earthquakes) as well as the deeper intraslab events occurring within the steeply dipping Benioff zone beneath Java. Intraslab earthquakes in this region are particularly hazardous due to their potential to cause widespread ground shaking on the island. By covering this transition from the shallow trench interface to the intermediate-depth slab, the study aims to characterize the full spectrum of seismic hazards in the region, providing insights into both tsunami generation potential and ground motion amplification risks. The spatial distribution of the seismicity analyzed in this study is visualized in Figure 1.

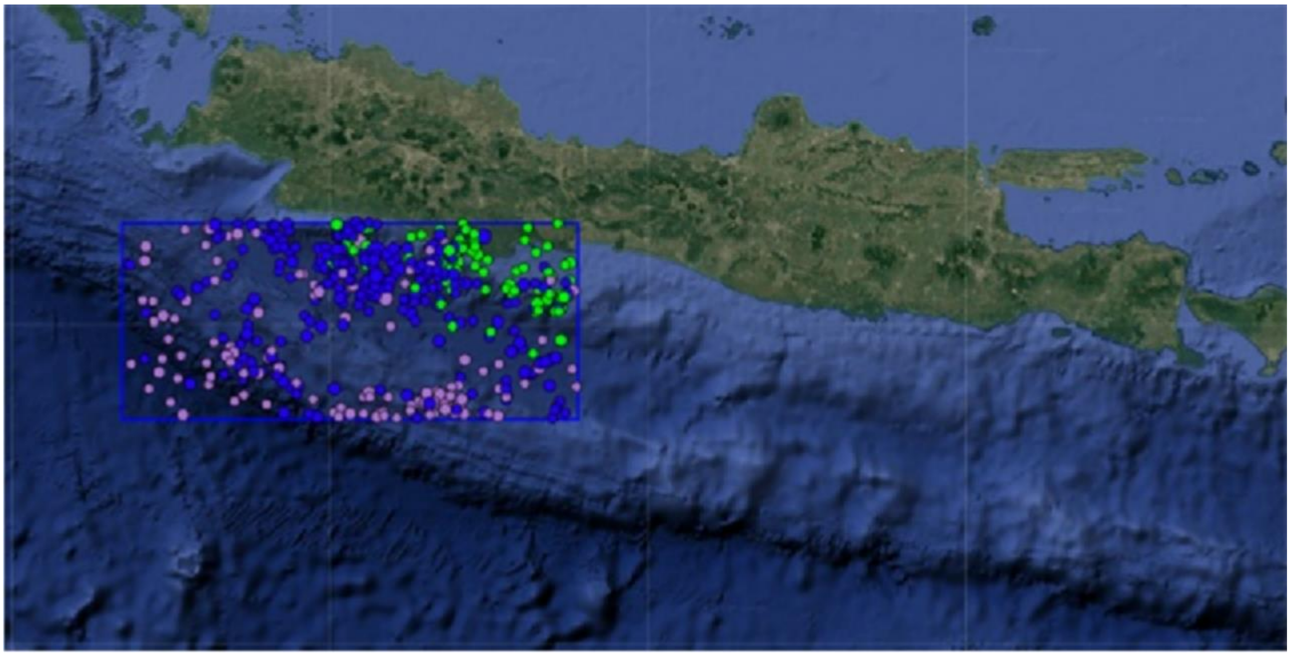

Figure 1. Study area (source : IRIS, 2025)

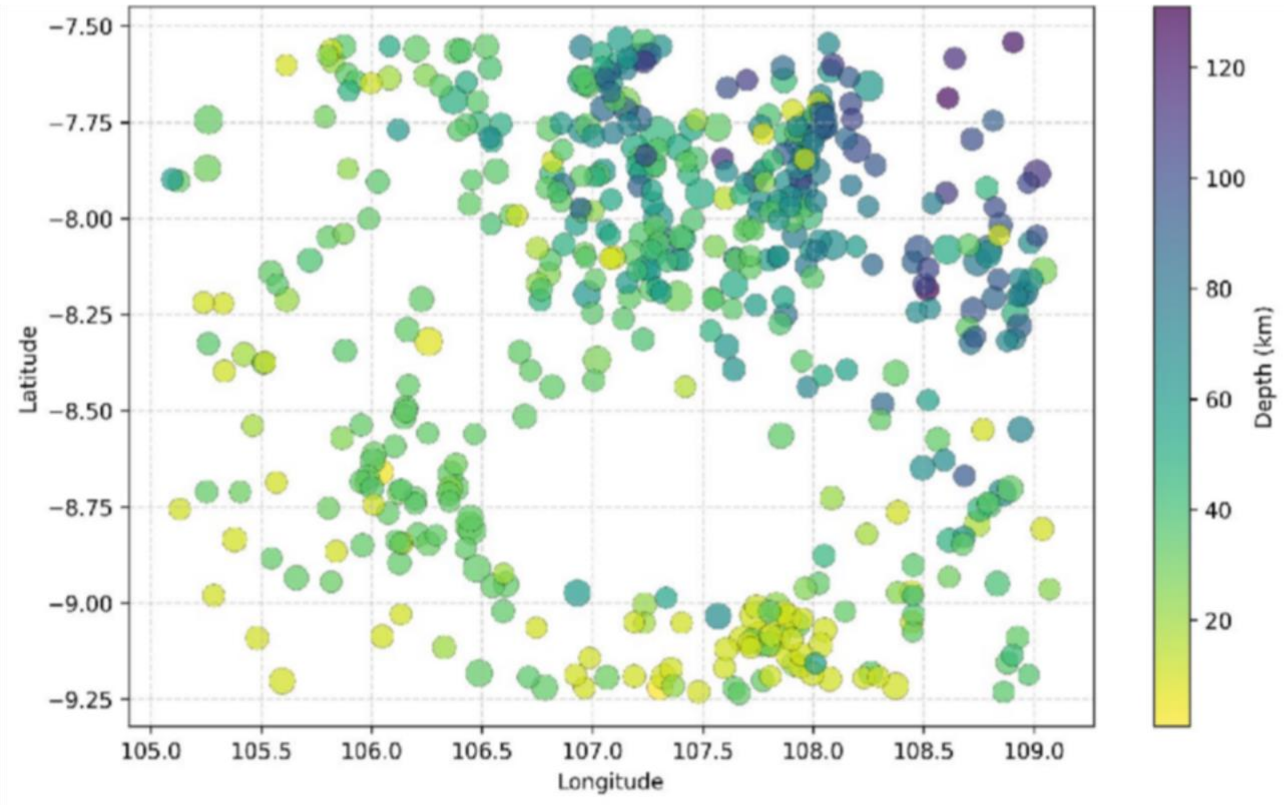

Figure 2: Seismicity map of the Indian Ocean South of Java. The color scale represents the focal depth (km), and the circle size corresponds to the earthquake magnitude.

2.2. Data Acquisition

The primary dataset used in this study is a compiled earthquake catalog covering a duration of approximately 53 years. The data was compiled from available earthquake repositories from USGS catalogs, capturing significant seismic events in the region. The catalog includes the following parameters for each event: Origin time (UTC), Epicentral coordinates (Latitude and Longitude), Focal depth (km), Magnitude (*M*). To ensure data quality, the catalog was pre-processed to remove duplicate entries and events with incomplete parameter fields. The dataset focuses on shallow to intermediate-depth earthquakes, which are most relevant for tsunamigenic potential and surface ground shaking.

2.3. Magnitude of Completeness (*Mc*)

A fundamental prerequisite for any robust statistical seismology analysis is the accurate determination of the Magnitude of Completeness (*Mc*). Theoretically, *Mc* represents the threshold magnitude above which the seismic network detects 100% of the events occurring within the monitored space-time volume (Apriyanti et.al ,2025). Below this threshold, the catalog is considered incomplete due to the limited sensitivity of seismographs, signal attenuation, and ambient noise levels, which obscure smaller seismic signatures. Failing to properly define and apply this cutoff results in a departure from the log-linear behavior predicted by the Gutenberg-Richter law. Specifically, the inclusion of incomplete data ($M < Mc$) artificially flattens the frequency-magnitude distribution curve, leading to a systematic underestimation of the *b*-value. Such bias can severely distort seismic hazard assessments by misrepresenting the relative proportion of large-to-small earthquakes (Daryono et.al, 2019).

In this study, the Mc was estimated using the Maximum Curvature (MAXC) method (Wiemer & Wyss, 2000), which is widely favored for its stability and non-parametric nature. This technique identifies *Mc* as the magnitude bin corresponding to the maximum value of the first derivative of the frequency-magnitude curve—or, more simply, the magnitude bin with the highest frequency of events (the mode) in the non-cumulative distribution plot. By strictly filtering the dataset to include only events where *M* ³ *Mc*, we ensure that the subsequent regression analysis to determine the *a* and *b* values is performed solely on the complete portion of the catalog, thereby satisfying the assumption of scale invariance inherent in the Gutenberg-Richter relationship.

2.4. Seismicity Analysis (Gutenberg-Richter Law)

To characterize the statistical distribution of seismicity within the study area, we employed the Gutenberg-Richter (G-R) power law relation, which remains the fundamental empirical relationship in statistical seismology. This law describes the self-similar nature of earthquake occurrence, positing that the relationship between frequency and magnitude follows a predictable log-linear scaling. Specifically, for the valid range of the catalog defined as earthquakes with magnitude *M* greater than or equal to the magnitude of completeness *Mc* the cumulative frequency distribution is mathematically expressed to establish a coherent model of regional seismic productivity. In this framework, the cumulative number of earthquakes *N* with magnitudes ³ *M* is given by the equation:

$$log_{10} N(M) = a - bM \qquad \ldots\ldots (1)$$

Where *N(M)* represents the cumulative frequency of seismic events, defined as the total count of earthquakes having a magnitude greater than or equal to a specific threshold *M* within the catalog duration. Unlike discrete frequency counts, this cumulative measure integrates all events from the maximum observed magnitude down to *M*, which effectively stabilizes the dataset against statistical fluctuations and reveals the fundamental power-law scaling of seismic energy release. *M* is the earthquake magnitude, a is a constant describing the seismic productivity (seismicity rate) of the region. *b* is the slope of the distribution, describing the relative size distribution of events (stress scaling). The parameters *a* and *b* are estimated using the linear regression method on the logarithmic cumulative distribution.

2.5. Return Period Estimation

The return period (or recurrence interval) is a probabilistic measure of the average time between earthquakes of a certain magnitude. Based on the calculated *a* and *b* values from Equation (1), the mean return period *T* for an earthquake of magnitude *M* is calculated as follows:

$$T\,(M) = \frac{\Delta t}{N(M)} = \frac{1}{10^{a-bM}} \text{ x Yearly Normalization} \qquad \ldots\ldots (2)$$

Where *N(M)* represents the normalized annual rate of occurrence for events meeting the magnitude condition, derived from the total productivity of the seismic volume over the observation period Δt. The outcomes of this calculation provide the estimated statistical time gaps (recurrence intervals in years) for earthquakes reaching or exceeding critical magnitude thresholds of 5.0, 6.0, 6.5, and 7.0. These specific magnitudes were deliberately selected to correspond to distinct tiers of seismic hazard relevant to engineering and mitigation planning. Magnitude 5.0 events serve as a baseline for frequent, lower-intensity shaking that tests operational resilience; Magnitude 6.0 represents moderate events capable of inflicting structural damage on non-engineered buildings; Magnitude 6.5 is widely regarded as the threshold for significant, widespread damage and liquefaction potential; while Magnitude 7.0 characterizes major tectonic ruptures with the capacity to generate tsunamis and catastrophic regional impact. By quantifying the recurrence for these specific tiers, the study delivers essential inputs for developing seismic design spectra and long-term disaster preparedness strategies.

3. RESULTS AND DISCUSSION

3.1. Seismicity Distribution and Magnitude of Completeness

The spatial analysis of the compiled earthquake catalog demonstrates a distinct and intense concentration of seismic activity aligned parallel to the Java Trench, confirming the active nature of the subduction zone. The epicenter distribution is not uniform but forms a clear band that tracks the subduction front, extending deeper northward. Vertical cross-sections of the hypocentral distribution reveal a dipping seismogenic zone characteristic of an oceanic subduction system. The depth profile analysis indicates that the majority of the recorded events are classified as shallow earthquakes (depth £ 70 km), which are primarily attributed to the frictional interplate coupling along the megathrust interface and deformation within the overriding plate. Deeper events, extending beyond 100 km, trace the Wadati-Benioff zone, delineating the geometry of the subducting Indo-Australian slab as it descends into the mantle. This depth distribution is consistent with the standard mechanical models of subduction, highlighting both the shallow locked zone potential for tsunamigenic events and the deeper intraslab seismic hazard.

To ensure the statistical validity of the seismicity parameters, the Magnitude of Completeness (*Mc*) was rigorously determined using the Maximum Curvature (MAXC) method. This technique identifies the magnitude bin with the highest frequency of events in the non-cumulative frequency- magnitude distribution plot as the point of maximum curvature, which serves as a robust proxy for the lowest magnitude reliably detected by the seismic network. Magnitude of Completeness (*Mc*): Based on the MAXC analysis of the frequency-magnitude distribution (FMD), the catalog yielded a Magnitude of Completeness (*Mc*) of 4.6. This value serves as a quantitative threshold representing the sensitivity limit of the seismic network coverage in the Indian Ocean south of Java over the study period. This threshold indicates that the seismic monitoring network is capable of reliably detecting 100% of seismic events with magnitudes equal to or greater than 4.6 in this offshore region. Earthquakes falling below this magnitude were systematically excluded from the subsequent Gutenberg-Richter analysis. Including such incomplete data would introduce significant undersampling bias, artificially flattening the frequency-magnitude curve and leading to an erroneous estimation of the *b*-value, which in turn would compromise the accuracy of return period calculations.

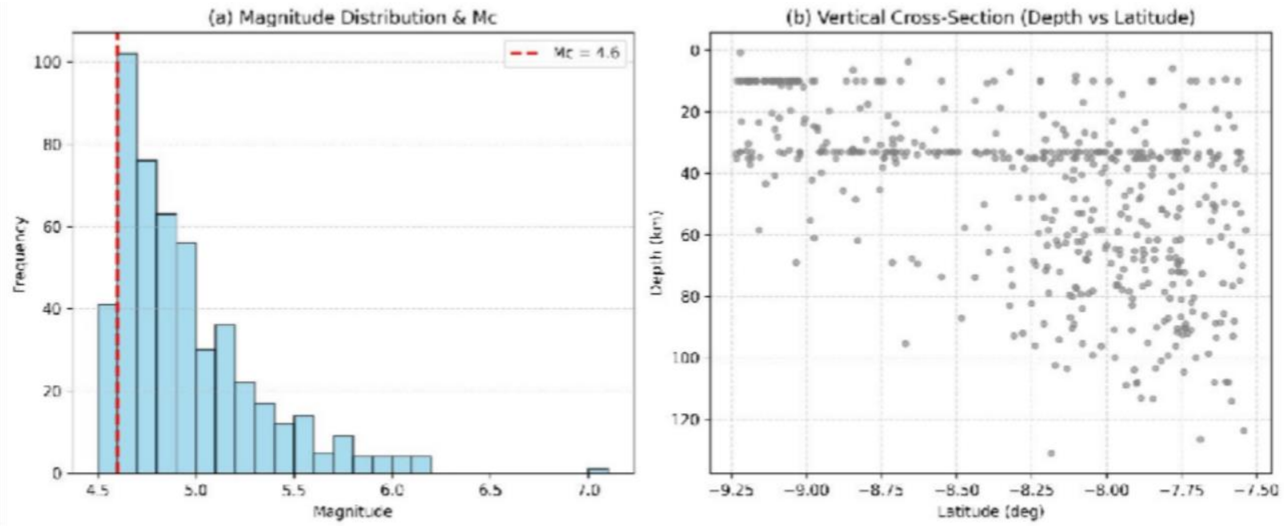

Figure 2: (a) Frequency-Magnitude distribution showing the estimated Magnitude of Completeness (Mc). (b) Vertical cross-section of seismicity (Depth vs. Latitude) showing the subduction profile.

3.2. Gutenberg-Richter Parameters

Applying the linear regression method to the cumulative frequency-magnitude distribution for all events satisfying the criterion M ³ 4.6, we derived the fundamental seismicity parameters *a* and *b*, which are critical for characterizing the regional seismic regime. The relationship is visualized in Figure 3. *a*-value (Seismicity Rate): The regression analysis yielded an *a*-value of 8.07. This parameter, which represents the y-intercept of the frequency-magnitude distribution at magnitude zero, serves as a quantitative measure of the overall seismic productivity within the monitored volume. A value of this magnitude indicates a highly active seismogenic zone, reflecting a substantial rate of background seismicity over the 53-year observation period. This high productivity is consistent with the active subduction processes occurring along the Java Trench, where continuous plate convergence drives frequent stress release.

b-value (Stress Parameter): The slope of the Gutenberg-Richter relationship, represented by the *b*-value, was calculated to be 1.17. This value is notably higher than the global average of approximately 1.0, providing critical insights into the tectonic stress regime. In seismotectonic terms, a higher *b*- value is physically indicative of a region characterized by significant crustal heterogeneity, high thermal gradients, or the presence of pore fluids which may reduce effective normal stress. Consequently, this suggests that the subduction interface south of Java is not a uniform, fully locked asperity but rather a complex system where stress is partially released through frequent small-to- moderate earthquakes rather than solely through infrequent giant ruptures.

Correlation Coefficient (*R*): The statistical robustness of these parameters is confirmed by the correlation coefficient (*R*) of -0.9952. This near-perfect linear fit demonstrates that the frequency-magnitude distribution of the analyzed catalog adheres strictly to the power-law scaling predicted by the Gutenberg-Richter relation. The high correlation coefficient validates the quality of the dataset above the magnitude of completeness and confirms that the derived *a* and *b* values are reliable descriptors of the regional seismicity, minimizing the likelihood of artifacts due to catalog inconsistencies or transient noise.

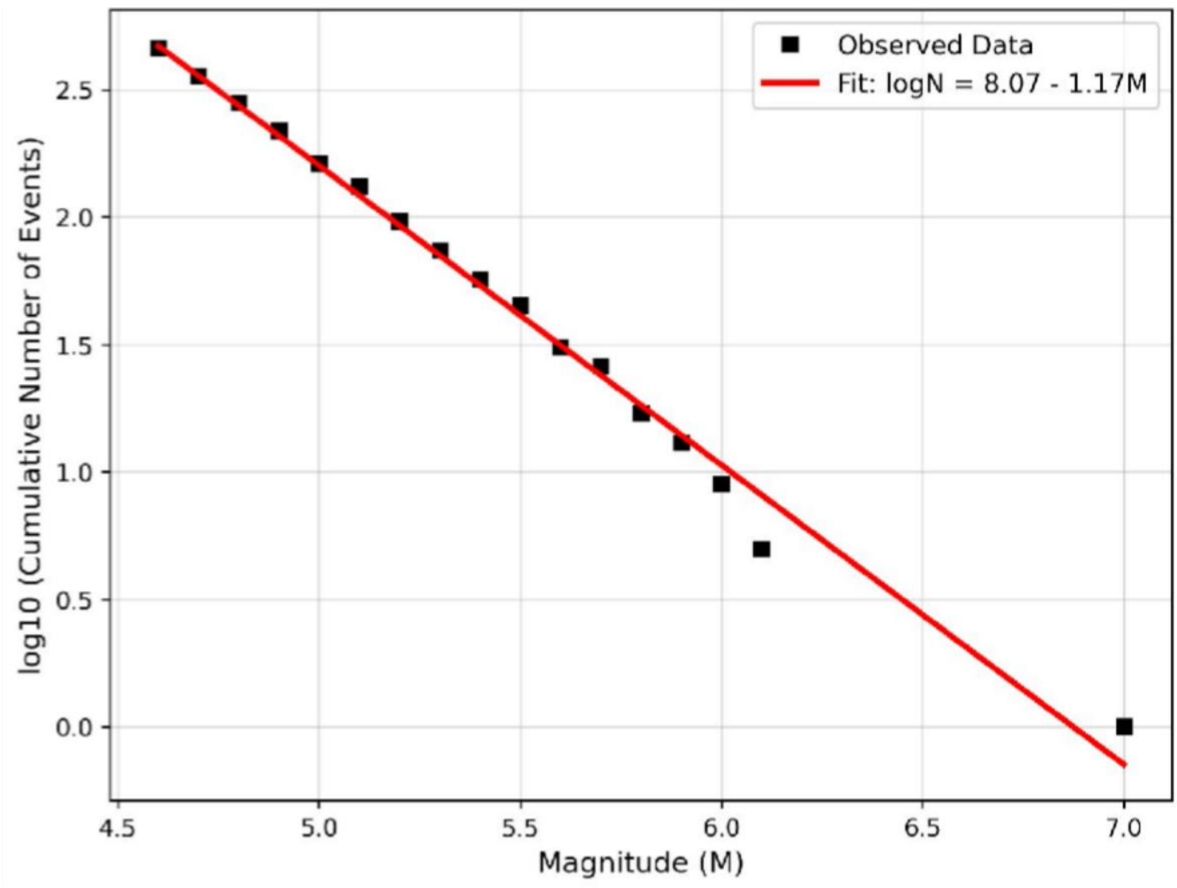

Figure 3. Gutenberg-Richter frequency-magnitude relationship. The red line represents the best-fit regression for events above *Mc* determining the *b*-value.

3.3 Earthquake Return Periods

Based on the empirically derived seismicity parameters (*a*=8.07 and *b*=1.17), the probabilistic return periods for earthquakes across a range of significant magnitudes were calculated using Equation (2). This probabilistic assessment transforms the Gutenberg-Richter statistics into a temporal forecasting model, providing a crucial framework for understanding future seismic risks. The results of this analysis are comprehensively summarized in Table 1, which delineates the mean recurrence intervals for distinct magnitude thresholds.

Table 1. Estimated Return Periods for the Indian Ocean South of Java

Magnitude	Estimated Return Period (years)	Estimated Return Period (months)
5	0.33 years	± 4 months
6	4.98 years	± 5 months
6.5	19.24 years	± 19 months
7	74.34 years	± 74 months

The results presented in Table 1 reveal a stratified hazard profile for the region south of Java. For moderate seismic events (M » 5.0), the estimated return period is exceedingly short at 0.33 years, implying that earthquakes of this magnitude occur approximately every four months. Such high frequency characterizes the continuous background seismicity of the subduction zone, serving as a reminder of the active tectonic convergence but generally posing minimal risk to well-engineered structures.

As the magnitude threshold increases, the recurrence intervals lengthen but remain within timescales relevant for medium-term planning. Earthquakes of magnitude 6.0, capable of causing structural damage to non-reinforced buildings, are estimated to occur roughly once every 5 years. More critically, significant earthquakes with magnitudes ³ 6.5, which represent the threshold for potential tsunami generation and widespread infrastructure damage, have a recurrence interval of approximately 19.24 years. This relatively short interval is less than the typical 50-year design lifespan of major infrastructure projects, necessitating that engineers explicitly account for these forces in structural design codes. Furthermore, the analysis estimates that a major tectonic rupture of magnitude 7.0 has a return period of 74.34 years. While less frequent, this aligns with the historical periodicity of major tsunamigenic events in the region (e.g., the span between the 1921, 1994, and 2006 events). This finding underscores a critical inter-generational risk: the gap between such catastrophic events is long enough to fade from public memory, yet short enough to inevitably recur within the lifetime of a community, highlighting the imperative for sustained disaster education and early warning system maintenance.

3.4 Tectonic Implications of the *b*-value

The primary finding of this study is the calculated b-value of 1.17 for the Indian Ocean sector south of Java, a parameter derived from the slope of the frequency-magnitude distribution. In seismotectonics, the *b*-value serves as a critical proxy for the differential stress state of the crust. Experimental rock mechanics and field observations have consistently demonstrated an inverse correlation between the *b*-value and applied shear stressessentially, as stress accumulates towards the failure point of a rock mass, the proportion of small cracks decreases relative to larger ones, leading to a drop in the *b*-value .

Our calculated value of 1.17 is notably higher than the global average of approximately 1.0, which typically characterizes standard tectonic seismicity. High *b*-values (> 1.0) are physically indicative of regions characterized by high material heterogeneity, intense fracturing, or the presence of high pore fluid pressures which reduce the effective normal stress on faults. In the specific context of the Java subduction zone, this elevated parameter suggests that the plate interface is not a uniform, homogenous surface. Instead, it appears to be highly segmented and structurally complex. This complexity promotes the release of tectonic strain through frequent, small-to-moderate magnitude earthquakes rather than allowing stress to accumulate uniformly over vast areas to generate singular, giant megathrust ruptures.

Several geological factors likely contribute to this observed heterogeneity. The subduction of topographic features on the Indo-Australian plate, such as seamounts and bathymetric highs associated with the Roo Rise, can act as asperities that mechanically fracture the overriding plate and disturb the coherence of the subduction interface. Furthermore, the high *b*-value may signal the presence of fluids released from slab dehydration, which increases pore pressure and facilitates brittle failure at lower stress thresholds. While a high *b*-value is often interpreted as a sign of aseismic creep or stress release via micro-seismicity, it is crucial not to interpret this as an absence of seismic hazard. The historical occurrence of tsunamigenic earthquakes in this region warns that strain accumulation still persists. It is likely that the subduction zone is characterized by a heterogeneous coupling model, where small, strongly locked asperities are embedded within a broader zone of creeping or stable sliding material. This configuration can lead to complex rupture patterns and tsunami earthquakes, where rupture propagates slowly through compliant sedimentary wedges, generating tsunamis disproportionate to their surface wave magnitudes.

3.5 Seismic Hazard and Return Period Analysis

The return period analysis provides a temporal dimension to the seismic hazard assessment. The estimation that a Magnitude 7.0 earthquake has a return period of 74.34 years implies a moderate probability of occurrence within the standard lifespan of infrastructure (usually 50-100 years).

Comparing our results with historical records, the calculated return periods align with the regional seismic history. The gap between significant events (e.g., the 1994 and 2006 tsunamigenic earthquakes) suggests a cycle that is captured reasonably well by our probabilistic model. This highlights the urgency for:

1. Strict Building Codes: Infrastructure in the southern coastal regencies must be designed to withstand ground accelerations associated with M ³ 6.5 events, which recur approximately every 19 years.
2. Tsunami Preparedness: Given that these return periods apply to the offshore subduction zone, the potential for tsunamis remains a primary concern. Early warning systems must be maintained to handle the estimated recurrence of these large-magnitude events.

Our results show interesting correlations when compared to previous studies. Nuannin et al. (2005) reported varying *b*-values along the Sumatra-Java arc, ranging from 0.9 to 1.4 depending on the specific segment and depth, which supports our finding of 1.17 as being within the expected regional range. In contrast, Widiyantoro et al. (2020) identified potential seismic gaps with locked patches south of Java which typically exhibit lower *b*-values (< 1.0). The higher *b*-value observed in our study using data up to 2024 may reflect the inclusion of recent aftershock sequences or seismic swarms that are statistically richer in smaller magnitude events. This difference underscores the dynamic nature of the seismic cycle and emphasizes the importance of using the most up-to-date catalogs for continuous hazard assessment.

4. CONCLUSION

This study successfully characterized the seismicity of the Indian Ocean sector south of Java using updated earthquake catalog data spanning 53 years. The analysis yielded a magnitude of completeness (*Mc*) of 4.6 and a seismicity rate (*a*-value) of 8.07, alongside a *b*-value of 1.17. This *b*-value reflects a tectonic stress regime characterized by high heterogeneity, suggesting that while stress accumulation is ongoing, the release mechanism significantly involves frequent moderate seismicity. These statistical parameters confirm that the frequency-magnitude distribution in this region adheres robustly to the Gutenberg-Richter law (R » -0.99), providing a reliable basis for seismic hazard assessment.

Furthermore, the probabilistic return period analysis indicates that significant earthquakes with magnitudes greater than 6.0 have a recurrence interval of approximately 4.98 years, while potentially destructive events (M ³ 7.0) are estimated to recur every 74.34 years. These relatively short recurrence intervals for moderate-to-large events underscore the high seismic hazard potential of the offshore region. Consequently, these findings emphasize the critical necessity for strict enforcement of earthquake-resistant building codes and the continuous maintenance of tsunami early warning systems to protect the densely populated coastal communities of Southern Java (Patria & Aulia, 2020).

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