

Intensity Assessment and Seismotectonic Causes of Historical Earthquakes in Bangladesh and Surrounding Areas

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Abstract: Bangladesh lies at the junction of the Indian and Eurasian plates with the Burmese sub-plates, making it one of the most seismically active regions of South Asia. Existing hazard models for the country are largely outdated and omit recent seismic activity; therefore, seismic hazard in Bangladesh must be continually reassessed. A declustered and completeness-screened earthquake catalog has been compiled for Bangladesh and its surrounding tectonic setting. Since seismic hazard analysis assumes that earthquakes occur as statistically independent events, dependent aftershocks and foreshocks must be removed from the catalog. After removing 46.5% of the original catalog as dependent aftershocks and foreshocks, 2,811 independent events remained. The Gutenberg–Richter recurrence analysis is limited to earthquakes of $M_w \geq 4.5$, as the catalog is only reliable above this threshold. This gave a b -value of 0.97, which reflects the relative proportion of smaller to larger earthquakes, within the range typically observed for ordinary crustal seismicity, and a mean return period of approximately 437 years for a M_w 8.0 event. This return period is close to the roughly 400-year strain-accumulation cycle estimated independently from GPS geodesy along the region's locked plate boundaries. Mapping the spatial density of recorded earthquakes shows three concentrated zones of activity: the Sylhet–northeastern border, the Chittagong Hill Tracts, and a smaller cluster along the Madhupur Fault just north of Dhaka. Each zone is supported independently by Peak Ground Acceleration (PGA) values from a global seismic hazard model, ranging from 0.14g–0.2g near Dhaka to 0.26g–0.29g in the Chittagong Hill Tracts. These results suggest that an underrecognized intraplate fault north of the capital shapes seismic hazard in the region as much as the country's two major plate-boundary systems, namely the Shillong Plateau margin and the Indo-Burman subduction zone, with implications for where seismic code enforcement and retrofitting should be prioritized.

Keywords: *Earthquake catalog, Declustering, Gutenberg-Richter relationship, b-value, Peak Ground Acceleration*

Introduction

Bangladesh is highly vulnerable to seismic hazards due to its active tectonic location at the junction of the Indian, Eurasian, and Burmese plates (Akhter, 2010; Morino et al., 2011; Steckler et al., 2016). Historical events—such as the 1897 Great Assam (M_s 8.1) and

1918 Srimangal (M_s 7.6) earthquakes—demonstrate this severe risk, which is further amplified by dense population and rapid urban expansion (Ambraseys, 2004; Bilham and Hough, n.d.; Rahman and Siddiqua, 2016). Because instrumental records only date back to 1906, seismic hazard assessments must be continually updated as new data emerges. Existing hazard models for Bangladesh are largely outdated and omit recent activity, most notably the November 21, 2025, Narsingdi earthquake (M_w 5.5–5.7) near Dhaka (Rezwan, 2025). To address this gap, this study compiles a filtered regional earthquake catalog to estimate Gutenberg–Richter recurrence parameters and map spatial seismicity patterns across Bangladesh.

Abbreviations and Acronyms

M_w -Moment Magnitude

M_s - Surface Wave Magnitude

m_b - Body Wave Magnitude

KDE-Kernal Density Estimation

PGA- Peak Ground Acceleration

Methodology

The methodology adopted in this research is systematically outlined in the flowchart presented in Figure-01.

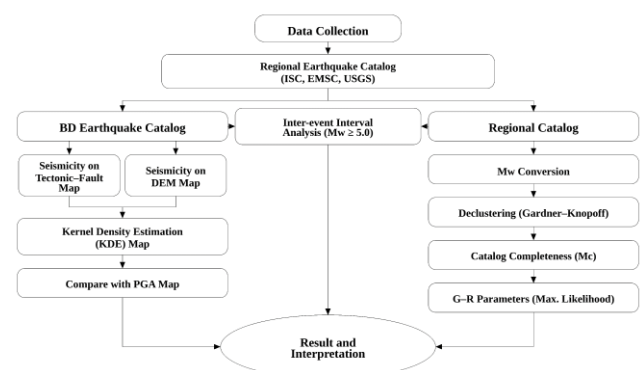


Figure 1, Methodology Flowchart

Magnitude Homogenization

$$M_W = 0.67M_S + 2.07 \quad 3.0 \leq M_S < 6.2 \quad (i)$$

$$M_W = 0.99M_S + 0.08 \quad 6.2 \leq M_S \leq 8.2 \quad (ii)$$

$$M_W = 0.85m_b + 1.03 \quad 3.5 \leq m_b \leq 5.5 \quad (iii)$$

$$M_W = 1.46m_b - 2.42 \quad 5.5 \leq m_b \leq 7.3 \quad (iv)$$

Catalog Completeness

$$\lambda = \frac{1}{n} \sum_{i=1}^n k_i \quad (v)$$

$$\sigma_\lambda^2 = \frac{\lambda}{n} \quad (vi)$$

$$\sigma_\lambda = \sqrt{\frac{\lambda}{T}} \quad (vii)$$

G–R Parameters and Earthquake Return Period

$$\frac{\sum_{i=1}^m t_i M_i \exp(-\beta M_i)}{\sum_{i=1}^m t_i \exp(-\beta M_i)} = \frac{\sum_{i=1}^m N_i M_i}{\sum_{i=1}^m N_i} \quad (viii)$$

$$b = \frac{\beta}{\ln(10)} \quad (ix)$$

$$N_0 = \frac{\sum_{i=1}^m N_i}{\sum_{i=1}^m t_i \exp(-\beta M_i)} \quad (x)$$

$$a = \log_{10}(N_0) \quad (xi)$$

$$\log_{10} N(M) = a - bM \quad (xii)$$

$$T_r(M) = \frac{1}{10^{a-bM}} \quad (xiii)$$

The catalog is prepared using reviewed earthquake data from the International Seismological Centre (ISC), European-Mediterranean Seismological Centre (EMSC), and USGS. Homogenization has been carried out using global empirical relations. Approximately 46.5% of the earthquake events in the catalog were identified as aftershocks and foreshocks (dependent events) using the Gardner and Knopoff (1974) algorithm; after removing the dependent events, the final declustered catalog contains 2,811 independent earthquake events. The Stepp-derived (Stepp, 1972) completeness windows adopted for recurrence-parameter estimation, and these windows were incorporated into the maximum-likelihood procedure of Weichert (1980), which accounts for unequal observation periods across magnitude classes. The equation has been solved numerically using Python to determine the value of β at which the two sides balance. The b -value and activity-rate parameters (a and N_0) obtained following the formulation proposed by Weichert (1980). Assuming a Poisson temporal occurrence of earthquakes, the mean return period, T_r , is defined as the reciprocal of the annual exceedance rate (Cornell, 1968).

Result and Discussion

Recurrence Parameters and Return Period: Applying the Weichert (1980) maximum-likelihood method to the completeness-screened magnitude range M_w 4.5–8.0 gives the overall rate of earthquake occurrence, $a = 5.1332$, and the ratio of small to large magnitude earthquakes, $b = 0.9117$. This b -value falls within the 0.88–1.12 range reported by Gutenberg and Richter (1944) for ordinary crustal seismicity, which under the

framework of Scholz (1968), suggests a moderate rather than unusually high level of stress within the regional source system. Geodetic evidence still points to substantial accumulated strain in the region: 13–17 mm/yr of convergence along a locked decollement beneath the Indo-Burman Ranges has left more than 5.5 m of slip unreleased since the 1762 Arakan earthquake, potentially enough for an M_w 8.2–9.0 event if released in a single rupture (Steckler et al., 2016). This strain accumulation shows up not in the b -value but in the model's return periods. Based on the model, the estimated return periods are approximately two months for M_w 4.5, six months for M_w 5.0, and about 437 years for M_w 8.0 (Table-01). That 437-year figure is close to the roughly 400-year physical strain-accumulation cycle suggested by the same geodetic evidence (Steckler et al., 2016).

Table-01: Gutenberg–Richter annual exceedance rates (λ_M) and mean return periods (T_r) for M_w 4.5–8.0.

Magnitude Moment, M_w	$\log_{10} N(M)$	Annual Rate (λ_M)	Return Period, T_r (yr)
4.5	0.7606	5.7630	0.1735
5.5	-0.2110	0.6151	1.6256
6.5	-1.1827	0.0657	15.2298
7.5	-2.1544	0.0070	142.6813
8.0	-2.6402	0.0023	436.7201

Spatial Distribution of Seismicity in and around Bangladesh: At the national scale, the largest events (≥ 5.5 M_w) are concentrated around the Shillong-margin fault system in the northeast and the Indo-Burman fold-thrust belt in the southeast (Alam et al., 1990; Steckler et al., 2016; Kayal et al., 2012). At the broader plate-boundary scale, the regional map shows the same convergent margin and associated fault network extending through the Himalaya–Indo-Burman arc; the earthquake clusters within Bangladesh therefore appear as part of a wider, relatively continuous belt of seismic activity rather than isolated groups (Petersen et al., 2014; Steckler et al., 2016) (Figure-02).

Comparative Analysis of KDE and PGA Distribution: The Kernel Density Estimation map divides this distribution into three high-intensity zones — Sylhet and the northeastern border, over the Shillong-margin fault system; Chittagong and the adjoining hill tracts, above the locked updip section of the Indo-Burman Megathrust; and central Bangladesh, north of Dhaka toward Tangail and Gazipur, corresponding to the Madhupur Fault. PGA (10% probability of exceedance in 50 years, GEM Foundation, 2026) rises from $\sim 0.08g$ in the southwest toward the same three zones: 0.23g–0.26g at Sylhet, 0.26g–0.29g across the Chittagong Hill Tracts, and 0.14g–0.2g around Madhupur. The three areas of relatively high PGA correspond closely to the areas of highest earthquake density, confirming that the clustering reflects genuine seismotectonic structure. PGA values of 0.2g–0.29g, as observed in Chittagong and Sylhet, indicate a level of ground shaking that can

cause significant structural damage to buildings not designed to current seismic standards (Figure-03).

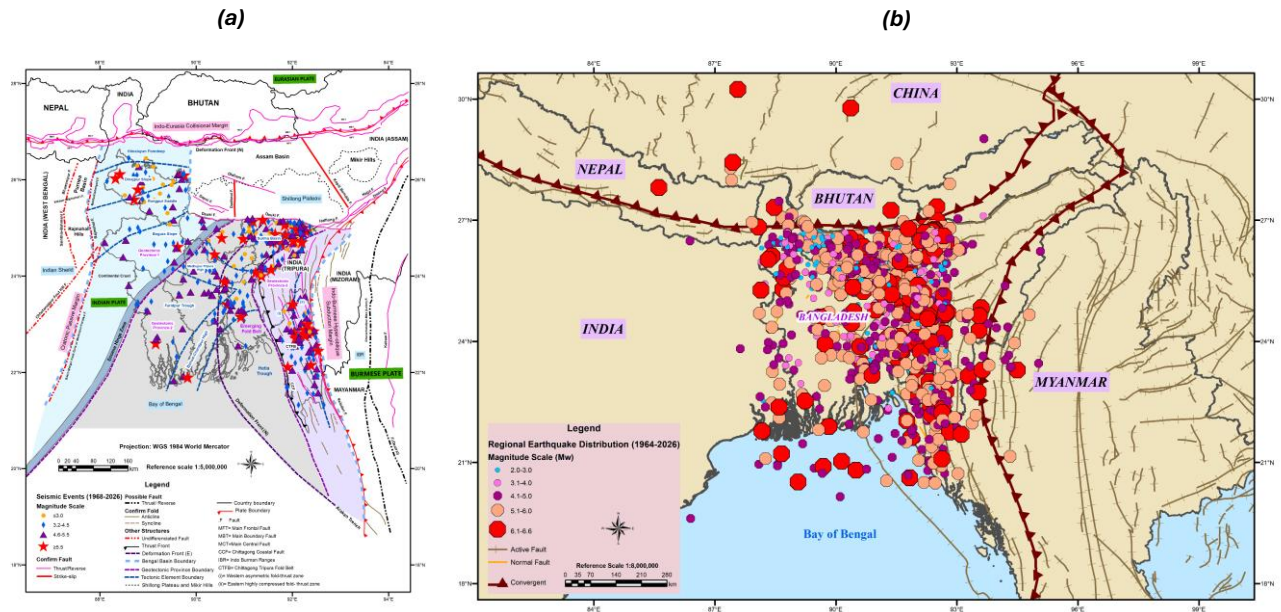


Figure -02: Magnitude-classified seismicity across (a) Bangladesh, shown on a tectonic and fault base map (modified after Hossain et al., 2020), and (b) the broader Himalaya-Indo-Burman collision zone, shown against the regional fault network (modified after Akhter, 2010).

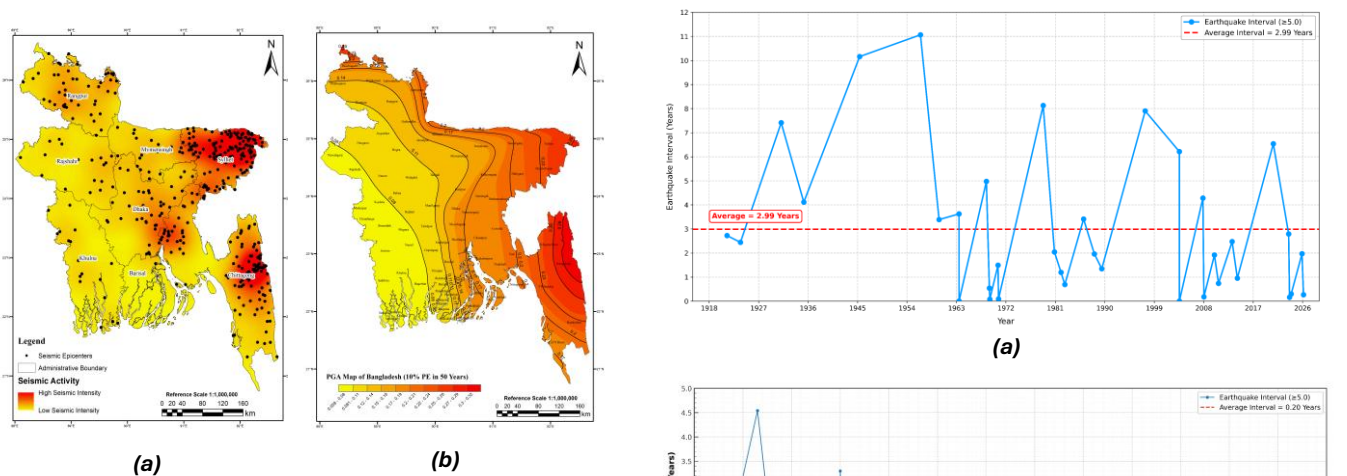


Figure-03: (a) Kernel density estimation (KDE) map of seismic epicenter distribution across Bangladesh, and (b) peak ground acceleration at 10% probability of exceedance in 50 years, derived from the Global Seismic Hazard Map (GEM Foundation, 2026).

Temporal Trends in Seismicity: Within Bangladesh, the number of $M_w \geq 5.0$ mainshocks remained relatively low through much of the twentieth century before increasing noticeably since the 1990s, giving a mean inter-event interval of 2.99 years across the 1918–2026 record. At the regional scale, the same threshold produces a much shorter mean interval of 0.20 years, consistent with several independent convergent structures acting simultaneously across the wider area. Some long national intervals may partly reflect earthquakes that went undetected, since a national digital network was introduced only in 2007 (Figure-04).

B

Conclusion

This study reveals that Bangladesh's seismic hazard does not come from one uniform threat but from three geographically distinct sources. Using Weichert's (1980) maximum-likelihood method on events of $M_w \geq 4.5$, we obtain $a = 5.1332$ and $b = 0.9717$ — a b -value that sits comfortably within the 0.88–1.12 range typical of ordinary crustal seismicity. The model puts the average return period for a $M_w 8.0$ event at around 437 years, close to the roughly 400-year strain-accumulation cycle

independently estimated from regional geodesy. Inter-event intervals tell a similar story: earthquakes of $M_w \geq 5.0$ occur roughly every 2.99 years within Bangladesh, but every 0.20 years across the wider region, simply because more independent fault sources feed into that larger area. Seismicity itself clusters into three zones — the Sylhet–northeastern border, the Chittagong Hill Tracts, and central Bangladesh along the Madhupur Fault — each independently backed by PGA values of 0.23g–0.26g, 0.26g–0.29g, and 0.14g–0.2 g. That the same three zones emerge from both observed seismicity and an independent hazard model points to a genuine seismotectonic pattern, not coincidence. These results mark Sylhet and Chittagong as priorities for seismic-code enforcement, and the Madhupur Fault as a hazard in its own right given how close it sits to Dhaka.

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