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An updated earthquake catalog for Bangladesh: an attempt at a seismic risk evaluation

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Abstract: A unique, consistent, and uniform earthquake catalog is crucial for assessing seismic hazards in any locality. This study aims at compiling and processing a better uniform earthquake catalog, using this catalog to identify the probable subduction zone, and assessing seismicity parameters for Bangladesh. The study area is bounded by the geographical limits 16–29°N and 86–96°E. It includes a sum of 48,342 events which are compiled as 1.0 to 8.5 magnitudes (M_W) and time period from 1548 to 2020 yrs. Uniformization is made between the body, surface wave, and moment magnitude scales to unify the catalog in terms of M_W. For seismic hazard assessment or prediction studies, this catalog comprises earthquake events from Bangladesh and adjoining regions. The assessed M_C obtained is around 4.0–5.0, which leads to *a*, *b* value varying between 0.71–1.12 and an *a* value varying between 4.85–7.12. The findings show that the M_C is lower at the border of the Chittagong-Sylhet through Hill tracts than the northern part of the area with an M_C 4.5–5.0 and *a*, *b* value close to 1.00. The results indicate that the study area is a seismically highly active zone in the context of seismicity parameters. Finally, the compiled catalog, seismicity of the area and a probable deformation front are presented and are recommended for use in assessing seismic hazard analysis in Bangladesh.

Keywords: earthquake catalog, seismic hazard, magnitude, deformation front

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INTRODUCTION

A consistent and uniform earthquake catalog is a significant precondition in probabilistic seismic risk evaluation. Essentially, an earthquake catalog compiles all events that contribute to a seismic threat. The catalog represents a compilation of events, i.e. consists of data from all available sources, and therefore, one source is not appropriate to present all earthquakes. Earthquakes recur in and around Bangladesh due to the country's position at the plate margins of India and Eurasia, where severe earthquakes have occurred in the past (Bolt 1930, Stickler et al. 2017). Hence, a comprehensive catalog is crucial for seismic risk assessment. The prime objective of this study is to compile a reliable and uniform earthquake catalog of Bangladesh from the perception of seismic threat scrutiny. Another goal is to identify the probable subduction zone in Bangladesh, which is situated between the Indian and Burmese plate margins. Furthermore, to prepare this catalog, the subduction zone needs to be identified with the help of the elevation profile and focal points, with the final findings represented as input factors for probabilistic seismic risk evaluation.

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The first earthquake catalogs were introduced in India and the Bay of Bengal by Oldham (1883), Milne (1911), Tendon (1950), Gupta et al. (1986), Ansary (2000), and Alam & Dominey-Howes (2016) covering the time frames between 1664–1869, 1870–1899, 1833–1971, 1839–1900, and 1897–1962. Recently, attempts were made to compile catalogs for Bangladesh (Tahsin et al. 2018) and Pakistan (Zare et al. 2014) and use them for assessing seismic threats. Consequently, a reliable and uniform attempt was made to compile the earthquake catalog in this study. The earthquake catalog compiled in this research includes historical and instrumental earthquakes in the study area. It may be considered as Building Code of Bangladesh. The catalog was made on the basis of a uniform scale of moment magnitude for the period of 1548–2020, but omitted some significant historical events due to the unreliability of sources.

Bangladesh, positioned at the northeastern Indian plate, is located at the junction of three tectonic platforms: the Indian plate, the Eurasian plate and the Burmese micro plate (Akhter 2010) (Fig. 1), constituting the main reason for the active seismicity in Bangladesh. The earthquake catalog compiled in this study is bounded within the latitudes 16–29°N and the longitudes 86–96°E around Bangladesh. Recordings of near and regional earthquakes from surrounding countries are essential for a reliable probabilistic seismic risk evaluation.

The compiled catalog consists of three parts: (i) ancient earthquakes from the period of 1548–1900, (ii) historical earthquakes from 1901–1971, and (iii) instrumental earthquakes from 1972–2020 yrs. The minimum threshold is fixed to a moment magnitude of 1.0. In order to make a uniform magnitude scale (M_W), conversion relations were established between moment magnitude and others scales of magnitudes, which were recorded in the available sources. Removing the reliant events from the catalog amounted to sorting for correctness using the declustering algorithms from Gardner & Knopoff (1974), Reasenberg (1985), Uhrhammer (1986), and Gruenthal (personal communication). Finally, seismicity parameters (deformation front) for potential seismic sources in Bangladesh were found.

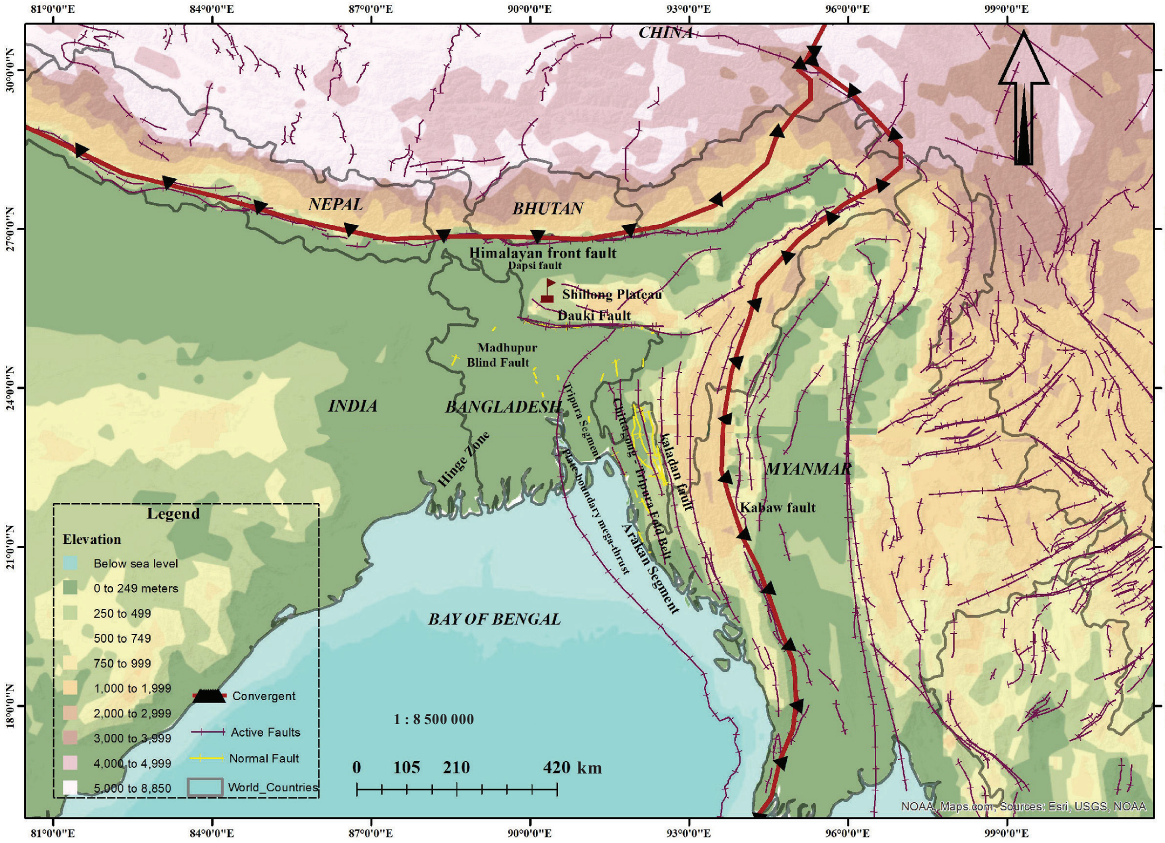

Fig. 1. *Regional tectonic set up and plate configuration of Bangladesh and surroundings (after Akhter 2010)*

METHODOLOGY

In this study the source indicators or parameters of earthquake events collected from various sources in the study area covered the time period of 1548–2020. In that time, under the various earthquake hazards programs of various countries, millions of earthquake events were recorded in the world. The authors believe that the South Asian Catalog (SACAT), World Data Center (WDC), International Seismological Center (ISC), Volcano Discovery, National Earthquake Information Center (NEIC), and Bangladesh Meteorological Department (BMD) are reliable sources of seismic events in the world. Earthquake events were collected from these sources for compilation. Then, earthquakes recorded at various scales: M_W – moment magnitude scale, M_L – local magnitude scale, M_S – surface-wave magnitude scale, M_D – duration magnitude scale, M_N – regional magnitude scale, modified Mercalli intensity (MMI) and m_b – body wave magnitude scale were uniformed in magnitude for better uniformity. After this step, declustering, magnitude ambiguity and data inclusiveness processes were conducted to remove duplicate data. Hence, a catalog was created on the basis of earthquake events, magnitude intensities, and focal depths. After preparing the earthquake catalog of Bangladesh, a cross-section was drawn from the Indian Craton to the Sagaing Fault (23° latitude from West to East) with the help of the elevation profile and focal depths for identifying the probable subduction zone.

The magnitude of completeness, denoted by M_C, referred the minimum magnitude at where the majority of the earthquake events were preferably identified as 100% in a space time volume. The evaluation of M_C was essential since too high a value of M_C could lead to under-sampling by removing usable data, while too a low value could lead to erroneous seismicity indicators by utilizing incomplete data (Mignan & Woessner 2012). For any seismicity analysis, the frequency magnitude distribution (FMD) of earthquakes developed by Gutenberg & Richter (1944) and called as G-R law was the base. To understand the interpretation of FMD in an earthquake catalog, the magnitude completion, M_C, was defined. The G-R law was presented in the Equation (1):

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

where:

M – magnitude,

$N(M)$ – the number of earthquakes happened in a specific time with magnitudes $M \geq M_C$,

a – the earthquake productivity,

b – the relative distribution of small and large earthquakes.

The value of b in the G-R law was an indicator explaining the seismic status of the area. Several methods were proposed to determine M_C upon validity of the G-R law (Wyss et al. 1999, Weimer & Wyss 2000, Cao & Gao 2002, Amorese 2007). In this study, the goodness of fit test (GFT) developed by Weimer & Wyss (2000) was used for calculating M_C. Parameter R, i.e. absolute difference of the events number in each magnitude bin between the synthetic G-R and observed distribution was utilized in the GFT test. The distributions of synthetic events were determined utilizing calculated a and b values of the observed events for $M \geq M_{Co}$ as a function of ascending cutoff magnitude M_{Co}:

$$R(a,b,M_{Co}) = 100 - \left(\frac{\sum_{M_{Co}}^{M_{\max}} |B_i - S_i|}{\sum_i B_i} \times 100 \right) \tag{2}$$

where:

S_i, B_i – the predicted and observed cumulative number of events in each magnitude bin,

M_C – observed at the first magnitude cutoff, at which the observed events for $M \geq M_{Co}$ were modeled by a straight line for a fixed confidence level,

R = 90% or 95%.

The maximum curvature method (MAXC) is a non-parametric method representing a quick and forthright way to determine M_C. In this method, the point of maximum curvature is utilized by assessing the maximum value of the first derivative of the frequency-magnitude curve (FMD) (Wyss et al. 1999, Wiemer & Wyss 2000, Mignan & Woessner 2012):

$$M_C = m, \quad \text{while max} = \frac{d(N(m))}{dm} \tag{3}$$

In this study this method was used to determine M_C for different instrumental earthquake catalogs (e.g. International Seismological Center and Volcano Discovery etc.) and to obtain the changes of M_C values in different data sources.

DATA COMPILATION

The first step in the seismic risk evaluation of any area is to make an identical catalog that comprises both historical and instrumental occurrences (Munima et al. 2018).

The study area under investigation is the whole of the Bengal Basin and the adjoining areas of Bangladesh. The area lies within the latitudes of 16–29°N and the longitudes of 86–96°E. The Bengal Basin is positioned at the northeast corner of the Indian Shield along with the junction of three plates: the Indian, the Eurasian and the Burmese micro plate (Akhter 2010) (Fig. 1).

Historical earthquake events such as the great earthquake in 1950 (Tendon 1950), Nepal earthquake in 1833 (Bilham 1995), and the great Assam earthquake in 1897 (Bilham & England 2001) etc., which happened in and around Bangladesh, were collected from literature (Oldham 1883, Brunnschweiler 1966, Bath 1981, Biswas & Majumdar 1997, Vigny et al. 2003, 2005, Gahalaut & Gahalaut 2007, Steckler et al. 2008, Reddy et al. 2009, Morino et al. 2011, Akhter et al. 2016, Tahsin et al. 2018).

The instrumental events from the period of 1972–2020 were collected from the following seismic sources: South Asian Catalog (SACAT), World Data Center (WDC), International Seismological Center (ISC), Volcano Discovery, National Earthquake Information Center (NEIC), Bangladesh Meteorological Department (BMD). A sum of 54,268 earthquake events were collected. The Volcano Discovery and ISC sources were treated as the most wide-ranging catalogs based on the findings of cautious and methodical historical analysis. However, only one kind of data source was not suitable for a uniform catalog because some events may have been absent in the studied area. While several sources were compiled to make this earthquake catalog, duplicate data were still possible. Duplicate data were excluded by finding the same time and latitude-longitude of the events. The results of the compilation of all source data are listed in Table 1.

Table 1
List of sources for the historical and instrumental earthquake catalogs (1548–2020)

Reference	Time frame	Magnitude type	N
Oldham (1883)	1664–1869	M_W, I_O	41
Milne (1912)	1870–1899	M_W, I_O	25
Tendon & Srivastava (1974)	1833–1971	M_W, I_O	19
Gupta et al. (1986)	1839–1900	M_W, I_O	46
Ansari (1998)	1897–1962	M_S, m_b, M_W, M_L	122
Tahsin et al. (2018)	1548–2015	M_W	2,865
South Asian Catalog	1600–1900	M_S, m_b, M_W, M_L	326
World Data Center	1901–1948	M_S	102
International Seismological Center	1972–2020	M_S, m_b, M_W, M_L, M_D	22,365
Volcano Discovery	1980–2020	M_S, m_b, M_W, M_L, M_D	28,220
National Earthquake Information Center	1975–2000	m_b, M_W, M_L, M_S	156

Explanations: N – the number of earthquakes happened according to the sources, I_O – reference earthquake intensity, M_S – surface-wave magnitude scale, m_b – body-wave magnitude scale, M_W – moment magnitude scale, M_L – local magnitude scale, M_D – duration magnitude scale.

HOMOGENIZATION

To prepare the catalog, the earthquake events compiled at various scales of magnitude were recalculated to a uniform scale due to homogeneity. In this study the scale of moment magnitude was utilized.

Few historical earthquakes documented in MMI scale were renewed to M_S using Equation (4) (Ambraseys & Melville 1982). The magnitudes of surface waves were mostly documented by the ISC databases. Scordilis (2006) observed a worldwide bilinear trend between M_W and M_S scales. Equations (5) and (6) established the bilinear relations and converted M_S to M_W.

Additionally, body wave magnitude scales were changed to moment magnitude using Equation (7).

Relationships between magnitude types according to Scordilis (2006), Rafi et al. (2012) and Zare et al. (2014) and conversion from m_b to M_W, and M_S to M_W scales are presented in Table 2.

$$M_S = 0.77 \times I_O - 0.07 \tag{4}$$

$$M_W = 0.58 \times M_S + 2.46\ (\pm 0.03);\ \text{for } 3.5 \le M_S \le 6.0 \tag{5}$$

$$M_W = 0.94\ (\pm 0.04) \times M_S + 0.36;\ \text{for } 6.1 < M_S \le 8.3 \tag{6}$$

$$M_W = 0.93\ (\pm 0.03) \times m_b + 0.45;\ \text{for } 4.0 \le m_b \le 6.1 \tag{7}$$

$$M_W = 1.01 \times M_L - 0.05;\ \text{for } 4.0 \le M_L \le 8.3 \tag{8}$$

$$M_W = 0.5 \times M_D;\ \text{for } M_D < 3.0 \tag{9}$$

$$M_W = 0.6 + M_D;\ \text{for } 3.0 \le M_D \tag{10}$$

$$M_W = 0.739 \times M_N + 1.409;\ \text{for } 3.5 \le M_N \le 6.3 \tag{11}$$

Table 2
Relationships between magnitude types according to Scordilis (2006), Rafi et al. (2012) and Zare et al. (2014) and conversion from m_b to M_W and M_S to M_W scales

Magnitude type	Conversion relationship	Limitation	Events	R^2	Standard deviation (σ)	Reference
m_b, M_W	$M_W = 0.93\ (\pm 0.03) \times m_b + 0.45$	$4.0 \le m_b \le 6.1$	785	0.61	0.26	This study
	$M_W = 0.85\ (\pm 0.04) \times m_b + 1.03\ (\pm 0.23)$	$3.5 \le m_b \le 6.2$	39,784	0.53	0.29	Scordilis (2006)
	$M_W = 1.04 \times m_b - 0.07$	$4.0 \le m_b \le 6.9$	–	–	–	Rafi et al. (2012)
	$M_W = 0.87 \times m_b + 0.83$	$3.5 \le m_b \le 6.0$	16,752	0.88	0.30	Zare et al. (2014)
M_S, M_W	$M_W = 0.58 \times M_S + 2.46\ (\pm 0.03)$ $M_W = 0.94\ (\pm 0.04) \times M_S + 0.36$	$3.5 \le M_S \le 6.0$ $6.1 < M_S \le 8.3$	523 256	0.69 0.78	0.5 0.71	This study
	$M_W = 0.67\ (\pm 0.005) \times M_S + 2.07\ (\pm 0.03)$ $M_W = 0.99\ (\pm 0.02) \times M_S + 0.08\ (\pm 0.13)$	$3.0 \le M_S \le 6.1$ $6.2 \le M_S \le 8.2$	23,921 2,382	0.77 0.81	0.17 0.2	Scordilis (2006)
	$M_W = 0.63 \times M_S + 2.21$	$3.5 \le M_S \le 8.0$	–	–	–	Rafi et al. (2012)
	$M_W = 0.66 \times M_S + 2.11$ $M_W = 0.93 \times M_S + 0.45$	$2.8 \le M_S \le 6.1$ $6.2 \le M_S \le 8.2$	4,123 129	0.94 0.88	0.28	Zare et al. (2014)

Explanations: M_S – surface-wave magnitude scale, m_b – body-wave magnitude scale, M_W – moment magnitude scale, M_L – local magnitude scale, M_D – duration magnitude scale.

Due to the lack of a theoretical relationship for M_L and M_W, the empirical relation Equation (8) from Zare et al. (2014) was used to renew the M_L scale. Similarly, Kaviris et al. (2008) developed a conversion tool from M_D to M_W (Equations (9) and (10)) which was used in this study. Then, Equation (11) was used for M_N (regional magnitude scale) to M_W conversion (Karimiparidari et al. 2013).

DECLUSTERING

The seismicity of an earthquake is recorded by fore-shock and after-shock events. Thus, statistical analysis is essential to recognize the independent occurrence of the main shock. The techniques of space-time windowing are usually utilized for this purpose (Gardner & Knopoff 1974, Knopoff et al. 1982, Reasenberg 1985, Uhrhammer 1986). The earthquake events were declustered using four algorithms from Gardner & Knopoff (1974), Reasenberg (1985), Uhrhammer (1986), and Gruenthal (unpublished) in Z-map (Wiemer 2001). Each algorithm reflected dissimilar distances and times for declustering (Tab. 3). The default standard indicator values of Reasenberg's algorithm are given in Table 4.

Table 3
Declustering algorithms

<table>
<tr><th>Algorithm</th><th>Time [days]</th><th colspan="3">Distance [km]</th></tr>
<tr><td>Gardner & Knopoff (1974)</td><td>$10^{0.032M+2.7389}$ if $M \geq 6.5$
$10^{0.5409M-0.547}$ else</td><td colspan="3">$10^{0.1238M+0.983}$</td></tr>
<tr><td>Uhrhammer (1986)</td><td>$e^{-2.87+1.235M}$</td><td colspan="3">$e^{-1.024+0.804M}$</td></tr>
<tr><td>Gruenthal (unpublished)</td><td>$|e^{-3.95+(0.62+17.32M)2}|$ if $M \geq 6.5$
$10^{2.8+0.024M}$ else</td><td colspan="3">$10^{1.77+(0.037+1.02M)2}$</td></tr>
<tr><td rowspan="8">Reasenberg (1985)</td><td rowspan="2">Parameter</td><td rowspan="2">Standard</td><td colspan="2">Range of simulation</td></tr>
<tr><td>Max.</td><td>Min.</td></tr>
<tr><td>τ_{max} [days]</td><td>10</td><td>15</td><td>3</td></tr>
<tr><td>τ_{min} [days]</td><td>1</td><td>2.5</td><td>0.5</td></tr>
<tr><td>x_k</td><td>0.5</td><td>1.8</td><td>1.6</td></tr>
<tr><td>x_{meff}</td><td>4</td><td>1</td><td>0</td></tr>
<tr><td>r_{fact}</td><td>10</td><td>20</td><td>5</td></tr>
<tr><td>P</td><td>0.95</td><td>0.99</td><td>0.90</td></tr>
</table>

Explanations: τ_{max} [days] and τ_{min} [days] – maximum and minimum look-ahead time of observing the next earthquake at a certain probability, P; x_{meff} – magnitude cut-off for the earthquake catalog, x_{meff} is raised by a factor x_k – the largest earthquake in the cluster; r_{fact} – the number of crack radii surrounding each earthquake.

Table 4
Results of clustered and declustered events from the algorithms

Algorithm	Sum of events	Clusters	Events in final	Events out of final catalog
Gardner & Knopoff (1974)	48,342	2,596	11,730	36,612 (75.74%)
Reasenberg (1985)		3,789	28,966	19,376 (40.08%)
Uhrhammer (1986)		1,258	18,971	29,371 (60.76%)
Gruenthal (unpublished)		2,558	8,566	39,776 (82.28%)

MAGNITUDE AMBIGUITY AND DATA INCLUSIVENESS

In the study area, the prehistorical (erstwhile to 1900) records were somehow inconsequential. Several sources based on prehistoric, but immaterial data (Oldham 1883, Milne 1911, Dunbar et al. 1992) enabled building a catalog based on the prehistoric macroseismic events occurring in Bangladesh and adjoining areas. The data was compiled for bigger magnitudes (>6) and for large periods (1548–present) (Akhter 2010). In early studies, magnitude and position of an event was measured utilizing macroseismic intensity data with great uncertainty. Previous historical data (1900–1972) were compiled utilizing various relevant online data that reported earthquakes in magnitude scales of M_W, M_S and m_b (Tab. 1) (Tandon 1950, Gupta et al. 1986, Ansary 2000, Tahsin et al. 2018).

Magnitudes of the main shocks from the instrumental data (1972–2020) of conspicuous errors of 0.26 units for m_b and 0.50 units for M_S (Tab. 2) were included to the catalog. Those data helped to make the catalog uniform and correct. The homogenous events of the earthquake catalog of Bangladesh are presented in the M_W scale.

PROCESSING OF DATA

To prepare the earthquake catalog, the scales of magnitude were compiled in an order of M_W, m_b, M_S, M_L, I_O, M_N and M_D based on their primary level. A sum of compiled data was showed in Figures 2–7. Earthquake events having zero magnitudes were removed from the prepared catalog. Similarly, duplicate data at the same time, magnitude and epicenter were removed. After a uniform compilation, the prepared earthquake catalog consisted of 48,342 events. Those earthquake catalog comprised of moment magnitudes varying from 1.0 to 8.5 for the 1548–2020 time period.

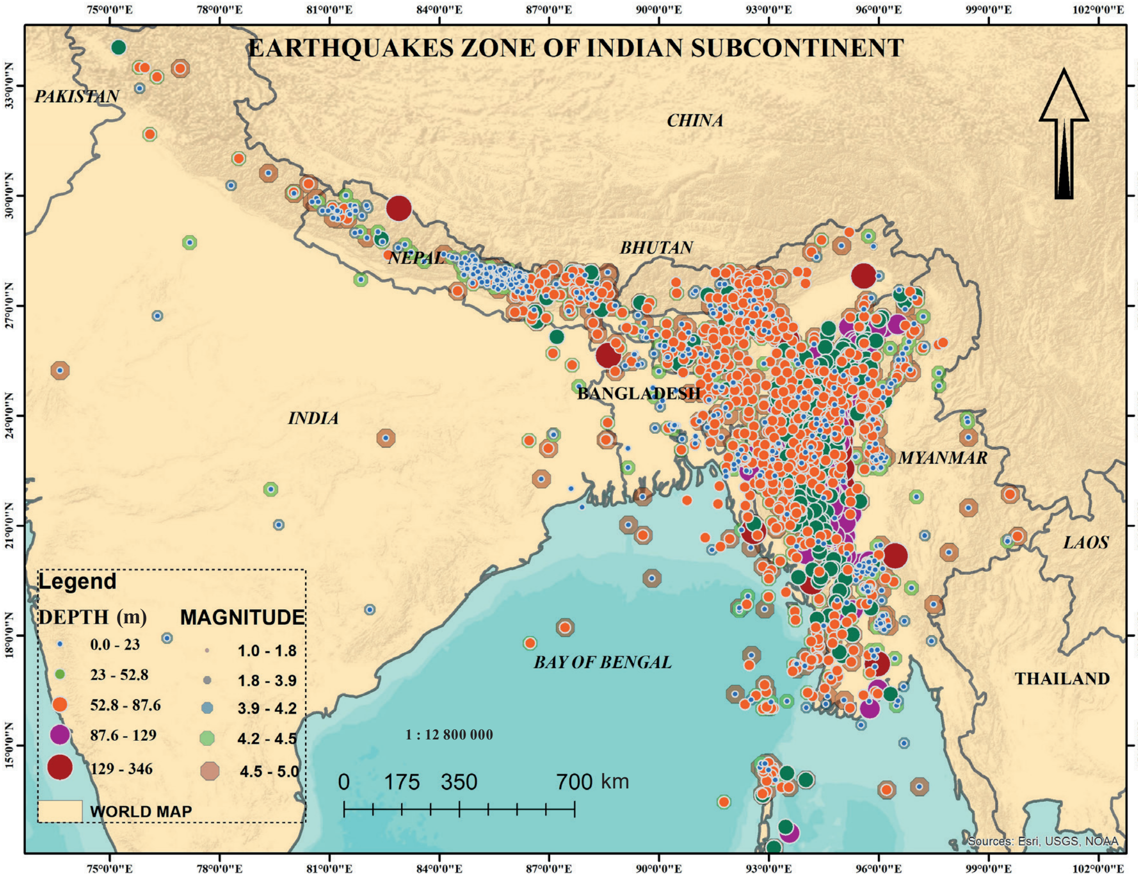

Fig. 2. *Earthquake catalogue of Bangladesh with depth 0–346 m and magnitude 1.0–5.0*

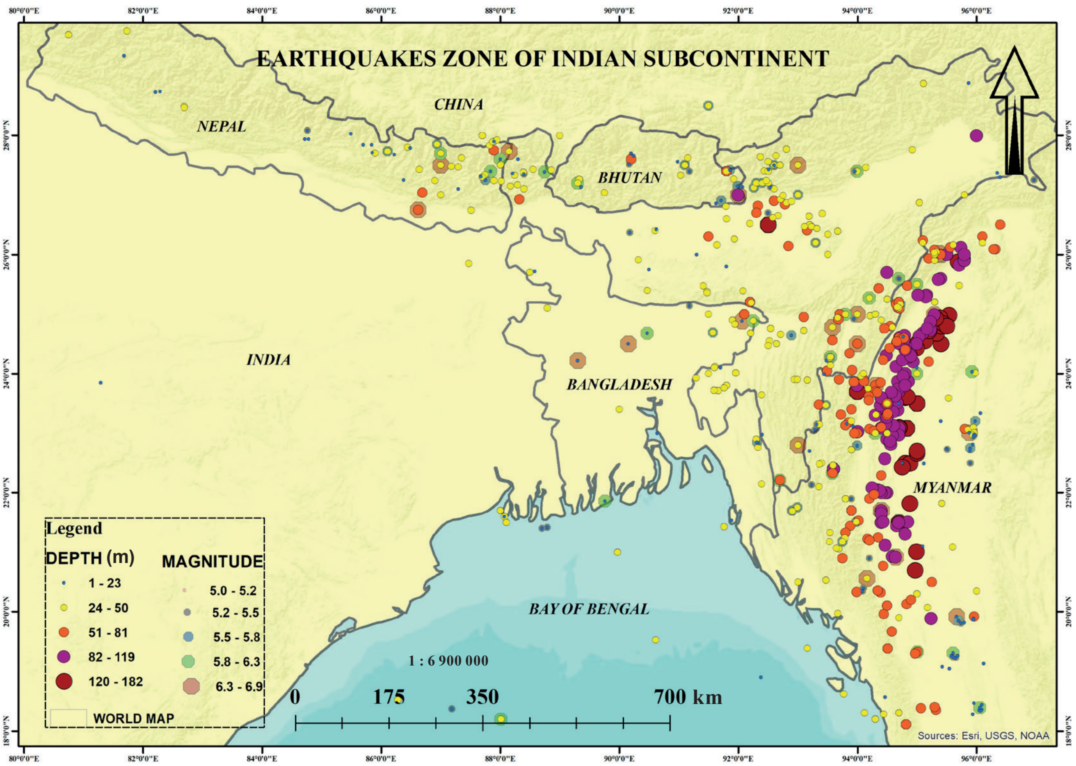

Fig. 3. Earthquake catalogue of Bangladesh with depth 1–182 m and magnitude 5.1–6.9

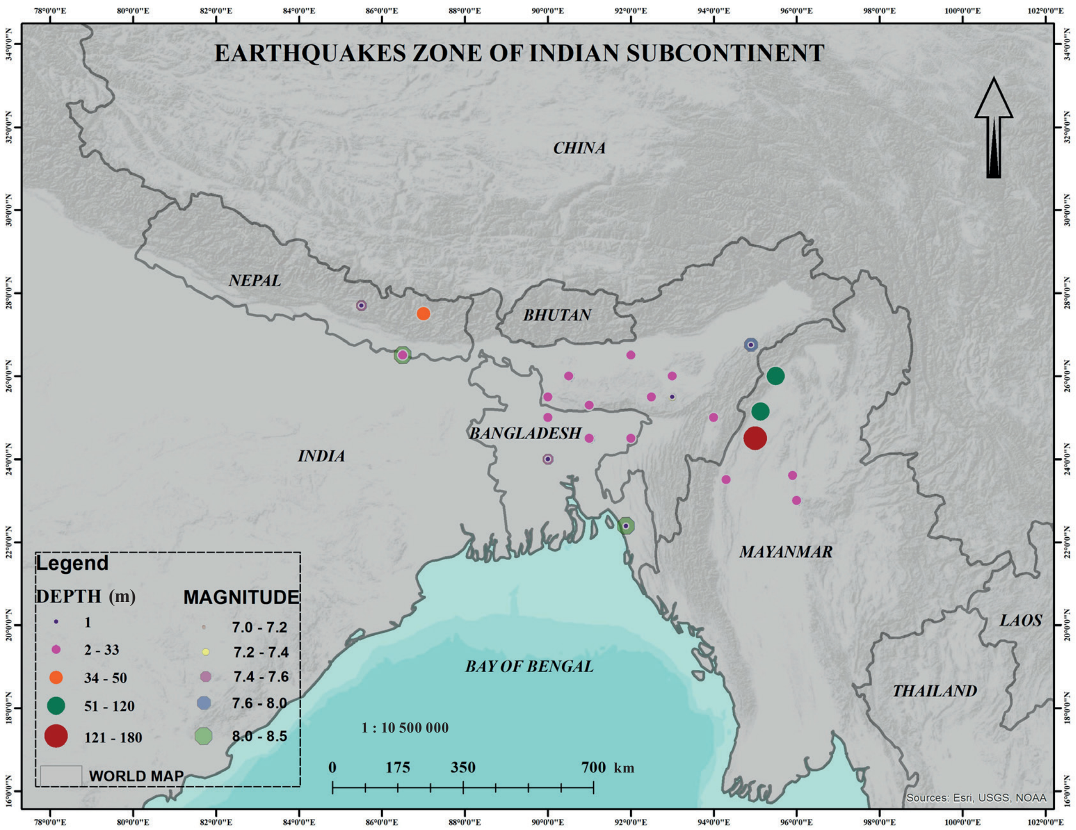

Fig. 4. Earthquake catalogue of Bangladesh with depth 1–180 m and magnitude 7.0–8.5

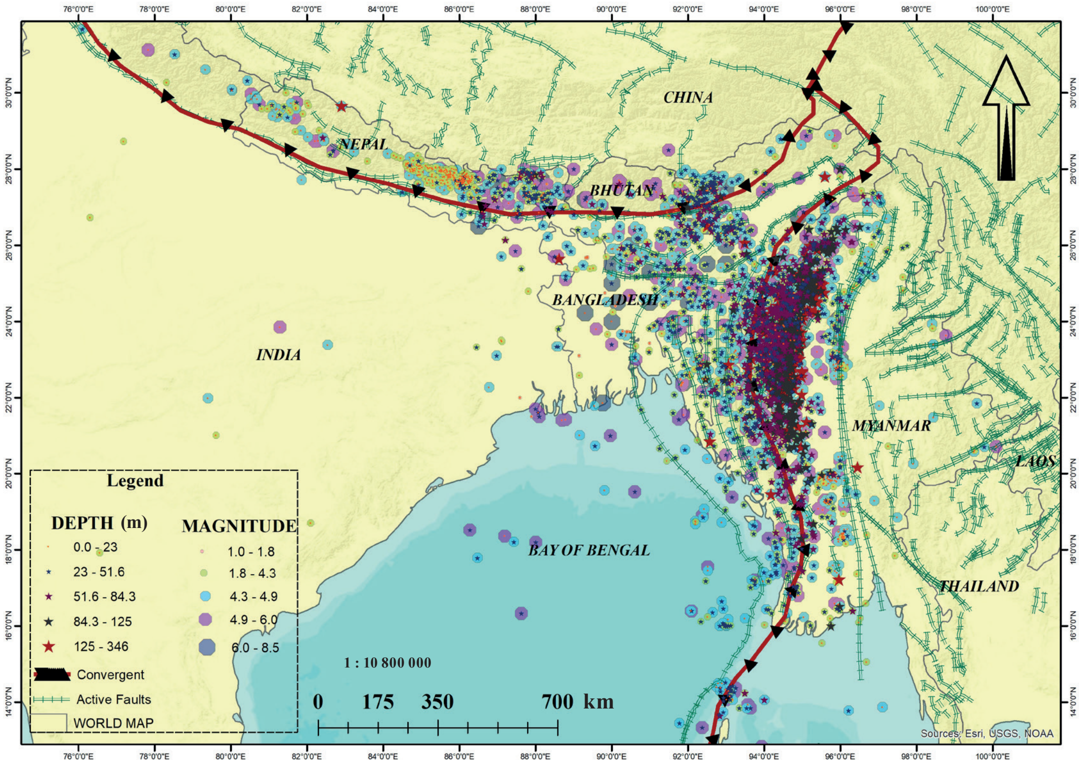

Fig. 5. *The overall earthquake catalogue of Bangladesh from 1548 to 2020 associated with major faults*

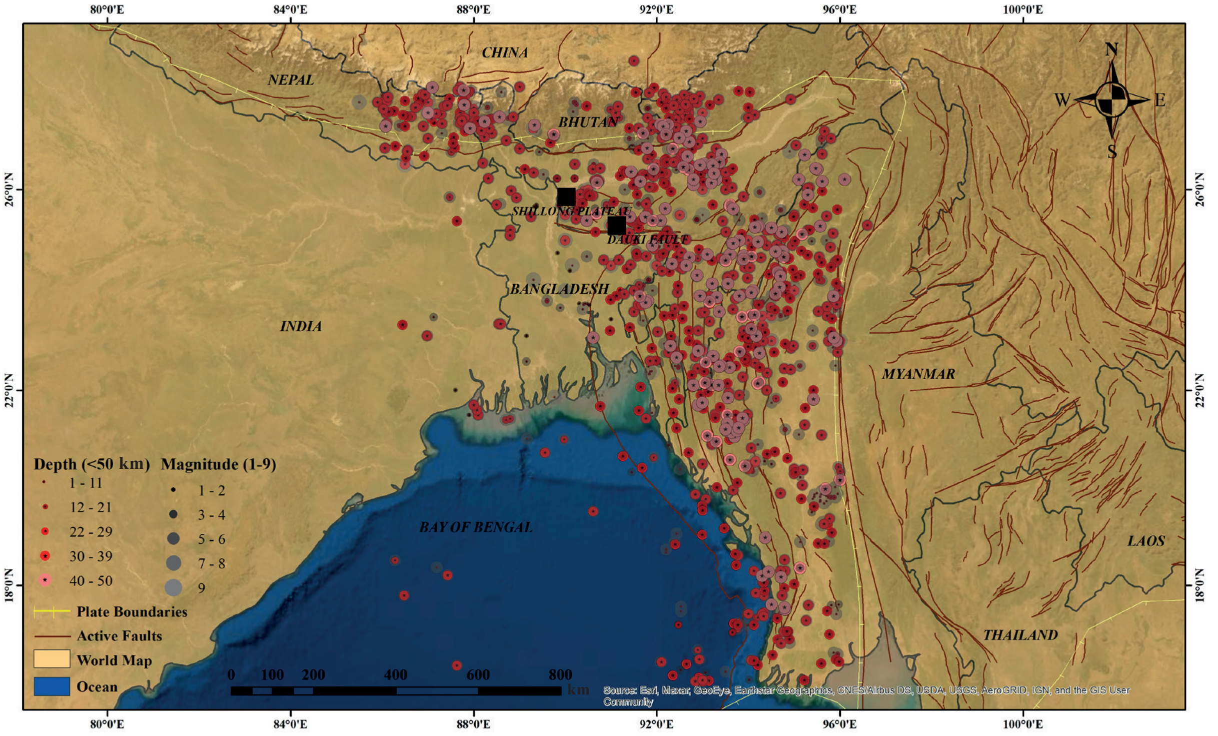

Fig. 6. *Spatial distribution of shallow earthquakes (focal depth <50 km) of Bangladesh and surroundings from 1548 to 2020 associated with major faults*

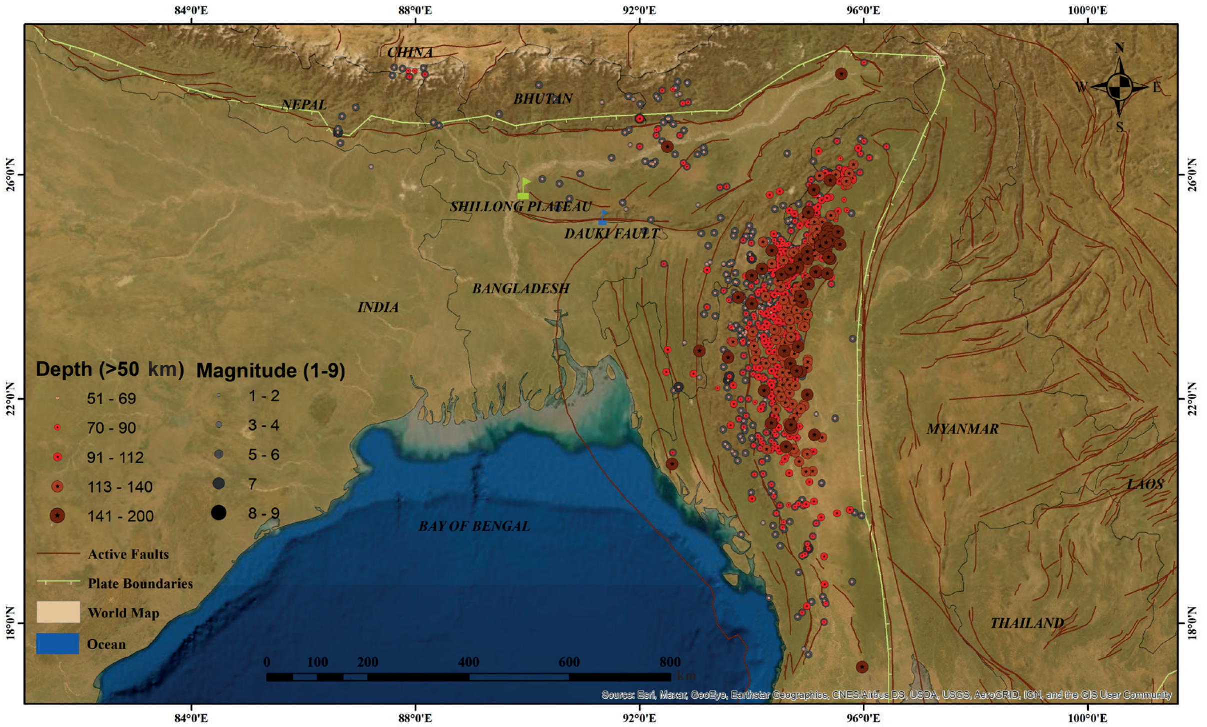

Fig. 7. *Spatial distribution of deep earthquakes (focal depth >50 km) of Bangladesh and surroundings from 1548 to 2020 associated with major faults*

The catalog was divided into three types based on magnitude, such as:

1) magnitude 1.0 to 5.0 (Fig. 2),
2) magnitude 5.1 to 6.9 (Fig. 3),
3) magnitude 7.0 to 8.5 (Fig. 4).

Finally, Figure 5 shows the overall historical and instrumental earthquake events (magnitude 1.0 to 8.5) associated with major active faults from the period of 1548–2020.

Additionally, based on the focal depth of the earthquakes, the catalog was also divided into two groups:

1) shallow earthquakes (focal depth <50 km) (Fig. 6),
2) deep earthquakes (focal depth >50 km) (Fig. 7).

IDENTIFYING SUBDUCTION ZONE

A cross-section was drawn from the Indian Craton (A) to the Sagaing Fault (B) (23° latitude from West to East) (Fig. 8). The final results in the compiled earthquake catalog showed that the region of the Bengal Basin subsides near the Tripura segment. Furthermore, the focal depths become greater than in the western region of the Bengal Basin. The majority of the earthquake events occurred in the eastern and northeastern parts of Bangladesh (Fig. 5). Seismicity increased from the western to the eastern part of the country (Fig. 8). While seismicity also increased from the Indian Craton to a probable subduction zone, the recurrence interval rate was the shortest near the Indo-Burma Range.

Although the region of Indo-Burma Range was considered as an unlocked region (Stickler et al. 2017) due to the occurrence of earthquake events of varying magnitude, the regions from the Indian Craton to Tripura could be considered as a locked region since no earthquake has been observed for a long time. With the help of above evidence, a probable deformation front was drawn in between the Indian Craton to Tripura region where the front was suggested as locked area. During a similar study, Burgi et al. (2021) found a decollement surface (deformation) with a depth of around 9 km in the northeast and southeast in Bangladesh, and around 5 km in the east-central Bangladesh. They stated that it had the potential to host an 8.5+ magnitude earthquake.

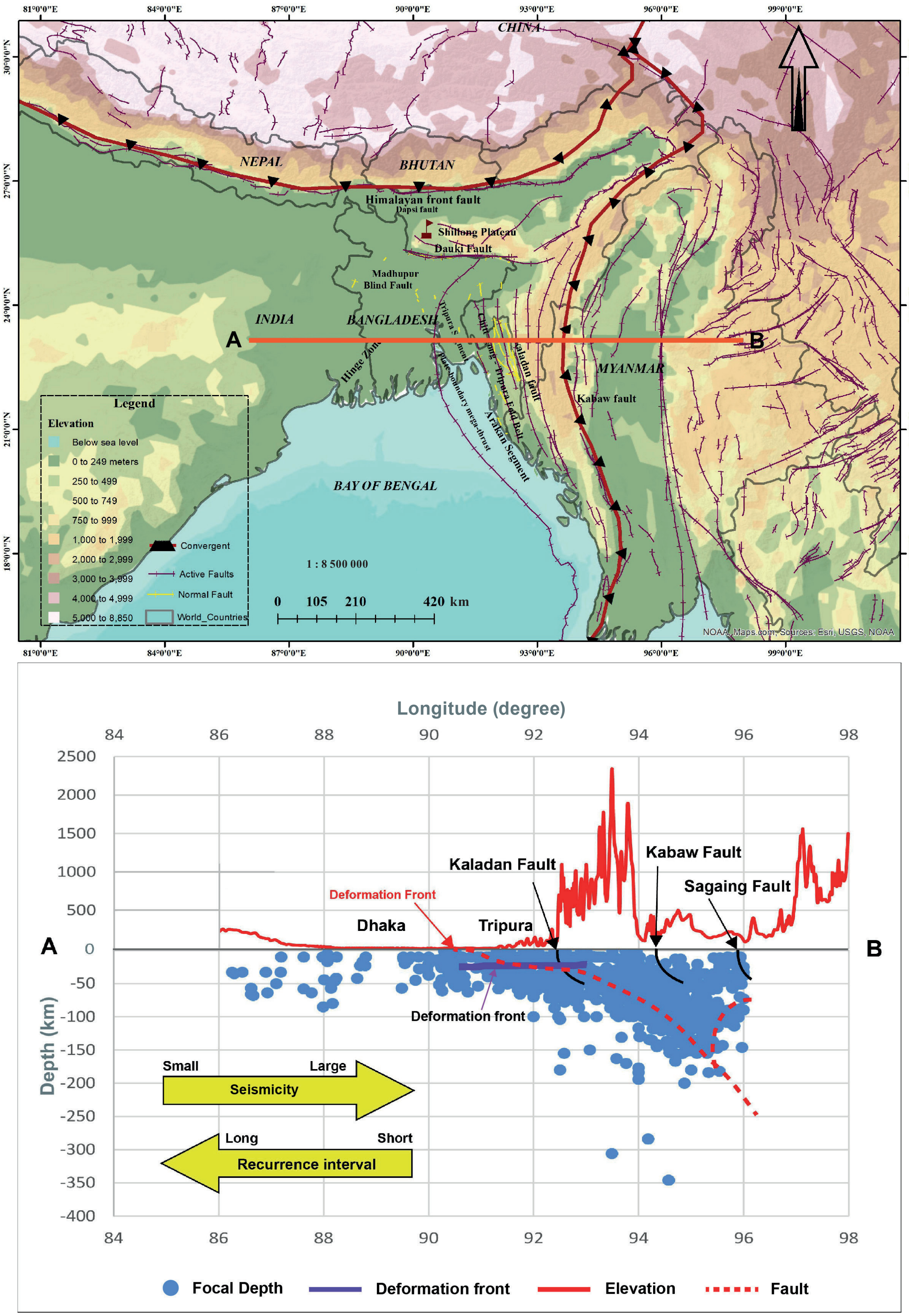

Fig. 8. *Figure shows that the cross section of the AB line (elevation profile vs focal points) identifying the probable subduction zone*

MAGNITUDE OF COMPLETENESS

Magnitude of completeness, M_C, is a vital indicator for analyzing seismic hazards. The M_C values observed for Bangladesh using the goodness of fit test and maximum curvature method, along with the potential seismic sources are presented in Figure 9. The lowest magnitude of completeness found in the studied area was equal to M_C 4.0 for some central and southern parts while the highest M_C was equal to 5.0 for the north-western and north-eastern parts (Tab. 5). The magnitude completions in the capital Dhaka and nearby were observed to be M_C 4.0–4.3 and M_C 4.2–4.5 in the Sylhet-Chittagong foldbelt areas, some of the northern part and the southern part of the studied area (Tab. 5). On the other hand, Mymensingh and Rajshahi, together with some parts of the Sylhet and Chittagong regions, were observed to be M_C 4.8–5.0, respectively with higher estimated *b* value (Tab. 5). It was observed that where the greater values of M_C were evident, remarkable earthquakes were to be found beyond the threshold level.

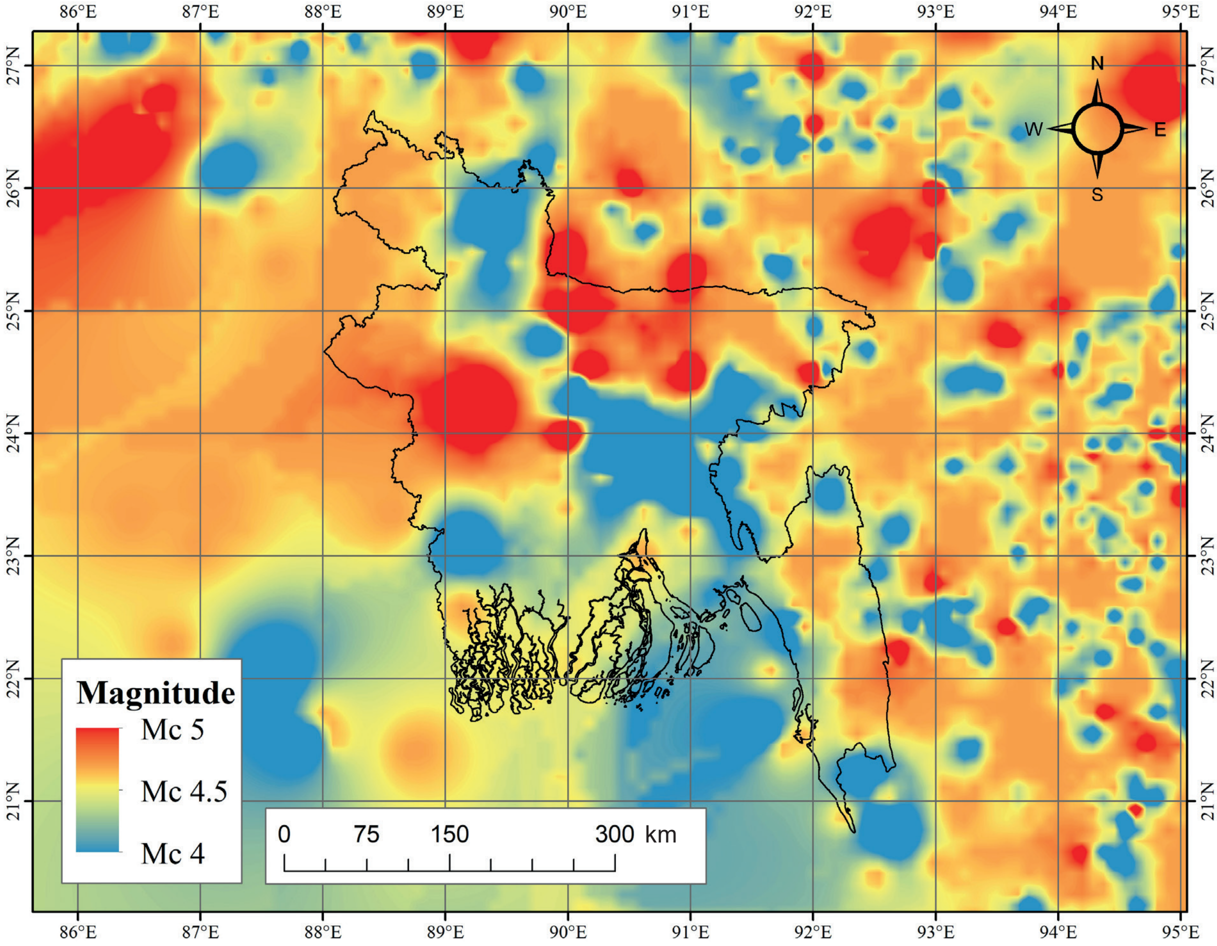

Fig. 9. *The* M_C *values observed for Bangladesh along with the potential seismic sources*

For seismicity analysis, the *b* and *a* values are similar in importance as the magnitude of completeness. The *b* and *a* values obtained for the data in the completed catalog varied in the ranges 0.71–1.12 and 4.85–7.12, respectively (Tab. 5). In the whole study area (and around it) *b* values were found to be close or above to 1.00, making the area a seismically active zone.

Table 5
Spatial distribution of seismic parameters for Bangladesh

Latitude °N	Longitude °E	M_C	*a* value	*b* value
21	86	4.4	5.12	0.89
	87	4.2	4.99	0.77
	88	4.1	4.85	0.71
	89	4.4	5.00	0.88
	90	4.3	4.98	0.87
	91	4.0	4.82	0.71
	92	4.0	4.85	0.72
	93	4.4	5.20	0.88
	94	4.5	5.25	0.92
	95	4.5	5.22	0.95
22	86	4.5	5.20	0.92
	87	4.2	5.10	0.75
	88	4.1	4.99	0.71
	89	4.5	5.35	0.90
	90	4.4	5.16	0.91
	91	4.0	4.85	0.72
	92	4.1	4.87	0.72
	93	4.6	6.05	0.87
	94	4.1	4.99	0.71
	95	4.0	4.85	0.72
23	86	4.6	6.50	0.89
	87	4.6	6.75	0.88
	88	4.5	6.22	0.90
	89	4.0	5.01	0.71
	90	4.4	5.25	0.79
	91	4.5	6.10	0.81
	92	4.5	6.00	0.85
	93	4.6	6.33	0.87
	94	4.6	6.25	0.84
	95	4.6	6.26	0.85
24	86	4.6	6.33	0.91
	87	4.6	6.35	0.90
	88	4.6	6.35	0.88
	89	5.0	6.85	1.05
	90	5.0	6.87	1.07
	91	4.0	4.85	0.72
	92	4.3	5.00	0.84
	93	4.5	5.25	0.88
	94	4.5	5.50	0.91
	95	4.6	6.05	0.93
25	86	4.8	7.02	0.98
	87	4.7	6.98	0.97
	88	4.6	6.65	0.95
	89	4.4	5.99	0.85
	90	5.0	7.00	1.12
	91	4.7	6.90	1.02
	92	4.5	6.50	0.88
	93	4.6	6.90	0.92
	94	4.8	7.02	0.95
	95	4.5	6.88	0.96
26	86	5.0	7.12	1.00
	87	4.2	5.22	0.80
	88	4.4	5.69	0.77
	89	4.2	5.26	0.75
	90	4.4	5.75	0.80
	91	4.5	5.80	0.92
	92	4.5	6.05	0.93
	93	5.0	6.99	1.10
	94	4.8	6.98	1.05
	95	4.8	6.97	1.05
27	86	4.5	6.25	0.91
	87	4.7	6.55	0.99
	88	4.5	6.30	0.93
	89	4.6	6.50	0.92
	90	4.6	6.55	0.91
	91	4.0	4.98	0.82
	92	5.0	6.80	0.99
	93	4.5	6.22	0.91
	94	4.4	6.00	0.95
	95	5.0	7.02	1.05

Explanations: M_C – magnitude of completeness, *a* – the earthquake productivity, *b* – the relative distribution of small and large earthquakes.

DISCUSSION AND CONCLUSION

An earthquake catalog compiled for Bangladesh was the main tool used for this seismic risk analysis. To prepare the catalog, all accessible sources comprising local networks, international agencies, literatures and previously made catalogs were compiled and consulted. A homogenized earthquake catalog of 48,342 events was compiled, with the magnitude range of 1.0–8.5 in terms of the scale of moment magnitude. The catalog comprised data between geographical borders of 16–29°N and 86–96°E. Domestic relationships were established between M_W, m_b, M_S, M_L, I_O, M_N and M_D used for the homogenization and deduction of dependent events. The exclusion of dependent events (declustering) followed the published algorithms (Reasenberg 1985, Uhrhammer 1986, and Gardner & Knopoff 1974, algorithms from Z-map (Wiemer 2001)). The results showed the presence of epistemic vagueness reflected in seismic disaster analysis for Bangladesh. The catalog was used to establish the relationships for various seismic sources, before supplying the basis to subdivide the earthquakes in Bangladesh into shallow and deep types. The magnitudes of minimum (1 to 5) with shallow depths were observed mostly in the northwestern part of study area and maximum (7 to 8) in the eastern fold belt part (Chittagong Hill Region) (Fig. 6). Likewise, maximum completions with deeper depth were experienced in the Chittagong Hill Tract region (Fig. 7).

In addition, the capital of Bangladesh, Dhaka, lies within the shallow depth zone but unfortunately the city lies near to the deformation front zone which was suggested as a locked area (Fig. 8). The city is highly vulnerable due to the Madhupur Fault, which is also considered a blind fault (Akhter 2010). Similar evidence was found in this study (Fig. 8). The potential seismic zone (deformation front) is very close to the capital city. The capital, similarly to the middle region of the country, might be exposed to shallow depth events rather than deep ones. Conversely, the northeastern, eastern foldbelt and Chittagong Hill areas are more exposed to deep and maximum magnitude events and the seismicity in those areas was observed as higher. Additionally, the greater amount of sediment deposited in the north and south of Bangladesh weighed down the surface of the Earth and warped the decollement/deformation front and this led to the conclusion that the region had the potential to host earthquakes above a magnitude of 8.

In this study, the assessed magnitude of completeness M_C varied in the range 4.0–5.0, meaning that it was well observed. Recent studies have revealed almost identical measurements of magnitude of completeness in the studied area. Rahman et al. (2018) observed that the estimated M_C value was 3.9–4.7 and the overall b value in and around Bangladesh was 0.84. Similarly, Kolathayar et al. (2012) found that M_C varied from 4.25 to 4.5 for in and around Bangladesh region. On the other hand, Das et al. (2012) calculated that the northern and the southern part of Bangladesh had observed M_C values of 3.9 and 3.7, respectively. It was also observed that M_C was lower in the Chittagong and Sylhet through Hill tracts than the northern part of the study area (Fig. 9). Khan et al. (2011) found b values in NE India (24.5–25.2°N and 90–90°E) for zone I, where the b value varies from 0.5–0.7. Likewise, Rahman et al. (2018) observed that the b value was within the range of 0.77–1.15. Nevertheless, the variability of the seismicity rate across the whole of India and adjoining areas was observed as the b values in the range of 0.7–0.8 (Kolathayar et al. 2012). In the present study, the b value varied between 0.71–1.12 (Tab. 5), what was similar or slightly higher. Overall a, b and M_C values of the seismicity parameters assessed in Bangladesh and adjoining areas showed that the studied area is a highly active seismic zone.

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