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A Modified Mercalli Intensity map of Bangladesh: a proposal for zoning of earthquake hazard

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Bangladesh is vulnerable to a variety of natural hazards including frequent tropical cyclones, floods and, less commonly, earthquakes and tsunamis. The country has developed an effective response mechanism for frequently experiencing hazards. However, at the same time, the nation has not developed an effective response mechanism for earthquake as a result of limited experiences with this type of hazard in the recent past. This research constructs a new catalogue consisting of 144 earthquakes (between 810BC and 2015) occurring within Bangladesh and the adjacent region. From this new catalogue, the effects of earthquakes are available for 80 events which are used in order to construct the geography of hazard in Bangladesh. The construction of a detailed Modified Mercalli Intensity (MMI) map using the new earthquake data suggests that this will be useful for supporting future risk reduction efforts in Bangladesh. Specifically, the findings support the revision of the current seismic zoning map of Bangladesh to include Chittagong and Dhaka in the high-risk zone for effective earthquake risk reduction. Finally, this research concludes that analyses of long-term data helps to identify new hazard exposure and develop knowledge that is useful to formulate new disaster risk reduction policies and rectify existing know zones in Bangladesh.

KEYWORDS

earthquake, hazard, intensity, risk, data, Bangladesh

1 Introduction

Bangladesh has developed a well-planned disaster responses and mitigation mechanisms for tropical cyclones and floods, however, the mitigation programme for earthquake risk reduction is still in progress. Bangladesh is susceptible to earthquakes due to its location between active seismic zones within and adjacent to the nation. Earthquakes occurring from the adjacent region of Bangladesh has significantly affected this country (Alam and Dominey-Howes, 2014; Alam and Dominey-Howes, 2016). The present seismic zoning map and policies to mitigate the effects of the earthquake hazard in Bangladesh have been developed based on those earthquakes occurring only after 1885, neglecting the potential for large earthquakes from adjacent active faults, particularly the detachment thrust (Choudhury, 2005). Bangladesh is a heavily densely populated country having over 1,000 people per km^2 and fragile infrastructure in major city areas. There is no Modified Mercally Intensity map to identify areas of social risk based on long-term hazard data. Therefore, more detailed archival research is required to identify high risk areas based upon available earthquake hazards in Bangladesh and adjacent regions.

In order to construct geographies of the earthquake hazard, it is necessary to understand the sources of hazards that originate in the region of Bangladesh. The Himalayan Mountains are located

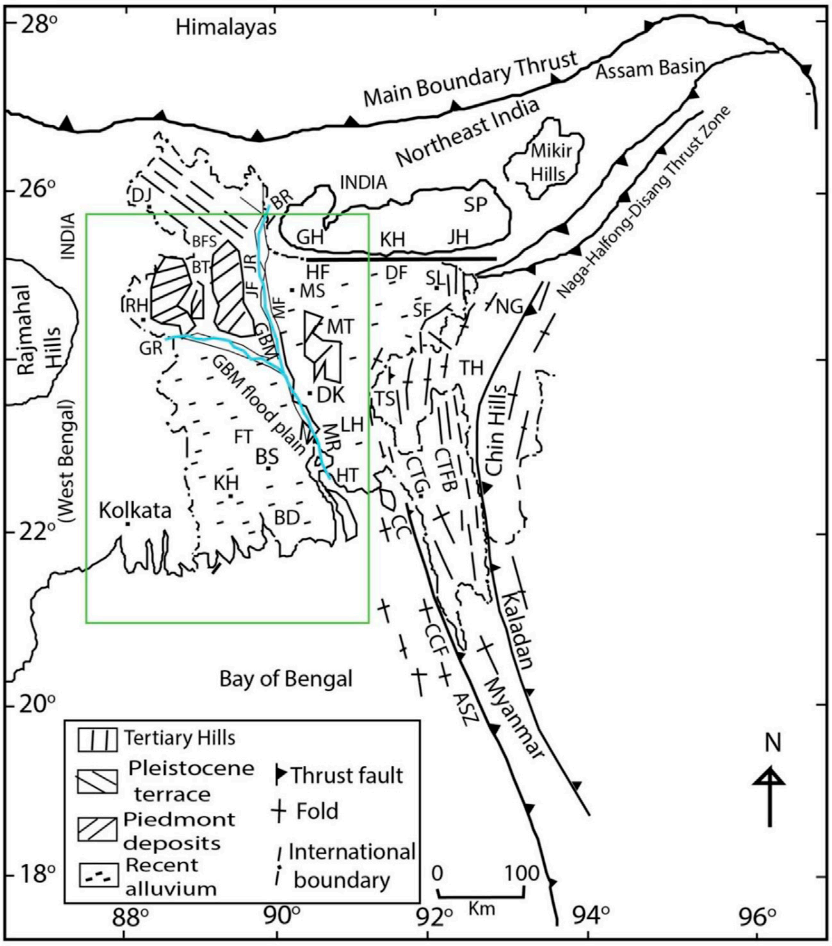

FIGURE 1
Location of Bangladesh in relation to regional active fault sources and the primary physiographic units: Tertiary Hills, Pleistocene uplands (the Barind and Madhupur terrace) and Recent sediments. The red solid contour lines show the demarcation of different zones from the mean sea level. The green box shows the location of the Bengal Basin. Key features include ASZ, Arakan Subduction Zone; BD, Bengal Delta; BFS, Bogra Fault System; BR, Brahmaputra River; BT, Barind Tract; BS, Barisal; **CC**, Chittagong coast; CTFB, Chittagong-Tripura fold belt; DF, Dauki Fault; DK, Dhaka; FT, Faridpur Through; GH, Garo Hills; GR, Ganges River; HF, Haluaghat Fault; HT, Hatiya Through; JF, Jamuna Fault; JH, Jaintia Hills; KH, Khasi Hills; LH, Lalmai Hills; MF, Madhupur Fault; MT, Madhupur Tract; MR, Meghna River; MS, Mymensingh; RH, Rajshahi; SF, Sylhet Fault; SL, Sylhet Hills and SP, Shillong Pleateau (Source: map prepared adapting tectonic elements from Alam et al., 2003; Ali and Choudhury, 2001; Khan, 2012; Mukherjee et al., 2009).

200 km from the northern border of Bangladesh. Between the Himalayan Mountains and Bangladesh, the Dauki Fault and the Assam Seismic Fault are located (Figure 1). Additionally, the Bogra Fault System (BGF), the Jamuna Fault (JF), the Madhupur Fault (MF) and the Sylhet Fault (SF) are located within Bangladesh (Figure 1). To the south, the country is bordered by the Bay of Bengal. The Arakan Subduction Zone (ASZ) along the northern end of the Bay of Bengal extends up to the SE Bangladesh. It is a tropical low-lying country having a long funnel shaped coast (Figure 1). Bangladesh has experienced earthquakes those originated from within and adjacent seismic sources in recent and distant past.

The country is affected by earthquakes originating in India and Myanmar. In order to construct a complete geography of the hazard, it is necessary to consider active seismic sources from the adjacent countries particularly adjoining Bangladesh (Figure 1). The research proposes a new Modified Mercalli Intensity map which has been developed based upon the average effects of 80 earthquakes in Bangladesh occurring between BC810 and 2015 in Bangladesh and adjacent regions.

This paper begins with discussing earthquake hazard zoning and preparation activities. This is followed by a review of data sources used for this research. The methods of the new MMI map construction are detailed and illustrated followed by a presentation of the results. The last sections discuss the significance of the findings and detail the conclusions.

2 Earthquake hazard zoning and preparation activities in Bangladesh

In the late 1970s and early 1980s, was a period were many bridges, buildings and industrial structures constructed

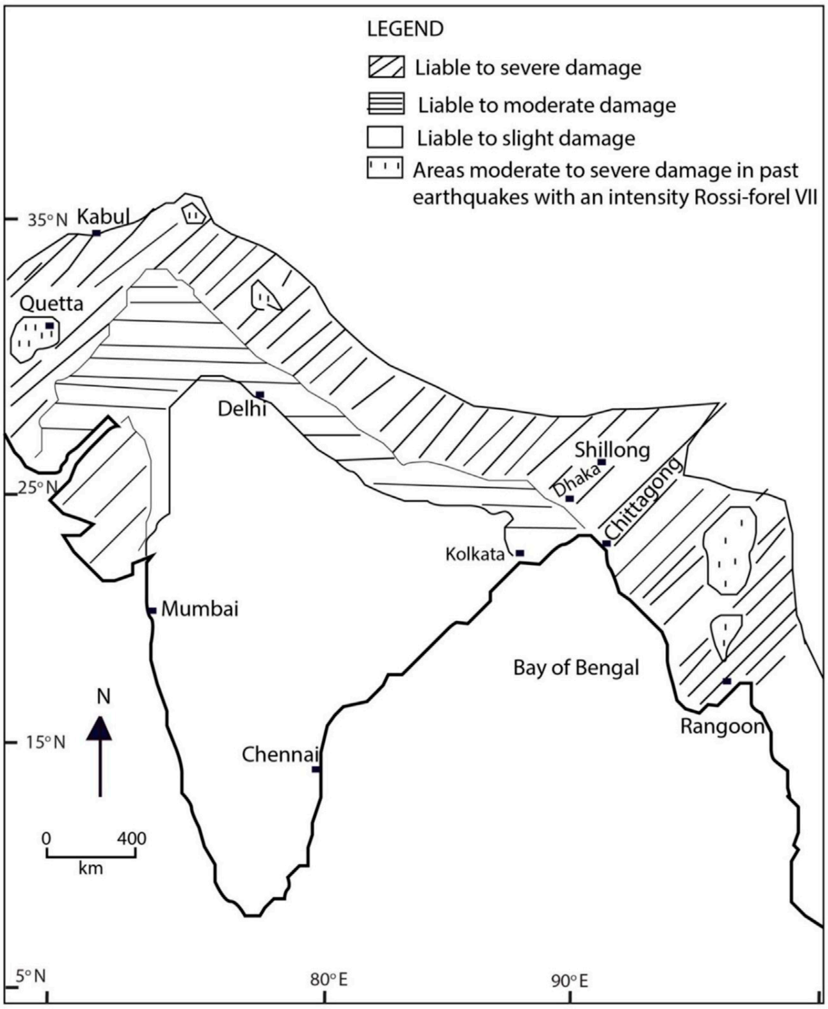

FIGURE 2
Indian sub-continent seismic zone map which was prepared by the Geological Survey of India in 1935 (Source: redrawn from Ali and Choudhury, 2001).

throughout Bangladesh. Following this, the assessment of seismic risk in different regions in the country was a great concern of engineers and scientists (Ali and Choudhury, 2001). Research was undertaken to identify areas liable to severe seismic effects in Bangladesh (Kamal, 2008; Sarker et al., 2010). The seismic zoning maps of Bangladesh have been revised continuously with the revised standing orders on disasters which was published in 2010, emphasised the need for mapping areas liable to earthquake damage. To understand the effectiveness of program and policies in relation to earthquake risk reduction, it is necessary to review relevant policies and how they align. Earthquake hazard management includes three key initiatives a) seismic zoning and introduction of building codes, b) seismic and geomagnetic observatories and c) public education and awareness. The first two initiatives are much relevant to the background of this study have been detailed in the following sections.

2.1 Seismic zoning and introduction of building codes

The Geological Survey of India developed the first seismic zoning map for the sub-continent in 1935. North, north-east and south-east regions of Bangladesh had been included in the severe seismic risk zone of the Geological Survey of India map (Figure 2). After Bangladesh became an independent country in 1971, separating from Pakistan the mid 1970s, saw large industrial complexes (e.g., fertilizer factories et al.) built and designed which demanded a sophisticated investigation of seismic risk (Ali and Choudhury, 2001). The 12 May 1977 earthquake (M_s 5.7) along Bangladesh-India border further reaffirmed this requirement to be incorporated in their design. Consequently, in June 1977, the Government of Bangladesh formed a committee of experts to undertake seismic zoning of Bangladesh and formulate policy options. The committee reviewed all the available information,

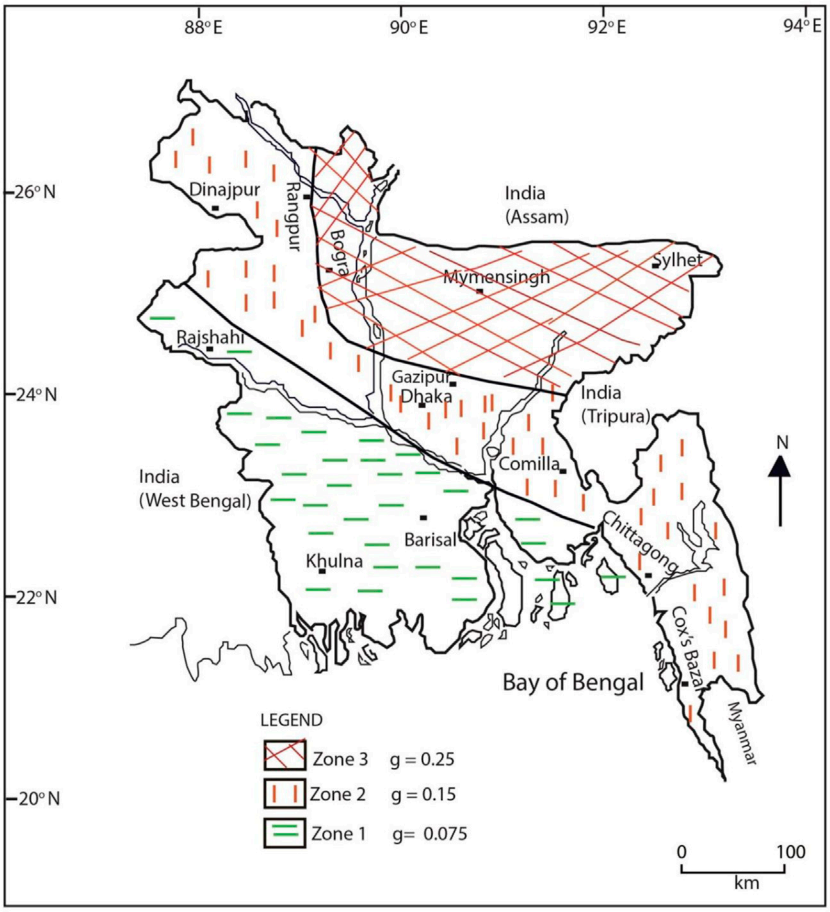

FIGURE 3
The current seismic zoning map of Bangladesh indicating probable earthquake zone coefficients. The g value equals maximum ground acceleration that can be expected based upon historic earthquakes over the last 200 years. Zone 1 includes NE of Bangladesh and Sylhet City lies within this zone. Zone 2 includes Dhaka and Chittagong cities. Zone 3 includes SW Bangladesh (Source: redrawn from Ali and Choudhury, 2001).

revised seismic risk maps and outlined the newly established building codes for earthquake resistant designs. In 1992, this exercise was repeated, with policies, rules and laws embracing new research and knowledge in earthquake zones and engineer and construction practices. Furthermore, seismic risk maps and building codes were revised to provide improved guidelines for earthquake resistant design. For this mapping exercise, Bangladesh was divided into three zones (Figure 3): Zone 3 (liable to severe damage); Zone 2 (liable to moderate damage); and Zone 1 (liable to slight damage).

2.2 Seismic and geomagnetic observatories

The Bangladesh Meteorological Department established an observatory in Chittagong in 1954, with facilities for seismic and geomagnetic observations (Ali and Choudhury, 2001). Until 2007, this was the only seismic observatory in Bangladesh. Although in 1977 the committee of experts recommended the establishment of a minimum of three observatories throughout the country, it has taken over 30 years to establish such observatories which are located in Sylhet, Rangpur and Gazipur (Figure 3) including the modernisation of the Chittagong centre in 2007. Currently in Bangladesh, different institutions such as Dhaka University Earth Observatory (DUEO), Bangladesh University of Engineering and Technology (BUET), Geological Survey of Bangladesh (GSB) and Bangladesh Meteorological Department (BMD) operate seismic monitoring networks separately of each other.

Efforts to identify areas of high seismic risk in Bangladesh have been in progress for some time (Kamal, 2008; Sarker et al., 2010). A number of UN funded projects have worked and been continued to work retrofitting in Dhaka, Sylhet and Mymensingh. There is also still an outstanding need to identify and retrofit fragile buildings in Dhaka and other major cities of Bangladesh (Paul and Bhuiyan, 2010). The pre 2012, policies and practices, which are based on tropical cyclones and floods, may not be adequate to mitigate the consequences of earthquake and tsunamis. However, the drafted disaster management policies of 2012, have initiated several effective measures for earthquake risk reduction. These include:

- enhancing institutional capacity to mitigate earthquake risk, updating building codes, purchasing equipment for the fire

service and civil defense department to effectively respond in the post disaster period;
- generating awareness among people about earthquake hazard and risk and arranging training for volunteers;
- developing seismic hazard risk maps for urban areas (for example, Dhaka, Chittagong, Sylhet and Rangpur);
- retrofitting fragile buildings in the above urban areas and developing guidelines for people about the retrofitting;
- developing a program of actions to mitigate consequences of earthquake occurrence in local level urban administration. For example, forming disaster management committee and volunteer teams for awareness generation and operating search, rescue operations with highest participation of local people;
- enhancing earthquake hazard response mechanisms in institutions (Hospital, school and garments);
- conducting research about earthquake hazard and risk; and
- enhancing efficient and professional management team in post disaster rehabilitation.

The review of the work of the Ministry of Disaster Management and Relief, and Disaster Management Department suggests that the Government of Bangladesh is still working towards identifying earthquake prone areas and improving DRR for earthquake related hazards. In order to develop an effective earthquake risk reduction program, it is necessary to review past hazard events and their geographical distribution and impacts in Bangladesh. This research will show how reviewing long-term earthquake data can help accurately identify appropriate seismic risk mapping in Bangladesh.

3 Data sources and methods

The records of Bangladesh earthquakes can be classified according to four types of data sources: geological, archaeological, historical and instrumental data. Each type of record has been collected from existing recognised and published sources. In order to develop a comprehensive earthquake catalogue, data sources were obtained from online global earthquake databases e.g., the National Geophysical Data Center (NGDC, 2012) and Geoscience Australia (GA), (Geoscience Australia, 2011a), International Seismological Centre (ISC, 2023), Incorporated Research Institutions for Seismology (IRIS, 2023), the Novosibirsk Tsunami Laboratory, Russia (NTL), regional catalogue (i.e., Oldham, 1883), annals, chronicles, diaries, letters, travellers, published earthquake catalogues, articles in the peer reviewed literature, books, reports, newspaper articles, local historical books, institutional and administrative memoirs and the historical archive from the India Office Records of the British Library and Royal Society, London. Whilst this research focuses on identifying events that have affected Bangladesh, it has broadened the study to include the area located between Latitude 18.5°S to 28.15°N and Longitude 87° E to 95.5° E to ensure the comprehensive coverage of the study area and adjacent seismically active regions (Figure 1).

3.1 Recording and conversion of earthquake magnitudes

While collecting and collating earthquake magnitudes from secondary sources listed below Table 1, it has been noted several challenges relating to the use of different magnitude scales and the lack of any magnitude scale for some events. On occasion, a source provides Modified Mercalli Intensity (MMI) values for the effects of an earthquake. However, when neither an MMI or magnitude scale was provided, it has been attempted to collect and review the effects of the earthquakes if available. After careful analysis of the effects, this has been converted to the MMI scale and a new MMI value has been provided in Table 1. In this study, when a source material item has been consulted, it is considered to be a secondary source. For example, for the 1764 event, this study has consulted several sources (Anon., 1897; Chandra, 1977; Nandy, 1994), which are considered as secondary sources. Nandy (1994) referred to Campbell (1809) from where information was collected for this particular event. At this stage, this study is not able to consult Campbell (1809) and consider this reference as a primary source for that event. Hence, primary sources are those that this study has not yet consulted for a particular event and secondary sources are those that this has consulted.

For quantification and graphical presentation of the earthquakes, the size of earthquakes should be classified based on their magnitude or intensity scales. For the new earthquake catalogue presented in Table 1, the size of earthquakes was provided in magnitude scales by most source materials. The conversion of earthquake scales from either "magnitude" to "intensity" or *vice versa*, could distort the actual values of the size of each earthquake. In some cases, intensity values were recorded from secondary sources (Table 1). For example, for the 1676 earthquake (Even #13 in Table 1), an intensity value of 7 was provided by the source document; this intensity value has been converted to 5.7 on the magnitude scale. This conversion of the intensity values of earthquakes to magnitude measured on the Richter scale were performed using the magnitude and intensity relationship (see supplementary material Table 1) provided by the Missouri Department of Environmental Resources (Gere and Shah, 1984). It should be borne in mind that MMI values are often skewed to higher values by locations with higher shaking susceptibility, certain types of soil texture, or locations with buildings that respond to a particular ground shaking frequency in disastrous ways (Ambraseys and Douglas, 2004). As such, converted magnitude from the MMI that has been provided in Table 1 should be treated with caution for the purpose of reuse and further research to more accurately refine these MMIs is required but was beyond the scope of this research.

3.2 Cross checking and validation of data

A total of 99 source documents were consulted to assist with development of the new earthquake catalogue (Table 1). However, inconsistencies in citations, differences in the date of events, differences in magnitude and intensity were identified. Accordingly, it was necessary to employ a rigorous system for cross-checking and validating data. This has been achieved by cross-checking multiple sources and performing a content

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TABLE 1 A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
1*	810BC-400	*	*	India: Assam	26.1	92.56	*	*	*	*	*	*	*	-	99	Radiocarbon dating of sediments calibrated age 810BC-400
2	535BC-530	*	*	India: Assam	26.1	92.56	*	*	*	*	*	*	*	-	99	Radiocarbon dating of sediments calibrated age 535BC-530
3	645–980	*	*	India: Assam	26.1	92.56	*	*	*	*	*	*	*	-	99	Radiocarbon dating of sediments calibrated age 645BC-980
4	825–835	*	*	India: Assam	26.1	92.56	8	*	*	*	*	*	*	-	5, 15, 99	The earthquake destroy temples and palaces in Assam
5	1440–1470	*	*	Bangladesh	25.15	90.3	*	*	*	*	*	*	*	-	30	The radiocarbon age of charcoals shows date as 1440–1470
6	1548	*	*	India and Bangladesh	26	94	7	9	*	*	*	*	*	45	30, 42, 52, 98	The first recorded earthquake in Bangladesh. Sylhet and Chittagong were violently shaken
7	1596	*	*	India: Assam	26.1	92.56	7	9	*	*	*	*	*	-	92	
8	1601	*	*	India: Assam	26.1	92.56			*	*	*	*	*	-	92	
9	1642	*	*	India: Assam	26.1	92.56	6	*	*	*	*	*	*	-	22, 42, 46, 92	Most severe damage occurred in Bangladesh

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TABLE 1 (*Continued*) **A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.**

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
10	1649	*	*	India: Assam	26.1	92.56	3	3	*	*	*	*	*	-	46	
11	1663	2	19	India: Assam	26.1	92.56	8		*	*	*	*	*	-	42, 92, 96, 97, 98	The earthquake was so devastative that Mir Jumla is believed to have fled Assam
12	1664	*	*	Bangladesh	25	90	M_w 7.79		*	*	*	*	*	-	30, 51	The earthquake may be relevant to the activity of the Dauki Fault
13	1676	9/10	*	Bangladesh	22.22	91.48	5.7	7	*	*	*	*	*	-	46	Chittagong was destroyed by an earthquake and severe tropical cyclone
14	1679	1	28	Myanmar	19.42	93.57	7	9	*	*	*	*	*	-	46	The earthquake was very severe and affected a wide area of Arakan, Bengal and India
15	1696	*	*	India: Assam	26.1	92.56		*	*	*	*	*	*	-	92	The reign of King Rudra Singha experienced earthquakes twice in 1696 and 1749
16	1749	*	*	India: Assam	26.1	92.56			*	*	*	*	*	-	92	-
17	1750	*	*	Myanmar coast	18.5	93.4	5.7	7	*	*	*	*	*	1	1, 16	The earthquake may have caused eruptions of mud volcanoes

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
18	1762	4	2	Bangladesh: Chittagong	22	92	8	11	*	200	*	*	*	6, 8,9,11,16, 17, 18, 19, 20	1, 2, 3, 4, 7, 34, 40,43, 50, 52, 77, 79,80, 91, 93	Alam et al. (2012) concluded the earthquake caused local tsunamis and huge effects on social infrastructures
19	1762	7	13	India: Kolkata	22.3	88.2	4.3	5 [71]	*	*	*	*	*	-	10, 20, 71	-
20	1764	6	4	Bangladesh-India: on the bank of the Ganga River	24	88	6	8 [10,71]	*	*	*	*	*	70	10, 21, 71	Many houses destroyed and large number of people and cattle were killed [21]
21	1772	*	*	India: Assam	26.1	92.56	M_s 6.5	*	*	*	*	*	*	-	93	The earthquakes damaged the part of Assam
22	1775	4	10	Bangladesh: Dhaka	23.38	90.25	4.3	5	*	*	*	*	*	-	42, 98	Severe earthquake felt in Dhaka
23	1787	*	*	Bangladesh	24.26	89.43	7	10	*	*	*	*	*	-	46, 54, 98	The earthquake caused shifting of river courses
24	1808	4	13	India: Kolkata	22.6	88.4	4.3	5 [10]	*	*	*	*	*	-	10, 20, 71	Cracks in house walls were observed
25	1810	4	1	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	-	10, 20, 71	The earthquake felt very severely in Kolkata
26	1810	5	13	India: Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*	-	10, 20, 71	-

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
27	1811	2	1	India: Kolkata	22.3	88.2	5	6 [10]	*	*	*	*	*	-	10, 20, 71	-
28	1812	5	11	Bangladesh		Dhaka	6	8	*	*	*	*	*	-	42, 98	The earthquake felt violently in Sylhet
29	1816	7	11	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	-	10, 20, 71	-
30	1822	4	3	Bangladesh	24.3	90.5	7.1 [99]	8 [10]	*	*	*	*	*	55	20, 71, 98	Several shocks felt in Bengal
31	1822	8	16	India: Kolkata	22.3	88.2	5	6 [10]	*	*	*	*	*	56	10, 20, 71	Walls of houses were moved from north to south
32	1823	4	3	Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*		10, 20, 71	-
33	1823	11	26	Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*	57	10, 20, 71	Accompanied by subterranean noises
34	1825	1	8	Bangladesh	24.4	90.33	4.3	5	*	*	*	*	*	57, 58	20	-
35	1827	1		India: Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*		10, 20, 71	-
36	1827	1	19	India: Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*	60	10, 20, 71	-
37	1828	7	8	India: Kolkata	22.32	88.23	5.7	7 [10]	*	*	*	*	*	61	10, 20	-
38	1828	9	18	India: Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*	62	10, 20, 71	-
39	1828	10	8	Bangladesh: Dhaka	23.42	90.24	5		*	*	*	*	*	62	20	Four distinct shocks in successions
40	1829	9	18	India: Kolkata	22.3	88.2	5	6 [10]	*	*	*	*	*	63	10, 20, 71	-

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations		Earthquake parameters				Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
41	1830	12	31	Bangladesh: Chittagong	22.47	91.59	6.5	*	*	*	*	*	*	64	20, 48	Very violent earthquake and all houses were seriously cracked
42	1832			India: Assam	26.1	92.56	6.5	*	*	*	*	*	*	-	93	The earthquakes damaged the part of Assam
43	1834	7	8	Bangladesh: Rangpur	25.33	89.1	6	8 (10)	*	*	*	*	*	74	10, 20, 71	-
44	1834	7	21	Bangladesh: Rangpur	25.33	89.1	6	8 (10)	*	*	*	*	*	74	10, 20, 71	-
45	1842	5	21	India: Bengal	25	87	5.7	7 (10)	*	*	*	*	*	73	10, 20, 71	-
46	1842	5	23	India: Bengal	25	87	4.3	5 (10)	*	*	*	*	*	73	10, 20, 71	-
47	1842	10	23	Bangladesh: Chittagong	22.47	91.59	4.3	5	*	*	*	*	*	73	20	Motion east to west
48	1842	11	11	Bangladesh	24	89.2	M_w 7.3	9 (10)	*	*	*	*	*	44	10, 20, 71, 73, 98	Felt also sharply at sea
49	1843	10	30	Myanmar: Ramree and Cheduba	18.5	94.1	6	8	*	*	*	*	*	67	20	Very sharp at Gukiong, on sea, 145 miles to south
50	1845	7	24	India: Serampore, Kolkata	22.7	88.4	4.3	5	*	*	*	*	*	-	10, 20, 71	-
51	1945	7	26	India: Serampore	22.7	88.4	4.3	5	*	*	*	*	*	-	10, 20, 98	-
52	1845	8	6	India: Guwahati, Sylhet	22.7	88.4	M_w 7.1 (99)	7 (10)	*	*	*	*	*	-	7, 10, 20, 71	-
53	1846	10	18	Bangladesh	23.52	90.23	M_s 6.2	*	*	*	*	*	*	Friend of India	7, 20	Masonry buildings were cracked in every direction in Dhaka

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

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				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
54	1848			India: Assam	26.1	92.56	5.7	7	*	*	*	*	*	-	93	The earthquake damaged the part of Assam
55	1848	2	20	India: Kolkata	22.3	88.2	4.3	5 [10]	*	*	*	*	*	Friend of India	20, 71	-
56	1848	11	30	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	Friend of India	10, 20, 71	-
57	1849	1	22	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	105	10, 20, 71	-
58	1851	1	8	Bangladesh: Chittagong	22.47	91.59	5.7	7	*	*	*	*	*	Hooker's Journal vol. 2	20	Motion apparently from south
59	1851	2	9	India: Kolkata	22.3	88.2	5.7 [71]	7 [10]	*	*	*	*	*	Friend of India	10, 20	-
60	1852	2	9	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	-	10, 20	-
61	1852	8	9	Bangladesh: Dhaka	23.43	90.24	4.3	5	*	*	*	*	*	Perry	20	Oscillation lasted 15 seconds
62	1861	2	16	India: Kolkata	22.3	88.2	5.7	7 [10]	*	*	*	*	*	Friend of India	10, 20	Water in tanks rose about 0.3 m above its level
63	1861	4	18	India: Kolkata	22.3	88.2	3.7	4 [10]	*	*	*	*	*	-	10, 20, 71	-
64	1864	1	5	Bangladesh: Dhaka	23.42	90.24	4	*	*	*	*	*	*	Friend of India	10, 20	Houses much shaken
65	1864 or 1865	*	*	Bangladesh: Chittagong	22.22	91.50	5.7	7	*	*	*	*	*	-	41	A violent shock of an earthquake in the year 1764 or 1765, triggered mud volcanoes

(Continued on following page)

TABLE 1 (*Continued*) **A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.**

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
66	1865	11	17	Bangladesh: Jessore	23.2	89.2	4.3	5 [(10)]	*	*	*	*	*	Official Record	10, 20, 71	-
67	1865	12	19	Bangladesh	23.23	91.13	5.5		*	*	*	*	*	-	7, 20, 37, 91	Many buildings were cracked in Chittagong
68	1866	1	6	Bangladesh: Chittagong	22.22	91.48	3.7	4	*	*	*	*	*	Friend of India	10, 20	Light shock
69	1866	5	23	India: Bengal	25	87	5.6 [(71)]	8 [(10)]	*	*	*	*	*	Friend of India	7, 10, 20, 71	Some houses fell down
70	1869	1	10	India: Assam	24.75	93.25	M_w 7.3		*	*	*	*	*	-	51, 93,97,98	-
71	1869	6	9	India: Kolkata	22.3	88.2	4.3 [(71)]	5 [(10)]	*	*	*	*	*	-	10, 20, 71	-
72	1870	4	22	Bangladesh: Dhaka	23.42	90.24	5.5		*	*	*	*	*	Times	7	-
73	1874	5		Bangladesh: Bhola	22	89	*	*	*	*	*	*	*	-	82, 83	-
74	1876	12	13	Bangladesh	23.42	90.25	4.3	5	*	*	*	*	*	-	85, 98	It was felt in Dhaka
75	1885	7	14	Bangladesh	24.8	89.5	M_w 6.9	7 [(10)]	*	75	*	*	*	-	1, 7, 10, 28, 47, 51, 71, 85, 86	The felt areas extended in the entire northeast India and Myanmar
76	1891	6	17	Bangladesh: Sirajganj	20.5	86.55	5	5 [(10)]	*	*	*	*	*	-	7, 10	-
77	1897	6	12	India: Assam	26	91	M_s 8.7	*	60	1626	*	*	*	9, 11, 12, 13, 14, 18, 23	1, 7, 21, 24, 25, 33, 40, 49, 68, 73, 87, 91, 92	A great tidal wave swept up the Brahmaputra River over 250 miles from sea

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
78	1906	9	29	India: Kolkata	22.3	88.2	5 [71]	6 [10]	*	*	*	*	*	78	10, 71	-
79	1906	12	6	India: Kolkata	22.3	88.2	5 [71]	6 [10]	*	*	*	*	*	78	10, 71	-
80	1918	7	8	Bangladesh	24.5	91.7	M_s 7.6	*	14	9	50	*	*	-	1, 25, 81, 76, 92, 98	Severe damage in Srimangal, but minor effects in Dhaka
81	1923	9	9	Bangladesh	25.18	91	M_s 7.1	*	*	50	*	*	*	-	40, 88, 92, 95, 98	The earthquake caused heavy damage in Mymensingh
82	1930	7	2	India: Assam	25.8	90.2	M_s 7.1	*	*	1	*	*	*	-	1, 28, 92, 94	The earthquake caused major damage in the eastern Rangpur district
83	1930	9	24	Bangladesh	24.9	93.86	M_w 6.18	*	*	*	*	*	*	-	89	-
84	1932	3	24	Bangladesh: North	25	90	M_s 5.7	*	*	*	*	*	*	-	10, 38, 40, 71	-
85	1932	3	27	Bangladesh	24.3	92	M_w 5.7	*	*	*	*	*	*	-	40, 89	-
86	1932	9	11	India	26.3	92	M_w 5.8	*	*	*	*	*	*	-	40, 89	-
87	1933	3	6	Bangladesh	26	90.3	M_w 5.9	*	*	*	*	*	*	-	89	-
88	1934	1	15	Bihar-Nepal	26.5	86.5	M_s 8.4	*	*	*	*	*	*	-	76, 88	The earthquake caused damage in Rangpur
89	1935	3	21	Bangladesh: Pabna	24	89.14	M_w 5.8	*	*	*	*	*	*	27	10, 71, 89, 98	-
90	1941	1	21	Bhutan	27	92	M_w 6.43	*	*	*	*	*	*	-	40, 89	-

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TABLE 1 (*Continued*) **A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.**

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
91	1950	8	15	India: Assam	28.12	94.05	M_w 6	*	*	*	*	*	*	-	29, 31, 32, 42, 89	Water bodies in Dhaka remained in a state of agitation for an hour
92	1954	3	22	Myanmar	24.5	95.3	M_s 7.4	*	*	*	*	*	*	-	1, 26, 98	In Dhaka residents wake up and ran outdoor
93	1957	7	1	India-Myanmar border	25	94	M_s 7	*	*	*	*	*	*	-	92	-
94	1957	12	6	Bangladesh: Dhaka	24	90		*	*	*	*	*	*	10	11	-
95	1964	2	27	Myanmar	21.7	94.4	M_w 6.1	*				*	*	-	89, 90	-
96	1965	6	11	Bhutan	27.12	91.36	M_b 5.1	*	*	*	*	*	*	-	40, 38	-
97	1967	9	6	Bangladesh	24.6	91.42	M_w 5.1	*	*	*	*	*	*	-	40, 89	-
98	1967	9	15	Bhutan	27.24	91.48	M_w 5.8	*	*	*	*	*	*	-	40, 89	-
99	1967	11	14	Bangladesh	25	91.3	M_w 5.3	*	*	*	*	*	*	-	40, 89	-
100	1968	12	27	Bangladesh	24.06	91.36	M_w 5.4	*	*	*	*	*	*	-	40, 89	-
101	1969	5	11	Bhutan	27.42	90.12	5	*	*	*	*	*	*	-	40	-
102	1970	7	25	Bangladesh	25.42	88.3	M_w 5.4	*	*	*	*	*	*	-	40, 89	-
103	1970	8	28	Bangladesh	24.42	91.42	M_w 5.3	*	*	*	*	*	*	-	40, 89	-
104	1971	2	2	Bangladesh	23.48	91.48	M_w 5.4	*	*	*	*	*	*		40, 89	-
105	1972	11	6	India: Assam	27	88.42	M_b 4.8	*	*	*	*	*	*	-	40, 38	-
106	1974	9	21	India: Assam	25.42	90.54	M_b 4.8	*	*	*	*	*	*	-	40, 89	-
107	1976	6	23	Bangladesh	21.24	88.42	M_b 5.3	*	*	*	*	*	*	-	40, 89	Water movement in sea adjacent to the Chittagong coast was observed by local people

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TABLE 1 (*Continued*) **A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.**

Event number	Year	Month	Day	Earthquake locations		Earthquake parameters			Earthquake effects					Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
108	1977	5	8	Bangladesh	24.89	92.25	M_b 5.6	*	*	*	*	*	*	-		The earthquake had led to cracking of at least 5 buildings in Sylhet
109	1977	5	12	Bangladesh-Myanmar border	21.75	92.99	M_s 5.7	*	*	*	200	*	*	-	89, 98	Cracks were developed in buildings in Chittagong and numerous people were injured
110	1979	4	11	Bangladesh	25.9	88.8	M_b 4.8	*	*	*	*	*	*	72	71, 89	-
111	1984	5	21	Bangladesh	23.42	91.3	M_b 5.3	*		*	*	*	*		40, 89	-
112	1984	9	30	Bangladesh	23.42	91.3	M_b 5.1	*	*	*	*	*	*	-	40, 89	-
113	1984	12	31	India: Assam	24.64	92.89	M_w 6	*	*	*	*	*	*	-	89, 93	-
114	1988	2	6	Bangladesh: Sylhet	24.68	91.57	M_s 5.8	*		2	100	*	*	-	1	-
115	1988	8	6	Myanmar	25.14	95.12	M_s 7.3	*		2	12	*	*	-	93	-
116	1988	8	21	India-Nepal border	26.7	86.8	M_s 7.8	*	998	*	*	*	*	-	36,98	Seismic seiches observed in many rivers including capsizing boats in the Jamuna River killing 2 people and missing almost 30 people
117	1989	6	12	Bangladesh: Banaripara	21.86	89.76	M_s 5.1	*	6	1		*	*	38, 39	1	-
118	1993	6	12	Bangladesh: South	21.83	89.7	5.7 [71]	*	*	*	*	*	*	-	71	-

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TABLE 1 (*Continued*) A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.

Event number	Year	Month	Day	Earthquake locations		Earthquake parameters				Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
119	1997	5	8	Bangladesh	24.89	92.25	M_w 6.0 [89] Mb 5.6	*	34	*	*	*	*	-	75, 84	The earthquake had led to cracking in at least 5 buildings in Sylhet
120	1997	11	21	India-Bangladesh border: Chittagong	22.21	92.7	M_w 6.1	*	54	23	200	*	1	39	1, 20, 42, 48, 65, 89, 95	The collapse of buildings and deaths occurred in Chittagong
121	1999	7	22	Bangladesh: Moheskhali Island	21.54	91.89	M_b 5.2[89] M_s 4.2 [35]	*	10	6	200	*	700	39	1, 35, 48, 75, 93	Houses cracked and in some cases collapsed
122	2000	1	3	India-Bangladesh border	22.13	92.77	M_b 4.6	*	33	*	*	*	*	39	1	-
123	2000	1	19	Bangladesh			M_s 4.5	*	*	*	100		*	-	98	Few buildings in areas of old Dhaka city were damaged
124	2003	7	26	Bangladesh: Borkal	22.85	92.31	M_w 5.7	*	10	3	25	*	500	39	1, 48, 53, 89, 98	Transformer of power supply exploded in Chittagong
125	2007	5	20	India	27.15	88.44	M_w 4.9	*	*	*	*	*	*	-	40, 89	-
126	2007	8	11	India: Assam	26.27	89.24	M_b 5	*	*	*	*	*	*	-	40, 89	-
127	2007	9	19	India	25.18	90.59	M_b 5.1	*	*	*	*	*	*	-	40, 89	-
128	2007	11	7	Bangladesh: Bandarban, Chittagong, Rangamati	22.15	92.38	M_s 5.1	*	29	*	10	*	*	39	1	-
129	2008	1	12	Bangladesh: Rangamati	22.76	92.33	M_b 5	*	34	*	*	*	*	39	1, 89	-
130	2008	3	13	Bhutan	27.46	91	4.5	*	*	*	*	*	*	-	58	-
131	2008	5	29	India	26.24	91.46	M_b 4.5	*	*	*	*	*	*	-	40, 89	-

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TABLE 1 (*Continued*) **A catalogue of historical and palaeoseismic evidence of earthquake in Bangladesh and adjacent regions between BC810 and AD2015.**

Event number	Year	Month	Day	Earthquake locations			Earthquake parameters			Earthquake effects				Primary	Secondary	Comments
				Location names	Lat	Long	Magnitude	Intensity	Focal depth	Deaths	Injuries	Damage (in m US $)	House destroyed/ damaged			
132	2008	7	5	India	26.07	91.39	Ms 5.1	*	*	*	*	*	*	-	40, 38	-
133	2008	9	20	Bangladesh: Sylhet	23.5	91.07	M_b 4.5	*	*	*	*	*	*	-	40, 89	-
134	2009	1	6	Bangladesh	24.11	89.25	M_b 4.7	*	*	*	*	*	*	-	40, 89	-
135	2009	2	27	Bangladesh	20.29	89.31	M_b 4.8	*	*	*	*	*	*	-	40, 89	-
136	2009	7	13	India	26.09	89.39	Ms 4.5	*	*	*	*	*	*	-	40, 38	-
137	2009	9	21	Bhutan	27.4	91.36	M_w 6.1	*	*	*	*	*	*	-	1, 40, 89	-
138	2009	10	30	Bhutan	27.29	91.46	M_w 5.1	*		*	*	*	*	-	40, 89	-
139	2009	12	31	Bhutan	27.31	91.15	M_b 5.3	*		*	*	*	*	-	1, 40	-
140	2010	9	11	India	25.52	90.39	M_b 5.2	*	*	*	*	*	*	-	1, 40	-
141	2011	9	18	India: Sikkim	27.73	88.15	M_w 6.9	*	*	97	*	*	*	-	1, 89	-
142	2012	3	18	Bangladesh	23.66	90.26	M_b 4.5	*	*	44	*	*	*	-	89	People in Dhaka and adjacent district got panic
143	2015	4	25	Nepal: Gorkha	28.15	84.70	M_w 7.8		15	8200	17,866				1	-
144	2015	5	12	Nepal: Dolakha	27.83	86.07	M_w 7.3		15	117	2800				1	-

Note: Asterisk (*) indicates no information available.

Reference # and detail of primary and secondary sources for each earthquake event referred to in columns 15 and 16.

1. National Geophysical Data Center (NGDC), (2012), 2. Gulston, (1763), 3. Verelst, (1763), 4. Hirst, (1763), 5. Banerji, (1923), 6. Nutalaya, et al. (1985), 7. Milne, (1911), 8. Bapat, et al. (1983), 9. Chaudbury, (1965), 10. Chandra, (1977), 11. Singh, (1966), 12. Davidson, (1936), 13. Lomnitz, C., (1974), 14. Bath, (1973), 15. Chaudhury, (1964), 16. Berninghausen, (1966), 17. Benerji, (1957), 18. Wei, and Zhuoli, (1987), 19. Lyell, (1875), 20. Oldham, (1883), 21. Anon., (1897a). 22. Rizvi, (1970), 23. Richter, (1958), 24. Anon., (1897b), 25. Pervez and Ram, (1997), 26. Duda, (1965), 27. Gutenberg and Richter (1965), 28. Khan and Chouan, (1996), 29. Murty and Rafiq (1991), 30. Morino, (2011), 31. Tandon, (1950), 32. Tillotson, (1951), 33. Curray, (1982), 34. Rennell and Banks, (1781), 35. Ansary, et al. (2000), 36. Anon., (1988), 37. Islamabadi, (1987), 38. ISC, (2023) 39. NEIC (2023), 40. BMD (2011), 41. Hunter, (1876), 42. Islam, (2004), 43. Fergusson, (1863), 44. Mandal, et al. (2000), 45. United Nations Office for the Coordination of Humanitarian Affairs (1993), 46. Iyengar, et al. (1999), 47. Middlemiss, (1885), 48. Alam, et al. (2006), 49. Hough, et al. (2005), 50. Alam, et al. (2012), 51. Ambraseys and Douglas (2004), 52. Steckler, et al. (2008), 53. Khan (2010), 54. Kamaluddin and Rahman, (1985), 63. Anon., (1843b), 65. Khan, (2004), 66. Anon., (1843a), 67. Anon., (1844), 68. Ambraseys, (2000), 69. Anon., (1849), 70. Campbell (1809), 71. Nandy, (1994), 72. Singh and Shankar, (1992), 73. Anon., (2023), 75. Paul and Bhuiyan, (2010), 76. Gupta, (1993), 77. Gupta and Gahalaut, (2009), 78. Mithal and Srivastava (1962), 79. Webster, (1911), 80. Smith, (1844), 81. Ali and Choudhury, (2001), 82. Rastogi and Jaiswal (2006), 83. Jaiswal, et al. (2008), 84. Sharfuddin, (2010), 85. Rizvi, (1969), 86. Khan and Hossain, (2005), 87. Bilham and England, (2001), 88. Geoscience Australia, (2011b), 89. USGS (2023), 90. IRIS (2023), 91. Rizvi, (1970), 92. Chakrabarti and Gosh, (2011), 93. Martin, and Szeliga, (2010), 94. Choudhury, (2005), 95. Dasgupta, (2011), 97. Gait (1906), 98. Akhter, (2010), 99. Rajendran, et al. (2004).

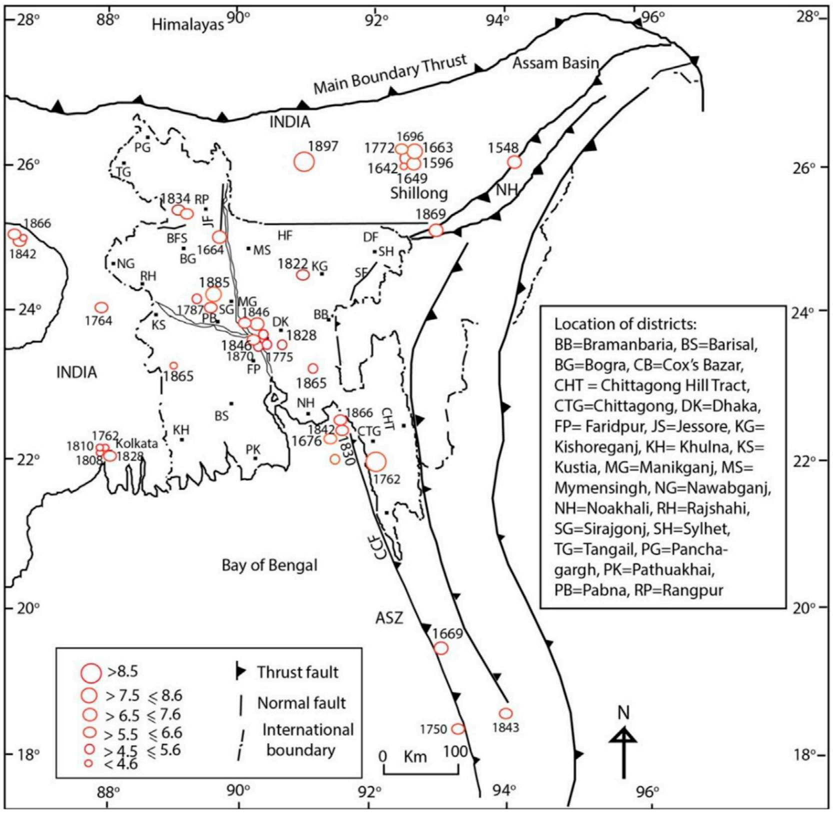

FIGURE 4
Earthquake distribution in Bangladesh and adjacent regions from BC810 to AD1900. The dates of all of the major events are labelled in map. High magnitude earthquakes are located in the active seismic areas in Bangladesh and adjacent India and Myanmar. ASZ, Arakan Subduction Zone; BFS, Bogra Fault System; CCF, Chittagong Cox's Bazar Fault; DF, Dauki Fault; HF, Haluaghat Fault; JF, Jamuna Fault and SF, Sylhet Fault (Source: base map adapted from Mukherjee et al., 2009).

analysis. This process verifies the date of occurrence of an event, explores inconsistencies in citations and identifies problems relating to magnitudes of earthquakes and evaluates likely effects. The new catalogue Table 1 is the output of this process.

3.3 Data analysis

To construct a geography of earthquake hazards in Bangladesh, the locations of earthquake epicenters are presented in a series of maps to reveal hazards and risks in Bangladesh. A new MMI map is constructed by using the content analysis of 47 source documents for 80 earthquake events occurring in Bangladesh and adjacent regions. Arc GIS was used to construct this map. The presentation and analysis of these earthquakes provides much better earthquake hazard geographies and associated risks in Bangladesh than has previously been available.

4 Results and discussion

In the following sections, it has been introduced key aspects of data, and discussed spatial-temporal distributions of earthquake events in the entire study region and analysed earthquake hazard geographies in Bangladesh.

A total of 144 earthquakes have been identified in the study region between 810BC and AD 2015. Of these events (Table 1) one earthquake (event # 5) was identified from archaeological sources, four earthquakes (event # 1, 2, 4, and 8) were identified from geological sources, the remaining 94 events were identified from historical and instrumental sources. The catalogue comprises the event number, the event date, earthquake locations (including coordinates and geographical location names), earthquake parameters (magnitude, intensity and focal depth), earthquake effects (deaths, injuries, damage in million US $ and house destroyed) information about primary and secondary sources for the event and key comments about earthquakes.

4.1 Earthquakes in and adjacent to Bangladesh

A total of 144 earthquakes are reported to have affected Bangladesh and the adjacent region (Table 1). The locations of these earthquakes are shown in Figures 4, 5. Evidence for three paleoseismic events in 810-400BC, 535-530BC and AD645-980 became available through the geological investigation of the great AD1897 earthquake in Assam (Rajendran et al., 2004). Banerji (1923) and Chaudhury (1964) found the evidence of the AD825-

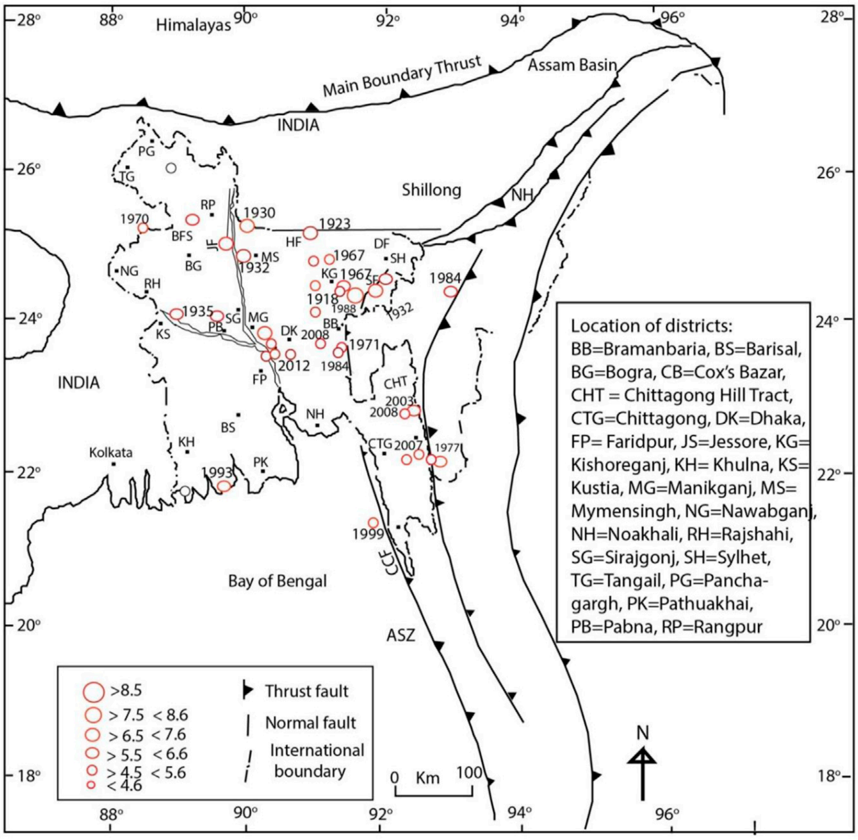

FIGURE 5
Earthquake distribution in Bangladesh and adjacent regions areas from 1900 to 2015. The dates of all of the major events are labelled in map. High magnitude earthquakes are located in the active seismic areas in Bangladesh and adjacent India and Myanmar. ASZ, Arakan Subduction Zone; BFS, Bogra Fault System; CCF, Chittagong Cox's Bazar Fault; DF, Dauki Fault; HF, Haluaghat Fault; JF, Jamuna Fault and SF, Sylhet Fault (Source: base map adapted from Mukherjee et al., 2009).

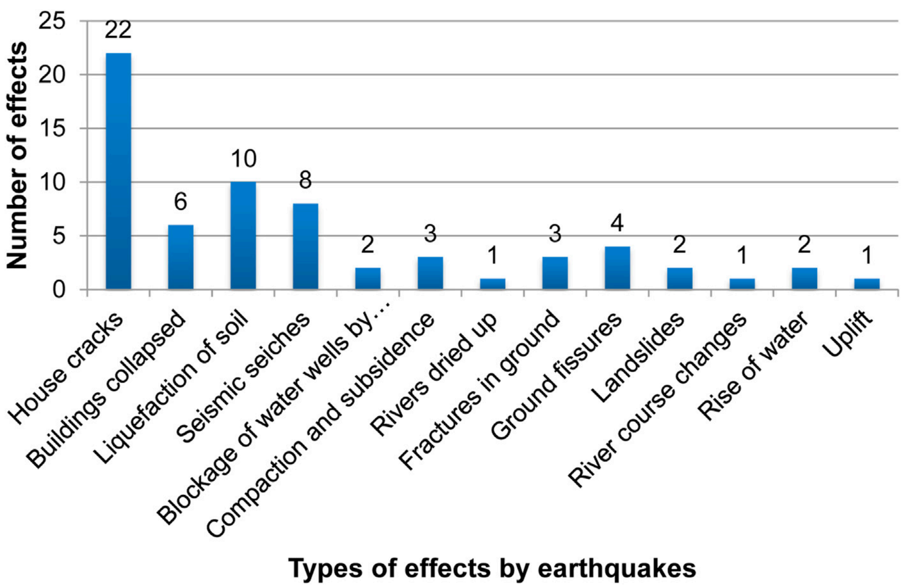

FIGURE 6
The types of impacts caused by earthquakes in Bangladesh (Source: reports numbers at the bottom of Table 1 #s 2, 3, 4, 5, 10, 11, 15, 21, 22, 23, 26, 47, 48, 50, 51, 52, 53, 54, 55, 56, 61, 62, 64, 65, 69, 70, 71, 75, 77, 80, 81, 83, 86, 99, 104, 111, 112, 114, 116, 127, 140, 143, 150, 151, 152, 153, 159, 161, 162, 163, 164, 165, 166, 167, 168).

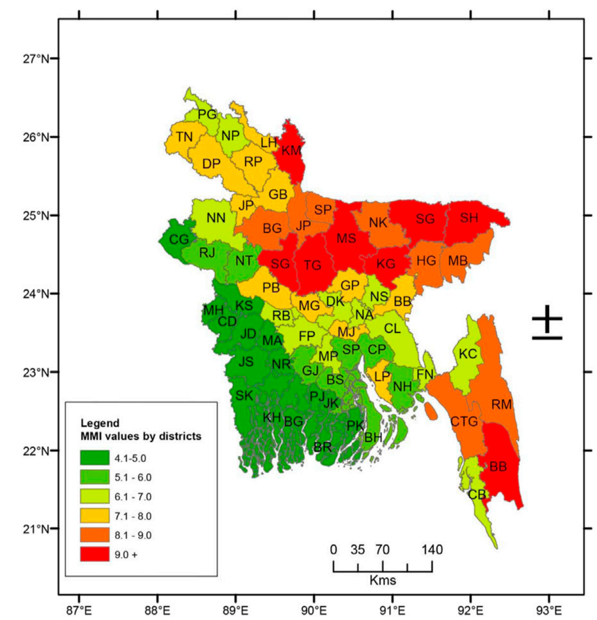

FIGURE 7
An MMI map of the average effects of 80 earthquakes in Bangladesh occurring between BC810 and AD2015 in Bangladesh and adjacent regions. BB, Bandarban; BE, Bagerhat; BG, Bogra; BH, Bhola; BR, Barguna; BS, Barisal; CB, Cox's Bazar; CD, Chuadanga; CG, ChapaiNawabganj; CL, Comilla; CP, Chandpur; CTG, Chittagong; DK, Dhaka; DP, Dinajpur; FN, Feni; FP, Faridpur; GB, Gaibanda; GJ, Gopalganj; GP, Gazipur, HG, Habiganj; JD, Jhenidah; JP, Jaipurhat; JL, Jamalpur; JS, Jessore; JK, Jhalkati; KC, Khagrachari; KG, Kishoreganj; LP, Lakshmipur; LH, Lalmonirhat; KH, Khulna; KM, Kurigram; KS, Kustia; MA, Magura; MB, Moulvibazar; MG, Munshiganj; MP, Madaripur; MS, Mymensingh; MH, Meherpur; NA, Narayanganj; NH, Noakhali; NK, Netrokona; NN, Noaganj; NT, Nattore; NP, Nilphamari; NR, Narail; NS, Narshingdi; PB, Pabna; PG, Panchgarh; PJ, Pirojpur; PK, Patuakhali; RB, Rajbari; RJ, Rajshahi; RM, Rangamati; RP, Rangpur; SG, Sunamganj; SJ, Sunamganj; SH, Sylhet; SK, Satkhira; SP, Shariatpur; TG, Tangail; TN, Thakurgaon (Source: reports numbers at the bottom of Table 1 #s 2, 3, 4, 5, 10, 11, 15, 20, 21, 22, 24, 32, 33, 34, 35, 36, 37, 40, 41, 42, 43, 44, 46, 47, 48, 49, 51, 52, 53, 54, 56, 68, 71, 72, 79, 84, 85, 86, 87, 91, 93, 94, 95, 96, 97, 98, 99).

835 earthquake by conducting archaeological investigation in Assam. The geological records of the AD1440-1470 earthquake emerged from the work of Morino et al. (2011) at Mymensingh. Analysis of earthquakes generated in Bangladesh and adjacent areas indicate that the 1762, 1885 and 1897 earthquakes in Bangladesh caused widespread damage. A repeat of similar earthquakes from any of the active seismic sources could cause damage, destruction and death within major population centres in Bangladesh. The effects of recent earthquakes occurring in 1977, 1997, 1999, 2003, and 2007 suggest that lesser magnitude earthquakes could cause significant damage to urban centres that are home to large highly exposed and huge vulnerable communities.

4.2 The construction of a new MMI map for Bangladesh

Analysis of the 47 reports (see list of reports below Figure 6) that contain information relating to the effects of 80 earthquakes suggest that severe damage occurred to bamboo houses and masonry buildings in Bangladesh. Disturbances of inland water bodies were also observed in Bangladesh. Co-seismic subsidence, uplift, landslides and compaction were associated with the 1762 earthquake (Alam and Dominey-Howes, 2014). Subsidence and uplift are evidence of neotectonic activity in Bangladesh and adjacent areas (Khan and Chouan, 1996; Hoque and Alam, 1997; Das et al., 2010). The existing flow of the Jamuna River came into its present course only after the 1787 earthquake (Kamaluddin and Rahman, 1985; Bandyopadhyay et al., 2021; Richards et al., 2021). Before the shift of its course, it flowed further east by its original name 'Old Brahmraputra' before meeting the Meghna River (Rennell and Banks, 1781; Richards et al., 2021). Additionally, the uplift of the Madhupur surface was possibly associated with the occurrence of the 1762 earthquake (Fergusson, 1863).

The effects of earthquakes reports are obtained for 80 events (Table 1 events # 8, 9, 14,16, 17, 21, 23, 37, 38, 39, 42, 43, 44, 55, 64, 69, 74, 76, 79, 84, 85, 95, 97, 98, 107, 108, 161, 119, 153, 165, 168, 170, 178, 190, 191,196, 204, 209, 217, 236, 245, 260, 262, 268, 269, 274, 278, 282, 322, 333, 341, 363, 378, 382, 396, 401, 407, 408, 411, 426, 428, 429, 430, 439, 441, 442, 445, 446, 447, 452, 457, 459, 460, 475, 503, 512, 536, 561, 562). An analysis of 47 reports on 80 earthquakes suggests that in eight (i.e., Bandarban, Kurigram, Kishoreganj, Mymensingh, Sunamganj, Sirajganj, Sylhet, and Tangail) of 64 districts, the effects were over IX on the MMI scale (Figure 7). These districts are located in the northern region of Bangladesh and are close to the Bogra Fault System, Dauki Fault, Haluaghat Fault, Jamuna Fault, Madhupur Fault, Sylhet Fault, and Himalayan seismic sources. The results of the highest risk districts based on the effects of earthquakes measured on the MMI scale coincide with the current seismic zoning map of Bangladesh (Figure 2).

The damage intensity caused by earthquakes in Chittagong was rated VIII on the MMI scale. The high MMI value for Chittagong is due to the effects of historical and recent earthquakes that occurred in 1762, 1842, 1851, 1997, 1999, 2003, 2007, and 2008. Chittagong is located along the Arakan Subduction Zone and is close to seismic sources in Myanmar. The damage intensity reached VI on the MMI scale in Dhaka. Although, Dhaka city is comparatively far from seismic sources, the fragile infrastructure and fluvial delta experienced a multitude of different types of effects from earthquakes occurring from adjacent sources. The MMI in the SW districts were 5 or below indicating that they were prone to less damage.

5 Conclusion

This research documented and analysed geological, archaeological and documentary records of earthquakes in Bangladesh to better understand and quantify the hazard–a first step towards improved earthquake risk reduction. The key finding from this research reveals that using long-term hazard data in conjunction with spatial analysis could provide an opportunity to detect areas of high earthquake occurrences. However, records are only available for greater magnitude (7 and above) earthquakes of 1762, 1885, and 1997. No detailed records are available for lesser magnitude earthquakes. This research also supports the revision of current seismic zoning map of Bangladesh to include Chittagong and Dhaka in the high-risk zone for effective earthquake risk reduction. Finally, this research concludes that analyses of long-term data help identify new hazard exposure and develop knowledge that can be useful to formulate new disaster risk reduction policies and rectify existing ones in Bangladesh.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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