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REVIEW ARTICLE

An analysis of the AD1762 earthquake and tsunami in SE Bangladesh

Edris Alam · Dale Dominey-Howes

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Abstract In AD1762, a large earthquake originating within the Arakan Subduction Zone occurred. However, conflicting opinions exist as to whether this earthquake triggered a major regional tsunami in the northern Bay of Bengal (BoB) that struck southeast Bangladesh. This research aims to review and assess the effects of the AD1762 earthquake in Bangladesh and reviews what effects associated tsunamis had along the coast of southeast Bangladesh. Through field visits and investigations, this research confirms the locations of liquefaction, compaction, landslides, co-seismic subsidence, deaths and injuries using the descriptions of historical documents as a guide. The earthquake triggered land-level changes where the soil is young and soft, and these areas are located adjacent to the coast of the BoB and along the banks of the Karnafuli, Halda and Meghna rivers. The earthquake probably generated several submarine sediment slides that triggered local tsunamis that struck different locations (Bansbaria, Bharchhara and Burumchhara) along the Chittagong coast. Following an analysis of the earthquake effects, we consider that a repeat of the AD1762 earthquake would result in significant damage to fragile infrastructure and to vulnerable communities in Bangladesh. Further, we recommend (1) conducting geological and geomorphological studies at key sites to assess the nature and extent of land-level changes; (2) undertaking socially oriented community vulnerability assessments to earthquakes and tsunamis; and (3) implementing a variety of risk-reduction strategies to reduce vulnerability and enhance resilience to future events.

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1 Introduction

The 2004 Indian Ocean Tsunami (2004 IOT) originating from the Sunda Subduction Zone (SSZ) prompted growing concerns about earthquake and tsunami risk in the Bay of Bengal (BoB). Alam et al. (2012) confirmed that the AD1762 Arakan Subduction Zone (ASZ) earthquake, further north than the epicentre of the 2004 IOT, also generated a tsunami. This is the first known, potentially "large" earthquake-generated tsunami originating in the northern BoB. However, Alam et al. (2012) acknowledged that more systematic work is need to be done to better understand this event because no others have originated in the ASZ since AD1762. As such, the return periods of such earthquakes are not known and if such an event is repeated today, it would likely be catastrophic due to the very large, low-lying coastal populations. Further, recent work by Gupta and Gahalaut (2009) and Khan (2012) dismissed the possibility of the generation of large earthquake tsunamis in this region. Although several authors including Cummins (2007) and Gupta and Gahalaut (2009) have referred to historical evidence about the AD1762 earthquake, not enough detailed analysis of historical documentation has been undertaken to provide a robust understanding of the AD1762 earthquake event and its effects on Bangladesh. This lack of understanding stands as a barrier to effective disaster risk reduction in Bangladesh.

Historical records have been used effectively to reconstruct earthquake and tsunami histories in Greece, Italy and Japan (Ambraseys 1980; Atwater et al. 2005; Bolt 1930; Cisternas et al. 2005; Dominey-Howes 2002). To expand the "temporal window" (Guidoboni and Stucchi 1993) about the record of earthquake and tsunami risk in Bangladesh, this research collects and reviews historic documents about the effects of the AD1762 earthquake and verifies the data through field investigations and community consultation in SE Bangladesh. Used together, these sources and investigations help us to understand the extent of tsunami effects along the southeast (SE) Bangladesh coast. Specifically, the aims of this paper are to:

- provide a detailed description of the AD1762 earthquake and its effects using historical accounts, contemporary sources and field verification of these descriptions;
- provide a detailed description of the tsunami derived from contemporary sources, historical accounts and field verification of these descriptions; and
- identify further research priorities in the region in relation to earthquake and tsunami hazards by analysing the effects associated with the AD1762 event.

In the following sections, we introduce the tectonic setting of the northern BoB and outline the data sources collected and methods used for this research. This is followed by an interpretation of the historical evidence through the lens of contemporary field investigations in SE Bangladesh. We then evaluate the findings in the context of local geography and topography, the nature and extent of descriptions within historical documents combined with current earthquake and tsunami literature for the northern BoB region and beyond. Finally, we make a series of recommendations for future research.

2 Tectonic setting of the northern BoB

Bangladesh is located within the seismically active zones, surrounded by the Himalayan Arc, the Shillong Plateau and the Dauki Fault (DF) in the north, the ASZ in the south and the Naga-Haflong-Disang thrust zone (NHDTZ) in the northeast (Fig. 1). Several seismic faults, the Jamuna Fault (JF), the Haluaghat Fault (HF) and the Sylhet Fault (SF) are located within Bangladesh. In the north of the Andaman Trench (AT) (Fig. 2), the Indian Plate is moving northward with respect to the Sunda Plate at a rate of 37 mm/yr. This movement is accommodated by the Sagaing Fault in the east and by the Indo-Burmese Arc in the west. The rate of accommodation by the Sagaing Fault and in the Indo-Burmese Arc region is about 18 and 20 mm/yr, respectively (Gupta and Gahalaut 2009). The regional motion of plates is predominantly dextral strike-slip. Thus, the India–Burma plate boundary in the Arakan and Irrawaddy region is defined by oblique plate motion that generates strike-slip-dominated earthquakes with poor tsunami-generating capability (Gupta and Gahalaut 2009; Khan 2012; Nielsen et al. 2004; Socquet et al. 2006). The deformation front of the plate boundary between the India and Sunda plates in the northern BoB is either landward or in shallow water in the Arakan region (Fig. 2). Therefore, a giant earthquake could not displace significant volumes of water in the Arakan region, resulting in major tsunami. In contrast to the regional tectonics, Cummins (2007) assigned the AD1762 event a magnitude of M_w 8.8 and used this to simulate a tsunami. This simulation suggests that the Bangladesh coast was inundated by a tsunami with a maximum height of 2.5 m (Fig. 3). Despite some strong arguments that the AD1762 Arakan earthquake triggered a large tsunami, a consensus of opinion is lacking and there are no known records of large tsunamis in the region in the last 2,000 years (Gupta and Gahalaut 2009; Khan 2012).

Paul and Bhuiyan (2010) quoted the Geological Survey of Bangladesh for records of at least 465 earthquakes of minor-to-moderate magnitudes that occurred between AD1971 and AD2006 in Bangladesh. Earthquakes that occurred in AD1787, AD1822, AD1830, AD1865, AD1866, AD1885, AD1918, AD1935, AD1997, AD1999, AD2001, AD2003 and AD2012 significantly affected Bangladesh (Akhter 2010; Khan 2010). Historical records suggest the most damaging earthquake reported in Bangladesh was the 2 April AD1762 event that occurred at 5 p.m. local time. Earthquake shaking was most severely felt along the southeast coast of India and along the Bangladesh and Myanmar coasts (Oldham 1883). The earthquake caused huge damage, deaths and injuries in SE Bangladesh (Oldham 1883; Verelst 1763). The existing literature reveals that several epicentres have been proposed for the AD1762 earthquake. Martin and Szeliga (2010) suggested that the epicentre was to the east of Chittagong at 22.4°N and 92.2°E. However, Satyabala (2003) suggested that the epicentre was adjacent to Kolkata at 22°N and 88°E. Ganse and Nelson (1982) using an analysis of the earthquake damage suggested the epicentre was at 22°N and 92°E, in the middle of Chittagong (Fig. 1).

3 Research processes, methods and approaches

To better understand the AD1762 earthquake and tsunami, a thorough search on historical documents was conducted in local libraries and government authorities in Bangladesh between November AD2010 and January AD2011. The search for historical documents eventually extended to India and Myanmar and the British Library (BL). Thus, a total of 20 historical documents (Alam 1947; Allen 1912; Anon 1763; Burke 1763, 1764; Chhibber 1934; Fergusson 1863; Gulston 1763a, b; Halstead 1843; Hirst 1763; Hunter 1876; Islam 2004; Islamabadi 1987; Mallet 1878; Oldham 1883; Rizvi 1969, 1970; Verelst 1763; and

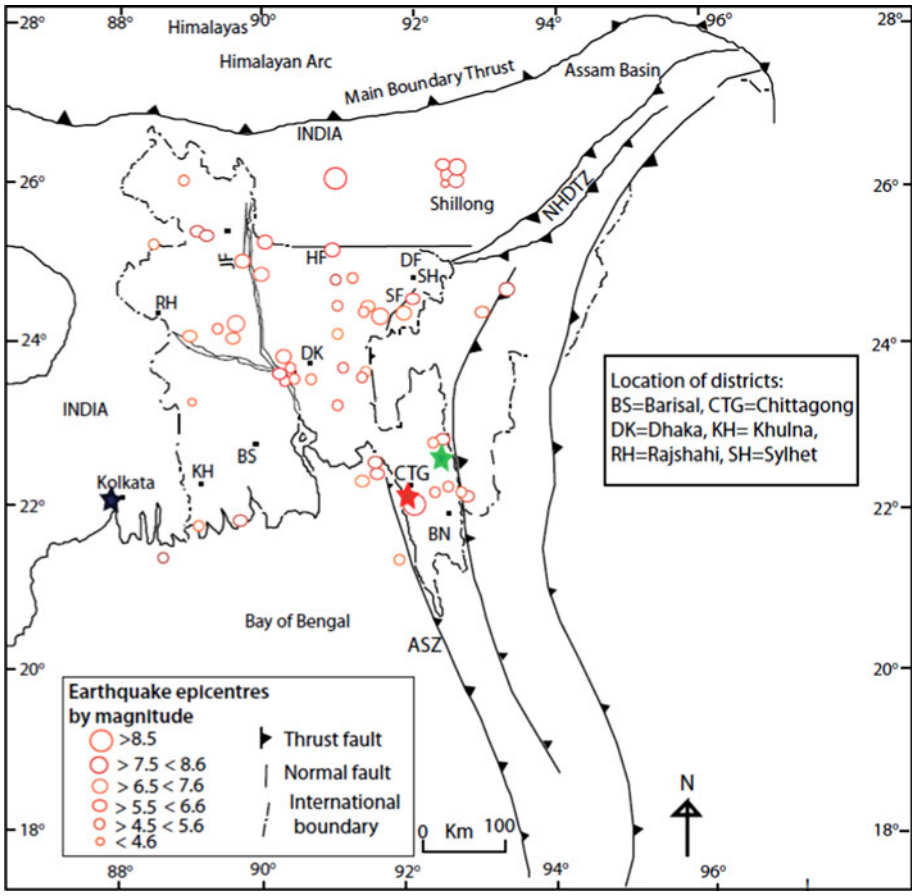

Fig. 1 Location of Bangladesh and adjacent seismic sources. The epicentres of earthquakes (above 4.6 Ms) that occurred within and adjacent to Bangladesh from AD1548–AD2012 are shown (Akhter 2010; Khan 2010). *Black*, *green* and *red stars* represent the proposed locations of the epicentre of the AD1762 earthquake proposed by Satyabala (2003), Martin and Szeliga (2010) and Ganse and Nelson (1982), respectively. *DF* Dauki Fault, *ASZ* Arakan Subduction Zone (ASZ), *NHDTZ* Naga-Haflong-Disang thrust zone, *JF* Jamuna Fault, *HF* Haluaghat Fault and *SF* Sylhet Fault (*Source* map prepared adapting tectonics elements from Alam et al. 2003; Ali and Choudhury 2001; Khan 2012; Mukherjee et al. 2009)

Webster 1911) were located. Of these historical documents, two reports by Gulston (1763a) and Verelst (1763) have been used extensively because the authors were the first British servicemen from Chittagong to document the AD1762 earthquake. Observing the devastation caused by the earthquake, they were concerned for the future of their administration and sent immediate detailed accounts of the effects to the British Administration in the United Kingdom. Whilst extensive use of limited primary sources such as these is acceptable in this type of research, we do acknowledge that they only represent the perspectives of the original authors and other valuable details about the events which may be over looked due to a variety of contextual reasons at the time of writing. We acknowledge immediately that future efforts should be made to identify and consult with other primary sources to improve our knowledge of the effects of the AD1762 earthquake in Chittagong.

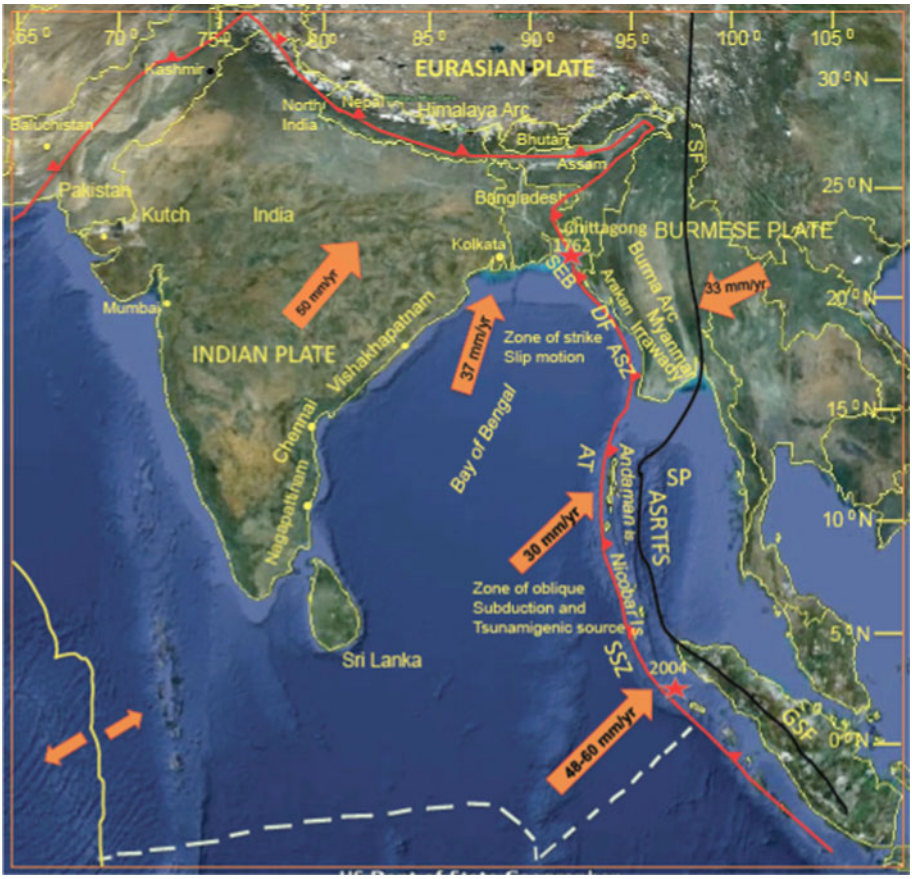

Fig. 2 The tectonic setting of the northern BoB with respect to three tectonic plates: the Eurasian, Indian, and Burmese plates. The *red* and *yellow solid lines*, and the *white dashed line* indicate convergent, divergent, and diffuse plate boundaries, respectively. The *black solid line* shows major faults. Rates of plate motion with reference to the Indian Plate are given in mm/yr and are adapted from Gahalaut and Gahalaut (2007) and Gupta and Gahalaut (2009). *Red stars* indicate the source locations of AD1762 Arakan Subduction Zone and AD2004 Sumatra Subduction Zone earthquakes. *ASZ* Arakan Subduction Zone, *ASRTFS* Andaman Sea Ridge Transform Fault System, *AT* Arakan Trench, *DF* Deformation Front, *GSF* Great Sumatra Fault, *SEB* Southeast Bangladesh, *SF* Sagaing Fault, *SP* Sunda Plate, *SSZ* Sunda Subduction Zone (*Source* adapted from Khan (2012) and Google Earth)

Seven BL documents (Anon 1763; Burke 1763, 1764; Gulston 1763a, b; Hirst 1763; Verelst 1763) were written in old English. To better understand the contents of these documents, we translated them into modern English. We also consulted online archives that contained these sources previously noted by Gupta (2009). Key comments about earthquake effects by location are provided in Table 1. To understand the effects of the earthquake, we cross-checked the contents of the historical documents before analysing the information using "manifest content analysis". Content analysis is a "set of methods for analysing the symbolic content of any [written] communication. The basic idea is to reduce the total content of a communication to a set of categories that represents some characteristics of research interest" (Singleton and Straits 1999, p. 383). Through the process of the content analysis, the types and locations of effects were identified and categorised.

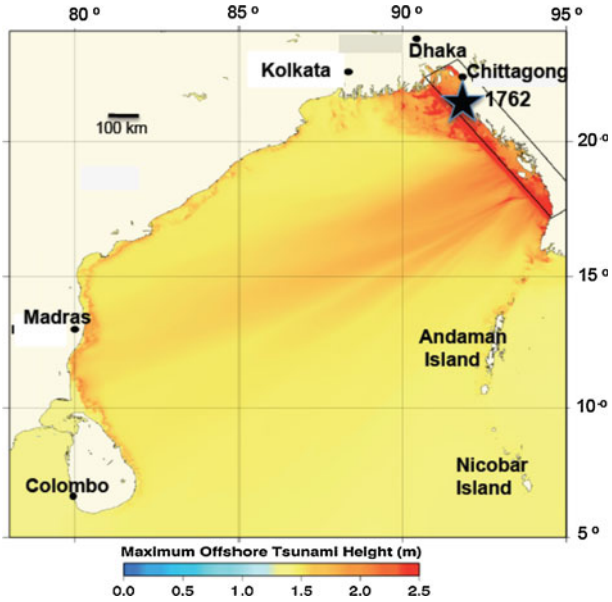

Fig. 3 Maximum offshore 2.5 m tsunami heights from the west coast of Myanmar to SE Bangladesh coast based on the AD1762 earthquake. The *rectangle block* along the eastern coast of the northern Bay of Bengal indicates a fault model for the AD1762 Chittagong earthquake, with length 700 km, width 125 and depth 10 m. The *star* indicates the epicentre of the AD1762 earthquake (*Source* Modified after Cummins 2007)

These were then used to guide field investigations in November and December AD2010 in SE Bangladesh (Fig. 4).

The fieldwork investigations helped to verify the reliability of the descriptions taken from the content analysis. Local maps coupled with consultation with local people were used to confirm the identity of the locations in the historical documents. The context of the descriptions and locations of the earthquake effects were then compared with each geographical location in SE Bangladesh. The confirmed effects of the earthquake are summarised in Table 1. On the basis of the description of earthquake effects at different locations, a modified Mercalli intensity (MMI) scale value is assigned to each location (Table 1). Whilst we attempt to assign intensities at specific geographical locations, we caution over reliance on their accuracy. The coastal sediments of the region are highly water saturated and are weak. Liquefaction can occur in such sediments, at lower ground-shaking intensities than in similar or less water-saturated sediments. Further research is needed to explore this issue.

We used the evidence of flooding triggered by the earthquake as an indicator to help answer the question of whether the tsunami struck the entire coast of SE Bangladesh or was only more locally experienced. To achieve this, we first undertook a detailed content analysis of the historical documents in relation to tsunamis. The locations of flooding effects were identified and mapped. The locations of the flooding were then compared with local contour maps and known tropical cyclone flooding heights. This helped to infer and place constraints on the possible height of the AD1762 tsunami.

In several cases, Gulston (1763a) and Verelst (1763) provided details on both the location of effects and the names of people whose houses were damaged (i.e. Hurry Singh's House at Dohazari, Santeeram Cannongoey house at Pathorgatha, Mr. Griffith's brick house at Kotwali) and the names of the dead and injured. This enabled us to consult

Table 1 The effects of the AD1762 earthquake and reported tsunami in the northern BoB region with a particular focus on the coast of SE Bangladesh

Location of effects			MMI	The effects of the AD1762 earthquake					
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Liquefaction or compaction or liquefaction and compaction in mainland	Flooding of the coast of the BoB	Compaction and inundation of the banks of rivers	Landslides along the banks of creeks or rivers	Uplift	Ground shaking felt severely
SE Bangladesh coast and Dhaka									
Akilpoor at Bansbaria	22.5/ 91.72	Akul Poor at Bans Burreah	X	2, 3	2	–	–	–	–
Baharchhara	22.42/ 91.93	Baharcharah or Bar Chara	X	14	2, 10	–	–	–	–
Bahngoo Changee	19.81/ 93.98	Bahngoo Changee	VIII	2, 3	–	–	–	–	2, 3
Bajalia	22.14/ 92.12	Bajaleeah	IX	3	–	–	2	–	–
Bandarban	22.11/ 92.18	Pardavan or Bardavan	VIII	–	–	–	–	–	8,10, 11, 12
Begamganj	22.56/ 91.06	Begumganj	VIII	15	–	–	–	–	–
Burumchhara	22.13/ 91.85	Baram Charah	X	–	2, 3	–	–	–	3
Chander-nagore	22.85/ 88.35	Chander-nagore	VII	–	–	–	–	–	4
Chittagong	22.59/ 91.57	Chattigraon or Islamabad	IX	–	–	–	–	–	1, 2, 3, 4,7, 10, 19
Chittagong	22.59/ 91.57	The brick house of Griffith	IX	–	–	–	–	–	3
Chittagong	22.33/ 91.83	The house of Shiam Ram	VIII	–	–	–	–	–	2, 3

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Liquefaction or compaction or liquefaction and compaction in mainland	Flooding of the coast of the BoB	Compaction and inundation of the banks of rivers	Landslides along the banks of creeks or rivers	Uplift	Ground shaking felt severely
Chittagong coast	22.59/ 91.57	Land subsidence in sea	X	–	–	–	–	–	–
Dhaka	23.72/ 90.35	Decca or Dacca	VI	–	–	–	–	–	1, 4, 7, 9, 16
Dohazari	22.16/ 92.07	Cavity at Do Hâzâry	IX	2, 3	–	–	–		2, 3
Hurry Singh Hazari	22.16/ 92.07	Hurry Sing Hazarry	VIII	–	–	–	–	–	2, 3
Goyparah	22.34/ 91.83	Goyparah	VIII	3	–	–	–	–	3
Halda River	22.43/ 91.88	Haldah	IX	2, 3	–	3	3	–	3
Howla	22.43/ 91.88	Howlâ	X	2, 3	–	–	–	–	2
Kodala adjacent to the Karnafuli River	88.45/ 92.06	Kad'd'aleah adjacent to the Karn Phooly	IX	–	–	–	3	–	3
Lakshmipur	23.03/ 90.66	Lockepoer	IX	–	–	–	–	–	–
Madhupur terrace	24.10/ 90.20	Madhupur terrace	IX	–	–	–	–	17	–
Pathorgatha	22.33/ 91.83	Patter Gottah	IX	2	–		–	–	–
Sitakund	22.62/ 91.67	Seeta Kund	IX	–	–	–	–	–	1, 2, 3, 10

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Liquefaction or compaction or liquefaction and compaction in mainland	Flooding of the coast of the BoB	Compaction and inundation of the banks of rivers	Landslides along the banks of creeks or rivers	Uplift	Ground shaking felt severely
Suabil	22.64/ 91.79	Sowabeel or Sawabill	IX	2	–	2, 3	2, 3	–	–
Kolkata and other west Bengal region, India									
Barrackpore	22.76/ 88.37	Ghirotty	V	–	–	–	–	–	1, 4
Cossimbazar	24.11/ 88.28	Cossimbazar	V	–	–	–	–	–	9
Kolkata	22.28/ 88.22	Calcutta	VI	–	–	–	–	–	1, 4, 7
Murshidabad	24.17/ 88.27	Moxudabath	VII	–	–	–	–	–	9
Myanmar coast									
Arakan but now familiar as Myanmar	19.81/ 93.98	Aracan	VII	–	–	–	–	–	4, 18
Cheduba Island	18.82/ 93.62	Cheduba Island	IX	–	–	–	–	6, 10	1, 6, 12
Foul Island	19.19/ 94.77	Foul Island	IX	–	–	–	–	6, 10	1, 6, 12
Pegu	17.19/ 96.29	Bago	VI	–	–	–	–	–	4
Ramree Island	19.10/ 93.78	Ramree Island	IX	–	–	–	–	6	1

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
SE Bangladesh coast and Dhaka									
Akilpoor at Bansbaria	22.5/ 91.72	Akul Poor at Bans Burreah	X	–	–	–	–	3	Gulston (1763a, p. 252) stated: "And by letter from Satoo Mester Daroogah of the salt-works [salt] at Bansbareeah, it so fell out, that, to the westward, Akl'poorah, an island of the fast-works, was leveled with the water on its east side, and on the north and south the ground opened from 5 to 7 cubits in width, and sunk like a pit to the depth of 10 cubits, the water spouting up; nor is there the least appearance of its subsiding: we know not what will come of it"
Baharchhara	22.42/ 91.93	Baharcharah or Bar Chara	X	–	–	–	–	–	Verelst (1763, p. 267) described the effects: "At Bar Chara, near the sea, five or six cess of ground immediately sunk, and out of four or five hundred people, about two hundred were lost, with all their cattle; and the greatest part of the remaining inhabitants, who ran into woods, have not yet been heard of"
Bahngoo Changee	19.81/ 93.98	Bahngoo Changee	VIII	–	–	–	–	3	"And Bahngoo Changee, a Joom Hill, rent in twain, and is sunk 30 cubits, and the house of most of the inhabitants in those parts thrown down" (Gulston 1763a, p. 255)
Bajalia	22.14/ 92.12	Bajaleeah	IX	–	–	–	–	2, 3	"At Bajaleeah, another Joom hill upon the river, opened 30 cubits, and sinking water rose up" (Gulston 1763a, p. 255). Gulston (1763a, p. 254) also stated "And at Bajaleeah…creeks were closed up by banks of sands rising from their bottom"

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
Bandarban	22.11/ 92.18	Pardavan or Bardavan	VIII	–	–	8, 10, 11, 12, 14	–	–	"… a place, called Bardavan, a large river is totally dried up by a bank of sand that rose up in the middle of it." (Annual Register, 1763, p. 61). Rizvi (1970, p. 54) stated: "According to Captain Lewin, a large river was dried up at Pardaban…"
Begamganj	22.56/ 91.06	Begumganj	VIII	–	–	–	–	–	A ground compacted in Begumganj (Webster 1911)
Burumchhara	22.13/ 91.85	Baram Charah	X	–	–	–	–	–	"…water was up to a man's waist, and the people there have betaken themselves to flight, through fear of perishing; no living creature but the cattle now remaining" (Gulston 1763a, p. 253)
Chander-nagore	22.85/ 88.35	Chander-nagore	VII	–	–	–	–	–	The earthquake shook Chandernagore (Hirst 1763)
Chittagong	22.59/ 91.57	Chattigraon or Islamabad	IX	–	–	–	–	–	The accounts of devastation in Chattigraon were remarkable (Hirst 1763)
Chittagong	22.59/ 91.57	The brick house of Griffith	IX	–	–	–	–	3	Mr. Griffith's brick house in Islamabad was cracked (Gulston 1763a)
Chittagong	22.33/ 91.83	The house of Shiam Ram	VIII	–	–	–	–	3	The house of Shiam Ram tax gatherer was broken down (Gulston 1763a)
Chittagong coast	22.59/ 91.57	Land subsidence in sea	X	10, 11, 12, 13, 14	–	–	–	–	The earthquake caused a permanent submergence of 155.40 km^2 adjacent to Chittagong (Rizvi 1970)

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
Dhaka	23.72/ 90.35	Decca or Dacca	VI	–	4, 9, 12, 16	–	–	–	Hirst (1763, p. 257) stated: "…the rise of the waters in the river was so very sudden and violent, that some hundreds of large country boats were driven ashore, or lost, and great numbers of lives lost in them"
Dohazari	22.16/ 92.07	Cavity at Do Hâzâry	IX	–	–	–	–	–	Gulston (1763a, b, p. 253) stated: "And at Do Hâzâry …there opened a cavity like a ditch of 200 cubits in length, which filled with water." Verelst (1763, p. 267) states: "Bazally Creek and Do Hazarry Creek, are stopped up"
Hurry Singh Hazari	22.16/ 92.07	Hurry Sing Hazarry	VIII	–	–	–	–	2, 3	"In the Purgunnah Do Hazarree, Hurry Sing Hazarry's brick house was entirely thrown down…" (Verelst 1763, p. 266)
Goyparah	22.34/ 91.83	Goyparah	VIII	–	–	–	–	3	"And Moktârâm Fowtadhar, dwelling at Goyparah, has written, that to the north and east his house was cracked…Water spouted up and the ground also compacted gradually (Gulston 1763a)
Halda River	22.43/ 91.88	Haldah	IX	–	–	–	–	–	Verelst 1763, p. 266) stated that: "At Halda Creek, near Sancharam Conguy's house, twelve don of ground is entirely sunk"
Howla	22.43/ 91.88	Howlâ	X	–	–	–	–	2	"At Howlâ, the house of Shiam Ram taxgatherer, broke down… in most places his house and fish-ponds were filled with sand-banks: even now the whole spot is two cubits under water" (Gulston 1763a, p. 253). "In Howla Purgunnah, Sam Roy Gaffildar's house broke down, and his compound was filled with water of two cubits deep for two days" (Verelst 1763, p. 267)

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
Kodala adjacent to the Karnafuli River	88.45/ 92.06	Kad'd'aleah adjacent to the Karn Phooly	IX	–	–	–	–	–	Gulston (1763a, b, p. 254) stated: "…the eastward of Kadr Katcheeah a large hill, called Kad'd'aleah, very near Karn Phooly, was rent, and it stopped up the passage for boats in and out that river"
Lakshmipur	23.03/ 90.66	Lockepoer	IX	9, 14	–	–	–	9	"…at Lockepoer, about two days journey from Decca (Dhaka), a circuit of land, near fifteen English miles in circumference, was swallowed up, and all the people and cattle on it were drowned" Burke (1764, p. 83). "An earthquake in April 1762 is said to have engulfed a tract country around Lakshmipur fifteen miles in extent, with all its inhabitants; and the Collector states that other depressions of the land, now the site of deep marshes, map be due to similar causes" (Hunter 1876, p. 250)
Madhupur terrace	24.10/ 90.20	Madhupur terrace	IX	–	–	–	–	–	The April AD1762 earthquake uplifted parts of Madhupur Terrace which is located approximately 29 km north of Dhaka City
Pathorgatha	22.33/ 91.83	Patter Gottah	IX	–	–	–	–	3	"From Patter Gottah to Howlah, about 8 cefs difference, the ground opened, and a great quantity of water was immediately thrown out, and in several places the ground entirely sunk" (Verelst 1763, p. 266)
Sitakund	22.62/ 91.67	Seeta Kund	IX	–	–	–	2, 10, 11, 12, 14	–	Verelst (1763) stated that two volcanoes erupted in Chittagong. Hunter (1876, p. 228) stated: "Two volcanoes are said to have opened in the Sitakund hills"

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
Suabil	22.64/ 91.79	Sowabeel or Sawabill	IX	–	–	–	–	–	Gulston (1763a, p. 255) mentioned that: "…the north side of the Chachlah Sowabeel, just by Haldah river, broke down and is swallowed up by the river, and also four people were overwhelmed in its ruins"
Kolkata and other west Bengal region, India									
Barrackpore	22.76/ 88.37	Ghirotty	V	–	–	–	–	–	The effect of the earthquake was also very alarming at Ghirotty (Hirst 1763). Sujit Das Gupta (pers. Com. 2011) confirmed the present location of Ghirotty: "I am certain that the place is Barrackpore (22.76°N, 88.37E; height 15 m), 15-18 miles north of Kolkata by the side of the Ganga River (on its east bank). Because this was the place in which the Dutch, French and British established cantonments during the 15-17 centuries. Colonel Coote was also in this cantonment in 1762"
Cossimbazar	24.11/ 88.28	Cossimbazar	V	–	–	–	–	–	The Annual Registrar described the effects of earthquake in Moxudabath based on a letter from Cassambazar (Anon 1763).
Kolkata	22.28/ 88.22	Calcutta	VI	–	4	–	–	–	Hirst (1763) reported that water rose in Calcutta up to six feet and direction was in north–south
Murshidabad	24.17/ 88.27	Moxudabath	VII	–	–	–	–	–	"…a most violent fire happened at Moxudabath, which had reduced that place to ashes" (Anon 1763, p. 83)

Table 1 continued

Location of effects			MMI	The effects of the AD1762 earthquake					Notes
The present day spelling or locations of effects	Latitude/ Longitude	Description of locations in historical records		Co-seismic subsidence	Water level raised in rivers	River dried up	Mud volcanic eruptions	Collapsed houses	
Myanmar coast									
Arakan but now familiar as Myanmar	19.81/ 93.98	Aracan	VII	–	–	–	–	–	The earthquake occurred on the 2 April was destructive in Aracan (Hirst 1763)
Cheduba Island	18.82/ 93.62	Cheduba Island	IX	–	–	–	6	–	The earthquake elevated approximately 3.97–6.70 m in the Cheduba Island (Halstead 1843)
Foul Island	19.19/ 94.77	Foul Island	IX	–	–	–	6	–	The earthquake elevated approximately 2.74-3.66 m in the Foul Island (Halstead 1843)
Pegu	17.19/ 96.29	Bago	VI	–	–	–	–	–	The earthquake occurred on the 2 April AD1762 was violent in Pegu (Hirst 1763)
Ramree Island	19.10/ 93.78	Ramree Island	IX	–	–	–	6	–	The effects of the earthquake were destructive off the north coast of Ramree Island (Oldham 1883)

The numbers in column 3 indicate the coding of references that are provided below

1. Oldham (1883), 2. Verelst (1763) 3. Gulston (1763a) 4. Hirst (1763) 5. Mallet (1878) 6. Halstead (1843) 7. Anon. (1763) 8. Burke (1763) 9. Burke (1764) 10. Rizvi (1970) 11. Alam (1947) 12. Islam (2004) 13. Islamabadi (1987) 14. Hunter (1876) 15. Webster (1911) 16. Allen (1912) 17. Fergusson (1863) 18. Chhibber (1934) 19. Gulston (1763b)

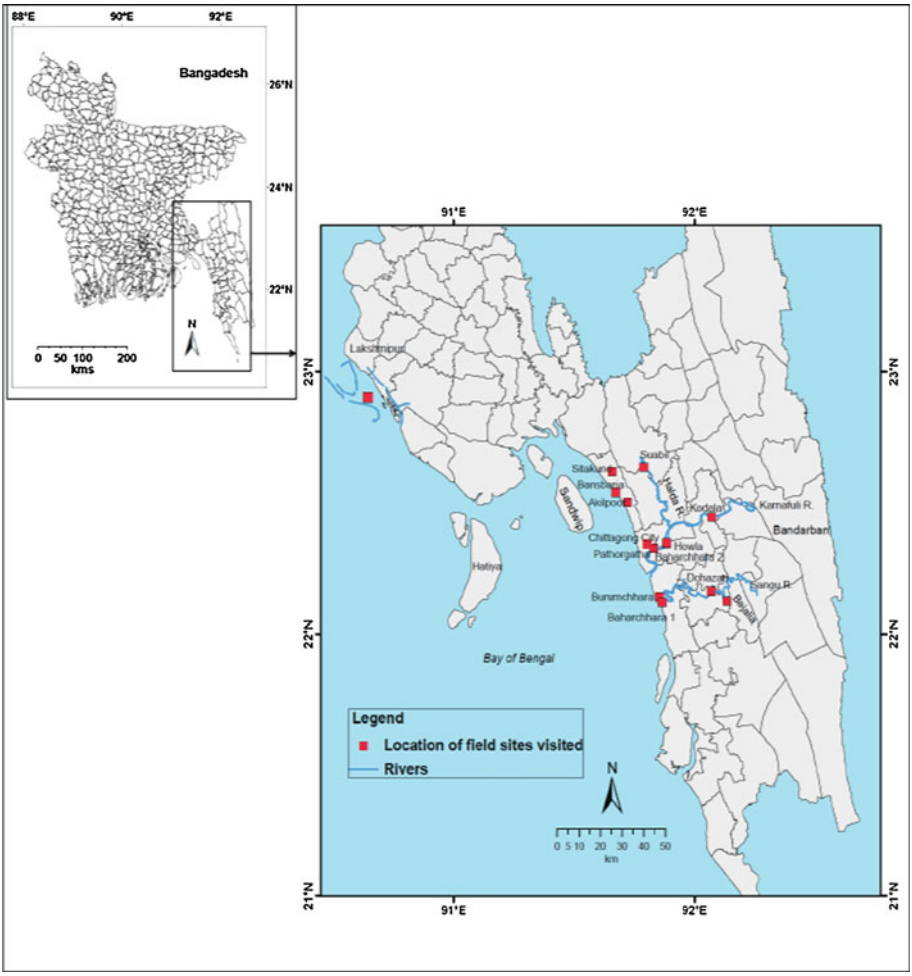

Fig. 4 Location of field sites visited and investigations undertaken along the SE coast of Bangladesh

with their descendants when possible and appropriate. A genealogical analysis was therefore performed to confirm the location of reported effects. Genealogy is defined as the study of lineal descent from an ancestor (Wright 1995, p. 2). Descendants of Hurry Singh Hazari and Santeeram Cannongoey were identified in Dohazari and Pathorgatha, respectively. The descendants were asked if they possessed any information about the earthquake effects that had been passed down from previous generations. The descendants were only able to confirm the locations of the respective areas and the names of family members alive in AD1762. They did not have any information regarding the earthquake and its effects on past generations. These data were used to verify and map the locations of the earthquake effects. Finally, the updated descriptions of earthquake effects have been rewritten using the terms used in the modern earthquake literature. Many non-English terms have been used in our research and an explanation of these is provided in Table 2. For consistency, the modern names of the places have been used, but the respective old names reported in the historical evidence are also provided in Table 1.

Table 2 The meaning of non-English terms

Non-English term		Meaning or uses of the term
Present spelling	Term in the historical documents	
Bhumikompo	–	*Bhumikompo* is the Bengali word for "earthquake"
Cannongoey	Cannoon-Goey or Cannoon-goij	Cannongoey were record keepers of lands for the British Government. They are now known as the Registrar by the Government of Bangladesh, but at a village level they are still called "Cannongoey"
*	Cess	It was meant to indicate a unit of land liable for taxes. No longer in use
Chhara	Chara	*Chhara* means land formed by the sea or river tides
Cubit	Cubit	1 cubit $\approx$45.72 cm
Darogah	Daroogah	In use since the Mughal administration (AD1500) as the identity of a provincial governor, head of a department, head of city management, chief of police and so on
Doan	Doan	A doan of ground is equal to 1,920 cubits long and 1,600 cubits broad (Verelst 1763). Thus, one doan is equal to $\approx$0.64 km^2
District, Upazila, Union and Village	None	There are sixty-four districts in Bangladesh. A district is the second largest administrative unit and is considered the most important level of government administration. It consists of several *upazilas*. An *upazila* (sub-district) consists of several *unions* and several villages form a *union*. A typical village in Bangladesh contains between 30–500 households (BBS 2011)
Jalhosti	None	The term "*Jalhosti*" is a local dialect in Chittagong and means to the "turbulence of water that is caused by the ground shaking"
Jeels	Jeels/Jhils	A shallow non permanent water body
Jhum	Joom	Shifting cultivation practised by Tribal groups in hills is also familiar as *Jhum* in Bangladesh
Suabil	Sowabeel	The last part of Sowabeel is Beel that means the lowland areas of Bangladesh, which are under water during the rainy season
Talukdar	Taluckdar	From the mid-fifteen the century, a Talukdar was a landlord who would lend land to a tenant for crop cultivation
Kutchery	Cutcherry	An out-room or hallway of a big house used as a waiting room by a guest
Kutwal	Kutwâll	The head of an urban administrative unit

* No longer in use and no present spelling available

4 Results and discussion

In the following sections, we present our analysis of the contents of the historical documents about the AD1762 earthquake and tsunami effects. Sequentially, we explore the following:

The effects of the earthquake including:

- Liquefaction and compaction of river banks;

- Liquefaction-induced compaction and subsidence along the coast of the BoB;
- Landslides at Kodala on the bank of the Karnafuli River;
- Co-seismic submergence and subsidence;
- Mud volcanic eruptions;
- The collapse of houses, deaths and injuries;
- Evidence of recent earthquake effects and the context of vulnerability.

The effects of the tsunami including:

- Tsunamis on the coast of Chittagong;
- Water-level variation in the river adjacent to Dhaka;
- Location of the AD1762 earthquake and tsunami affected areas in Bangladesh;
- Historical records of tsunamis in Cheduba Island;
- Evidence of uplift along the Myanmar coast and the height of the tsunami; and
- Other examples of the effects of the earthquake on soft sediments and earthquake-triggered slides and tsunamis.

4.1 The content of historical documents

The content analysis of the historical documents and data collected throughout the field investigations revealed that the main effects of the earthquake were the following: liquefaction-induced surface cracking, compaction and subsidence, landslides, co-seismic subsidence, mud volcanic eruptions and inundations along the coast of the BoB (Table 1). As shown in Fig. 5, the effects of the earthquake were observed as far as west Kolkata in India and southeast of Bago in Myanmar—an area covering a total distance of over 1,220 km.

4.2 Evaluation of the historical evidence via ground-truthing during visits

A total of 16 areas affected by the earthquake and tsunami were identified from the historical documents. Field visits and investigations were subsequently conducted in Baharchhara, Burumchhara, Pathorgatha, Howla, Akilpoor, Bansbaria, Sitakund, Bandarban, Bajalia, Dohazari, Suabil, Kodala and along the Halda, Karnapfuli and Sangu rivers in Chittagong and the Meghna River in Lakshmipur, Bangladesh (Fig. 6). The identified effects of the earthquake and tsunami on these areas are discussed in the following sections.

4.2.1 The effects of the earthquake

4.2.1.1 Liquefaction and compaction of river banks Liquefaction-induced surface cracking and compaction occurred in Pathorgatha, Howla, Dohazari, Bajalia and Kodala, all of which are located along river banks in Chittagong.

Pathorgatha is located on the northern bank of the Karnafuli River, which flows in an east–west direction adjacent to the city of Chittagong. Howla is located near the confluence of the Halda and Karnafuli rivers (Figs. 6, 7a). From the descriptions of the effects (key comments for Pathorgatha are detailed in Table 1) sourced from the BL in relation to Pathorgatha and Howla, it can be determined that liquefaction-induced surface cracking and compaction occurred on the river banks between these areas.

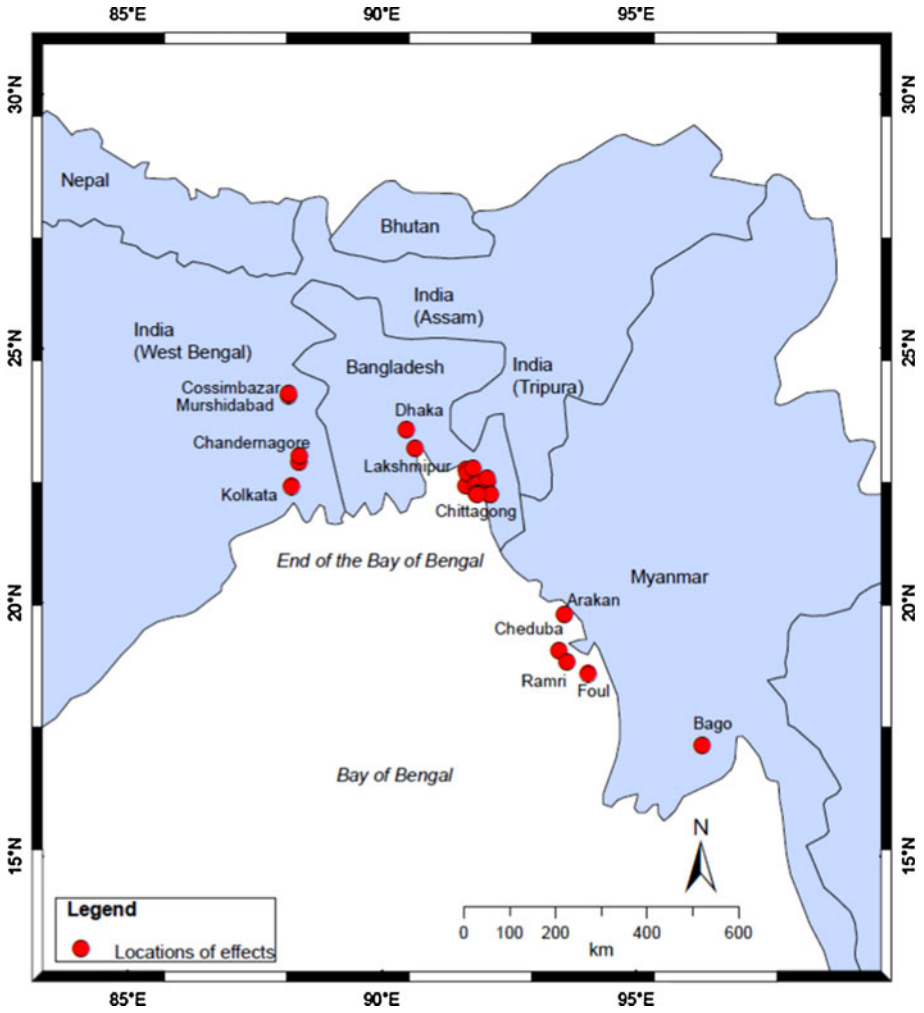

Fig. 5 The locations of the AD1762 earthquake effects extended as far west as Kolkata, India and SE to Bago, Myanmar. The cluster of *red circles* along the Chittagong coast show widespread damage (*Data sources* Gulston 1763a, b; Hirst 1763; Verelst 1763 and Table 1)

Dohazari is a *union* at Chandanaish *upazila*, Chittagong (Fig. 6). The main effect caused by the earthquake at Dohazari (Table 1) was liquefaction related to surface cracking. Dohazari Creek is now a part of the Sangu River. Earthquake-induced liquefaction occurred in saturated soil along the banks of the river where soil lost its strength after being shaken by the earthquake. Discussions with the descendants at the Dohazari's house revealed that they do not have any record of this event.

Bajalia is located to the east of Chittagong adjacent to Bandarban (Fig. 6). BL sources accurately describe its location on the bank of river and provide evidence of a tribal community living in the area. The descriptions of the effects (Table 1) by Gulston (1763a) identify liquefaction-induced surface cracking in the hills along the Bajalia Creek. The Bajalia Creek is now called the Sangu River, and field visits revealed that there are hills

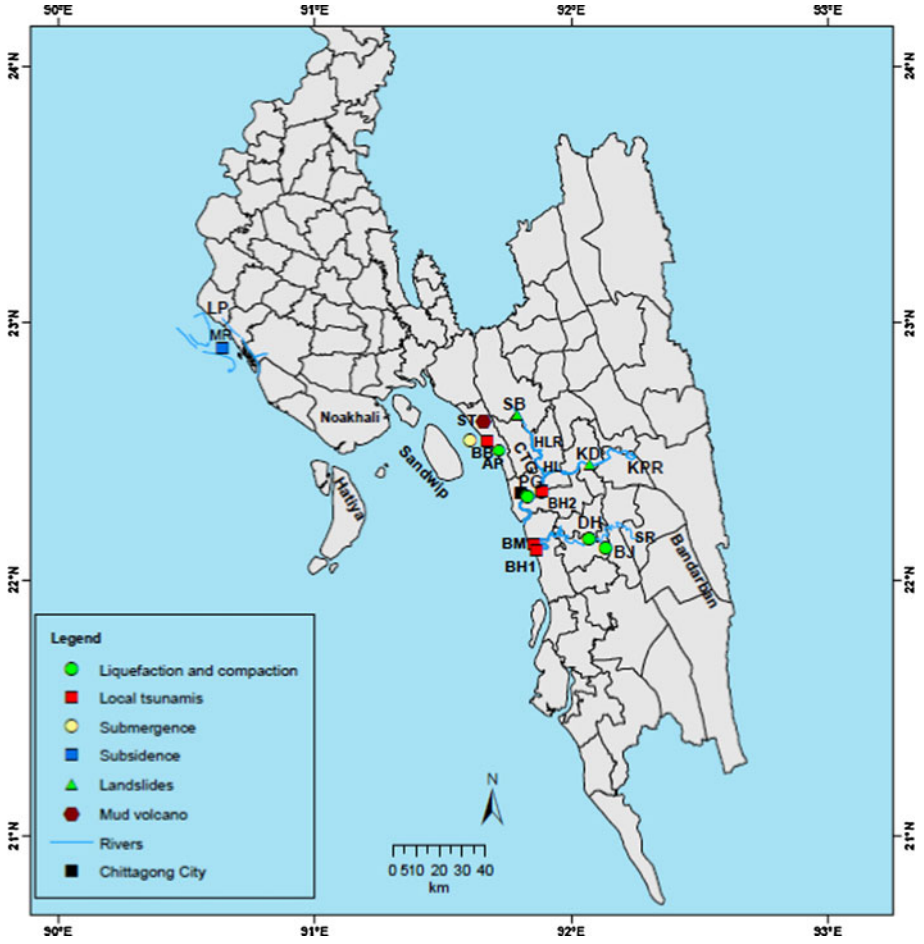

Fig. 6 Location of the effects of the AD1762 earthquake along the SE Bangladesh coast. *AP* Akilpoor, *BB* Bansbaria, *BM* Burumchhara, *BH1* Baharchhara 1, *BH2* Baharchhara 2, *BJ* Bajalia, *CTG* Chittagong City, *DH* Dohazari, *HL* Howla, *KD* Kodala, *LP* Lakshmipur, *PG* Pathorgatha, *ST* Sitakund, *SB* Suabil, *KPR* Karnafuli River, *MR* Meghna River, *SR* Sangu River

along the Sangu River at Bajalia. Consultation with local historical works (Rizvi 1970) suggests that the *Jhum* cultivation (shifting cultivation in hills practised by the tribal community in Bangladesh) occurred in that area. The tribal group also once dominantly lived in that area. Information derived from the field visits indicate that Gulston (1763a) was correct in his descriptions of the earthquake effects experienced at Bajalia.

Gulston (1763a) reported liquefaction and compaction of approximately 1,211.65 sq km of land along the Halda River (Figs. 6, 7b). Gulston (1763a, p. 253) stated "And at Haldah about 12 doan of land belong to Sacheeram Cannoonĝoeij is entirely sunk into the water". Further, Gulston's (1763a) report (Table 1) also suggests the occurrence of landslides and inundation at Suabil which is located within the floodplain of the Halda River. The Halda River continuously deposits sediment to form new floodplain and also erodes young sediment from the banks of the river (Rizvi 1970). Saturated soft soils when shaken by large earthquakes loose their cohesive strength causing slipping to occur. Thus,

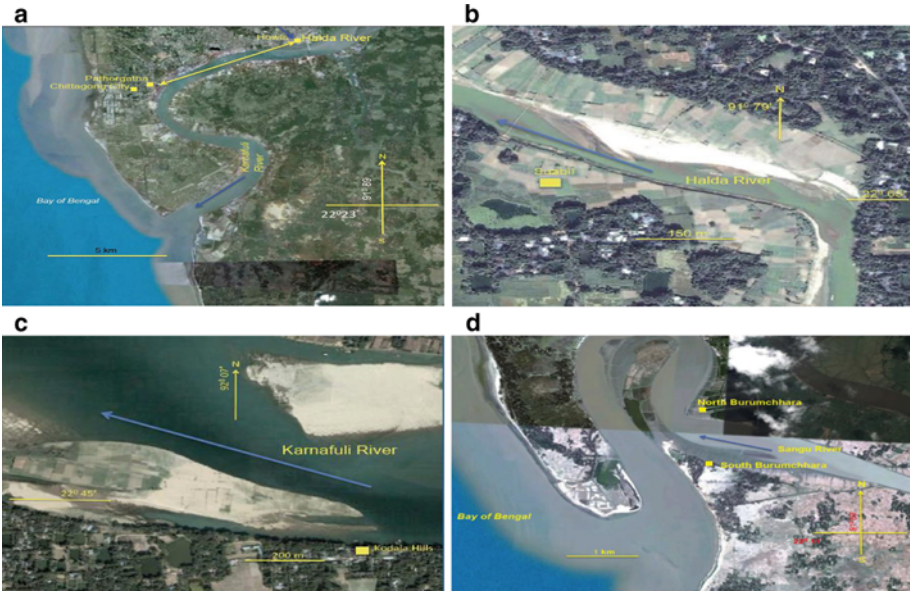

Fig. 7 **a** The region between Pathorgatha and Howla on the bank of Karnafuli River, Chittagong City; **b** The location of Suabil on the bank of the Halda River. Gulston (1763a) reported liquefaction and compaction of the low land of the Suabil by the earthquake on the bank of the Halda River; **c** The location of Kodala on the bank of the Karnafuli River. Gulston (1763a) reported a landslide triggered by the earthquake from the Kodala Hills on the bank of the Karnafuli River; **d** The particular location of Burumchhara, the Sangu River and the Bay of Bengal. The north and south Burumchharas were dissected by the Sangu River. The Sangu River empties into the BoB at its western end. This is the only location where the BL sources clearly report the damage by tsunami and the deaths of people (*Source* adapted from Google Earth)

it is extremely likely that liquefaction and compaction did occur in unconsolidated land along the Halda River.

4.2.1.2 Liquefaction-induced compaction and subsidence along the coast of the BoB Gulston (1763a) and Verelst (1763) describe the effects of the AD1762 earthquake at Akilpoor, a village in the Bansbaria *union*, located on the Chittagong coast (Fig. 6). Referring to Akilpoor, Verelst (1763, p. 266) observed that "at Bans Burrreah, Akul Poor, near the sea, the earth opened in seven places, like wells, throwing up the water ten cubits high; the great Cutcherry there, with brick walls, is cracked and shivered into pieces". Gulston (1763a) also provided similar descriptions of these effects (Table 1) at Akilpoor and Bansbaria. From the field visits and investigations, we believe that the descriptions of the earthquake effects on this village are likely and would have included liquefaction-induced surface failure, compaction and subsidence of the lose sediment along the coast of the BoB. However, the spatial distribution of these effects appears to have been limited.

4.2.1.3 Landslides at Kodala on the bank of the Karnafuli River The descriptions of surface failures at Kodala located on the bank of the Karnafuli River (Fig. 6) can be attributed to landslides triggered by the earthquake. Gulston (1763a, p. 254) stated: "…the eastward of Kadr Katcheeah a large hill, called Kad'd'aleah, very near Karn Phooly, was rent, and it stopped up the passage for boats in and out that river." Kodala (Kodala spelt as

Kad'd'aleah in Gulston's (1763a) description)) is located on the bank of the Karnafuli River, 50 km northeast of Chittagong City. The width of the Karnafuli River is less than 125 m adjacent to Kodala (Fig. 7c). It appears that a portion of the Kodala Hills along the Karnafuli River was "broken into pieces" by the shaking of the earthquake, and subsequent landslides blocked access to the adjacent river for incoming and outgoing boats.

4.2.1.4 Co-seismic submergence and subsidence Content analysis of the available historical documents suggests that co-seismic submergence occurred due to the earthquake. It is reported that the earthquake caused submergence of approximately 155.40 sq km along the west coast of Chittagong (Burke 1764; Rizvi 1970; Fig. 6).

Co-seismic subsidence was reported in Baharchhara and Lakshmipur (Fig. 6). However, there may have been unreported places where co-seismic subsidence also occurred. This can be inferred from Verelst (1763, p. 268) who comments, "By the accounts already come in, there are 120 Dons of ground lost in different part of the province; but these I am afraid will not be one-eighth part of the whole damages, as we have further relations coming in every hour."

Hunter (1876) and Anon (1763) reported (Table 1) co-seismic subsidence of 24 sq km of land in Lakshmipur (Fig. 6). Laskhmipur is located in the lower estuarine region, where the Meghna River flows into the BoB. Through the formation of sand bars and mouth bars in the Meghna estuary, the sediments are soft, young and unconsolidated in this region (Brammer 1966, 2002; Gupta and Khan 1996). It is possible that severe ground shaking by the earthquake resulted in compaction and subsidence of the land beneath the water of the Meghna River.

4.2.1.5 Mud volcanic eruptions The earthquake is said to have caused the discharge of sulphur-mixed water and two volcanic eruptions in the Sitakund Hills (Fig. 6), Chittagong (Akhter 1979; Alam 1947; Gulston 1763a; Hunter 1876; Islamabadi 1987; Verelst 1763). Verelst (1763, p. 269) observed: "As we are informed, that there are two volcanoes opened…" Akhter (1979) investigated the sediments of the Sitakund Hills and found that two mud volcanoes had erupted as a consequence of the earthquake. Following Akhter's (1979) analysis, we accept the reports of eruptions of mud volcanoes triggered by the earthquake as reliable. Another earthquake that occurred in AD1865 is said to have caused sand and mud ejections in the Sitakund Hills (Rizvi 1970).

4.2.1.6 The collapse of houses, deaths and injuries Historical documents record both earthquake effects on housing and the number of deaths and injuries that sustained as a result of the event. The earthquake caused extensive damage to houses in Chittagong. Even "well-built" houses made of bricks are reported to have experienced cracking or complete collapse. For example, Verelst (1763, p. 265) stated: "… as there is not a brick wall or house but is either greatly damaged or fallen." Evidence from field visits and data from location and genealogical analysis identify at least ten locations where damage to houses was reported. Some of these include the house of Sacheeram Cannoongoey at Halda, Hurry Singh's house at Dohazari, Santeeram Cannongoey's house at Pathorgatha, Mr. Griffith's brick house at Kotwali, a mud building, *Kutchery* houses and mud buildings in Akilpoor, Bansbaria, Burumchhara, Baharchhara and Howla (Fig. 6). Discussion with locals could only confirm the locations of these places, but no stories of earthquake damage are available.

Deaths and injuries sustained as a result of the earthquake were reported in several places. The BL sources detailed those locations where physical changes in land and damage to houses resulted in deaths and injuries. The reports of deaths and injuries were stated in a particular manner. For example, "the break down of the Santaram Cannoon-Goey brick house and injury of his relations", "Taluckdar's ground sunk and four people killed at Suabil" (Verelst 1763), "loss of two hundred people at Baharchhara", "the break down of Hurry singh's house at Do Hazari which hurt one of his family members", "a bricked room of Santeeram Cannoon-Goey's house in Chittagong broken down and his brother, Rajah Ram, was killed by the falling down of brick" (Gulston 1763a). Discussions with descendants in Dohazari and Pathorgatha, where deaths and injuries were reported did not reveal any such records of the earthquake.

4.2.1.7 Evidence of recent earthquake effects and the context of vulnerability Similar to the AD1762 earthquake, a Ms 6.1 event in AD1997 whose epicentre was in Bandarban caused liquefaction-induced subsidence of a five-floor building in Chittagong in which thirty-two people died (which is over 60 km from the epicentre (Khan 2004)). In addition, numerous hilly areas developed cracks and experienced slumping in Bandarban (Islam 2001). Another two earthquakes that occurred in AD1999 and AD2003, whose epicentres were in Chittagong, caused damage to houses, deaths and injuries. A repeat of the AD1762 earthquake would be expected to cause numerous slope failures in heavily deforested (Alam et al. 2005) and fragmented hilly areas in Chittagong resulting in further deaths and injuries. Recently, heavy monsoon rainfall has caused widespread slope failure resulting in landslides associated with deaths and injuries in every rainy season (Alam et al. 2005; Mahmood and Khan 2008). Due to poor infrastructure and a lack of preparedness in Chittagong and Dhaka, the consequences of a repeat of the AD1762 earthquake would be devastating. It should be noted that total population and population density in Dhaka and Chittagong have increased at least tenfold since the first census in AD1872 to the most recent in AD2011 (BBS 2010; Rizvi 1969, 1970).

4.2.2 The effects of the tsunami

4.2.2.1 Tsunamis on the coast of Chittagong Local tsunamis were observed in three places—Bansbaria, Baharchhara and Burumchhara following the earthquake (Fig. 6). The context of descriptions and the extent of inundations are evaluated in the following sections.

Gulston (1763a) quotes a letter from Satoo Mester Darogah (a local administrator and resident at Bansbaria) to describe the effects of the earthquake in Chittagong. Referring to the tsunami at Bansbaria, Gulston (1763a, p. 252) stated that: "And from the reports of the people there we hear, that these places were never before overflowed by the water…a mud building of your servant's (the writer of this account) was almost destroyed by the shock, but it still stands upright". There is no river inside or adjacent to Bansbaria. This suggests that the area along the Bansbaria coast that was affected by liquefaction and subsidence was also struck by a tsunami generated by the earthquake. The mud building inhabited by Satoo Mester Darogah is reported to have cracked as a result of the shaking of the earthquake, but it remained standing following the earthquake. This suggests that the height of tsunami and maximum run-up was very low, and it did not reach up to the wall of a mud building, causing it to collapse. Therefore, this research suggests that a medium-to-large tsunami did not occur in this area.

Gulston (1763a), Verelst (1763) and Rizvi described the effects (Table 1) of the earthquake at Baharchhara. Verelst (1763) stated that: "At Bar Chara, near the sea, five or six cess of ground immediately sunk, and out of four or five hundred people, about two hundred were lost, with all their cattle; and the greatest part of the remaining inhabitants, who ran into woods, have not yet been heard of." The Baharchhara is a *union* at Banskhali. This suggests co-seismic subsidence in Baharchhara, resulting in both human and animal deaths. Verelst's (1763) descriptions indicate that the inhabitants at Baharchhara experienced a tsunami triggered by the earthquake and fled to higher ground to save their lives.

However, Rizvi (1970) proposed an alternative area (see Baharchhara 2 in Fig. 6), which is located in the present Boalkhali *upazila*. Rizvi (1970, p. 54) stated that: "Baharchara means an outer strip of land, exposed and abandoned, and a tidal wave accompanying an earthquake would cover any of these places". In Bengali, Baharchhara consists of two words, *Bahar* (outer) and *Chhara*, which means land formed by sea or river tides. Boalkhali is an *upazila,* and part of it is located along the Karnafuli River, but at present, there is no location called Baharchhara. Rizvi's (1970) proposed that the location of Baharchhara was inside or along the Karnafuli River, having the *Chhara* as part of its name. The descriptions by Rizvi (1970) suggest that a tsunami triggered by the earthquake did inundate Baharchhara. Other locations are reported to have been affected around Baharchhara and include Pathorgatha and Howla where liquefaction-induced surface failures and compaction was mentioned (Figs. 6, 7a).

Gulston (1763a) and Verelst (1763) provide a clear description of a tsunami in Burumchhara. Baharchhara, a name of two *unions* called north and south Burumchharas, is located in Anawara and Banshkhali *upazilas,* respectively. Both north and south Burumchharas are dissected by the Sangu River, which flows into the BoB (Fig. 7d). In reference to the tsunami at Burumchhara, Gulston (1763a, p. 253) stated: "The Kutwâll, of Islamabad, also informed us with his own mouth, that, in a place called Baramcharah, the water was up to a man's waist, and the people there have betaken themselves to flight, through fear of perishing; no living creature but the cattle now remaining." Verelst (1763) reported that Burumchhara was inundated by sea water to an approximate depth of 90 cm. It is possible that the earthquake generated submarine sediment slides that triggered local tsunamis adjacent to the Burumchhara coast. Another explanation is that the sudden rise of water triggered by the earthquake could have raised its flow height at the particular geographical location along an oxbow lake in Anawara and Banskhali adjacent to the BoB. Given that the depth [height] of water at this location was described as reaching "up to a man's waist", the flow depth of any tsunami event can be assumed to have been less than 1.3 m in Bangladesh. An alternative explanation is that a part of the Burumchhara coast at this location subsided during the earthquake, causing seawater to inundate the low-lying land.

Our review of historical evidence coupled with field visits does not support the suggestion of inundation occurring over extended areas. There is no concrete evidence of a tsunami achieving a flood runup height of circa 2.5 m along the Chittagong coast. This argument is supported by an analysis of the flooding effects of the AD1985 tropical cyclone on the Bangladesh coast. Dube et al. (2004) indicated that the AD1985 Bhola tropical cyclone raised water levels by a maximum of 3 m at the northern end of the BoB and flooding the Chittagong coast with a 2.8-m-high storm surge. The middle and western coast was also flooded by a storm surge with a height of at least one metre. If water were raised 2–3 m in the northern BoB due to either a tsunami or a tropical cyclone, the entire SE Bangladesh coast would have been flooded. Here, it should be noted that the oldest report on the Ganges and Brahmaputra rivers by Rennell and Banks (1781) describes

flooding in the Lakshmipur district caused by a severe tropical cyclone in AD1763. However, they make no mention of flooding in the year before.

4.2.2.2 Water level raised in the river adjacent to Dhaka The earthquake severely shook the ground in Dhaka (Allen 1912; Burke 1764; Hirst 1763). Hirst (1763, p. 257) stated that: "At Dacca, in this kingdom of Bengal, the consequences have been terrible: the rise of the waters in the river was so very sudden and violent, that some hundreds of large country boats were driven ashore, or lost, and great numbers of lives lost in them." Allen (1912, p.131) added that: "At Dhaka the rivers and jhils were agitated, and rose high above their usual levels, leaving, when they receded, their banks strewed with dead fish." From these historical descriptions, it is unclear whether a tsunami originating in the BoB inundated as far as Dhaka. The logical explanation is that the severe shaking of the earthquake caused oscillations of river water from the Buriganga River that runs alongside Dhaka. During the 2004 IOT, seismic seiches were observed in all water bodies and pond water in Dhaka, for example, oscillated by up to 0.61 m (Akhter 2010).

Debate arises as to whether tsunami waves in the BoB reached as far inland as Dhaka (Cummins 2007). Analysis of the districts between Lakshmipur and Dhaka is useful for understanding whether flooding occurred from the coast inland as far as Dhaka. Although co-seismic subsidence occurred in Lakshmipur on the eastern bank of the lower Meghna River, no flooding was reported. In a north–south direction between Lakshmipur and Dhaka are the districts of Shariatpur, Chandpur, Comilla, Munshiganj and Narayangonj (Fig. 8). The distance from Lakshmipur to Dhaka is approximately 215 km. Without a tsunami in the coastal (Lakshmipur and Noakhali) and intermediate areas, the occurrence of tsunami in Dhaka is unlikely. However, it is possible that the sudden rise of water in the northern BoB could have been funnelled up the river in Dhaka without flooding low-lying settlements along the way.

4.2.2.3 Location of the AD1762 earthquake and tsunami affected areas in Bangladesh Analysis of the areas reported to have been affected by the earthquake and tsunami are useful for understanding whether the entire SE Bangladesh coast was impacted. Despite reports of tsunamis at Baharchhara, Burumchhara and Bansbaria (that are located in a south–north direction (Fig. 6) along the Chittagong coast), no flooding was mentioned throughout these areas from any direction. Additionally, Gulston (1763a) and Verelst (1763) thoroughly described the effects of the earthquake in Pathorgatha, but no inundation was observed in the adjacent city of Chittagong, where the British servicemen were residing. This suggests that if a local tsunami had occurred as a result of the earthquake, the height of any tsunami experienced at the Karnafuli River was too small to inundate the city of Chittagong. Currently, the review of historical documents from Chittagong, Noakhali, Lakshmipur, and Barisal does not provide any substantial evidence to support tsunami inundation from any direction. If a large tsunami had occurred in Chittagong (i.e. Baharchhara, Burumchhara and Bansbaria), the flooding would have swept over the offshore islands (i.e. Sandwip and Hatiya islands) at the funnel-shaped coast at the northern end of the BoB (Fig. 6). The coastal and offshore island areas adjacent to the BoB are low-lying and very flat. The ground height of the region, up to 200 km from the coast is lower than 3 m (Fig. 8; Umitsu 1985). Again, location analysis of these reported areas does not support flooding in these adjacent, connected and intersecting areas from any direction.

It is possible, however, that the earthquake could have triggered submarine sediment slides, which may have generated local tsunamis that inundated Baharchhara,

Fig. 8 The *contour lines* show the elevation above mean sea level (MSL). The western and estuarine regions have an average elevation of 0–3 m and the Chittagong coast 0–30 m. *Solid dots* show the locations of districts from Lakshmipur to Dhaka (*Source* base map from USGS (2011)

Burumchhara and Bansbaria. The thickness of sediment in the northern end of the BoB along the Chittagong coast is more than 13 km (Cummins 2007; Curray et al. 1982).

4.2.2.4 Historical records of tsunamis in Cheduba Island Captain Edward P. Halsted (1843), Captain of the British ship *Childers* conducted a survey along the Arakan coast in AD1841. Halstead quoted the experiences of a 106-year-old resident who came from the Cheduba Island (Fig. 5) during the AD1762 earthquake. The resident's description of the event is captured in the following text from Halstead's report:

> The earthquake was very violent, the sea washed to and fro several times with great fury, and then retired from the grounds, leaving an immense quantity of fish; the

> feasting on which is a favorite story throughout the Island; no lives were lost, no rents in the earth occurred, nor fire from the volcanoes of the Island (1843, p. 434).

Halstead also reported that local people fled to higher ground when the AD1762 tsunami occurred. Halstead's report of the tsunami may not be relied upon in isolation because he conducted his survey 77 years after the earthquake occurred. However, Verelst (1763), who documented accounts of the earthquake effects immediately after the event, observed that the locals fled to higher ground after seeing the tsunami in Baharchhara. Taken together, it is reasonable to accept the validity of the matching accounts.

4.2.2.5 Evidence of uplift of the Myanmar coast and the height of tsunami The AD1762 earthquake is reported to have resulted in co-seismic uplift along the west coast of Myanmar, Ramri, Cheduba and Foul islands (Fig. 5) between 2.74 and 6.70 m (Halstead 1843). The analysis of sediment on Phayonkar Island by Okamura et al. (2008) using radio carbon dating of coral and shell suggests that an identified uplift of 3–5 m could be attributed to the AD1762 earthquake. Further, recent geological investigations in 2006 and 2007 undertaken along the western coast of Myanmar suggest the occurrence of terrace uplift during the AD1762 earthquake, but there is no explicit evidence of tsunami deposits (Aung et al. 2006, 2008; Thein and Swe 2008). The recent estimation of 3–5 m of uplift off the coast of Myanmar by the earthquake is consistent with the historical reports by Halstead and Mallet (Halstead 1843; Mallet 1878).

Evidence of uplift of the Arakan coast is explicit, but evidence for tsunamis is less clear. One possibility is that the uplift along the Arakan coast had elevated coastal tracts above the reach of the subsequent tsunami. Another explanation is that although oscillations of ocean water in the BoB were observed following the earthquake, deep ocean tsunami did not affect the Myanmar coast.

5 Other examples of the effects of the earthquake in soft sediments and earthquake-triggered slides and tsunamis

The AD1762 earthquake ruptured the south of the ASZ including 250 km of the Bengal shelf (Fig. 2). The event triggered widespread land-level changes and human deaths and injuries that occurred along the adjacent SE Bangladesh. The soil in the reported areas of liquefaction, compaction and subsidence derived sand and silty sand deposits adjacent to the rivers of Karnafuli, Halda, Sangu and Meghna and on the coast of the BoB (Khan 2001; Umitsu 1997). Similar effects of earthquakes in the recently formed deposits occurred in Christchurch, New Zealand during the 22 February AD2011 earthquake (Jaiswal et al. 2011), in Alaska, USA following the 27 March AD1964 earthquake (Vellejo and Asce 1988), at the Frasher Delta, Canada during the 24 December AD1872 earthquake (Clague et al. 1992) and in Wenchuan, China following the 12 May AD2008 earthquake (Huang and Jiang 2010). It should be borne in mind that the AD1964 Alaska earthquake was generated in a similar sediment subduction zone (Ruff 1989), causing numerous surface cracking, liquefaction-induced landslides, local slide-generated tsunamis (McCulloch 1984) and a major Pacific Ocean tsunami (Nicolsky et al. 2010). Since the sedimentation rate in the northern BoB is very high, Cummins (2007) issued a precaution that the possibility of submarine or subareal landslide-generated tsunamis should be considered significant because, as we have already reported, the AD1762 earthquake probably triggered at least three local tsunamis along the Chittagong coast.

6 Conclusions

Drawing evidence from deep archival research and field visits, we identified historically reported locations of the AD1762 earthquake effects in SE Bangladesh. Gulston (1763a) and Verelst (1763) described the nature and extent of the effects in different places in Chittagong. The descriptions of historical evidence together with field visits do not support the flooding of large areas from any direction (i.e. north–south or east–west or west–east) along the coast of SE Bangladesh. However, historical evidence from the Chittagong and Arakan coasts are inconsistent in describing the occurrence of local tsunamis. It is possible that the earthquake generated several sediment slides in the northern BoB, generating tsunamis in Chittagong. Another possibility was that earthquake-induced subsidence, adjacent to the BoB, caused local tsunamis.

Although large areas were not affected by any tsunami, liquefaction, compaction and subsidence and damage to houses were extensive. Our analysis of the effects of the AD1762 earthquake suggested that significant damage occurred in the built environment and the vulnerable communities that lived along the Bangladesh coast. Thus, the findings of this research are significant for disaster management policies in relation to earthquakes and tsunamis in Bangladesh as well as for generating awareness among vulnerable coastal communities.

Gulston (1763a) and Verelst (1763) reported the effects of the earthquake quoting local administrative people and familiar local names. It is possible that effects in other locations have not been documented, limiting our understanding to fully quantify the earthquake. As such, we suggest conducting further investigations into archival sources to achieve a more complete understanding of the effects of the AD1762 earthquake and tsunami. Accordingly, there is also a further need for a geological and geomorphological study to be undertaken at the key sites in order to assess the nature and extent of palaeoenvironmental changes. However, it should be borne in mind that since the AD1762 earthquake, the SE Bangladesh coast has been flooded by at least fourteen severe tropical cyclones including the events in AD1767, AD1822, AD1970 and AD1991, which have already resulted in significant sediment deposition and reworking induced by storm surges. Additionally, in order to understand community vulnerability to earthquakes and tsunamis, a comprehensive survey should be conducted in Bangladesh. The resident populations of SE Bangladesh are at high risk from future earthquakes and tsunamis if they occur. As such, we recommend taking proactive measures in relation to earthquake and tsunamis in Bangladesh by launching appropriate awareness programmes and implementing risk management strategies.

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