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Impact of the 18 September 2011 Sikkim Earthquake (Mw 6.9) in Bangladesh: Assessment and Geologic Significance

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Abstract

The Mw 6.9 magnitude Sikkim earthquake of 18 September 2011 jolted whole Bangladesh including its capital city. It was the second highest shaking that the country experienced during the last about 65 years. A macroseismic assessment was done because for its wide-spread shaking capability and documentation for future research. The assessment was done on the basis of the information published in the daily newspapers, different websites, interviews with few local residents and published government documents. Although, there was no serious damage of properties and many casualties, the result brought a number of issues to be thought about to reduce seismic risk. A wide-spread panic situation among all walks of life generated during the quake resulting, in many cases, injuries. Many buildings, in different parts of the country, were affected due to development of cracks and fractures, and subsidence. Other findings are disruption in generation and supply of electricity, communication networks, subsidence of infrastructures etc. The intensity map showed a good correlation between shaking effect and sediment characteristics demonstrating clear relationship between the earthquake shaking and response of unconsolidated sediments. The maximum intensity (VI) was found in areas close to the epicentral region and higher intensity was found in areas of clay-rich deposits, which are occupied by Tista alluvial fan, depressions on the floodplains and Old Ganges delta. This country is mostly floored with Holocene fluvial and deltaic unconsolidated sediments, and water-saturated. Because of its close location to active tectonic region, Bangladesh would experience seismic shaking in future consequently sediments would also response according to their characteristics. However, more research in relevant fields is needed for better understanding about the regional geotectonic scenario. The Mw 6.9 magnitude Sikkim earthquake shows how vulnerable we are to seismic events. Proper measures should be taken to reduce future seismic risk for the sake of huge population in Bangladesh. Those preparedness measures include creation of awareness among the people and strict enforcement of building code etc.

Keywords: Earthquake impact, intensity map, infrastructural damage, casulties.

Introduction

Bangladesh is surrounded by high seismic regions and the seismicity is directly related to plate tectonic behaviour in and around the country. Due to the seismotectonic characteristics of this region, Bangladesh continually experiences shaking from small and moderate earthquakes. During the last few years, many parts of the country was shaken by Sylhet earthquake of 1997 (5.6), Chittagong earthquake of 1997 (6.0),

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Moheshkhali earthquake of 1999 (5.2), Dhaka earthquake of 2001 (4.2), Barkal earthquake of 2003 (5.2), Mymensingh earthquake of 2008 (4.9), Matlab earthquake of 2010 (4.8), Sikkim earthquake of 2011 (6.9), Manipur earthquake of 2016 (6.7) and Manu earthquake of 2017 (5.6) (AKHTER 2010, ALAM 2014, ALAM 2016 and ALAM & AHSAN 2016). But it also experienced several major earthquakes (Fig. 1) during the last 250 years viz. Arakan earthquake of 1762 (>8), Cachar earthquake of 1869 (7.3), Bengal earthquake of 1885 (7.0), Assam earthquake of 1897 (8.1), Srimangol earthquake of 1918 (7.1), Dhubri earthquake of 1930 (7.1), Nepal-Bihar earthquake of 1934 (8.2), Great Assam earthquake of 1950 (8.6) and Gorkha (Nepal) earthquake of 2015 (7.8) (BILHAM 2004, AKHTER 2010, MARTIN & SZELIGA 2010, SZELIGA et al. 2010, KUNDU & GAHALAUT 2012, KAYAL 2014). Although most of the epicentres of these great earthquakes were beyond its territory, those earthquakes affected the country because of morphotectonic continuity. Well-written documents (OLDHAM 1883, MIDDLEMISS 1885, OLDHAM 1899, STUART 1920, GEE 1934, ANON 1939, MOLDEN *et al.* 2016 and ALAM & AHSAN 2016) gave details of the impacts of those earthquakes in Bangladesh also. HOUGH & BILHAM (2008) re-evaluated the observations by OLDHAM (1899) based on accounts found in newspapers, government reports and other materials. The 1762 earthquake generated tsunami, changed landforms like submergence and uplift, destructed settlements and swept of inhabitants (FERGUSSON 1863, IYENGER *et al.* 1999, CUMMINS 2007, SWE & TUN 2008, WANG *et al.* 2012, WANG *et al.* 2013, WANG *et al.* 2014 and AKHTER *et al.* 2015). But impact of 1950 earthquakes in Bangladesh is not known.

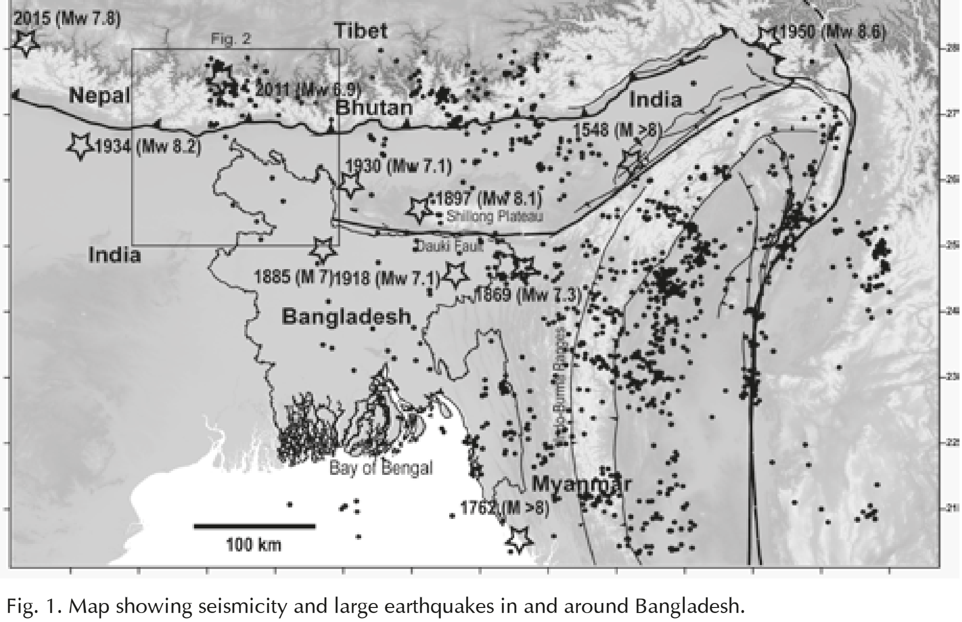

Fig. 1. Map showing seismicity and large earthquakes in and around Bangladesh.

The 3 January 2017 Mw 5.6 Manu (Tripura, India) earthquake caused singular house and wall collapse in Maulvibazar district and generation of liquefaction (DEBBARMA *et al.* 2017). ALAM (2017) and ALAM & ISLAM (2017) observed that there were evidences of changes in geomorphology and hydrological regime due to even low magnitude seismic events in Bangladesh. However, even continuous aseismic deformation generates micro-earthquakes (DASGUPTA 2011).

In a recent study LI PEI *et al.* (2015) anticipated that an Mw 8.0~8.2 earthquakes would occur in short-middle term in the Himalayan region north of Bangladesh, as shown in their map. Other researchers also showed similar findings (BERTHET *et al.* 2014).

The most pronounced impact of this Mw 6.9 Sikkim earthquake was generation of wide-spread panic among the people from almost all over the country. Besides this, after the Nepal-Bihar earthquake of 1934 probably no documents are available on the impacts of earthquakes in this part of the region. This is very important for seismic hazard assessment as well as for making estimates of damage and loss from earthquakes (MCGUIRE 2004).

This macroseismic observation (HOUGH & BILHAM 2008), documentation and assessment were made considering importance in seismic hazard assessment, potential use in earthquake resilience for risk reduction (KHAN 2010), support for future earthquake research, and even probable use in environmental planning (PANIZZA 1981). Moreover, accurate assessment of hazard with present-day scientific knowledge would become important for preventive measures (BANSAL & VERMA 2013). In reducing loss, in case of 2015 Nepal earthquake, GUPTA (2015) showed how regular earthquake drill helped.

This assessment was carried out in Bangladesh based on the accounts found in the daily newspapers, different websites, interviews with local residents, although very limited extent, and from published government documents. Information collected from daily newspapers published from Dhaka during 19-20 September 2011. To collect maximum information with effective coverage information were taken from twelve daily newspapers (ten Bangla and two English). Seismological data were collected from the websites of Bangladesh Meteorological Department, National Earthquake Information Center of US Geological Survey, Indian Meteorological Department and International Seismological Centre. These sites were visited several times to get updated information. Website of National Disaster Response Coordination Centre (NDRCC) of Ministry of Disaster Management and Relief were checked to learn situation report. Limited number of interviews of local residents were taken to record their feelings and observations.

The macroseismic observations (HOUGH & BILHAM 2008) describe how the shaking affected the people, artificial structures and natural bodies. All the data and information were compiled district-wise. After analysis, the compilation was arranged according to the indicators given in Modified Mercalli Intensity (MMI) Scale 1931 (WOOD & NEUMANN 1931 and REITER 1990) which was later compared with the geological map of Bangladesh to give qualitative evaluation of the relationship between shaking effect and geologic condition with geological explanation.

Regional Tectonics and Geology of Bangladesh

The Sikkim Himalaya is part of the active Himalayan Fold-Thrust Belt (BERTHET *et al.* 2014, WESNOUSKY *et al.* 2017, BILHAM *et al.* 2017 and RAJENDRAN *et al.* 2017). The origin of Himalaya is attributed to the continent-continent collision between the Indian and Eurasian plates. Bangladesh constitutes the major part of the Bengal Basin, which lies on the Indian plate that is gradually closing to Eurasian plate to the north at a rate of approximately 36-45 mm/year (RAJENDRAN *et al.* 2017). The eastern margin of the Bengal Basin is bounded by Indo-Burma Folded Belt where an atypical continent-continent subduction is going on (KAYAL 2010). The Indian Shield on the west borders the Bengal Basin, located north of the Bengal Deep-Sea Fan, on the north by the Shillong Massif, a large elevated area of Pre-Cambrian basement rocks with Mesozoic and Tertiary sedimentary rocks. Jurassic-Cretaceous volcanic rocks exist in the southern margin (NANDY 2001). The Dauki Fault Zone forms an active major east-west tectonic element (DAS *et al.* 1995) that separates the Shillong Massif from the subsided Surma basin of the Bengal Basin (ALAM & ISLAM 2017).

Tectonically, Bangladesh can broadly be classified into two geotectonic provinces (KHAN 2002)--(i) The PreCambrian Rangpur Platform (Stable Shelf) comprising three parts- a) Himalayan Fore-deep, b) Rangpur Saddle and c) Bogra Shelf; and (ii) The Bengal Foredeep having two parts-a) The Platform Flank and b) The Folded Flank. The Platform Flank comprises of a) Sylhet Trough, b) Faridpur Trough, c) Barisal-Chandpur Gravity High and d) Hatia Trough; and The Folded Flank (Sylhet-Tripura-Chittagong Folded Belt) has two systems of folding - one striking to NNW-SSE direction and the other in the East-West direction. The Stable Shelf is separated from the Bengal Foredeep by a 25-km wide and SSW-NNE trending Hinge zone.

Geomorphologically, major part of it is occupied by one of the largest delta of the world formed by the Ganges-Brahmaputra-Meghna river system originated from the uplift of the Himalayas. The delta prograded south accompanied by rapid subsidence in the basin resulting deposition of huge thickness of deltaic to fluvio-deltaic sediments. The delta building process is still continuing into the present Bay of Bengal and broad fluvial front of the major system gradually follows it from behind. Half of the country is lower than elevation of 12.5 m above mean sea level. The elevation of hilly areas, occupy the eastern and north-eastern parts, lies between 70 and 1000 m. The alluvial plains have the elevation from about 90 m in the north-western part of the country to 0 m along the coastal part. Apart from these, there are three tracts viz. Barind Tract, Madhupur Tract and Lalmai Hills (REIMANN 1993). The maximum elevation, about 40 m, was observed in the Barind Tract (MORGAN & MCINTIRE 1959), however, REIMANN (1993) found about 45 m above mean sea level.

Geologically, 80% of the surface and near surface of the country is formed of Holocene deposits (ALAM *et al.* 1990). The Holocene deposits, consisting of unconsolidated sand, silt and clay of varying amounts, are the products of piedmont, alluvial, fluvial, deltaic or coastal processes. Eight percent area is covered with Pleistocene clay residuum in the three uplifted terraces. The Tertiary sedimentary rocks, consisting mainly of sandstone, siltstone, shale and clay; cover 12%. The oldest exposed rock is the Tura Sandstone of Paleocene age but older rocks like Mesozoic, Paleozoic and Precambrian Basement have been encountered in the drill holes in the north-western part. Through a long geological time (Permian to Recent) the basement of Bengal Basin, below a thick sedimentary cover, has been severely faulted and fractured which are covered under Holocene surficial deposits.

All these materials under diverse tectonic frameworks and physical conditions behave differently during various geo-dynamic activities and geological hazards.

Geological Perspective of the 18th September 2011 Sikkim Earthquake

On the evening of the 18 September 2011 the whole country was shaken by an earthquake at 6.40 PM that lasted for about 100 seconds. Epicentre of this Mw 6.9 earthquake (Fig. 2) was at 11.5 km south-west of Kanchenjunga of Sikkim, India (MARTHA *et al.* 2015, KHANNA *et al.* 2012 and BARUAH *et al.* 2014). The quake was felt in India (West Bengal, Bihar, Uttar Pradesh, Jharkhand, Odisha, Assam, Tripura and Manipur states), Nepal, Bhutan and Bangladesh and China (KHANNA *et al.* 2012). But it was strongly felt in northern part of Bangladesh; Kathmandu valley of Nepal; Thimpu of Bhutan; and West Bengal, Assam and Bihar of India. Details of the instrumental data of the event are given in table 1. The E-W (top), N-S (middle) and vertical (bottom) components of the accelerogram recorded at Dhaka station of Geological Survey of Bangladesh are shown in Fig. 3.

The Sikkim earthquake caused significant fatalities, widespread damage and landslides in many parts of eastern Nepal, Sikkim and north Bengal of India (ASC 2013). The epicentre is located approximately close to the juncture of Tista and Kangchenjunga lineaments (GSI 2000), which are trending NW-SE, and NE-SW, respectively (PRADHAN *et al.* 2013, BARUAH *et al.* 2014 and BARUAH *et al.* 2018). However, BARUAH *et al.* (2014) show that Tista lineament as Tista fault and the earthquake occurred by strike slip mechanism. The seismological and geological maps indicate several active faults and 2011 Sikkim event ruptured along one of the active tectonic faults (PRADHAN *et al.* 2013, BARUAH *et al.* 2014, CHOPRA *et al.* 2013 and BARUAH *et al.* 2018). The macro-seismic and geomorphologic studies infer a dextral strike-slip faulting, possibly along a NW-SE oriented fault (RAJENDRAN *et al.* 2011 and KAYAL 2014). Based on GPS baseline analysis PRADHAN *et al.* (2013) observed that the region east of Kanchenjunga fault had undergone large deformation (~10 mm) while the region on the west appears more stable. However, fault plane solution and the resultant nodal plane orientation indicate that the causative fault for the Sikkim earthquake is most likely the Tista lineament (CHOPRA *et al.* 2013).

A three-component accelerogram unfiltered data, recorded at Geological Survey of Bangladesh, Segunbagicha, Dhaka were interpreted. The maximum ground acceleration was observed 0.0044g and 0.006g for E-W and N-S components respectively. Duration of strong motion lasted nearly for 20 second for E-W channel and 24 second for N-S channel. These characteristics are dependent on the magnitude of the earthquake, distance between the origin of the earthquake and recording station, and local soil condition.

Main shock (Mw 6.9) of the Sikkim earthquake was felt almost from entire Bangladesh followed by two aftershocks (4.8 and 4.7), felt in many parts of the country. A geologist living in the upper floor of a multi-storied building in Dhaka expressed his feeling as that the seismic wave travelled in an E-W direction. Similar expressions were also given by others, but somewhat like a cradle. Estimates of duration of seismic shaking, from people's perception, ranged from <20 seconds at Comilla, Chittagong, Bandarban, Brahmanbaria and Kurigram, to 120 seconds at Panchgarh, Dinajpur, Naogaon, Gaibandha, Chapai Nawabganj, Rajshahi, Phulpur and Gouripur of Mymensingh, Sherpur and Dewanganj of Jamalpur.

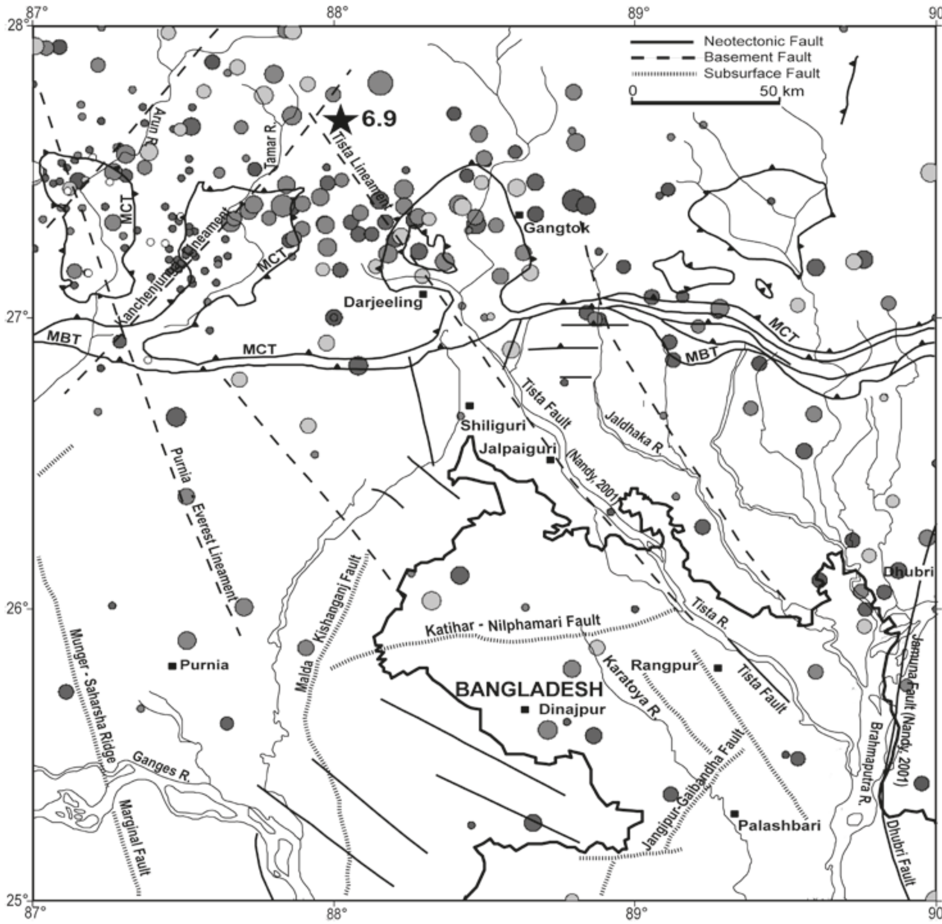

Fig. 2. Structural and tectonic map of the Sikkim area showing the epicentres of the earthquake. (Modified from Gsi 2000, information taken from Nandy 2001 and Pradhan *et al.* 2013, earthquake events during 1932-2018, shown in the background, taken from ISC website 2018).

Table 1. Seismological data on the 18th September 2011 Sikkim earthquake from different sources.

Date	BMD	IMD	NEIC, USGS	ISC
18 September 2011	6.8 6.40 PM BST 495 km NW of Dhaka	6.8 12:40:47 UTC 88.2°E, 27.7°N Depth 10 km	M 6.9 12:40:51 UTC 88.155°E, 27.730°N Depth 50 km	Mb 6.5/Mw 6.9 12:40:49.58 UTC 88.1536°E, 27.8039°N Depth 29.6 km
	5.3 7.11 PM BST 449 km NW of Dhaka	5.0 13:11:59 UTC 88.5°E, 27.6°N Depth 16 km	M 4.8 13:12:00 UTC 88.583°E, 27.520°N Depth 40.1 km	Mb 4.4 13:11:59.06 88.4989°E, 27.5462°N Depth 29.3 km
		4.5 13:54:17 UTC 88.4°E, 27.5°N Depth 9 km	M 4.7 13:54:19 UTC 88.452°E, 27.353°N Depth 28.2 km	Mb 4.5 13:54:18.36 UTC 88.2786°E, 27.3454°N Depth 22.0 km

BMD: Bangladesh Meteorological Department, IMD: India Meteorological Department, NEIC of USGS: National Earthquake Information Center of US Geological Survey, ISC: International Seismological Centre

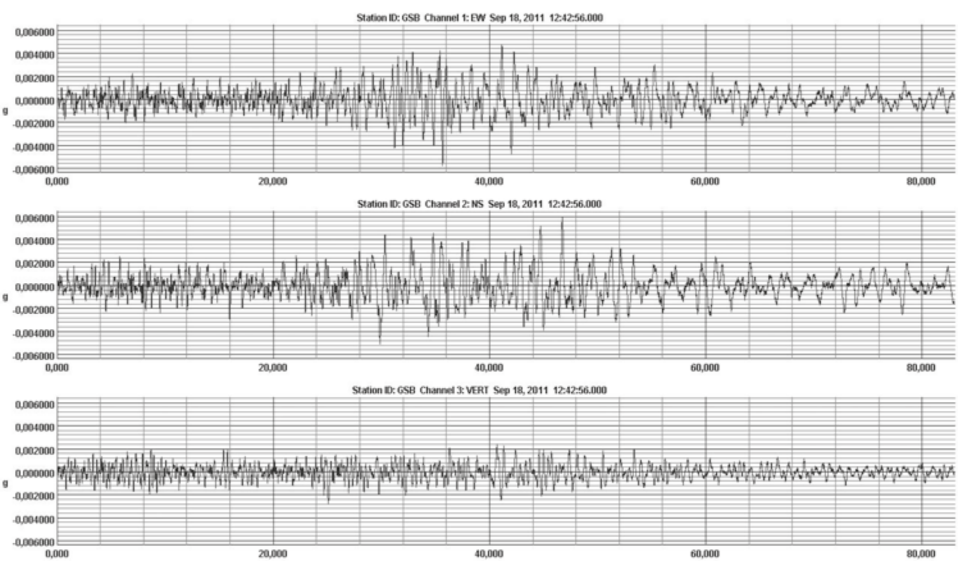

Fig. 3. Three-component accelerograms of the 18th September 2011 Sikkim Earthquake recorded at Dhaka station of Geological Survey of Bangladesh (Courtesy: Reshad Md. Ekram Ali).

Impacts of the 18th September 2011 Sikkim Earthquake in Bangladesh

Casuaties

Reports of casualties of the earthquake included two deaths and many injuries due mostly to collapse of walls and fear, and were mainly from the NW part of the country.

Deaths: Two persons were killed; one in Dhamoirhat Upazila of Naogaon district due to collapse of mud wall (TV News) and the other was in Lalmonirhat (JANAKANTHA 20/09/2011). However, no detail information was available.

Injuries: In general, injuries are related to structural damage, and fears and rushing for shelters. Ten persons were treated at Panchgarh Hospital and four persons injured in Boda upazila of this district. Two persons injured due to collapse of mud wall in Dinajpur town and another two persons were injured at Phulbari of Dinajpur (PROTHOM ALO 19/9/2011). Due to panic one student became faint at Atwari of Panchgarh (THE DESTINY 19/9/2011) and another student suffered cardiac problem in Thakurgaon. Two persons injured due to wall collapse and another became sick in Patgram of Lalmonirhat, and the later was hospitalised (THE KALER KANTHO 19/9/2011). Three persons injured from collapse of wall at Raigonj (AMADER SOMOY 19/9/2011) and 20 injured while rushing out of the building at Ullapara (JUGANTOR 19/9/2011) upazilas of Sirajganj district. One injured while rushing down the staircase at Mymensingh (PROTHOM ALO 19/9/2011). One student jumped from 2nd floor of a residential hall of the Islamic University in Kushtia and became injured (THE DESTINY 19/9/2011).

Panic

Due to panic the residents came out from their houses to open spaces in Dinajpur (JANAKANTHA 19/9/2011) and Nilphamari (BANGLADESH PROTIDIN 19/9/2011). People in Nilphamari called the Almighty offering ajan and ulu to get safety from the quake (BANGLADESH PROTIDIN 19/9/2011). Many people could not stand on foot and became panicky in Chilmari of Kurigram (SANGBAD 19/9/2011). It was difficult to stand in Rangpur and local people came out of their residences to open spaces out of fear (THE DESTINY 19/9/2011). Local residents came out of their houses in Lalmonirhat (THE DESTINY 19/9/2011), Gaibandha (JAI JAI DIN 19/9/2011), Naogaon (BANGLADESH PROTIDIN 19/9/2011 and JAI JAI DIN 19/9/2011), Bogura, Chapai Nawabganj, Natore (THE DESTINY 19/9/2011), Rajshahi, Sirajganj (SANGBAD 19/9/2011), Pabna (THE DESTINY 19/9/2011), Dhaka, Gazipur (JUGANTOR 19/9/2011), Narshingdi (JAI JAI DIN 19/9/2011), Munshiganj (JANAKANTHA 19/9/2011), Manikganj (THE DESTINY 19/9/2011, and AMADER SOMOY 19/9/2011), Narayanganj (THE DESTINY 19/9/2011), Mymensingh (JANAKANTHA 19/9/2011), Kishoreganj (THE DESTINY 19/9/2011), Tangail (THE DESTINY 19/9/2011 and SANGBAD 19/9/2011), Jamalpur, Netrakona (BANGLADESH PROTIDIN 19/9/2011), Sunamganj, Sylhet, Kushtia (THE DESTINY 19/9/2011), Meherpur (JUGANTOR 19/9/2011 and JANAKANTHA 19/9/2011), Jibannagar of Chuadanga (THE DESTINY 19/9/2011), Narail (BANGLADESH PROTIDIN 19/9/2011), Jessore (SANGBAD 19/9/2011 and JANAKANTHA 19/9/2011), Khulna (JUGANTOR 19/9/2011), Barishal (JANAKANTHA 19/9/2011), Pirojpur (THE DESTINY 19/9/2011), Barguna (JUGANTOR 19/9/2011) and Cumilla (SANGBAD 19/9/2011).

Infrastructures

The earthquake shaking damaged infrastructures which include crack, tilting, collapse of wall, fall of plaster, subsidence of building, etc.

Fractures and cracks were developed in more than 50 houses/buildings in Panchgarh district. Among those boundary wall of PWD office, collectorate building, dormitory of Youth Training Centre, Fire Station at Boda and Duckbanglow at Tetulia of the district may be mentioned (JUGANTOR 19/9/2011 and THE DESTINY 19/9/2011). In Dinajpur town, fractures were developed in more than fifty old and new buildings, and plasters were fallen (JANAKANTHA 19/9/2011). Fractures developed in, at least, three mud houses in Phulbari, pucca house in Parbatipur and collapse of mud houses in Parbatipur of the district (PROTHOM ALO 19/9/2011, AMADER SOMOY 19/9/2011 and DAILY KALER KANTHO 20/9/2011). Minor cracks were developed in a number of rooms of collectorate building and Sadar Police Station building in Thakurgaon, damage in mud houses in Ranishankail and Baliadangi, and minor cracks in some shops in Thakurgaon town (Website of NDRCC 2011). Subsidence, along the Barapukuria side, on the Badarganj-Phulbari road in Dinajpur district was reported (DAILY KALER KANTHO 20/9/2011), but detail information was not available.

Fractures developed in a number of houses and wall of the Sonali Bank Mithapukur of Rangpur (THE DESTINY 19/9/2011 and JAI JAI DIN 19/9/2011). In Lalmonirhat, development of cracks were reported from the buildings of residence of DC, guard shade of SP, residence of Sadar UNO, Duckbanglow at Kaliganj, 4-storey building at Patgram and in a number of houses at Hatibandha (Website of NDRCC 2011). Fractures developed in MCDP Market building and different houses in Nilphamari town (PROTHOM ALO 20/9/2011). Fractures developed in pillars of old hostel of Rangpur Government College (DAILY KALER KANTHO 19/9/2011). One storey building of railway collapsed in Patgram of Lalminorhat (DAILY KALER KANTHO 19/9/2011). Geomorphologically, this area is occupied by young Tista alluvial fan (BRAMMER 2012) and the sediments consist mainly of unconsolidated sand and silt.

In Joypurhat, the southern part of east guide wall of the Tulshiganga bridge on the Joypurhat-Santahar road damaged (PROTHOM ALO 20/9/2011). The 6-storey Touhid Plaza on the Sherpur road of Bogura town tilted (PROTHOM ALO 19/9/2011 and AMADER SOMOY 19/9/2011). Damage of mud wall in Maltinagar of Bogura town and Kahaloo of the district happened (JANAKANTHA 19/9/2011).

In Bholahat of Chapai Nawabganj, damage of mud houses were reported (AMADER SOMOY 19/9/2011). About 20 mud houses collapsed in Singra of Natore district (PROTHOM ALO 19/9/2011). Fractures were developed in walls houses in Singra and Sadar upazlias of the district (Website of NDRCC 2011). In Nowdapara area of Rajshahi city, subsidence of some buildings including lslami Bank Medical College occurred and cracks were developed (JUGANTOR 19/9/2011). Fractures developed in RUCSU building and in shops in Stadium Market of Rajshahi city (AMADER SOMOY 19/9/2011).

One building at Sutrapur in Dhaka city tilted (Website of NDRCC 2011). Another 4-storey building at Sutrapur also tilted and fractures developed in Kanthalbagan area of the city (PROTHOM ALO 20/9/2011). Fractures ware also developed in an 11-storey building at Jigatala and a 8-storey under construction building at Azimpur of Dhaka city (DAILY KALER KANTHO 19/9/2011). Plaster from the wall of a commercial building in Narayanganj city were fallen (THE DESTINY 19/9/2011). Fractures were developed in a number of buildings that included loan office super market, Krishi Bank and other old buildings in Tangail town (THE DESTINY 19/9/2011).

In Trisal of Mymensingh district, a number of houses were subsided (SANGBAD 19/9/2011). Fractures were developed in a number of buildings in Kishoreganj town (PROTHOM ALO 19/9/2011). Fractures were developed and damage occurred in a number of mud houses in Jhenighati of Sherpur district (THE DESTINY 19/9/2011).

In Tahirpur of Sunamganj, a number of buildings was damaged due to fractures (JUGANTOR 19/9/2011). Fractures were developed in the wall of main building of the Sylhet Railway Station (PROTHOM ALO 19/9/2011) and plaster also fell from the wall (DAILY KALER KANTHO 20/9/2011). About 12 mud houses tilted in Bamna of Barguna district (JUGANTOR 19/9/2011).

Household materials

Household materials that were affected by the shaking include hanging objects, unscrew or detached standing materials, furniture etc.

Materials from shelves fell at Panchgarh (JANAKANTHA 19/9/2011). Swinging of electric fan and lights, and disturbance in picture quality on television screen and computer monitor were reported from Rajshahi. Sound generated from utensils in the shelves in Rangpur. Materials fell from shelves in Senpara in Rangpur city (DAILY KALER KANTHO 19/9/2011). Fluorescent bulb fell in Saidpur of Nilphamari. Materials from under construction buildings fell in some parts of Dhaka city (PROTHOM ALO 19/9/2011). Shaking of furniture, computers were reported from Narayanganj (JUGANTOR 19/9/2011). Reports of shaking of photo-frame on the wall and furniture came from Srimangol of Moulvibazar (THE DESTINY 19/9/2011). Materials kept in shelves fell down at Gouranadi of Barishal (JANAKANTHO 19/9/2011), Kapasia of Gazipur (THE DESTINY 19/9/2011) and Haluaghat of Mymensingh

Water bodies

Water bodies include water of rivers and man-made ponds. Reports of generation of waves on pond and river water and other water bodies came from different parts of the country that included Panchgarh, Nilphamari, Natore (also in Chalan and Hatil beels), Pabna, Dhaka city (Dhanmondi lake), Manikganj, Mymensingh and Gouripur of Mymensingh, Sherpur, Narail, Jessore, Khulna, Bagerhat, Barishal and Barguna (JANAKANTHA 19/9/2011, THE DESTINY 19/9/2011, THE NEW AGE 19/9/2011 and DAILY KALER KANTHO 20/9/2011). Water level of the Tista River at Dalia Point rose 3 cm after the earthquake (JANAKANTHO 19/9/2011). However, wave height was higher in Pabna (~1 m) and Barguna (~1.5 – 2 m). River water rose in Dewanganj of Jamalpur district.

Living objects

Earthquake shaking also affected living objects like fishes and trees. Fishes jumped out of water in Khulna and Bagerhat (JUGANTOR 19/9/2011 and AMADER SOMOY 19/9/2011). Reports of swinging of trees came from Pabna, Phulpur of Mymensingh and Khulna areas (THE DESTINY 19/9/2011 and JAI JAI DIN 19/9/2011).

Land subsidence

A filled up pond at Millgate in Dhakkamara union under Panchgarh Sadar upazila again turned into a small water body as huge earth subsided under the impact of this strong earthquake (THE DAILY STAR 20/9/2011). The pond was filled in four months ago. As the time after filling the pond was short grains of the sediments still remained in loosely packed condition. But earthquake shaking effect forced to undergo rearrangement in the grains that caused considerable compaction and reduction in volume of the materials resulting subsidence.

Other impacts

As impacts of the quake, four rental power plants in Tangail, Thakurgaon, Jessore and Saidpur went off for nearly 30 minutes (THE DAILY STAR 19/9/2011). About 300 labourers remained trapped in underground for about 20 minutes at Barapukuria Coal Mine (Dinajpur) due to failure of electricity supply, however, were rescued after restoration of power (THE DAILY STAR 19/9/2011). Ten poles of 11 KV electric transmission line uprooted, along with transformers, in Haroa of Nilphamari municipal area (PROTHOM ALO 20/9/2011). Electricity supply was disrupted in Rangpur (AMADER SOMOY 19/9/2011), Bogura town (JANAKANTHA 19/9/2011), Sunamganj (AMADER SOMOY 19/9/2011), at Nalitabari of Sherpur (AMADER SOMOY 19/9/2011). Swinging of electric poles was observed in Phulpur of Mymensingh (JAI JAI DIN 19/9/2011).

Mobile phone and telephone network were disrupted in different parts of the country. Disruption of mobile phone networks were reported from Rangpur (AMADER SOMOY 19/9/2011) for about 15 minutes, Rajarhat of Kurigram (THE DESTINY 19/9/2011), Bogura (JUGANTOR 19/9/2011), Dhaka (THE NEW AGE 19/9/2011), Manikganj (THE DESTINY 19/9/2011 and AMADER SOMOY 19/9/2011), Mymensingh (JANAKANTHA 19/9/2011) and Sherpur (AMADER SOMOY 19/9/2011). Mobile phone and internet communication were disturbed for a short while in Nalitabari of Sherpur (AMADER SOMOY 19/9/2011) and Srimangol of Moulvibazar (THE DESTINY 19/9/2011).

Patients got struck in Medical College Hospital and other clinics, though the relatives came out of the buildings in Rangpur (PROTHOM ALO 19/9/2011).

One village under Gangachara upazila of Rangpur district was flooded due to damage in embankment of the Tista River (DAILY KALER KANTHO 20/9/2011).

Discussion

In this study, impacts of the Sikkim 2011 earthquake in Bangladesh are expressed by casualties (deaths and injuries), wide-spread panicky situation; damage in infrastructures; disruption in generation and supply of electricity; disruption in telephone, mobile phone and internet communications; land subsidence and flooding due to breach in embankment etc.

Examination of the impacts of the Sikkim earthquake showed that almost the entire country was shaken by the quake, except the south-eastern part. As mentioned earlier, impacts of the Sikkim earthquake 2011 on different objects and people were arranged according to MMI Scale. Later relationship between response and geologic conditions was examined and evaluated qualitatively. Based on these, the maximum intensity was estimated to be VI in Bangladesh (Fig. 4), assigned on the basis of evidence of generation of waves in water bodies. In MMI Scale generation of waves in water bodies falls at level VII, but other evidences of impacts of this quake were not strong enough to assign level VII. So the level was lowered to VI as a cautious step.

Learning from this earthquake is that what a strong magnitude, even from a distance, could do on our population, infrastructures and other lifelines. Two lives were lost and many injured in different parts of the country from fear and rushing out from buildings. Information on tilting of multi-storied buildings and development of cracks in many public and private buildings were reported. These might happen due either to poor quality construction or local soil condition; detail survey could give the real answer. But from now detail survey should be carried out, just after an event, to find out the reasons. Sparking of a wide spread and strong panicky situation among majority of the population throughout the country came to the electronic and print media, and that became the prime attention.

An attempt has been made here to give geoscientific explanation on the relationship between shaking effect and local geological conditions. The north-western part of the country was shaken severely and this region is close to the epicentral area. Other than NW part higher tremor was felt areas in south-western part of the country and low-lying depressions. The maximum intensity of the main shock was estimated to be VI (Fig. 4), area occupied by Tista alluvial fan (both old and young). Other higher shaking (intensity V) areas are depressions on floodplains and Ganges tidal plain i.e. Old Ganges Delta. Tista alluvial fan sediments consist mostly of sand with gravels, where sand is slightly oxidized in the western part of the fan. The Ganges deltaic sediments consist of unconsolidated sandy and clayey silt, and organic rich silt and clay in the mangrove swamp. Depression deposits consist mainly of clay with herbaceous peat and silt (Alam *et al.* 1990). Thus the intensity map shows close relationship between seismic shaking and geological characters of the sediments.

Very little or no information of tremors was reported from the south-eastern parts of the country which could have happened due to longer distance from the epicentral area and magnitude of the earthquake, however, local geological conditions played either no or insignificant role.

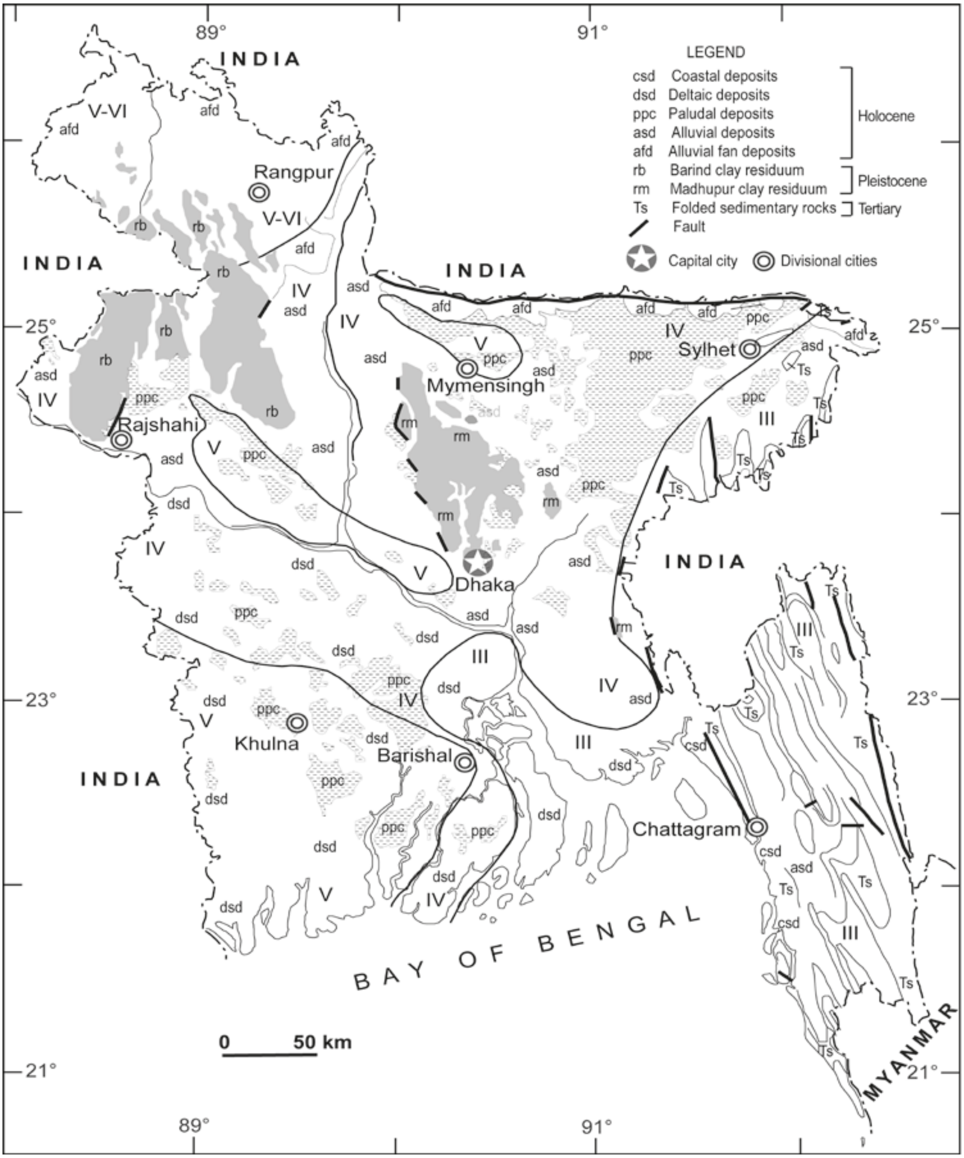

Fig. 4. Intensity map of the 18th September 2011 Sikkim Earthquake showing the relationship with geology of Bangladesh (Geological map slightly modified after ALAM *et al.* 1990).

Conclusions

Although, the Sikkim 2011 earthquake was not a highly destructive but it had impacts in Bangladesh like casualties (deaths and injuries), wide spread panicky situation among the people; damage in infrastructures; disruption in generation and supply of electricity; disruption in telephone, mobile phone and internet communications; land subsidence and flooding due to breach in embankment, etc. Intensity map clearly shows the relation between seismic shaking and local geological conditions. Besides, result of the study again show that impacts of an earthquake are magnitude and distance dependent and local geological condition as well, an established fact.

This was an alarming event for us, demonstrating how vulnerable our people, shelters and lifelines are to a seismic event, even of an Mw 6.9 earthquake. As anticipated by many researchers (Li Pei *et al.* 2015 and Berthet *et al.* 2014) if an earthquake occurs in the north of Bangladesh it would badly affect the country with impact on human life and natural system, and man-made structures of this region as well. So, for seismic risk reduction we must pay attention to the followings from geoscientific point of view.

For improved knowledge on earthquake geology and better understanding of seismotectonic behaviour of this region, geological studies including seismological, paleoseismological, tectonic geomorphology, neotectonics should be continued. Even strong (6.5) and moderate magnitude earthquakes should also be studied to assess their impacts on environment and its habitants. Geomorphological and hydrological changes and generation of liquefaction (Debbarma *et al.* 2017, Alam 2017 and Alam & Islam 2017) have impact on environment and livelihood of the local population. So, more research should be carried out on how and what extent these changes affect the environment, and also be evaluated in the context of climate change.

As morphotectonic elements and earthquakes know no political boundary, collaboration among the neighbouring countries on seismotectonic research and sharing of knowledge should be strengthened so that appropriate steps can be taken to reduce seismic risk in this region.

Till now no warning system for earthquake has been developed and preparedness for earthquake hazard is the only way to save life and property. Experience of this earthquake opened our eyes that we urgently need intensive awareness building activities among all the citizens of the country, and existing awareness building activities should be strengthened. People should be educated and trained how to react before, during and after an earthquake. Special attention should be given to students, teachers and members of management committee of the schools.

This small country is the home of about 170 million populations that create pressure on its land resources for shelter. With the increase of population and economic development rapid urban expansion is going on, unfortunately almost ignoring the geological condition and disobeying building code. Hence, mechanisms should be found out in order to strict enforcement of the national building code for safe and earthquake resilience urbanisation.

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এ. কে. এম. খোরশেদ আলম

সারসংক্ষেপ

১৮ সেপ্টেম্বর ২০১১ তারিখের ৬.৯ মাত্রার সিকিম ভূমিকম্পে রাজধানী ঢাকাসহ সারা বাংলাদেশ কেঁপে উঠে। গত ৬৫ বছরের মধ্যে এটি দেশটির জন্য দ্বিতীয় সর্ব্বোচ্চ কম্পন ছিল। ব্যাপক পরিধির কম্পন সক্ষমতা ও ভবিষ্যত গবেষণার জন্য এ ভূমিকম্পের উপর বর্তমান ম্যাক্রোসেইসমিক মূল্যায়নটি করা হয়েছে। এ মূল্যায়নের ভিত্তি ছিল দৈনিক সংবাদপত্রে প্রকাশিত সংবাদ, বিভিন্ন ওয়েবসাইট, স্থানীয়দের সাথে সাক্ষাৎকার ও প্রকাশিত সরকারি দলিলাদির উপাত্ত ও তথ্যাদি। যদিও জীবন ও সম্পদের মারাত্মক ক্ষতি হয়নি, তবু ভূমিকম্প দূর্যোগের ঝুঁকি হ্রাসের কথা বিবেচনা করলে এ মূল্যায়নের ফলাফল প্রণিধানযোগ্য। ভূমিকম্পে সর্বস্তরের জনগণের মাঝে সৃষ্ট ব্যাপক আতঙ্কে কেউ কেউ আহতও হয়েছেন। দেশের বিভিন্ন স্থানে ভবনে ফাটল সৃষ্টি হয়েছে ও ভবন দেবে গেছে। এছাড়াও বিদ্যুৎ উৎপাদন ও সরবরাহ এবং টেলিযোগাযোগে বিঘ্ন এবং অবকাঠামোতে অবনমন সৃষ্টি হওয়ার ঘটনাও রয়েছে। মূল্যায়ন থেকে কম্পনের প্রভাব ও অসংহত পললের প্রতিক্রিয়া এবং উভয়ের মাঝে সুস্পস্ট পারস্পারিক সম্পর্ক ভূমিকম্প তীব্রতা মানচিত্রে পরিস্কারভাবে দেখা গেছে। বাংলাদেশে সর্ব্বোচ্চ ৬ তীব্রতা দেখা গেছে যা উৎপত্তিস্থলের কাছাকাছি অঞ্চল, প্রধানত তিস্তা এলুভিয়াল ফ্যান দ্বারা গঠিত। এছাড়া কাদামাটি সমৃদ্ধ এলাকা যা প্লাবনভূমিতে অবস্থিত নিচু এলাকা ও পুরাতন গাঙ্গেয় বদ্বীপ এলাকায় উঁচু মাত্রার তীব্রতা ছিল। দেশের বৃহদাংশ প্রধানত হলোসিন যুগের নদীজ ও ব-দ্বীপবৎ অসংহত ও পানিসম্পৃক্ত পলল দ্বারা আবৃত। একটি সক্রিয় ভূগাঠনিক অঞ্চলে অবস্থানের কারণে ভবিষ্যতেও ভূমিকম্প বাংলাদেশকে কাঁপাবে এবং এখানকার পললও তাদের বৈশিষ্ট্য অনুযায়ি এসব কম্পনে প্রতিক্রিয়া দেখাবে। তবে আঞ্চলিক ভূগাঠনিক দৃশ্যপট সম্বন্ধে পরিস্কার ধারণার জন্য সংশ্লিষ্ট বিষযে আরো গবেষণা হওয়া দরকার। উল্লেখ্য যে, ৬.৯ মাত্রার ভূমিকম্পের প্রভাব প্রমাণ করে যে ভূমিকম্পে আমরা কতটা নাজুক। কাজেই ভূমিকম্পে ঝুঁকি হ্রাসে যথোপযুক্ত প্রস্তুতি নেওয়া প্রয়োজন যার মধ্যে গুরুত্বপূর্ণ হলো জনগণের মাঝে ভূমিকম্প বিষয়ে সচেতনতা বৃদ্ধি ও বিল্ডিং কোডের কঠোর প্রয়োগ।