UPAZILA-LEVEL EARTHQUAKE RISK ASSESSMENT FOR BANGLADESH

UNDRR/GR/2023/001 — Final Substantive Report

Version 1.0 — June 2024

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1 Introduction

Large parts of the landmass of Bangladesh and its surroundings are susceptible to earthquakes, ranging from the highly active Himalayan belt to the north of the country to the peninsula in the south which also suffers less frequent but nevertheless destructive earthquakes. Figure 1-1 shows the subduction plate boundaries around Bangladesh, with known earthquakes mapped on the southern end, and sections shown in black in the northern end that have not ruptured in the historic past but could potentially rupture.

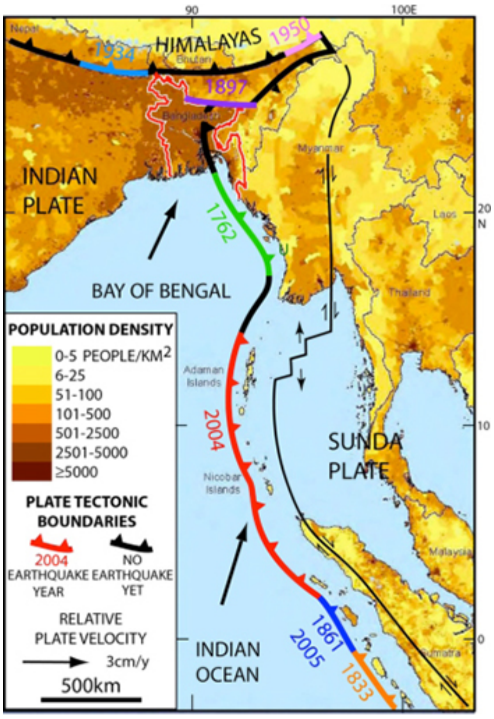


Figure 1-1. Subduction plate boundaries around Bangladesh
Source: Michael Steckler / Lamont-Doherty Earth Observatory

One of the earliest recorded major earthquakes was the 1762 Arakan earthquake. Significant damage and loss of life were reported, with widespread effects on the local landscape and communities. Several instances of soil liquefaction were linked with this event, which may have also triggered a tsunami. The 14 July 1885 Bengal earthquake originated near Bogra in Bangladesh, causing severe damage to houses in Sirajganj district and Sherpur town in Bogra district. The 1897 Assam earthquake, occurring on June 12 with a magnitude of 8.1, also had a profound impact on Bangladesh, although its epicenter was in the Indian state of Assam. The quake caused extensive damage to buildings and infrastructure. In the 20th century, the 18 July 1918 Srimangal earthquake, with a magnitude of 7.6, centered in northeastern Bangladesh, led to severe destruction and alteration to natural features, such as river courses.

On November 21, 1997, a magnitude 6.0 earthquake near the Bangladesh-Myanmar border led to the collapse of a building under construction in Chittagong, resulting in several fatalities.

On July 22, 1999, a magnitude 5.1 earthquake cantered close to Moheshkhali Island, near Cox's Bazar, extensively damaged rural mud-walled homes and a cyclone shelter's column. In December 2001, an earthquake exceeding magnitude 4.0 near Dhaka city caused panic and injuries among inmates at Dhaka Central Jail. The July 27, 2003, magnitude 5.6 earthquake in Rangamati, particularly in the village of Kolabunia, caused severe damage to brick masonry and mud-walled structures. The November 26, 2021 and December 2, 2023 Chittagong earthquakes fortunately resulted in minor damages, but served as a reminder about the threat of earthquakes in the country.

Bangladesh is amongst the most densely population countries on earth. According to the recently released figures from the 2022 Population and Housing Census, the country has over 165 million people, with the Dhaka metropolitan area alone home to over 22 million people of which 10.3 million reside in Dhaka City Corporation (North and South). Figure 1-2 shows the population density map of Bangladesh, in which the large concentration of population in the capital city is evident.

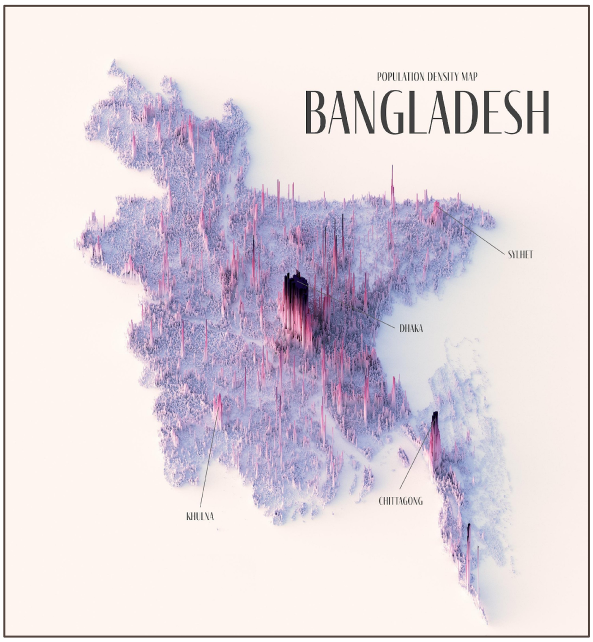


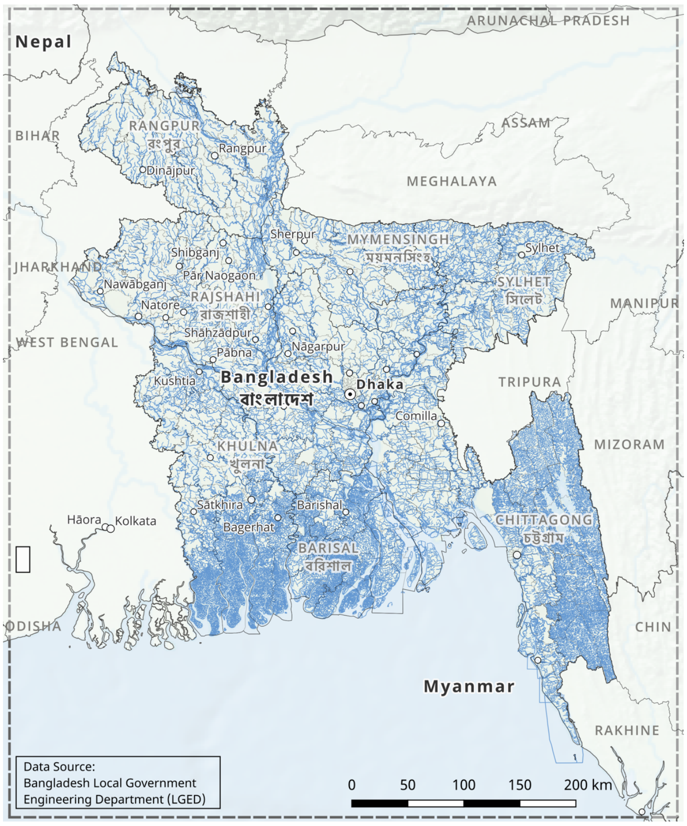
Figure 1-2. Population density map of Bangladesh.
Image source: Terence https://x.com/researchremora/status/1611560145280016385

The country has also been witnessing rapid urbanization, with millions of households moving from so-called *kancha* construction (involving light materials) and *jhupris* (huts) to *pucca* construction (solid and heavier construction involving masonry or reinforced concrete). No building codes existed prior to 1993 and even today enforcement of seismic design regulations or construction oversight is lacking. Severe vulnerabilities thus exist in the current building stock of Bangladesh. The tragic collapse of the 8-storey Rana Plaza garment factory in 2013 (Figure 1-3) which to 1,134 fatalities and 2,500 people injured was a stark example of the consequences of structural failure due to substandard construction practices. This incident raises questions about expected structural performance of buildings in Bangladesh if they were to be subjected to strong ground shaking or ground failure due to earthquakes.

Figure 1-3. Collapse of Rana Plaza on 24th April 2023.
Image source: Munir Uz Zaman/Agence France-Presse — Getty Images

Bangladesh is also home to the vast delta of the Ganges and Brahmaputra rivers (Figure 1-4). The deltas contain thick layers of alluvial silt which can be several kilometres deep in some places, washed from the Himalayas to the coast. In an earthquake, this low-lying substrate can often amplify earthquake ground shaking, and is also highly susceptible to liquefaction. Almost every year, the country experiences multiple cyclones and extensive flooding, which cause widespread devastation to property, agriculture, and infrastructure. This has rightly resulted in the prioritization of flood and cyclone management in national disaster policies and budgets. Unfortunately, earthquake risk mitigation has historically received less attention compared to the extensive efforts directed towards managing floods and cyclones. Consequently, infrastructure and community preparedness specifically for earthquakes have lagged behind.

Although much progress has been made in the last few decades in the field of earthquake engineering and on the development of seismic provisions for building codes in Bangladesh, a distressing proportion of the predominant building typologies, including much of the recent construction, remains highly vulnerable to earthquakes. The rise of increasingly dense urban agglomerations in regions with moderate-to-high seismic hazard, the presence of easily liquefiable soils in the river deltas, the overwhelming prevalence of non-engineered structures, the lack of enforcement for code-compliance and absence of ductile detailing practices for buildings, and little to no maintenance of the ageing building stock makes for high seismic risk in many parts of Bangladesh.



Data Source:
Bangladesh Local Government
Engineering Department (LGED)

Figure 1-4. Rivers of Bangladesh

Apart from direct human and economic losses, earthquakes can also lead to large-scale social disruptions and business interruptions, and recovering from these effects can often take several years. At present, evaluating the patterns of seismic risk across the country is of utmost importance to develop risk-informed building design guidelines, for more careful land-use planning, to optimise earthquake insurance pricing, and to enhance general earthquake risk awareness and preparedness. Decisions on the relative prioritisation of various earthquake risk mitigation policies can also be supported by the availability of an earthquake risk model for the country.

In order to fully characterise the seismic risk across the country, each of the three major components that contribute to the risk needs to be studied and modelled in detail: (1) the seismic hazard component, which involves estimating the levels of shaking intensity that can be expected to occur in different regions of the country and their frequencies of occurrence; (2) the exposure component, which describes the geographical distribution and physical characteristics of buildings, infrastructure, and population; and (3) the seismic vulnerability component, which involves studying the behaviour of structures under earthquake loading to quantify the susceptibility of different types of buildings to the impacts of earthquakes. Whereas scenario-based or “deterministic” seismic risk analyses typically focus on highlighting the potential earthquake-induced damage and losses likely to occur for the scenario under consideration, a fully probabilistic seismic risk model takes into account any inherent variabilities and uncertainties that have been identified at every step, in an attempt to provide a more holistic representation of the earthquake risk in the region of interest.

There is clearly a gap signalled by the absence of an open seismic risk model for Bangladesh that may undermine the efficacy of earthquake risk management policies, programs, and investments. Within the scope of this project, we aim to bridge this gap to develop an open-source probabilistic seismic risk model for Bangladesh, and transfer key insights from the risk assessment to decision makers in the government and other key stakeholders in the disaster risk mitigation community in the country.

2 Needs and gaps assessment

Since its creation in 1972, the Ministry of Disaster Management and Relief (MoDMR) of Bangladesh has undertaken various disaster risk assessment and mitigation projects in collaboration with national and international organisations. The Comprehensive Disaster Management Plan (CDMP) was developed in 2004 as a collaboration between the MoDMR and United Nations Development Programme (UNDP). In recent years, several studies have been completed under the aegis of the CDMP, including studies on Engineering Geological Mapping, Quaternary Geological Mapping, Time-Predictable Fault Modelling, Seismic Hazard Assessment, and Seismic Vulnerability Assessment for the city corporations of Dhaka, Chittagong, and Sylhet (Figure 2-1). The CDMP project also involved the development of a building inventory through three levels of surveys of increasing detail in six cities in Bangladesh.

Time-Predictable Fault Modeling
of Bangladesh

June 2009

Printing supported by:
Comprehensive Disaster Management Programme
Ministry of Disaster Management and Relief

Engineering Geological Mapping
of
Dhaka, Chittagong And Sylhet
City Corporation Area of
Bangladesh

June 2009

Printing supported by:
Comprehensive Disaster Management Programme
Ministry of Disaster Management and Relief

Seismic Hazard Assessment
of
Dhaka, Chittagong and Sylhet
City Corporation Area of
Bangladesh

June 2009

Printing supported by:
Comprehensive Disaster Management Programme
Ministry of Disaster Management and Relief

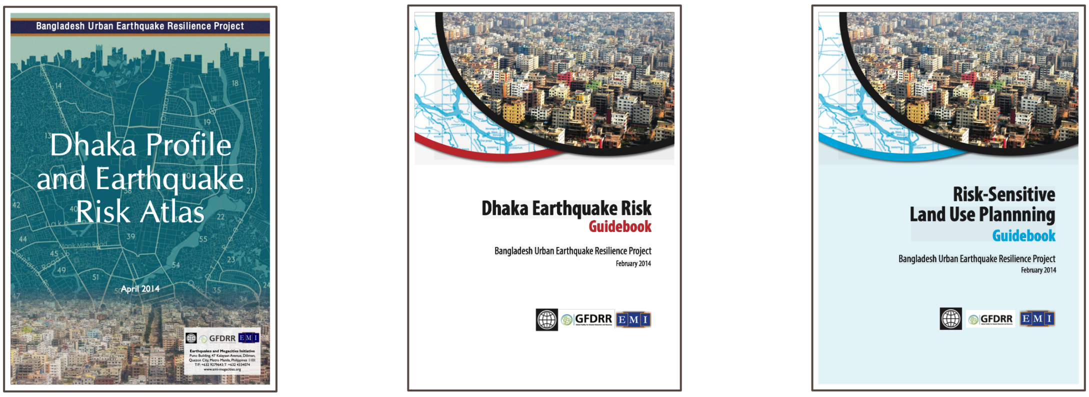
Earthquake Vulnerability
Assessment of
Dhaka, Chittagong and Sylhet
City Corporation Area

June 2009

Printing supported by:
Comprehensive Disaster Management Programme
Ministry of Disaster Management and Relief

Figure 2-1. Reports from the Comprehensive Disaster Management Plan (CDMP)

With the support of the Global Facility for Disaster Reduction and Recovery (GFDRR), the World Bank has also been working with the Government of Bangladesh (GoB) and the Earthquakes and Megacities Initiative (EMI) since 2012, through the Bangladesh Urban Earthquake Resilience Project (BUERP) to understand the structural vulnerability of urban buildings and infrastructure and address the seismic risk. The first phase of this project culminated in 2014 with the publication of the Dhaka Profile and Risk Atlas and the companion Dhaka Hazards, Vulnerability and Risk Assessment (HVRA) Guidebook, and Risk Sensitive Land Use Planning Guidebook (Figure 2-2). The vulnerability and risk analyses undertaken within BUERP relied significantly on the previous studies such as the CDMP.



Bangladesh Urban Earthquake Resilience Project

Dhaka Profile and Earthquake Risk Atlas

April 2014

Dhaka Earthquake Risk Guidebook

Bangladesh Urban Earthquake Resilience Project

February 2014

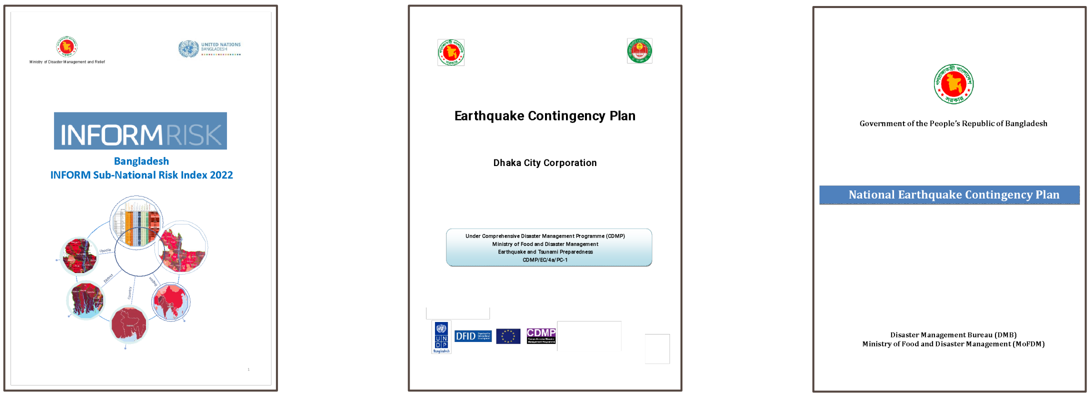
Risk-Sensitive Land Use Plannning Guidebook

Bangladesh Urban Earthquake Resilience Project

February 2014

Figure 2-2. Reports from the Bangladesh Urban Earthquake Resilience Project (BUERP)

More recently, a localised, sub-national Index for Risk Management (INFORM) was developed by the United Nations Resident Coordinator's Office (UNRCO) with funding from UNDRR and in collaboration with MoDMR with support from the Network for Information, Response and Preparedness Activities on Disaster (NIRAPAD) and the Bangladesh Bureau of Statistics (BBS). Earthquake contingency plans have been drafted both at the national level, and for Dhaka city corporation (Figure 2-3).



INFORMRISK

Bangladesh

INFORM Sub-National Risk Index 2022

Earthquake Contingency Plan

Dhaka City Corporation

Under Comprehensive Disaster Management Programme (CDMP)
Ministry of Food and Disaster Management
Earthquake and Tsunami Preparedness
CDMP/EC/4a/PC-1

Government of the People's Republic of Bangladesh

National Earthquake Contingency Plan

Disaster Management Bureau (DMB)
Ministry of Food and Disaster Management (MoFDM)

Figure 2-3. INFORM Index, and Earthquake Contingency Plans for Dhaka City Corporation and Bangladesh

In addition to the INFORM, CDMP, and BUERP studies, there are also a significant number of informative publications in academic journals related to the earthquake hazard and risk in Bangladesh, eg. Morino et al. (2014)[1] who studied the Dauki fault, Alam and Dominey-Howes

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[1] Morino, M., Kamal, A. S. M. M., Akhter, S. H., Rahman, M. Z., Ali, R. M. E., Talukder, A., Khan, M. M. H., Matsuo, J., & Kaneko, F. (2014). A paleo-seismological study of the Dauki fault at Jaflong, Sylhet, Bangladesh: Historical seismic events and an attempted rupture segmentation model. *Journal of Asian Earth Sciences*, 91, 218–226. doi:10.1016/j.jseaes.2014.06.002

(2016)[2] who have compiled an earthquake catalogue for the Bay of Bengal and Bangladesh, Rahman et al. (2020)[3], and Haque et al. (2020)[4] on probabilistic seismic hazard analysis. Rahman et al. (2015) have also undertaken a liquefaction hazard mapping for Dhaka.

The Bangladesh National Building Code (BNBC) 2020 provides a seismic zone map (Figure 2-4) which divides the country into four seismic zones with different expected levels of intensity of ground motion. However, this map — which attempts to provide guidance about the expected peak ground acceleration (PGA) values across the country for earthquakes corresponding to the maximum considered earthquake (MCE) — is not currently based on a comprehensive seismic hazard assessment.

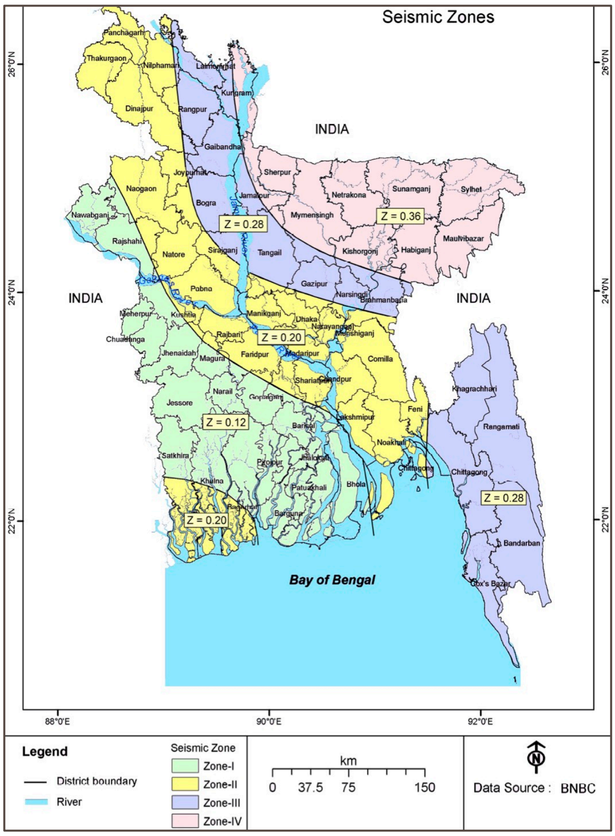

Figure 2-4. Seismic zone map of Bangladesh
Source: Bangladesh National Building Code (BNBC) 2020

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[2] Alam, E., & Dominey-Howes, D. (2016). A catalogue of earthquakes between 810BC and 2012 for the Bay of Bengal. Natural Hazards, 81(3), 2031–2102. https://doi.org/10.1007/s11069-016-2174-7

[3] Rahman, M. Z., Siddiqua, S., & Kamal, A. S. M. M. (2020). Seismic source modelling and probabilistic seismic hazard analysis for Bangladesh. Natural Hazards, 103(2), 2489–2532. doi:10.1007/s11069-020-04094-6

[4] Haque, D. M. E., Khan, N. W., Selim, M., Kamal, A. S. M. M., & Chowdhury, S. H. (2020). Towards Improved Probabilistic Seismic Hazard Assessment for Bangladesh. Pure and Applied Geophysics, 177(7), 3089–3118. doi:10.1007/s00024-019-02393-z

In consultation with key stakeholders within the disaster risk management domain in the country, including the MoDMR and other national and local government authorities, these previous studies and others were reviewed to develop a shared understanding of what already exists in the country in terms of datasets and knowledge, and to identify gaps and the needs and priorities of the potential end-users of the risk model and information.

Detailed deterministic hazard analysis, vulnerability, and risk assessments have been conducted for Dhaka, focusing on buildings, lifelines, and populations as elements at risk in previous projects. However, the same type of risk information is not available for other cities and regions in Bangladesh with similar seismicity profiles. Though there are a few local level earthquake assessments present in the country, these are generalized and not in the same format, making it challenging to compare among cities and or administrative units. To date, no comprehensive studies have been conducted covering all of the administrative divisions of Bangladesh and end-user's application and information needs requirements have not been well assessed.

The main objective of this project was to develop a detailed, open, sub-national earthquake risk model and evaluate seismic risk for Bangladesh at the zila and upazila levels. The complete risk model itself comprises a probabilistic seismic hazard model, a building exposure model, and a seismic fragility and vulnerability model for the building stock of Bangladesh. Additionally, it includes critical modelled scenarios for key cities, identified based on the results of the probabilistic risk assessment and in consultation with local stakeholders and experts. The work undertaken on various aspects of this project is described in the following chapters.

3 Historic and hypothetical earthquake scenario development

3.1 Introduction

Bangladesh has a long history of damaging earthquakes, but in the past 100 years there have been relatively few large earthquakes. Therefore, we supplement the probabilistic seismic hazard analysis described subsequently in Chapter 4, which is based in part on seismicity recorded with modern geophysical instruments, with a study using a suite of damaging earthquakes over the past several centuries as well as some particular hypothetical scenarios.

We developed 12 earthquake scenarios including seven historical and five hypothetical events using all available data and other information. Each earthquake scenario is based on a three-dimensional earthquake rupture rather than a point source, and the size of the rupture is scaled to the estimated magnitude. These events are shown below in Figure 3-1.

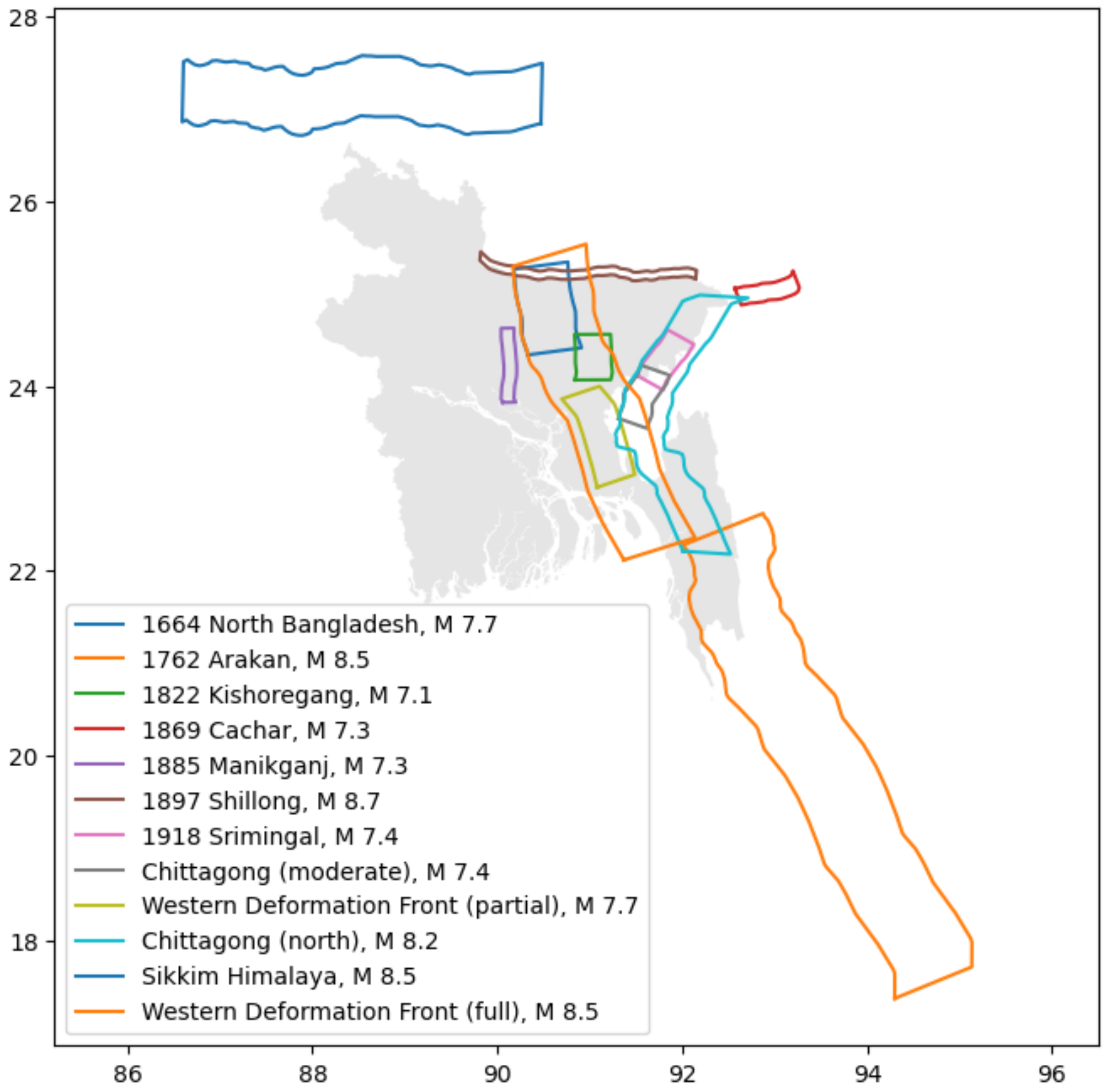

Figure 3-1. Scenario set, including both historical and hypothetical earthquakes

The locations and magnitudes of the historical ruptures are generally based upon the literature — primarily, from location and magnitude estimates based on historical reports of damage. However, the final values are modified to better fit the geology and tectonics of the region. In particular, all earthquakes are placed on nearby known faults, rather from hypocentres derived from the inversions of historical seismic intensity data. This increases the accuracy of the modelling because a) it is highly unlikely that these large earthquakes occurred on unknown faults; and b) because this lets us use much more realistic geometries for the ruptures, including the spatial extent and depth variations of the earthquakes, which can dramatically impact the ground shaking and infrastructure damage in the affected communities.

In addition, we have also selected five potential hypothetical ruptures, mostly in the east, placed on well-known, fast-slipping faults. Some of these represent worst-case earthquakes for Bangladesh, and while their likelihoods of occurrence remain small, they are, nevertheless, deemed plausible events.

Modelling earthquake scenarios is crucial for understanding the potential impacts of seismic events on a community, its infrastructure, and its environment. This process involves creating detailed simulations of earthquakes based on various parameters such as magnitude, depth, fault type, and distance from urban centres. These models help scientists, engineers, and emergency planners estimate the ground shaking intensity, the likelihood of surface rupture, and the potential for secondary hazards like landslides and tsunamis. By visualizing the possible outcomes of an earthquake, stakeholders can better prepare for and mitigate these impacts, thereby reducing the potential for casualties and property damage.

The importance of modelling earthquake scenarios extends beyond immediate disaster response to long-term urban and regional planning. Such models are instrumental in the design of buildings and infrastructure that are resilient to earthquakes. They help in determining the optimal placements for critical facilities such as hospitals, emergency shelters, and utilities, ensuring that these remain operational during and after seismic events. Furthermore, these scenarios are essential for developing effective emergency response strategies, conducting drills, and educating the public about earthquake risks and safety measures. In essence, earthquake modelling is not just about predicting the physical effects of earthquakes but also about creating a framework for societal resilience and readiness that enhances public safety and reduces economic losses.

3.2 Overview of regional tectonics and faulting

Bangladesh is located in a complex tectonic region, where the Indian tectonic plate is converging with the crust of both Eurasia to the north (at the Himalayan fault) and the tectonic microplates of southeast Asia to the east (at the Chittagong-Tripura fold and thrust belt). These two areas have rapid deformation and regularly host large earthquakes. Additionally, smaller fault zones with slower rates of deformation are found closer to central Bangladesh. These are the Western Deformation Front (called the Madhupur fault in the north), which is a cryptic fault zone that is interpreted to surface east of the Brahmaputra and Padma rivers, but dip gently to the east where it merges with the faults of the Chittagong-Tripura fold belt; and the Dauki fault, which is a steeply-dipping fault at the southern margin of the Shillong plateau.

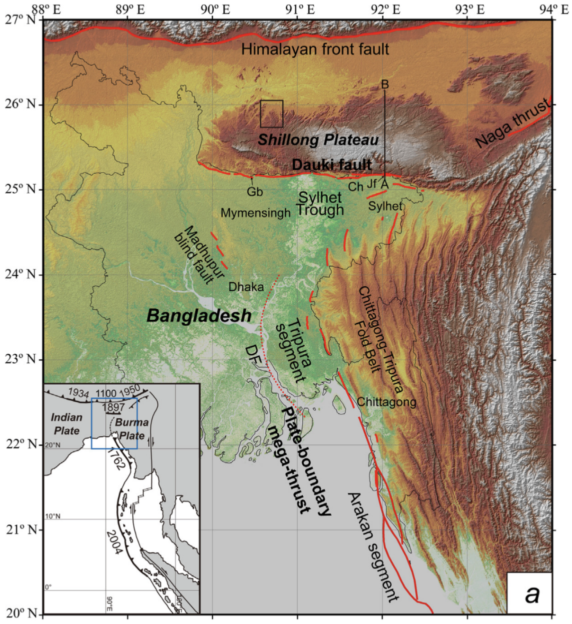

Figure 3-2. Tectonic environment of Bangladesh
Source: Morino et al. (2014) [5]

3.3 Historical events

The seven historical earthquakes considered for scenario damage and loss analysis include the 1664 M7.7 North Bangladesh earthquake, the 1762 M8.5 Arakan earthquake, the 1822 M7.1 Kishoreganj earthquake, the 1869 M7.3 Cachar (Silchar) earthquake, the 1885 M7.2 Manikganj earthquake, the 1897 M8.7 Shillong / Assam “Great Indian” earthquake, and the 1918 M7.4 Srimangal earthquake. Further information about each of these earthquake ruptures is provided in the subsections below.

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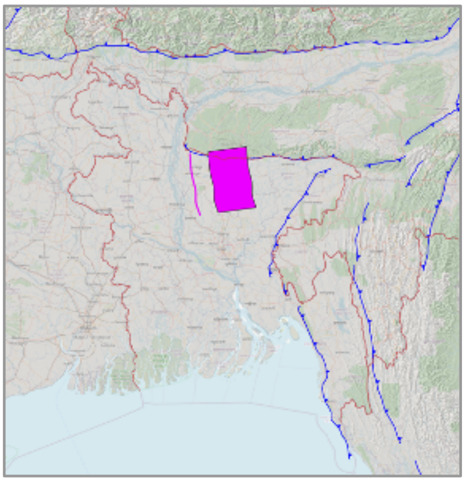
[5] Morino, M., Kamal, A. S. M. M., Akhter, S. H., Rahman, M. Z., Ali, R. M. E., Talukder, A., Khan, M. M. H., Matsuo, J., & Kaneko, F. (2014). A paleo-seismological study of the Dauki fault at Jaflong, Sylhet, Bangladesh: Historical seismic events and an attempted rupture segmentation model. *Journal of Asian Earth Sciences*, 91, 218–226. doi:10.1016/j.jseaes.2014.06.002

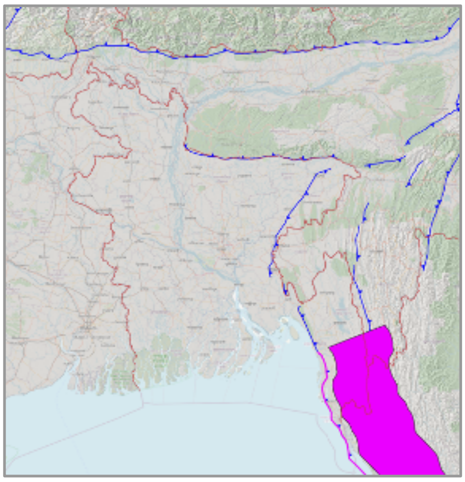
3.3.1 1664 M7.7 North Bangladesh earthquake



The 1664 North Bangladesh earthquake is poorly known but given a crude location and magnitude estimate by Ambraseys and Douglas (2004)[6]. Ambraseys (2004)[7] notes that, according to contemporary reports, aftershocks were felt for over a month and that the quakes 'swallowed up houses and towns' as well as 'several men', indicating strong liquefaction. Reports of ground shaking within this timeframe (1663–1664) were reported from Tibet to Chittagong. Hence, a long section of the Madhupur fault is modelled as rupturing in the event. Magnitude-area scaling relations yield a magnitude of 7.7.

3.3.2 1762 M8.5 Arakan earthquake

The 1762 Arakan event is well known, due to well-preserved uplifted coastal features[8][9]. The rupture occurred on the southern Chittagong-Tripura fold belt, and its continuation offshore 500 km to the south as the Sunda Megathrust. The broad extent and great uplift (>5 m) during the event suggest a magnitude of ~8.5. It is worth noting that an earthquake of this style on this fault could generate a large tsunami[10], though no solid historical evidence has been presented that the 1762 earthquake indeed produced one[11].



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[6] Ambraseys, N. N., & Douglas, J. (2004). Magnitude calibration of north Indian earthquakes. *Geophysical Journal International*, *159*(1), 165-206.

[7] Ambraseys, N. N. (2004). Three little known early earthquakes in India. *Current Science*, *86*(4), 506-508.

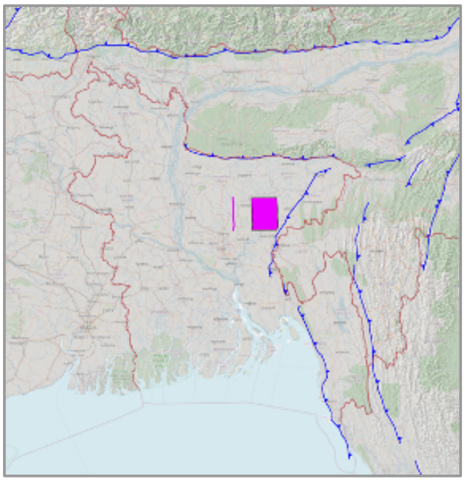
[8] Wang, Y., Shyu, J. B. H., Sieh, K., Chiang, H. W., Wang, C. C., Aung, T., ... & Tun, S. T. (2013). Permanent upper plate deformation in western Myanmar during the great 1762 earthquake: Implications for neotectonic behaviour of the northern Sunda megathrust. *Journal of Geophysical Research: Solid Earth*, *118*(3), 1277-1303.

[9] Mondal, D. R. (2018). *Evidence of the 1762 Arakan and Prior Earthquakes in the Northern Sunda Subduction*. City University of New York.

[10] Cummins, P. R. (2007). The potential for giant tsunamigenic earthquakes in the northern Bay of Bengal. *Nature*, *449*(7158), 75-78.

[11] Gupta, H., & Gahalaut, V. (2009). Is the northern Bay of Bengal tsunamigenic? *Bulletin of the Seismological Society of America*, *99*(6), 3496-3501.

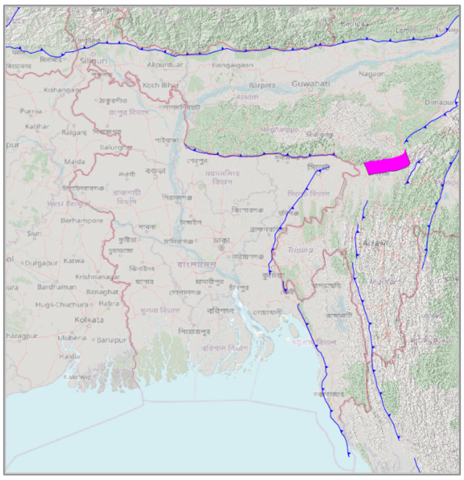
3.3.3 1822 M7.1 Kishoreganj earthquake



The 3rd April 1822 Kishoreganj earthquake locally caused severe damage in Mymensingh and Dhaka[12]. The magnitude was estimated at 7.1, with a location ~70 km north and east of Dhaka 👽. Placing this on the Madhupur fault (Western Deformation Front) with a more eastern location yields a slightly deeper hypocentre for the earthquake, as the fault dips eastward.

3.3.4 1869 M7.3 Cachar earthquake

The 1869 Cachar (Silchar) earthquake was located in northeastern India, with damage at Silchar, Shillong and Manipur, with noticeable shaking in Dhaka[12]. In a contemporary report, Oldham[13] notes that shaking was worst in Silchar. The earthquake was therefore placed on a fault section along the Jatinga river, dipping moderately south. The fault dimensions and historic intensity data suggest a magnitude of around M 7.3. The earthquake is primarily known for the extreme earthquake-induced ground deformation (liquefaction and landsliding), particularly localised on certain Quaternary sediment layers in the region. Most notably, this deformation resulted in a rerouting of the Barak river in Silchar.



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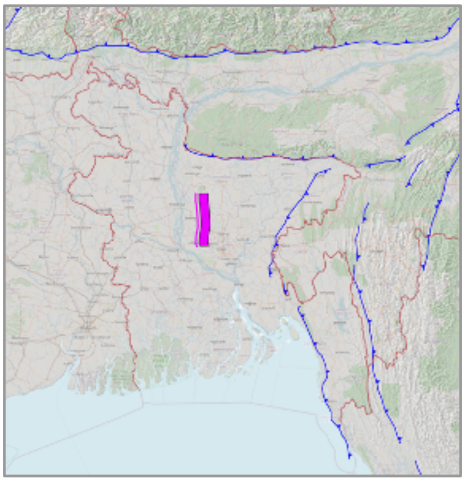
[12] Akhter, S. H. (2010). Earthquakes of Dhaka. Environment of Capital Dhaka—Plants wildlife gardens parks air water and earthquake. Asiatic Society of Bangladesh, 401-426.

[13] Oldham, & Mallet, R. (1872). Notice of some of the Secondary Effects of the Earthquake of 10th January, 1869, in Cachar: With Remarks by Robert Mallet, Esq., CE, FRS, FGS. *Quarterly Journal of the Geological Society*, *28*(1-2), 255-270.

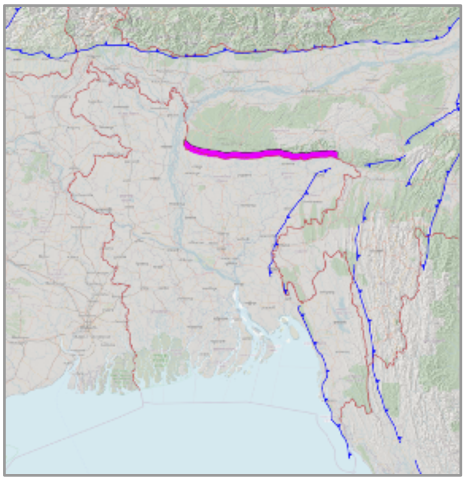
3.3.5 1885 M7.2 Manikganj earthquake



The 1885 Manikganj earthquake, also known as the Bengal earthquake, caused substantial damage and a number of deaths in Dhaka[12], and at least 75 deaths throughout the region[14]. Based on the regional damage distribution, the earthquake is thought to have been centred near Manikganj, some 40 km NW of Dhaka. It is suspected to have occurred on the Madhupur fault[12]; given this westward location and the eastward dip of the fault system, the earthquake would have had to be quite shallow, which increased the resulting ground shaking.

3.3.6 1897 M8.7 Shillong / Assam “Great Indian” earthquake

The 1897 Shillong earthquake was felt over a huge region, throughout and beyond eastern India. The ground shaking was extreme in Shillong. Charles Richter estimated the magnitude at 8.7. Despite the great magnitude of the earthquake, which is possibly the largest continental earthquake known that is not on a plate boundary, its location is still unknown. Though some recent work places it on unmapped faults on the northern margins of the Shillong plateau, other work places it on the Dauki fault. We follow with the latter because the fault is known and mappable.



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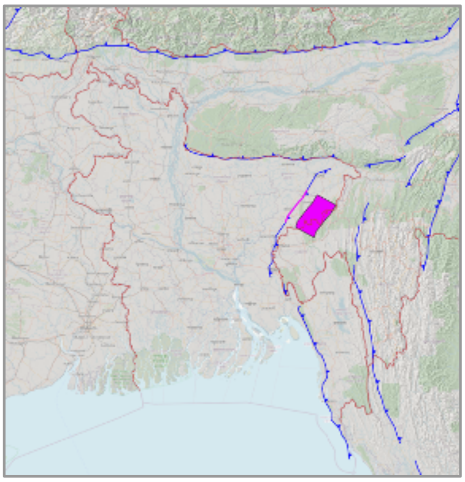
[14] Martin, S., & Szeliga, W. (2010). A catalogue of felt intensity data for 570 earthquakes in India from 1636 to 2009. *Bulletin of the Seismological Society of America*, *100*(2), 562-569.

3.3.7 1918 M7.4 Srimangal earthquake



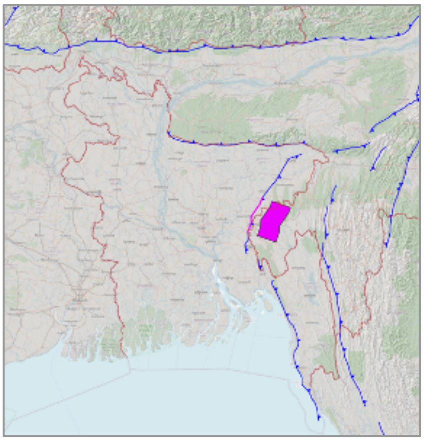
The 1918 Srimingal earthquake is somewhat better known than the previous earthquakes because of the increased capabilities of seismological networks by this time in the 20th century. The earthquake has a magnitude estimated at 7.2–7.6, so we choose a moderate 7.4. The location places it as likely on the outer thrusts of the Chittagong-Tripurakot fold belt[12].

3.4 Hypothetical events

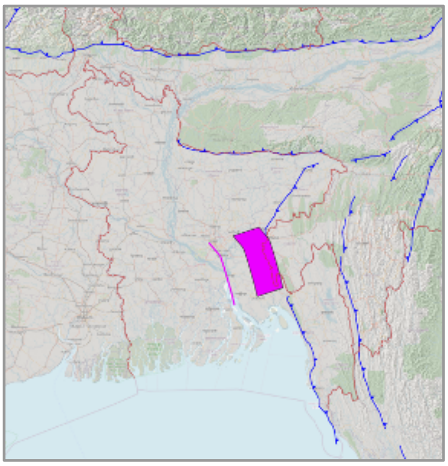
In addition to the seven historical events, we also modelled five hypothetical events ranging from moderate magnitude events closer to Dhaka to potential worst-case scenarios for Bangladesh. These hypothetical events are described briefly in the subsections below.

3.4.1 M7.25 Chittagong rupture

The first and smallest hypothetical event is a moderate rupture on the Chittagong-Tripurakot fold belt. It is quite similar to the 1918 Srimingal event, but slightly smaller in magnitude and located farther south. It was proposed and modelled before the 1918 event was added to the historical earthquake set. Its consequences can be expected to be similar to those of the 1918 Srimangal earthquake were that to occur again.

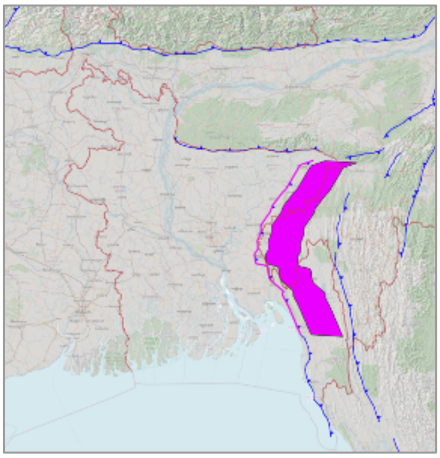


3.4.2 M7.7 Western Deformation Front partial rupture



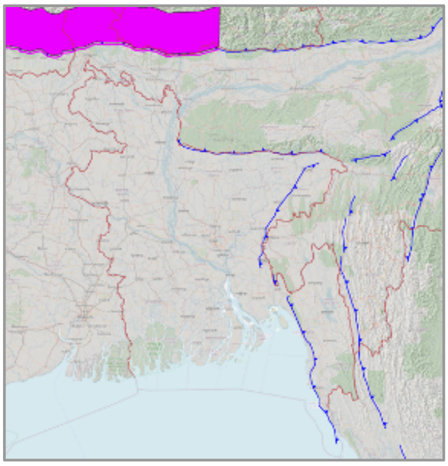
The next largest hypothetical event is a partial rupture on the Western Deformation Front fault. Because this location has several kilometres of unconsolidated sediment of the Bengal fan (which is not seismogenic) overlying the seismogenic crust, the shallowest depth of this earthquake is given at 7 km. This limits the ground shaking of the event that would be felt on bedrock or other rigid strata, but the sediments may also lead to a larger amplification of shaking. Liquefaction is also a major concern at this location.

3.4.3 M8.2 Chittagong rupture



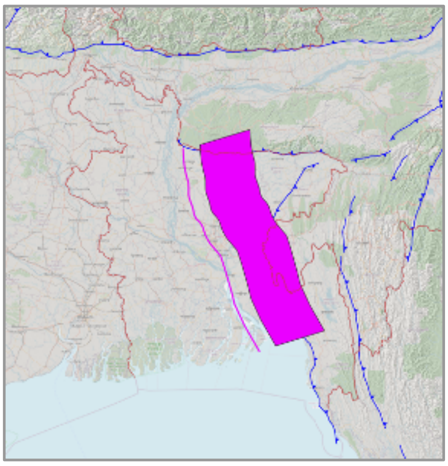
This event is a ‘worst case’ hypothetical event for the eastern region of Bangladesh, if the entire Chittagong/ Sylhet-Assam thrust north of the 1762 earthquake ruptured in its entirety. Area-magnitude scaling relationships yield a M 8.2 for this scenario.

3.4.4 M8.5 Sikkim Himalaya rupture



This earthquake is a major rupture on the Main Himalayan Thrust centred around Sikkim, close to the northwesternmost portion of Bangladesh. It is similar to the 1934 Bihar, Nepal earthquake, although a bit farther east to place it with more relevance to Bangladesh.

3.4.5 M8.5 Western Deformation Front full rupture



This event is truly the worst-case scenario for the entirety of Bangladesh given its large magnitude and proximity to highly populated areas, though fortunately one that has no comparison in the known earthquake record. It represents a full rupture on the Western Deformation Front fault, with its epicentre very close to Dhaka, but spanning the north-south extent of the country. While the likelihood of such an event is uncertain, there is no scientific reason to consider it impossible.

3.5 Summary of selected events

Figure 3-3 shows maps of the historical earthquakes in Bangladesh (including a few small to moderate magnitude events that were not modelled in this project) and of the 12 selected rupture scenarios described in the previous subsections of this chapter.

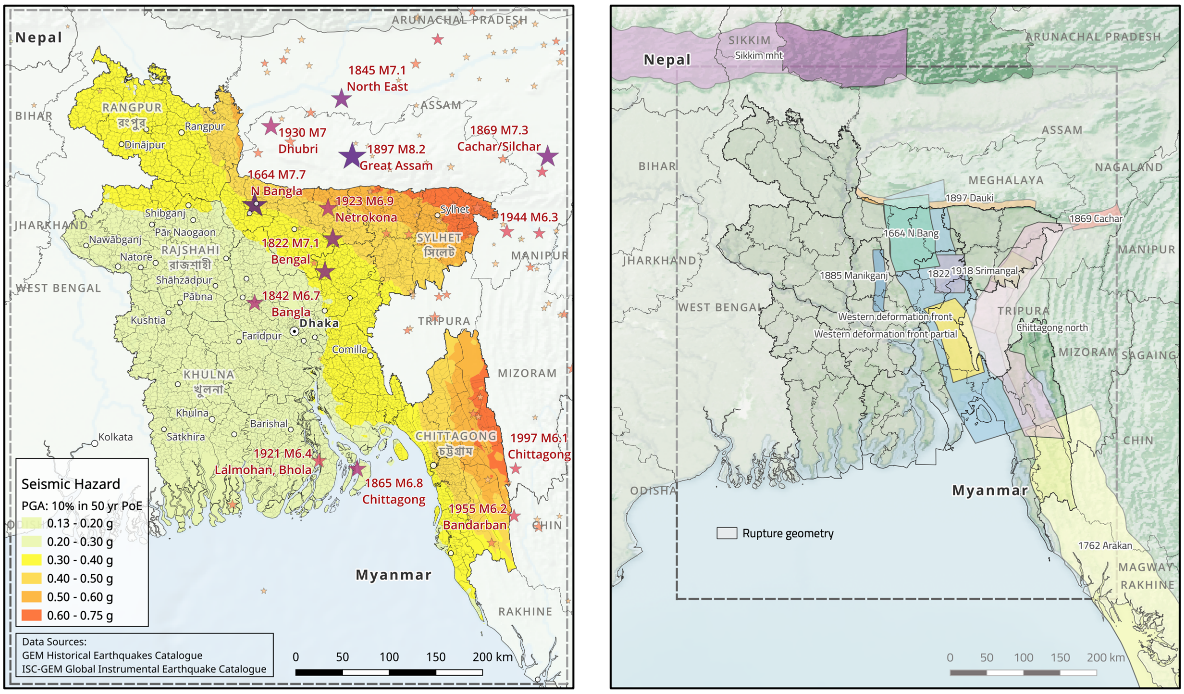


Figure 3-3. Map of historical events (left) and map of modelled ruptures (right)

4 Probabilistic seismic hazard modelling and mapping

4.1 Introduction

Probabilistic Seismic Hazard Analysis (PSHA) is a methodology used to estimate the likelihood of various levels of earthquake shaking occurring at a specific site over a given time period. This approach integrates seismology, geology, and engineering to understand and quantify the potential hazard posed by earthquakes. PSHA is grounded in the principle of not just considering the most severe or most likely earthquakes expected, but all potential earthquakes and their probabilities. By aggregating the effects from these potential events, PSHA provides a comprehensive picture of seismic hazards, quantifying the probability that certain ground motion levels will be exceeded within a defined time frame.

The applications of PSHA are extensive and critical for disaster risk management and urban planning. Engineers and architects use the results of PSHA to design and retrofit buildings, bridges, and infrastructure to withstand potential earthquake impacts, adhering to local and international building codes that incorporate seismic standards. In urban planning, PSHA helps in zoning decisions and the development of evacuation strategies by identifying areas at greater risk of severe shaking. Furthermore, the insurance industry relies on PSHA to set premiums for earthquake insurance, balancing the risk homeowners face with the potential costs of earthquake damage. By providing a probabilistic framework, PSHA enables a more informed approach to reducing earthquake risks and enhancing public safety.

For the probabilistic seismic hazard assessment (PSHA) of Bangladesh, we started with the probabilistic seismic hazard model for the Indian subcontinent developed by Nath and Thingbaijam (2012)[15]. This seismic hazard model covers India, Bangladesh, Bhutan, and Nepal. An update and implementation of this model for the OpenQuake engine has been undertaken by Ackerley (2016)[16]. This model contains three seismogenic source models to account for epistemic uncertainties in the definition of earthquake occurrence: a single set of areal seismogenic source zones, and two smoothed-gridded point source models. A wide range of tectonic regions are considered, and epistemic uncertainties affecting the modelling of ground-shaking are accounted for by using multiple ground motion models (GMMs) per tectonic region. This model was also used to evaluate the seismic hazard in the Indian subcontinent for GEM's Global Seismic Hazard Map (versions 2019.1 and 2023.1)[17].

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[15] Nath, S. K., & Thingbaijam, K. K. S. (2012). Probabilistic Seismic Hazard Assessment of India. Seismological Research Letters, 83(1), 135–149. doi:10.1785/gssrl.83.1.135

[16] Ackerley, N. (2016). An Open Model for Probabilistic Seismic Hazard Assessment on the Indian Subcontinent. Istituto Universitario di Studi Superiori (IUSS), Pavia, Italy.

[17] K. Johnson, M. Villani, K. Bayliss, C. Brooks, S. Chandrasekhar, T. Chartier, Y. Chen, J. Garcia-Pelaez, R. Gee, R. Styron, A. Rood, M. Simionato, M. Pagani (2023). Global Earthquake Model (GEM) Seismic Hazard Map (version 2023.1 - June 2023), DOI: https://doi.org/10.5281/zenodo.8409647

4.2 Seismic source characterization

Within the ambit of this project, we undertook a review of the seismic source model for northeast India to try to improve the earthquake source characterization in areas where the ruptures generated by the Nath and Thingbaijam (2012)[15] model have unrealistic dimensions or orientations that would badly impact ground motion fields. We focused on two aspects: (1) ruptures of magnitude larger than M9 generated by source zone ASCSR-30 (see Figure 4-1 below), which includes the on-shore extent of the Arakan trench source and allows for events up to M9.55 which leads to some super large ruptures with unreasonable geometries (i.e., ones that completely cross Bangladesh with a very thin surface projection), and (2) sources with counter intuitive rupture orientations, including the two layers of intraslab ruptures in this area.

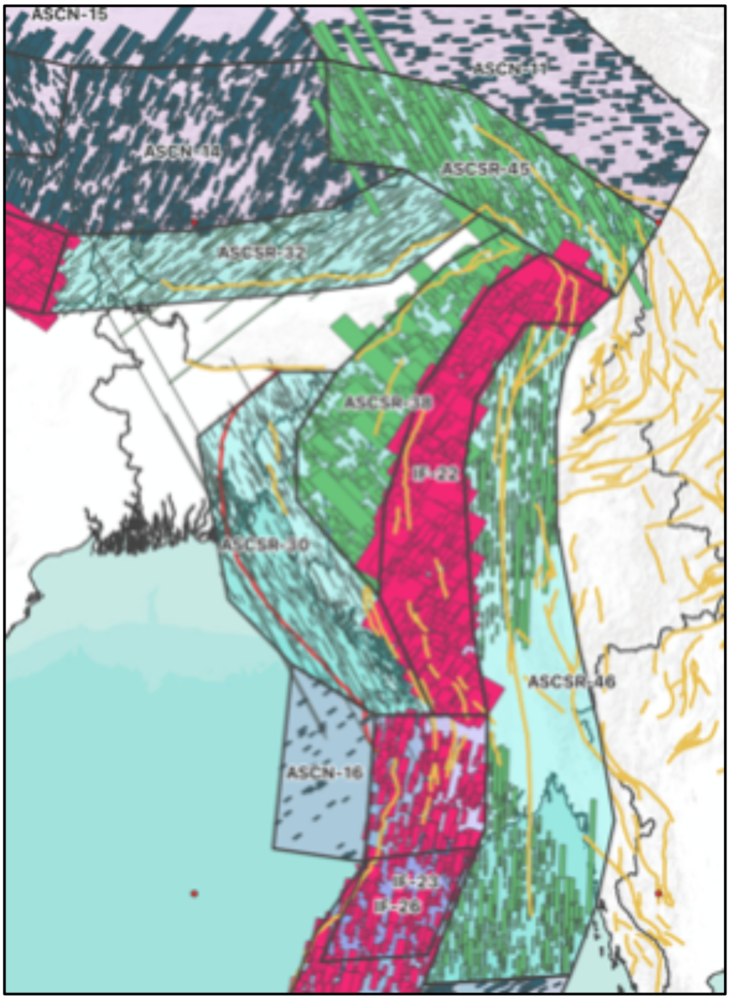

Figure 4-1. Active shallow crust source regions in and around Bangladesh

The Nath and Thingbaijam (2012)[15] model uses area sources for the Main Himalayan Thrust (MHT). This creates really long, narrow ruptures that are considered unreasonable – for instance, the ruptures in pink in Bangladesh depicted below in Figure 4-2. We have replaced a few of the area sources in Nath and Thingbaijam (2012)[15] with a simple fault source used to model the Main Himalayan Thrust in GEM's China seismic hazard model. This has the advantage that it now improves the geometry of the ruptures, although a potential disadvantage could be that it reduces along-strike variability in earthquake rates.

Figure 4-2. Main Himalayan Thrust

4.3 Ground motion characterization

For the ground motion characterisation, we completed a thorough review of the existing logic tree, including both the assignment of sources to tectonic regions types (TRTs), and the ground motion models (GMMs) assigned to each TRT, ultimately reducing the number of TRTs (i.e. using a single one for the active shallow crust (ASC), independent of focal mechanism), using ASC GMMs for the Himalayan Thrust, and removing GMMs that have unrealistic trends, or those constrained or selected using limited data. The updated ground-motion characterisation logic tree is provided in Figure 4-3.

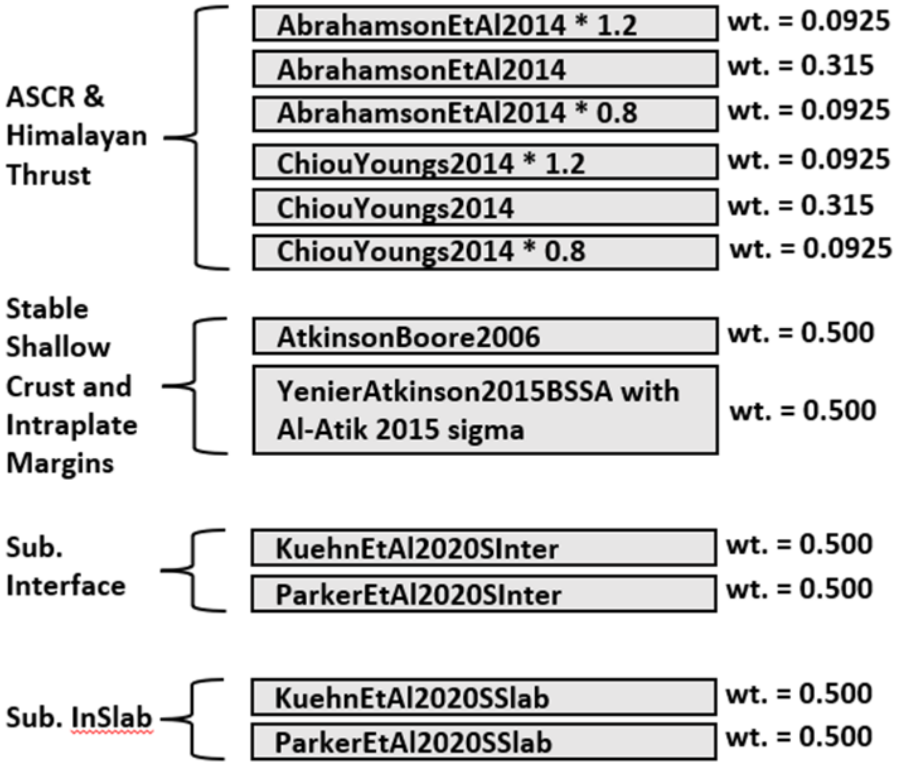

Figure 4-3. Revised ground motion characterisation logic tree for Bangladesh

When completing the review of the existing ground-motion characterisation logic tree, the behaviour of the considered GMMs was evaluated for both bedrock and very soft soils given that Bangladesh is located on a river delta. Some GMMs included in the existing logic tree were removed because of the unrealistically high levels of ground-shaking they provide when considering very soft soils. The removal of some GMMs from the existing logic tree reduced the level of epistemic uncertainty captured by selecting multiple GMMs. Subsequently, for the GMMs selected for some TRTs, scaling factors were applied to help improve the epistemic uncertainty which was lost by removing GMMs based on their performance on soft soils. The application of these scaling factors to the retained GMMs was found to capture the epistemic uncertainty which was lost by removing the GMMs which performed poorly when considering soft soils.

4.4 PSHA results

Probabilistic seismic hazard maps were developed for Bangladesh for a variety of ground motion intensity measures including peak ground acceleration (PGA), spectral acceleration at periods 0.1s, 0.2s, 0.3s, 0.6s, 1.0s, and 2.0s for two different return periods or probabilities of exceedance, i.e., 10% probability of exceedance in 50 years (corresponding to a 475 year return period), and 2% probability of exceedance in 50 years (corresponding to a 2,475 year return period). The PGA map for 10% probability of exceedance in 50 years is shown below in Figure 4-4.

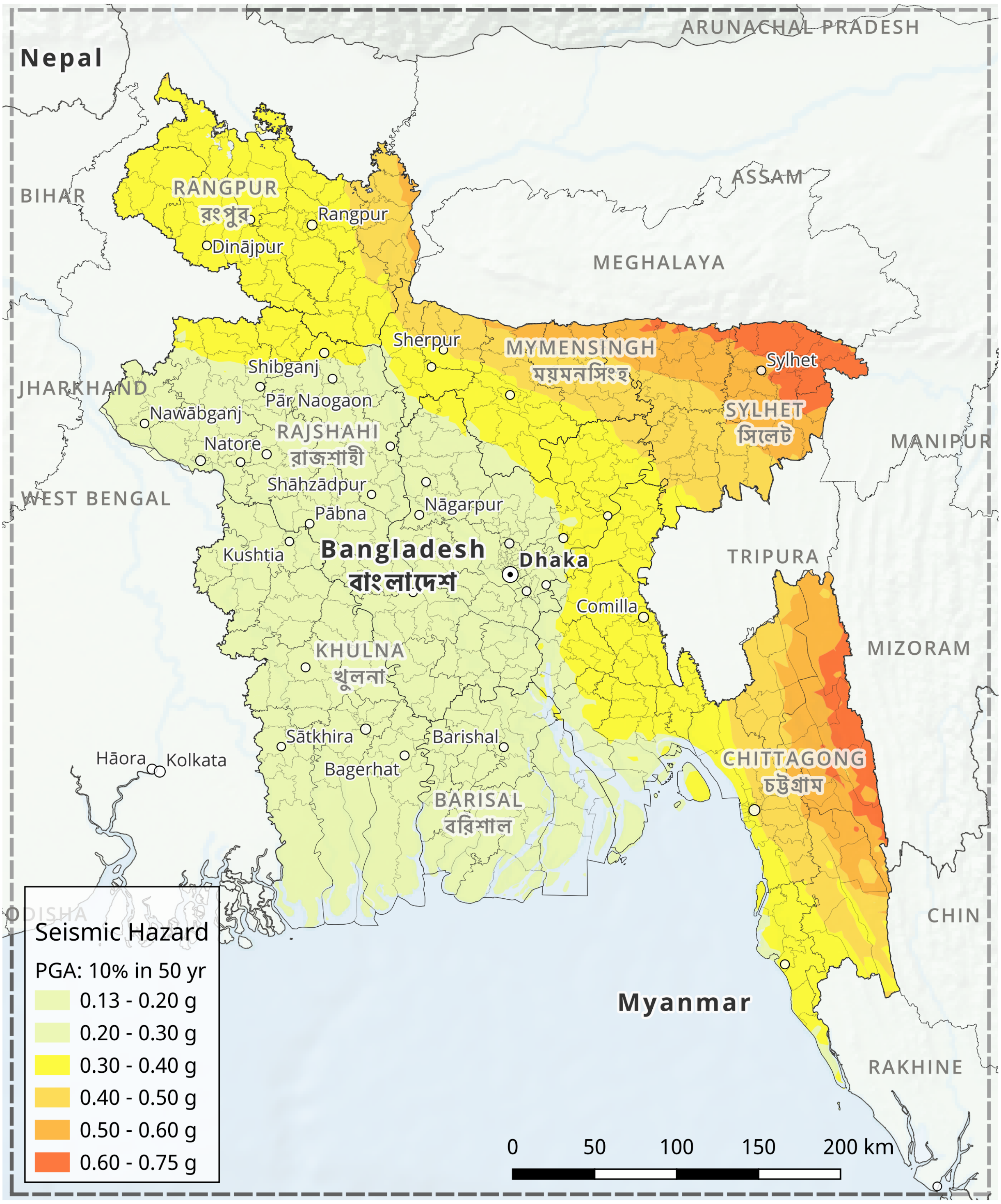

Figure 4-4. Peak ground acceleration (PGA) with a 10% probability of exceedance in 50 years

4.5 Hazard curves

Seismic hazard curves quantify the probability of exceeding various levels of earthquake shaking at a specific location over a given period of time. These curves are typically plot common earthquake intensity measures—such as peak ground acceleration (PGA), spectral acceleration, or velocity—against their annual probability of exceedance. Figure 4-5 below shows the seismic hazard curves for major metropolitan areas of Bangladesh. These results are also available for all upazilas of Bangladesh, but not shown in the figure below for purposes of clarity.

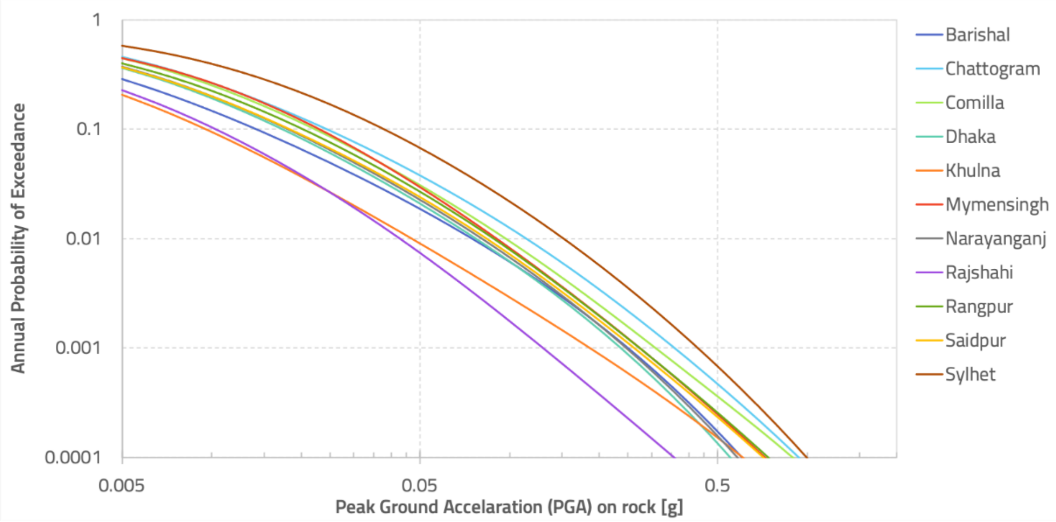

Figure 4-5. Seismic hazard curves for major metropolitan areas of Bangladesh

4.6 Uniform hazard spectra

Uniform Hazard Spectra (UHS) offer a composite representation of the seismic demands at various natural frequencies of vibration (or fundamental periods of vibration) for a structure, based on a specific level of earthquake hazard. The UHS is constructed by combining the spectral accelerations at different periods of a building's response, each corresponding to the same annual probability of exceedance. This results in a spectrum that provides the maximum expected acceleration for each vibration period, ensuring that all are equally probable within the given time frame. The advantage of the UHS lies in its ability to present a simplified yet comprehensive overview of potential seismic forces across a range of frequencies, enabling engineers to design structures that can withstand earthquakes that match the most severe expected within a certain return period. Figure 4-6 below shows the uniform hazard spectra for major metropolitan areas of Bangladesh. Similar to the seismic hazard curves, these UHS results are also available for all upazilas of Bangladesh, but not shown in the figure below simply for purposes of clarity.

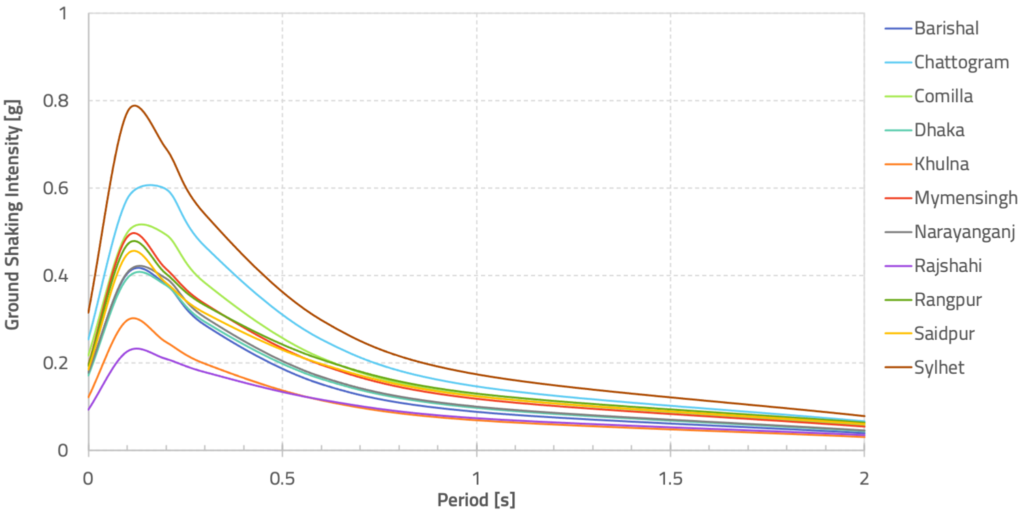

Figure 4-6. Uniform Hazard Spectra (UHS) for major metropolitan areas of Bangladesh

5 Liquefaction susceptibility and hazard assessment

Soil liquefaction is a spatially localised phenomenon in a saturated, cohesionless medium when the shear strength and stiffness decrease due to increased pore water pressure. Liquefaction hazard assessment requires answering several questions, starting with whether the soil deposit is susceptible to liquefaction occurrence or not. If yes, what is the level of shaking (e.g., amplitude, duration) that will lead to its occurrence. Lastly, one should answer how severe the consequences (e.g., ground settlement, lateral spreading) triggered by liquefaction are. Soil liquefaction does not happen everywhere but is rather limited to specific geological settings, where the sedimentation process, age of deposition, water depth, grain-size distribution, and geologic history characterise the ground failure susceptibility. Younger deposits (Holocene age) are more susceptible than older deposits (Pleistocene age). Areas settled in coastal regions to accommodate the growing population needs are typically filled in with hydraulic fill, artificial landfills, or young mud deposits, which are characterised by higher susceptibility. Given the topography, once the liquefaction is initiated, various ground failure types may occur, such as a crack opening in flat terrain, landslide-type failure on steep terrain, and lateral spreading on gentle slopes. These induced effects could lead to significant damage beyond economic repair.

A common practice in seismic risk assessment is to estimate the annual rate of exceeding a decision variable of interest to stakeholders (e.g., fatalities, economic loss) due to ground shaking. Assessing the hazard and risk due to ground failure, however, is still uncommon despite the severe consequences of ground failures (e.g., soil liquefaction). The reasons are numerous, some of them being relatively lower losses compared to those caused by ground shaking and an insufficient number of observations that would assist in developing robust large-scale assessment procedures (e.g., urban, national, and regional). Losses due to liquefaction contributed to 2.2% of direct economic losses in earthquake events worldwide, a statistic compiled from over 7,000 global earthquakes between 1900 and 2012 (Daniell et al., 2012)[18]. Considering indirect losses as well, the contribution increases to 3.6% (Paolella et al., 2021)[19]. However, in the case of Bangladesh, we have reason to expect damage and losses from earthquake-induced liquefaction to be much higher than the global average, considering that the major part of the country is situated in a river delta with deep deposits of saturated soft soils combined with high average annual precipitation which can alter the susceptibility of liquefaction.

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[18] Daniell, J. E., Khazai, B., Wenzel, F., & Vervaeck, A. (2012). The Worldwide Economic Impact of Historic Earthquakes. *15th World Conference on Earthquake Engineering*, Paper No. 2038.

[19] Paolella, L., Spacagna, R. L., Chiaro, G., & Modoni, G. (2021). A simplified vulnerability model for the extensive liquefaction risk assessment of buildings. *Bulletin of Earthquake Engineering*, *19*(10), 3933–3961. https://doi.org/10.1007/s10518-020-00911-2

Despite having seen no significant earthquakes in the last century, Bangladesh is an earthquake-prone country, ranging from the highly active Himalayan belt in the north to the peninsula in the south, which has witnessed less frequent yet destructive events such as the 1762 Mw 8.5 Arakan earthquake. The earthquake sources near high population density centres such as Dhaka (e.g., Madhupur fault) show potential for generating shallow crustal events. Furthermore, the country is underlain by deposits with a high potential for amplifying ground motions and liquefaction.

To address the assessment of liquefaction hazard, we conducted both scenario-based analyses (liquefaction potential due to specific earthquake ruptures) and event-based analysis in which we assessed the contribution of various earthquake sources (as depicted in Figure 4-1 and Figure 4-2) to the total liquefaction hazard. To perform the analysis on a national scale, we used geospatial models that rely on globally available proxies used to explain the mechanics behind liquefaction occurrence – such as average shear wave velocity in the top 30 metres of soil (Vs30), ground water depth (GWD), average annual precipitation, distance to the nearest river or coast, and peak ground velocity and acceleration due to earthquake ground shaking. Figure 5-1 below shows maps of four of these explanatory variables for Bangladesh, including Vs30, GWD, precipitation, and distance to the nearest water body. Geospatial models are more broadly applicable for regional analysis (though perhaps with reduced prediction accuracy) compared to locally applicable "site-specific" methods, which rely extensively on field surveys to measure soil parameters that correlate with soil liquefaction occurrence. The liquefaction analyses were conducted using the OpenQuake engine[20].

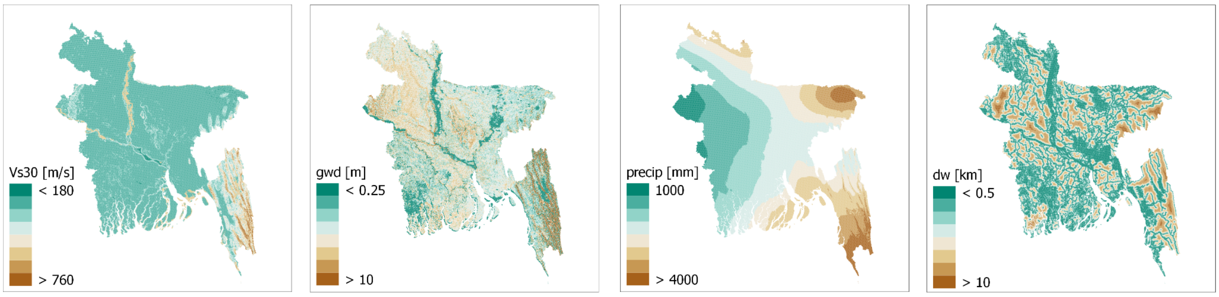

Figure 5-1. Explanatory variables characterising soil density and saturation

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[20] Pagani, M. M., Monelli, D., Weatherill, G. A., Danciu, L., Crowley, H. M., Silva, V., Henshaw, P., Butler, L., Nastasi, M., Panzeri, L., Simionato, M., & Viganò, D. (2014). OpenQuake Engine: An Open Hazard (and Risk) Software for the Global Earthquake Model. Seismological Research Letters, 85(3), 692–702. https://doi.org/10.1785/0220130087

We compared two models: a parametric model described by Allstadt et al. (2022)[21], the model used within the USGS Ground Failure Product[22], and a non-parametric model proposed by Todorovic and Silva (2022) [23]. The results of the scenario-based analysis are presented in terms of areal coverage, i.e., expected area to be covered with liquefaction surface manifestation. We considered each of the 11 scenarios described in the previous section; however, we only show here the results from the historical 1885 M7.25 "Manikganj" earthquake (Figure 7) that ruptured the Madhupur fault and caused destruction in Dhaka. The nonparamtric model predicts smaller footprint of region affected by liquefaction surface manifestations. Even though these methodologies are of the approximate nature, they represent an effort in understanding the consequences due to secondary perils.

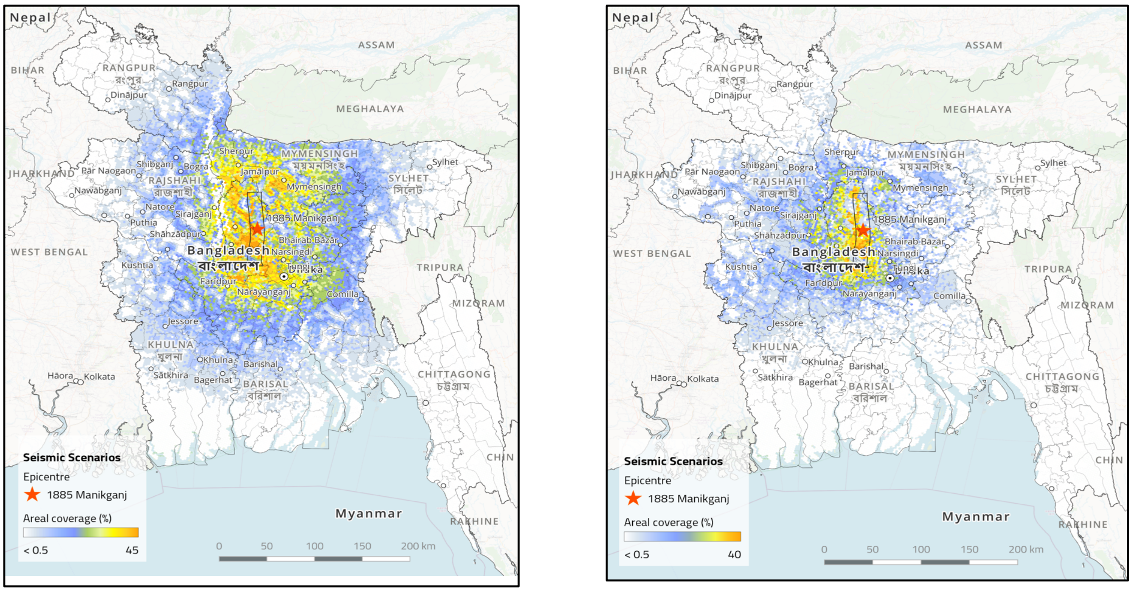

Figure 5-2. Scenario-based liquefaction assessment considering the 1885 M7.25 Manikganj earthquake; (left) using the parametric model described in Allstadt et al. (2022); (right) using the nonparametric model of Todorovic and Silva (2022)

In addition to scenario-based liquefaction assessment, we also undertook stochastic event-based liquefaction assessment, where we now consider the contribution of all possible earthquake sources to the total liquefaction hazard. The primary outcome of this analysis is the annual frequency of occurrence of liquefaction. To account for the epistemic uncertainty in liquefaction modelling, here we combined two geospatial models — parametric (Allstadt et

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[21] Allstadt, K. E., Thompson, E. M., Jibson, R. W., Wald, D. J., Hearne, M. G., Hunter, E. J., Fee, J., Schovanec, H., Slosky, D., & Haynie, K. L. (2022). The US Geological Survey ground failure product: Near-real-time estimates of earthquake-triggered landslides and liquefaction. *Earthquake Spectra*, *38*(1), 5–36. https://doi.org/10.1177/87552930211032685

[22] U.S. Geological Survey Ground Failure Product Scientific Background. URL: https://earthquake.usgs.gov/data/ground-failure/background.php

[23] Todorovic, L., & Silva, V. (2022). A liquefaction occurrence model for regional analysis. *Soil Dynamics and Earthquake Engineering*, *161*(February), 107430. https://doi.org/10.1016/j.soildyn.2022.107430

al., 2022) and nonparametric (Todorovic and Silva, 2022) models, with equal weights. This outcome is typically convolved with the exposure and vulnerability models to conduct probabilistic seismic risk assessment. Figure 5-3 shows the annual frequency of occurrence of earthquake-induced liquefaction in Bangladesh along with an overlay of the national, divisional, and district-level road network of the country. As evident from the map, the areas in the north and east of the country have a higher potential of liquefaction due to the combination of higher seismic hazard and higher precipitation leading to increased soil wetness compared to the rest of the country.

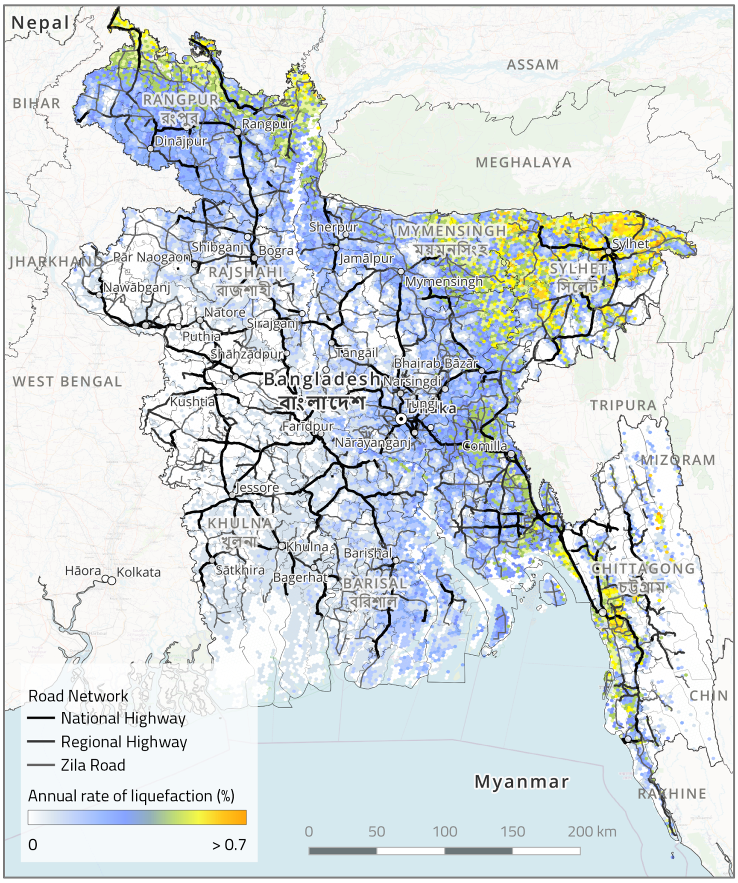


Figure 5-3. Annual frequency of occurrence of liquefaction

6 Population and building exposure

6.1 Introduction

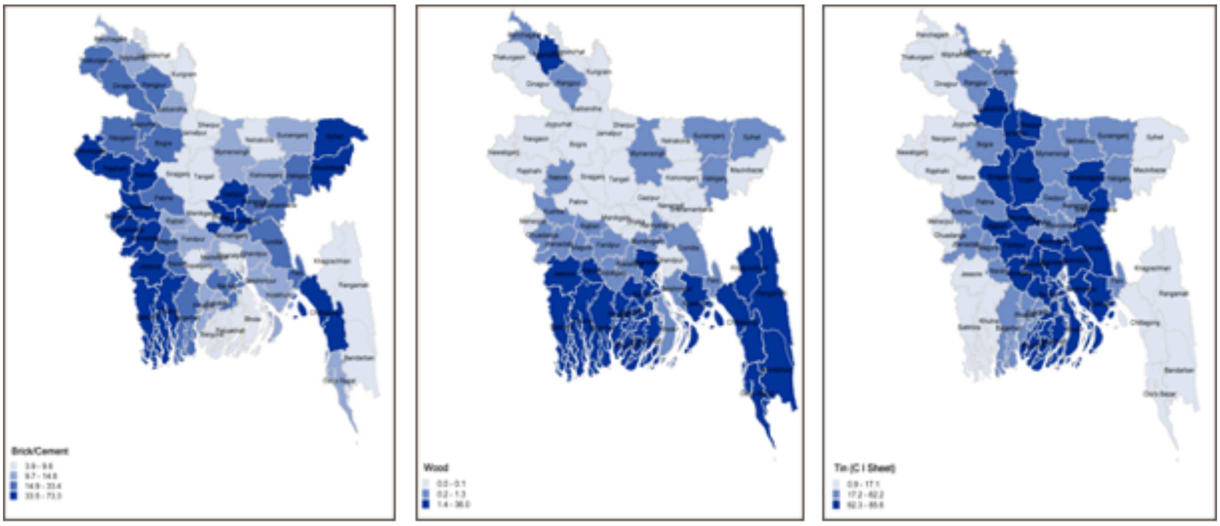
Exposure models play a critical role in seismic risk assessment by quantifying the potential exposure of buildings and infrastructure to earthquake hazards. These models are structured databases that catalogue the characteristics of buildings within a specific geographic area, including their location, construction material, age, occupancy type, and structural design. The depth and accuracy of this data directly influence the effectiveness of the seismic risk evaluations, as they allow for a detailed understanding of how different structures are likely to perform during an earthquake.

The application of building exposure models is essential for disaster risk reduction and management. By integrating these models with seismic hazard data (such as those derived from Probabilistic Seismic Hazard Analysis, or PSHA), policymakers and engineers can simulate potential earthquake scenarios and predict their impact on the built environment. This predictive capability is crucial for crafting building codes and retrofitting guidelines that aim to enhance the resilience of existing structures and ensure that new constructions are adequately equipped to withstand seismic events. Additionally, these models support emergency response planning by identifying areas with high concentrations of vulnerable buildings, thereby prioritizing regions for evacuation plans, emergency response resource allocation, and public awareness campaigns.

6.2 Residential, commercial, and industrial buildings

Overall, GEM's existing exposure data for Bangladesh prior to this project was developed in 2017–18 and covered the residential, commercial, and industrial built assets in the country. GEM's exposure dataset contains aggregated information about the building stock at the district (zila) and sub-district (upazila) level. GEM's existing residential exposure model for Bangladesh prior to the commencement of this project was based on the 2011 Population and Housing Census, and the commercial and industrial exposure model was based on the 2013 Economic Census. GEM's existing residential exposure model for Bangladesh had been deeply informed by the zila-level information regarding wall materials used to construct houses that was available through the 2011 Population and Housing Census (see Figure 6-1 below).

As part of this project, we undertook a complete update of GEM's existing residential exposure model for Bangladesh to reflect the findings of the 2022 Population and Housing Census. We have also updated the administrative division hierarchy used in the exposure model to reflect the current structure. Figure 6-2 below shows the population counts at the upazila level, from the results of the 2022 Population and Housing census.



Brick / Cement
2011 Census

Wood / Bamboo
2011 Census

Tin / CI Sheet
2011 Census

Figure 6-1. Geographical variation in predominant wall material of residential buildings. Source: 2011 Population and Housing Census, BBS.

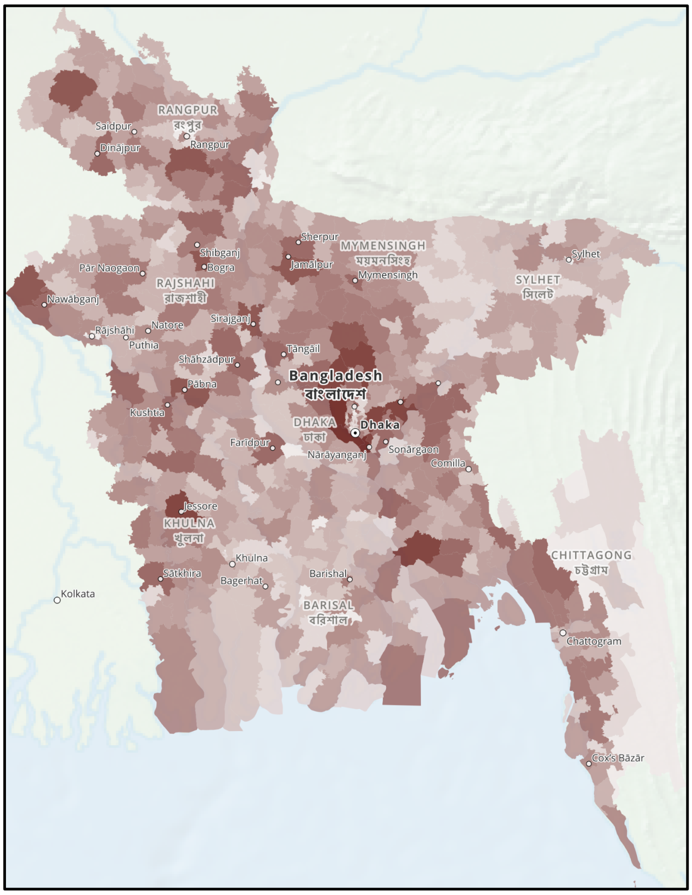
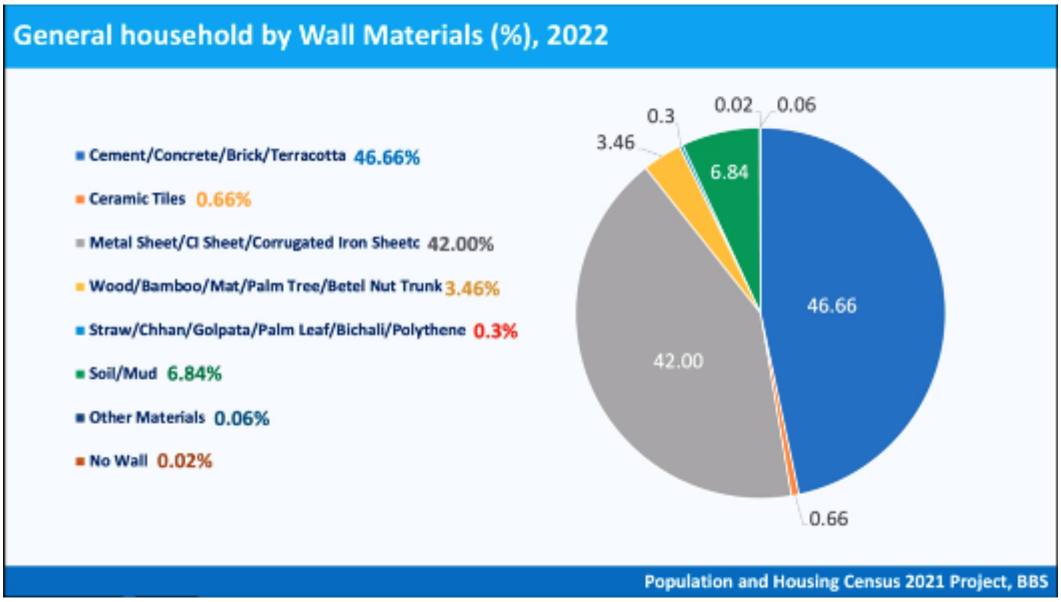


Figure 6-2. Population at the upazila level, from the 2022 Population and Housing census of Bangladesh

Although the detailed housing tables from the 2022 Population and Housing census at the union/ward, mauza/mahalla, and village level are not yet available, with support from the UN RC office in Dhaka, we sent in an official request for upazila-level information about wall, floor, and roof materials used for housing construction collected during the 2022 Population and Housing Census of Bangladesh. This request was granted, and the said information was made available to us for use in this project. Mr. Md. Dilder Hossain, project manager for the 2022 Population and Housing Census of Bangladesh, kindly presented the key findings of the latest census to the project technical panel, including changes observed in the construction materials used across the country (see Figure 6-3 below).


General household by Wall Materials (%), 2022

Population and Housing Census 2021 Project, BBS

Figure 6-3. Distribution of households by wall material. Source: Population and Housing Census 2022, BBS. Courtesy: Md. Dilder Hossain

Development of the exposure model followed a similar methodology as outlined in Yepes-Estrada et al. (2017)[24], Rao et al. (2020)[25], Crowley et al. (2020)[26], and Yepes-Estrada (2023)[27]. We also modelled the informal constructions in urban areas by using information from the 2014

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[24] Yepes-Estrada C, Silva V, Valcárcel J, et al. Modeling the Residential Building Inventory in South America for Seismic Risk Assessment. Earthquake Spectra. 2017;33(1):299-322. doi:10.1193/101915eqs155dp

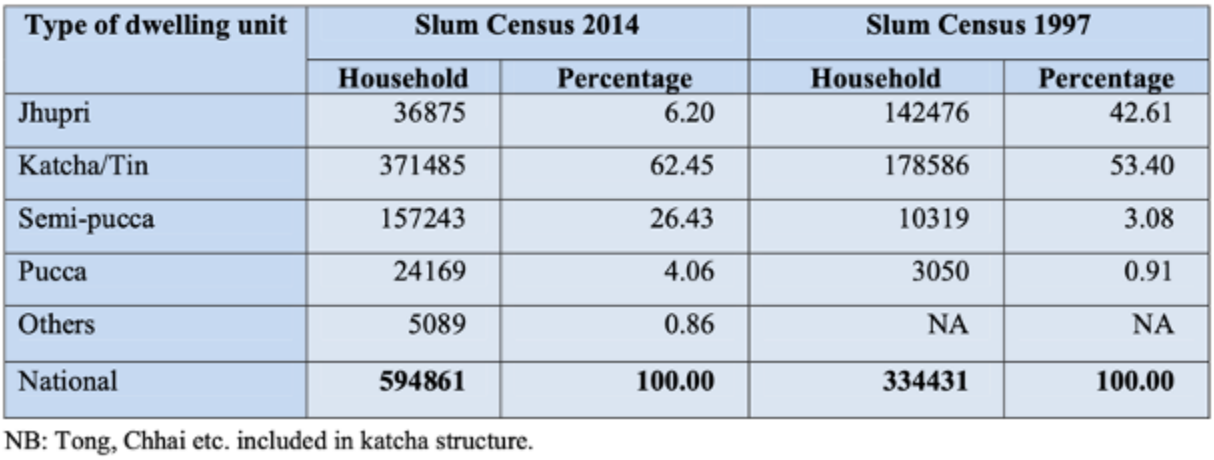
[25] Rao A, Dutta D, Kalita P, et al. Probabilistic seismic risk assessment of India. Earthquake Spectra. 2020;36(1_suppl):345-371. doi:10.1177/8755293020957374

[26] Crowley H, Despotaki V, Rodrigues D, et al. Exposure model for European seismic risk assessment. Earthquake Spectra. 2020;36(1_suppl):252-273. doi:10.1177/8755293020919429

[27] Yepes-Estrada C, Calderon A, Costa C, et al. Global building exposure model for earthquake risk assessment. Earthquake Spectra. 2023;39(4):2212-2235. doi:10.1177/87552930231194048

Census of Slum Areas and Floating Population (Table 6-1). In this case, the specific construction material is unknown; however, the type of dwelling unit – jhupri, katcha, semi-pucca, pucca – allows us to infer the vulnerability class of these structures. Similarly, the commercial and industrial building exposure models have been updated based on the results of the 2022 Bangladesh Economic Review. Building height distributions in each upazila were inferred based on a new satellite-derived dataset of building heights from the World Settlement Footprint 3D[28] raster which has been developed on a 90m grid (Figure 6-4).

Table 6-1. Distribution of slum dwellings by type of dwelling.
Source: Census of Slum Areas and Floating Population 2014, BBS.



Type of dwelling unit	Slum Census 2014		Slum Census 1997	
	Household	Percentage	Household	Percentage
Jhupri	36875	6.20	142476	42.61
Katcha/Tin	371485	62.45	178586	53.40
Semi-pucca	157243	26.43	10319	3.08
Pucca	24169	4.06	3050	0.91
Others	5089	0.86	NA	NA
National	**594861**	**100.00**	**334431**	**100.00**

NB: Tong, Chhai etc. included in katcha structure.

Total building counts and total estimated replacement costs for buildings at the upazila level are shown below in the maps in Figure 6-5. Figure 6-6 includes maps that display the fraction of buildings in each upazila according to primary material of construction, including unreinforced masonry, reinforced concrete, wood and/or bamboo, and corrugated iron (C.I.) sheet / tin sheets and other materials. We can see that a substantial fraction of buildings still fall under the non-engineered category, with C.I. / tin / metal sheet houses making up 42% of all dwellings in the country.

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[28] Esch, T., Brzoska, E., Dech, S., Leutner, B., Palacios-Lopez, D., Metz-Marconcini, A., Marconcini, M., Roth, A. and Zeidler, J., 2022. World Settlement Footprint 3D-A first three-dimensional survey of the global building stock. Remote sensing of environment, 270, p.112877.

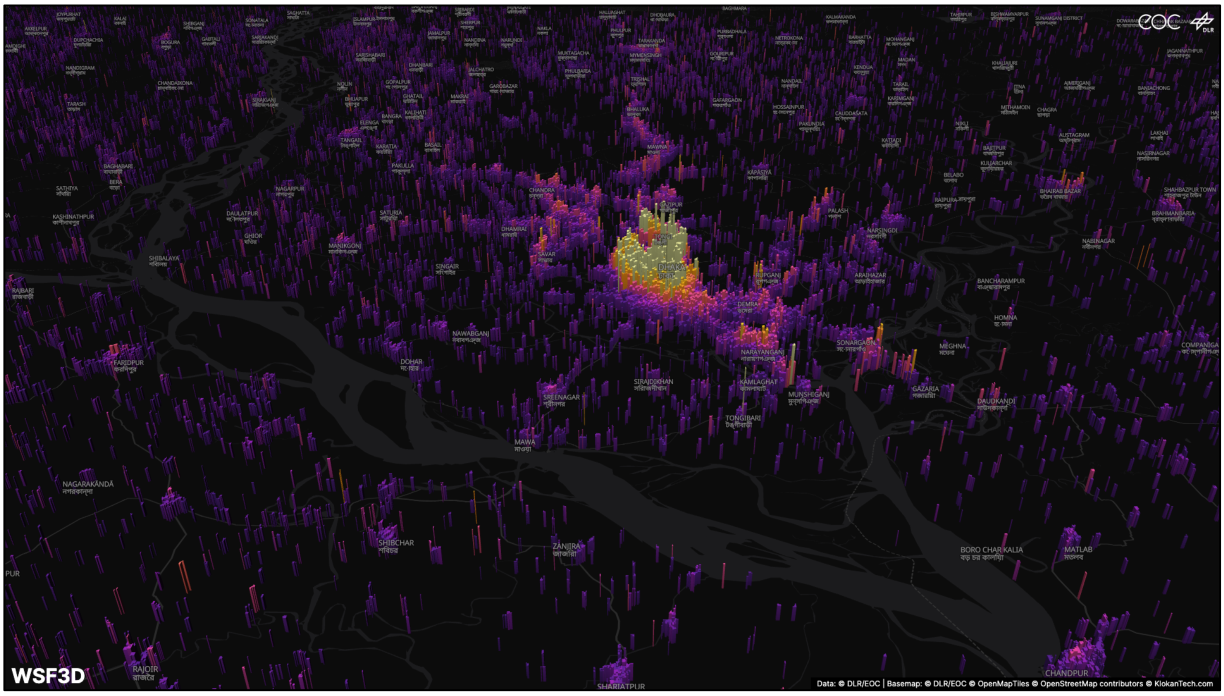


Figure 6-4. Building heights in and around Dhaka
Image source: World Settlement Footprint 3D

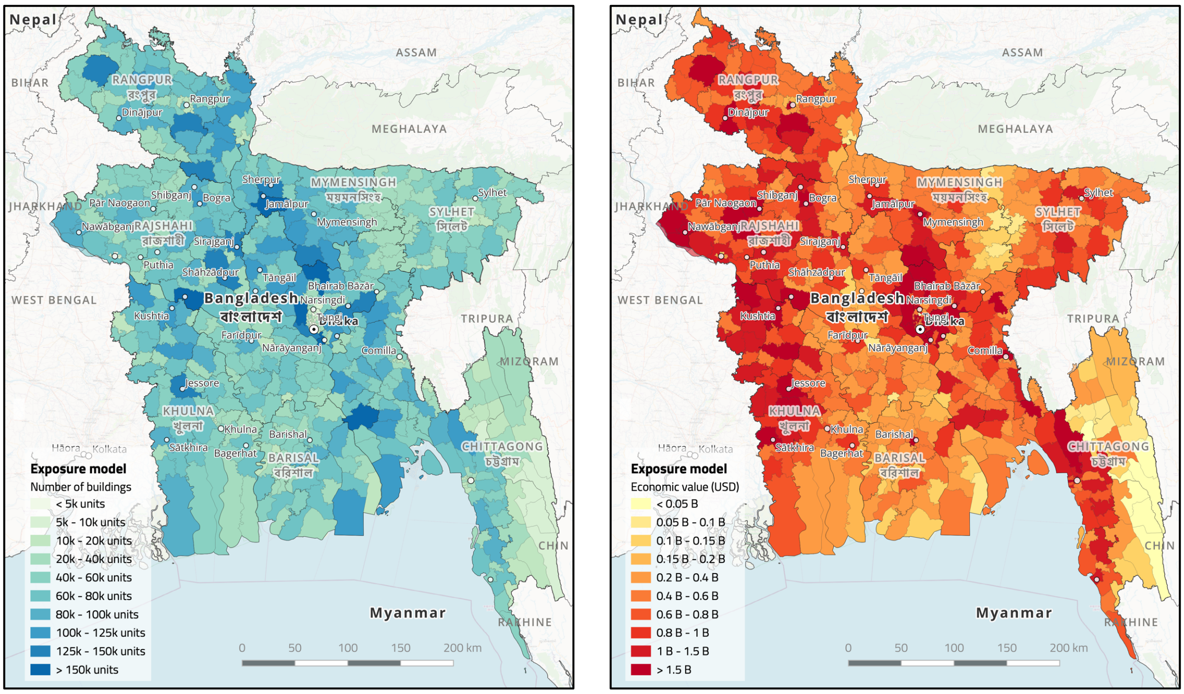
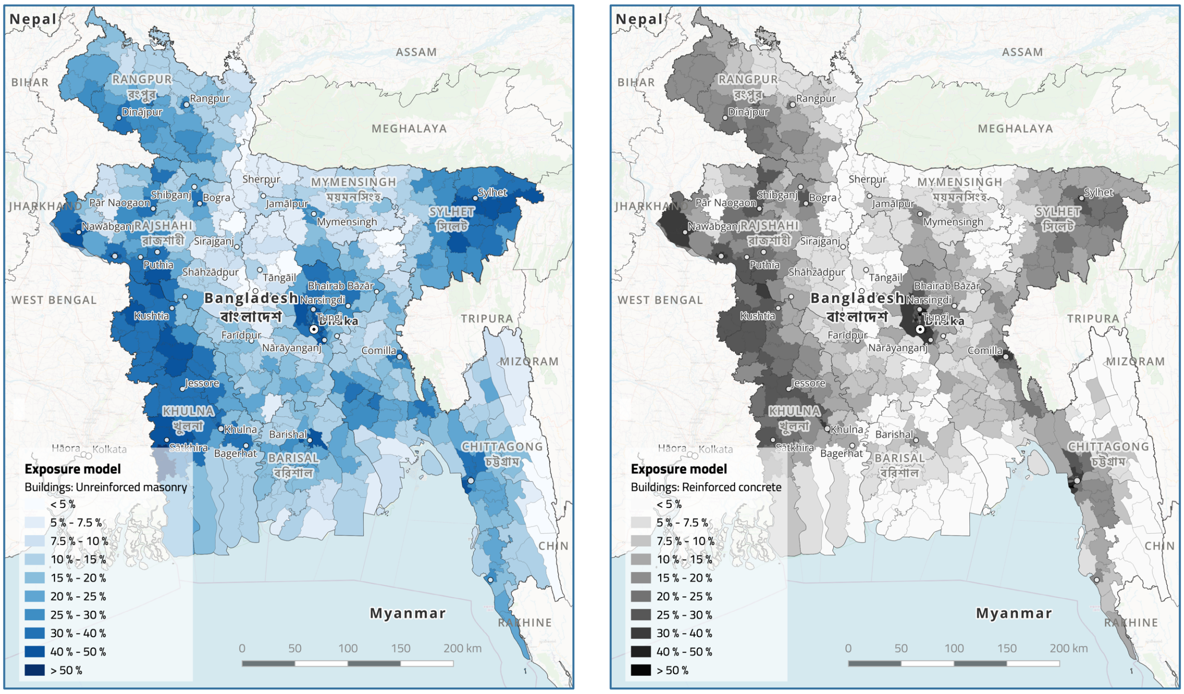
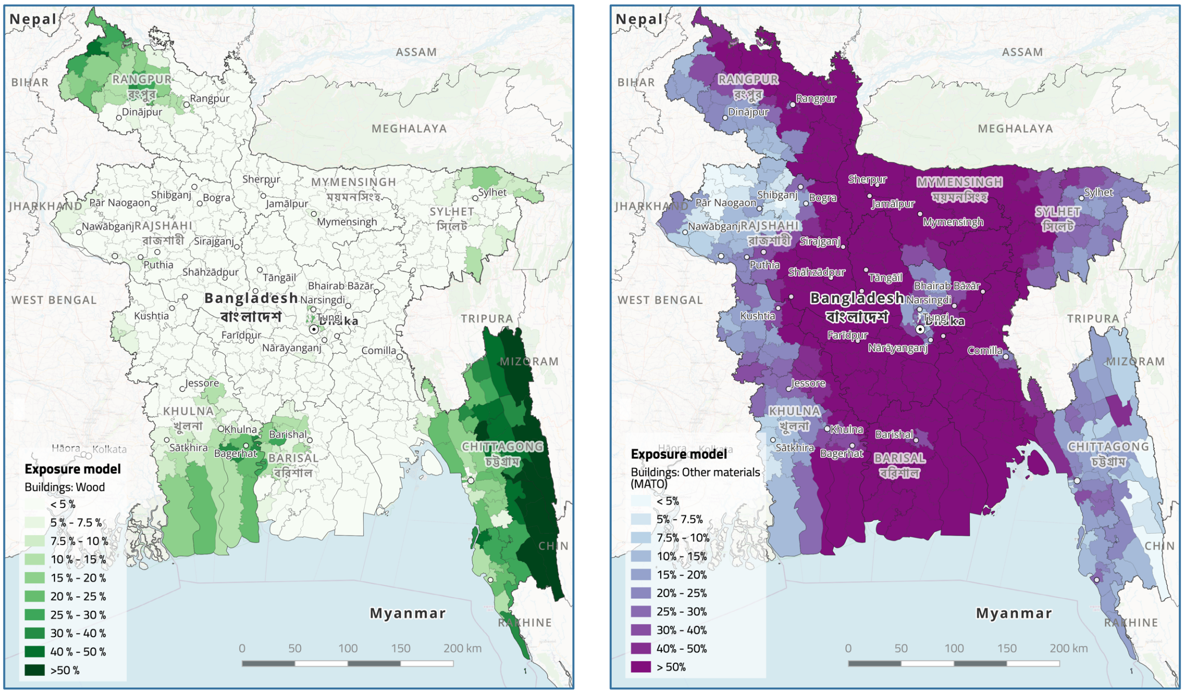


Figure 6-5. Building exposure of Bangladesh.
Left: Total number of buildings in each upazila;
Right: Total replacement value of the buildings in each upazila



(a) Unreinforced masonry (b) Reinforced concrete



(c) Wood and bamboo (d) C.I. / tin sheets and other materials

Figure 6-6. Fraction of buildings in each upazila according to primary material of construction

6.3 Educational and healthcare facilities

In addition to residential, industrial and commercial structures that were previously covered by GEM's exposure models at the zila level (which have been updated to the upazila level during the course of this project), we have also developed building inventory models for the healthcare and educational facilities in the country, including all hospitals and clinics, and all schools, colleges, and universities (see Figure 6-7). In contrast to the residential, commercial, and industrial exposure models which are based on aggregated information, the educational and healthcare building inventories include information on the exact locations of these facilities; however, we do not have sufficient information to reliably characterize the structural attributes of these buildings at the individual building level.

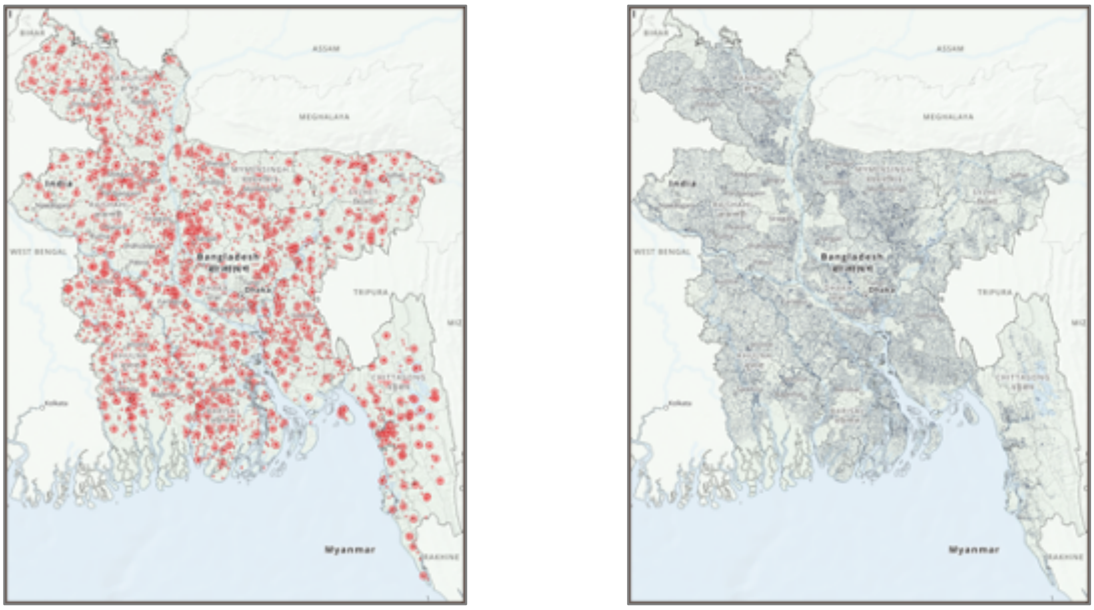


Figure 6-7. Distribution of hospitals and clinics (left) and schools and colleges (right). Source: Hospitals & Clinics Management Section, Directorate General of Health Services (DGHS), Bangladesh Bureau of Educational Information and Statistics (BANBEIS), Ministry of Education, and Bangladesh Primary Education Statistics & Annual Primary School Census 2021, Ministry of Primary and Mass Education

6.4 Linear infrastructure

Finally, we have also compiled databases of road network, including national and divisional highways, zila and upazila roads, as well as union and village level roads, and the railway network of Bangladesh (Figure 6-8). An attempt was also made to collect information about other critical lifelines such as water, wastewater, and gas pipelines and electricity transmission lines through a request to the Local Government Engineering Department

(LGED), however this information was deemed to be sensitive and the LGED indicated that these datasets could not be shared with us for the purposes of this project.

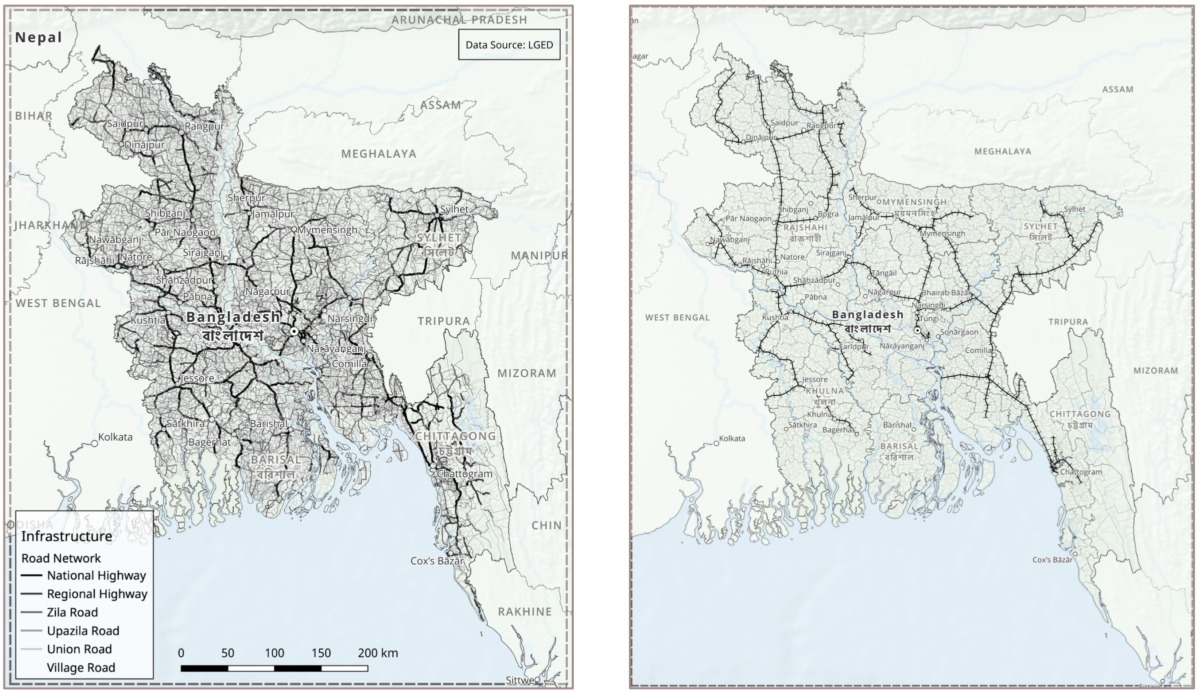


Figure 6-8. Road network (left) and railway network (right) of Bangladesh
Source: Local Government Engineering Department (LGED)

6.5 Residential exposure beyond the upazila level

Although the information regarding the wall, roof, and floor material of residential dwellings from the 2022 Population and Housing Census was shared with us only at the upazila level, the household and population counts are being released at finer resolutions, including union / paurashava, mauza / mahalla, and village levels. We have taken advantage of this to spatially disaggregate the upazila level residential exposure model described in Section 6.2 to the village level. While the upazila level exposure model was deemed sufficiently reliable for the purposes of earthquake risk assessment, the village level residential exposure model may prove to be useful for risk assessment of other perils such as floods and cyclones. The village level residential exposure model is illustrated below in Figure 6-9.

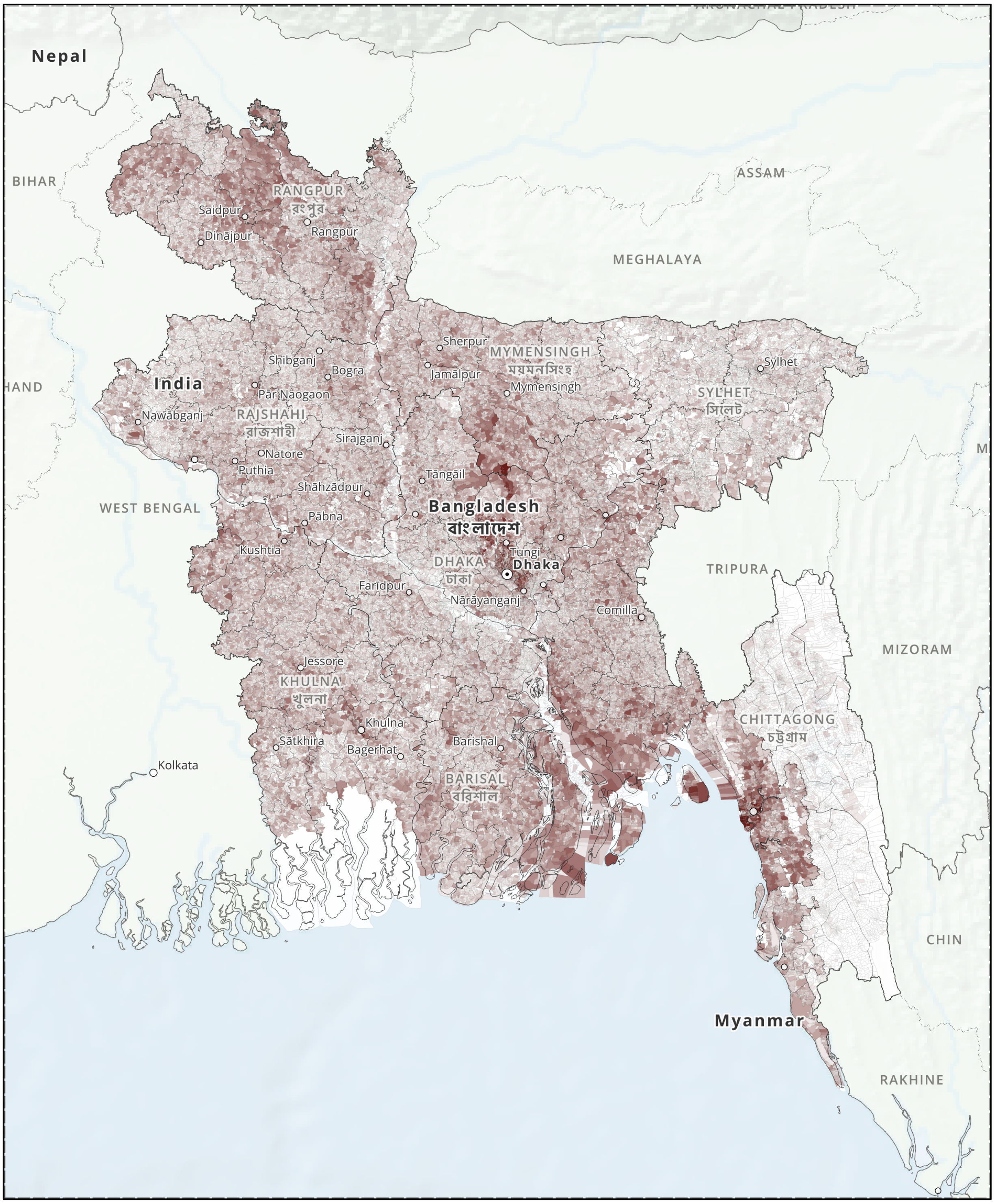


Figure 6-9. Village level residential exposure model of Bangladesh

7 Seismic fragility and vulnerability model

7.1 Introduction

Earthquake fragility and vulnerability models are a critical component for seismic risk assessment. These models describe the potential for damage and expected loss in buildings, other infrastructure elements, and for human occupants, conditional on the intensity of ground shaking due to an earthquake experienced at the location of the assets. In principle, such models can be developed by empirical methods using large datasets of damage and economic losses considering the impact of past destructive events. However, the lack of damage data from previous earthquakes in Bangladesh, or insufficient detail in the available information from neighbouring countries prevents the direct use of empirical models in earthquake loss estimation.

Thus, for the earthquake risk model for Bangladesh, we have employed a set of analytically derived fragility and vulnerability functions for the assessment of the economic losses. While the initial set of vulnerability functions used in this loss model have been selected from GEM's global earthquake vulnerability database[29], the specific characteristics of the building stock of Bangladesh are being accounted for through adjustments that reflect the structural particularities described in the exposure component. Adjustments to existing vulnerability functions, and the derivation of new functions was particularly necessary for the informal construction, including kutcha houses made of corrugated iron or tin sheets that are common in rural areas, and for houses made from thatch, polythene sheets or scrap material which are observed in the informal settlement areas in cities.

7.2 Fragility and vulnerability functions

A wide variety of structural types are found in Bangladesh, including adobe / earthen houses and bamboo / light wood houses with thatched roofs in rural areas, and C.I. / tin / metal sheet slum dwellings and high-rise reinforced concrete apartment and commercial buildings in the metropolitan areas (see Figure 7-1), and unreinforced masonry structures are also quite common in both urban and rural areas. A comprehensive seismic fragility and vulnerability model for the country thus needs to include fragility and vulnerability functions for all of these types of buildings. Figure 7-2 shows how the type of structural systems used for residential dwellings is evolving rapidly in recent years, underlining the necessity of developing and maintaining an up-to-date exposure model that is able to capture these geographical and temporal variations in construction in the country.

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[29] Martins, L., Silva, V. Development of a fragility and vulnerability model for global seismic risk analyses. Bull Earthquake Eng 19, 6719–6745 (2021). https://doi.org/10.1007/s10518-020-00885-1

Figure 7-1. Different construction types in Bangladesh
Top-left: Adobe / earthen house; Top-right: Bamboo house with thatched roof; Bottom-left: C.I. sheet slum dwellings in Dhaka; Bottom-right: High-rise reinforced concrete structures in Dhaka

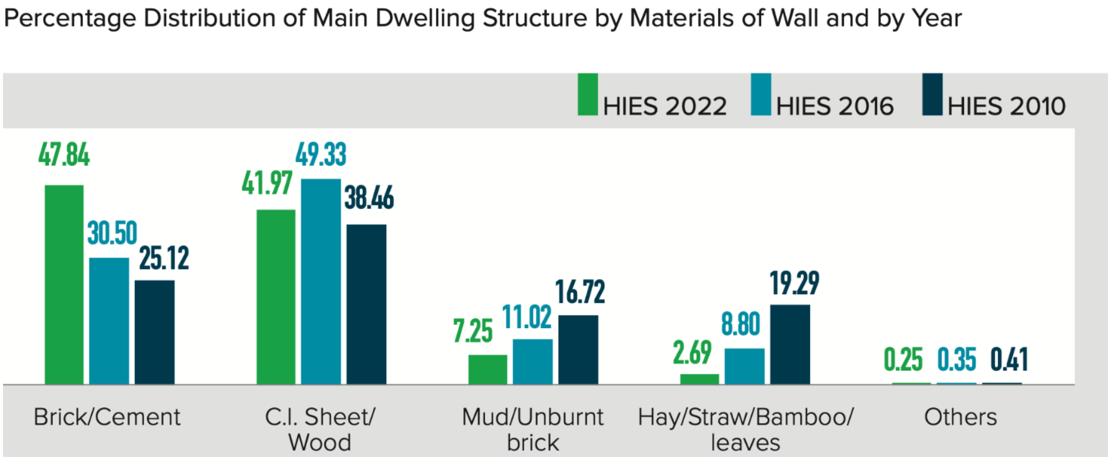
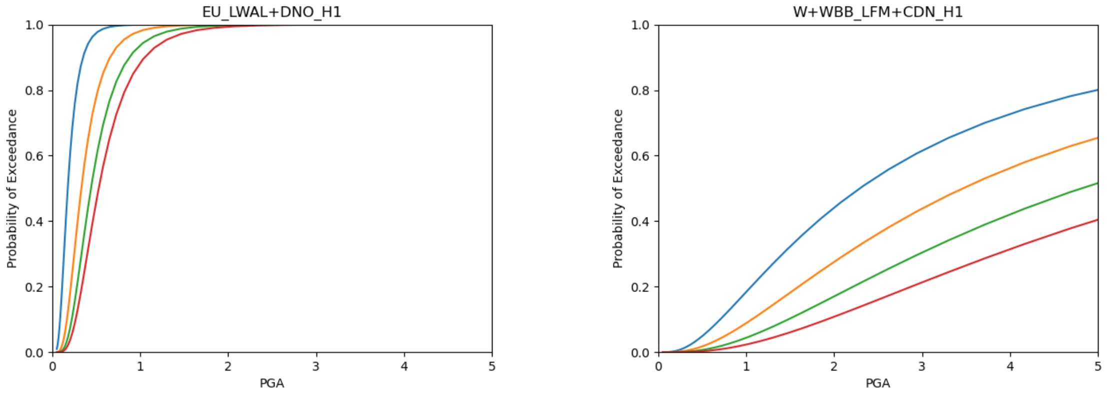
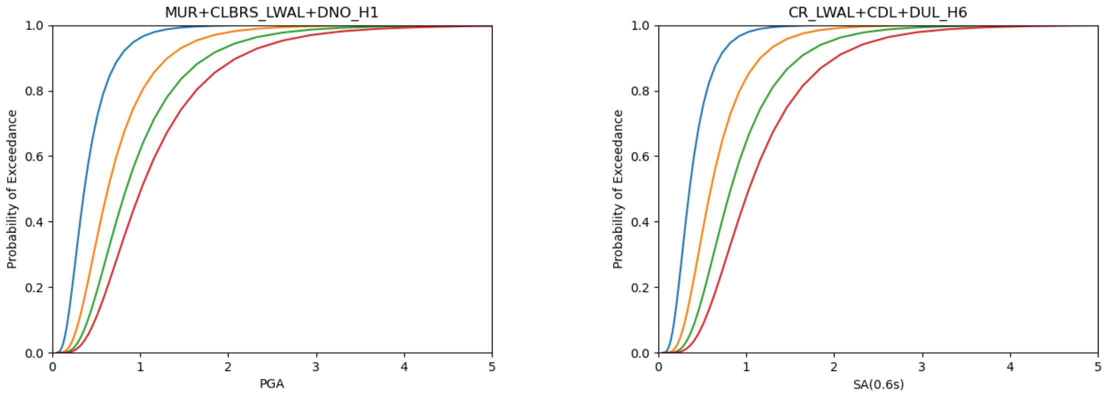


Figure 7-2. Changes in the type of structural system used for houses from 2010 to 2022

Seismic fragility functions are mathematically defined curves that describe the probability of a building or structure reaching or exceeding a certain level of damage state (such as slight, moderate, or complete damage) given a specific level of earthquake shaking intensity, typically measured in terms of ground acceleration or velocity. These functions are plotted for various damage states—slight, moderate, extensive, or complete damage. The fragility of a structure is influenced by several factors including its design, construction materials, age, maintenance, and the soil conditions on which its foundation is built. By incorporating these various structural characteristics into numerical models and simulation of structural behaviour under realistic earthquake loading, seismic fragility functions allow engineers and planners to predict the likely damage to different types of buildings under various seismic events. The seismic fragility functions for a few of the common building types in Bangladesh are illustrated below in Figure 7-3.



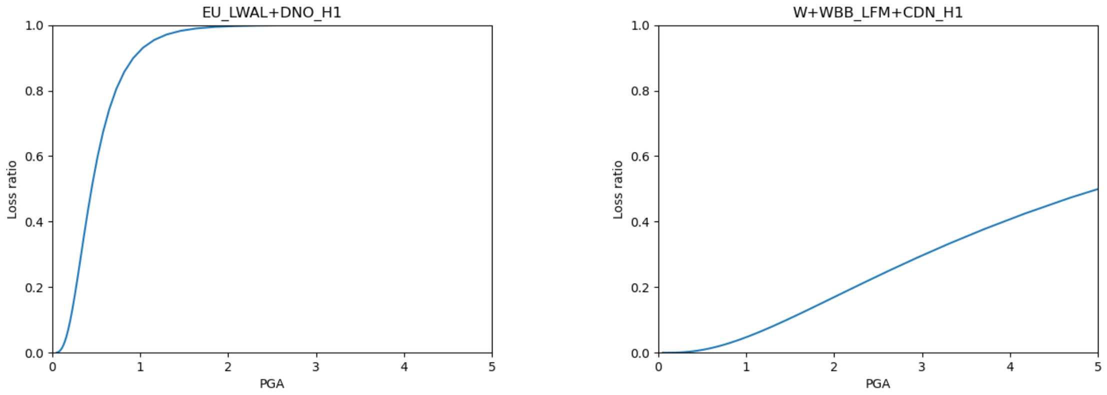
(a) Earthen / adobe house – 1 storey (b) Bamboo house – 1 storey



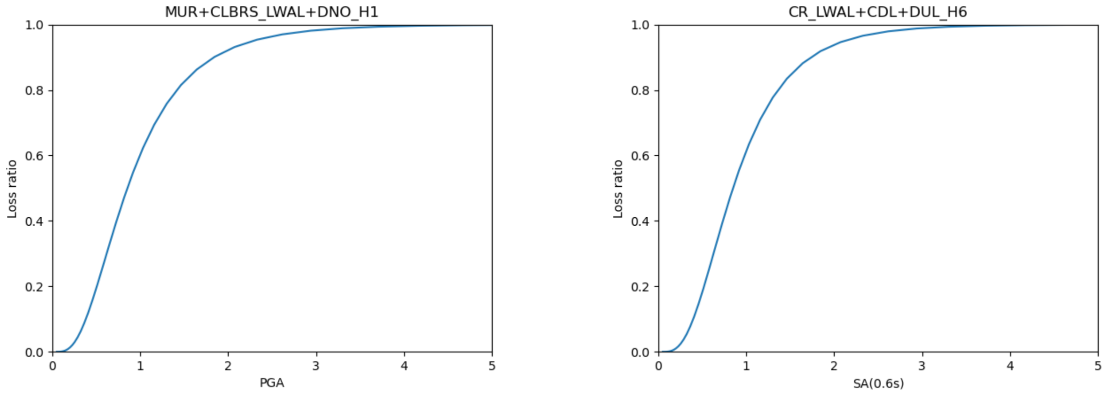
(c) Unreinforced masonry house – 1 storey (d) Reinforced concrete shear wall building – 6 storeys

Figure 7-3. Seismic fragility functions for typical building classes in Bangladesh

Seismic vulnerability curves are then developed from the fragility curves by converting the probabilistic damage assessments provided by fragility functions into estimations of expected losses or damage levels. While fragility curves detail the probability that a structure will exceed certain damage thresholds at specific levels of seismic intensity, such as peak ground acceleration (PGA, to derive vulnerability curves, the probabilities indicated by fragility curves are combined with corresponding loss ratios for each damage state. Loss ratios represent the estimated loss as a percentage of the total value of a building or structure associated with each level of damage. By multiplying the probability of each damage state by its associated loss ratio and integrating these values across all relevant seismic intensities and damage states, a vulnerability curve is created. This curve provides a continuous function that predicts total expected losses based on seismic intensity, thus offering a comprehensive tool for economic impact analysis in earthquake scenarios. The seismic vulnerability functions for the same four building types are illustrated below in Figure 7-4.



(a) Earthen / adobe house – 1 storey (b) Bamboo house – 1 storey



(c) Unreinforced masonry house – 1 storey (d) Reinforced concrete shear wall building – 6 storeys

Figure 7-4. Seismic vulnerability functions for typical building classes in Bangladesh

We can visually infer from these figures above that the seismic fragility and vulnerability of different building types to earthquake ground shaking can vary significantly. For instance, bamboo and wood framed structures are typically very light and ductile and consequently attract lower lateral forces, leading to lower fragility and vulnerability. On the other hand, construction based on weak materials such as earth or adobe usually exhibit a sudden and brittle mode of failure, leading to much higher fragility and vulnerability. The fragility and vulnerability of engineered construction such as reinforced concrete buildings depends substantially on the good design and construction practices followed during their erection.

7.3 Uncertainties and limitations

The paucity of empirical data on the behaviour of buildings typical in the region during past earthquakes imposes a serious limitation on both the calibration and validation of the analytically derived fragility and vulnerability models. We have attempted to offset this by using data from other regions of the world which have similar construction types and earthquake tectonic regions within the validation process for the fragility and vulnerability functions.

8 Seismic risk assessment

8.1 Scenario damage, loss, and fatality results

Developing earthquake scenarios is a fundamental aspect of earthquake preparedness and risk management. These scenarios provide detailed narratives or simulations of potential earthquakes, including their magnitude, location, depth, and expected ground shaking. By anticipating specific earthquake characteristics, these scenarios enable scientists, engineers, and emergency planners to visualize the potential impacts on communities, infrastructure, and environments. This foresight is crucial for testing the resilience of buildings and infrastructure against predicted seismic forces and for planning effective emergency response and recovery strategies.

Moreover, earthquake scenarios are instrumental in raising awareness and educating the public about seismic risks. They serve as the basis for drills and training exercises that prepare individuals and organizations for efficient action during and after an earthquake. Additionally, these scenarios help policymakers and urban planners make informed decisions regarding land use, building codes, and resource allocation to mitigate the effects of potential earthquakes. For insurance companies, earthquake scenarios are essential for assessing risk exposure and setting appropriate premiums. Overall, the development of realistic earthquake scenarios is key to enhancing societal resilience and reducing the potential devastation of future seismic events.

For each of the twelve scenarios described earlier in Section 3, we simulated the ground shaking for different intensity measures, propagating the uncertainty in ground motion given the rupture characteristics. While the full set of results are being made available on the project website[30], here we present the results for two of the major historical earthquake scenarios developed during the project – the 1885 Manikganj earthquake and the 1897 Great Indian earthquake.

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[30] Project website: https://www.globalquakemodel.org/proj/bangladesh

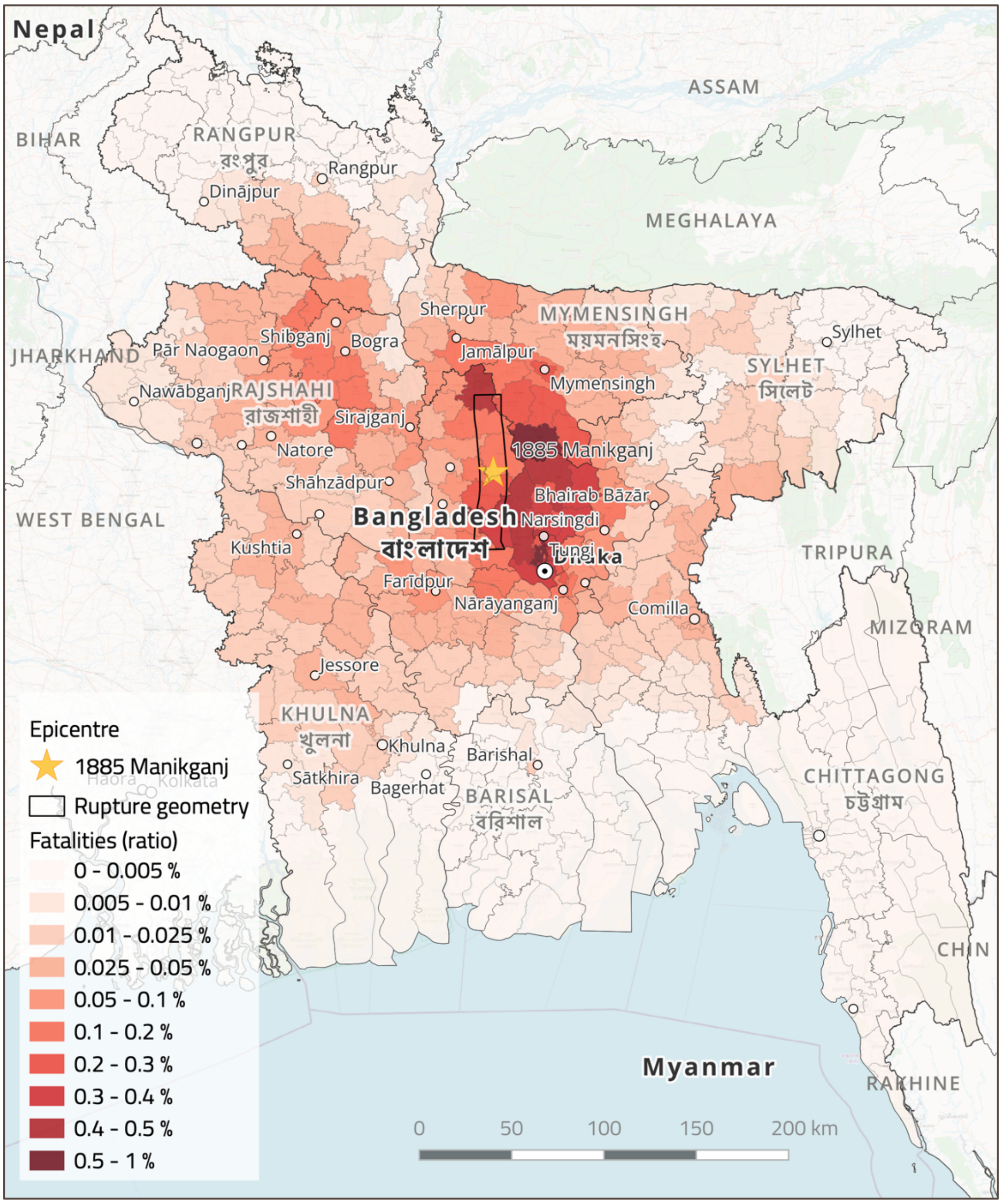
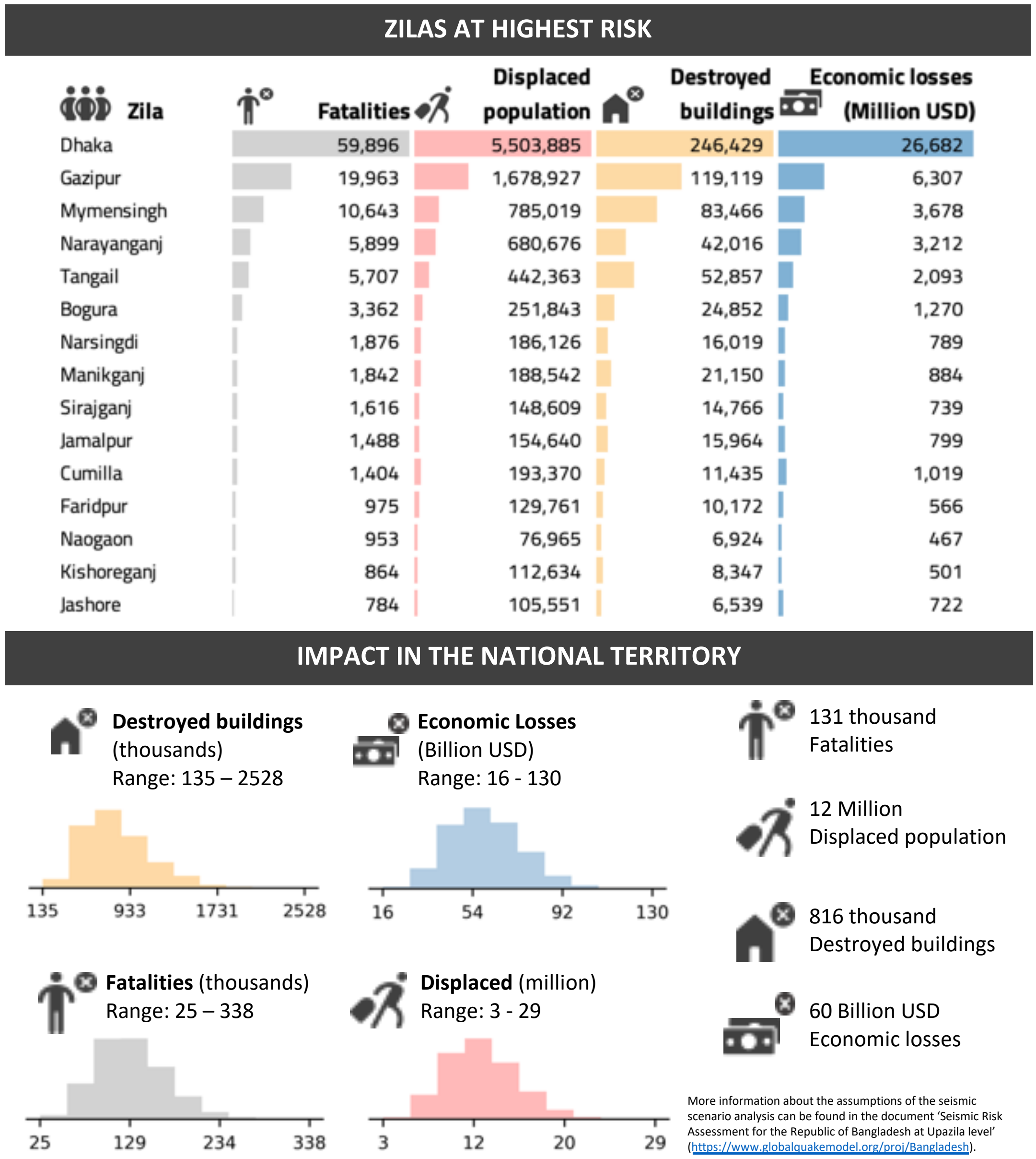


Figure 8-1. Estimated fatalities at the upazila level for the 1885 M7.2 Manikganj earthquake



ZILAS AT HIGHEST RISK

Zila	Fatalities	Displaced population	Destroyed buildings	Economic losses (Million USD)
Dhaka	59,896	5,503,885	246,429	26,682
Gazipur	19,963	1,678,927	119,119	6,307
Mymensingh	10,643	785,019	83,466	3,678
Narayanganj	5,899	680,676	42,016	3,212
Tangail	5,707	442,363	52,857	2,093
Bogura	3,362	251,843	24,852	1,270
Narsingdi	1,876	186,126	16,019	789
Manikganj	1,842	188,542	21,150	884
Sirajganj	1,616	148,609	14,766	739
Jamalpur	1,488	154,640	15,964	799
Cumilla	1,404	193,370	11,435	1,019
Faridpur	975	129,761	10,172	566
Naogaon	953	76,965	6,924	467
Kishoreganj	864	112,634	8,347	501
Jashore	784	105,551	6,539	722

IMPACT IN THE NATIONAL TERRITORY

Destroyed buildings (thousands)
Range: 135 – 2528

Economic Losses (Billion USD)
Range: 16 - 130

Fatalities (thousands)
Range: 25 – 338

Displaced (million)
Range: 3 - 29

131 thousand
Fatalities

12 Million
Displaced population

816 thousand
Destroyed buildings

60 Billion USD
Economic losses

More information about the assumptions of the seismic scenario analysis can be found in the document 'Seismic Risk Assessment for the Republic of Bangladesh at Upazila level' (https://www.globalquakemodel.org/proj/Bangladesh).

Figure 8-2. Summary of risk results at zila and national level for the 1885 M7.2 Manikganj earthquake

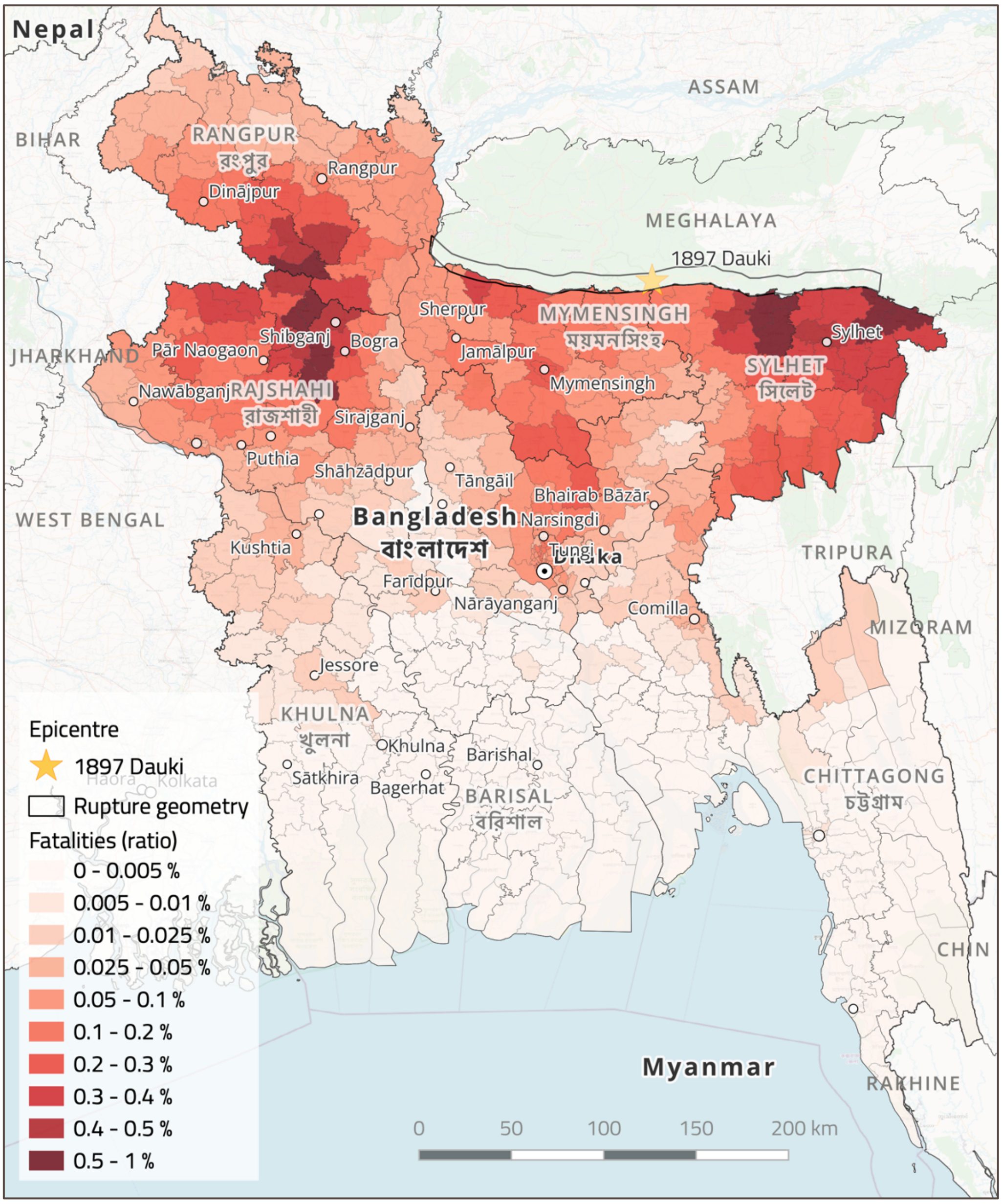
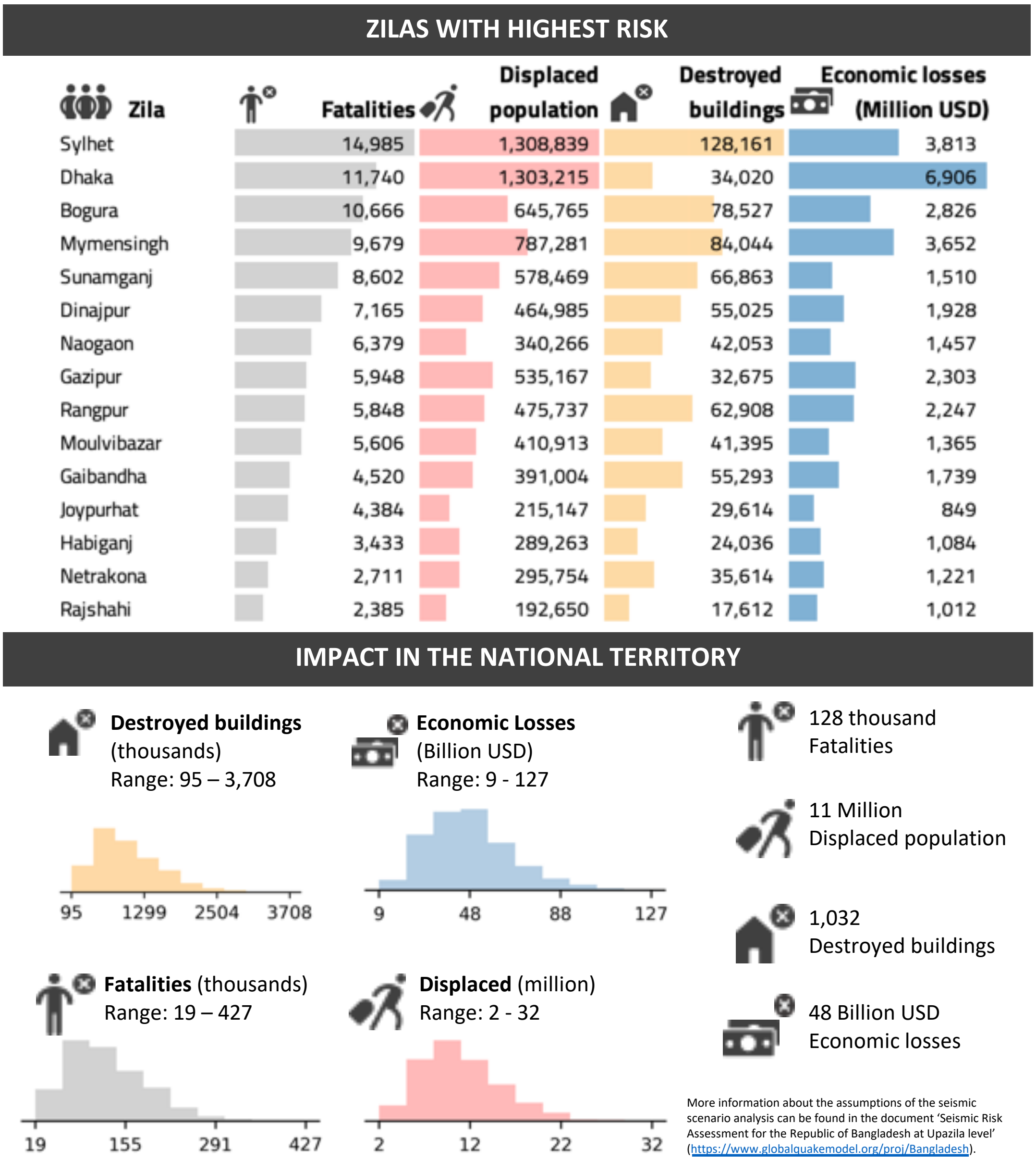


Figure 8-3. Estimated fatalities at the upazila level for the 1897 M8.7 Great Indian earthquake



ZILAS WITH HIGHEST RISK

Zila	Fatalities	Displaced population	Destroyed buildings	Economic losses (Million USD)
Sylhet	14,985	1,308,839	128,161	3,813
Dhaka	11,740	1,303,215	34,020	6,906
Bogura	10,666	645,765	78,527	2,826
Mymensingh	9,679	787,281	84,044	3,652
Sunamganj	8,602	578,469	66,863	1,510
Dinajpur	7,165	464,985	55,025	1,928
Naogaon	6,379	340,266	42,053	1,457
Gazipur	5,948	535,167	32,675	2,303
Rangpur	5,848	475,737	62,908	2,247
Moulvibazar	5,606	410,913	41,395	1,365
Gaibandha	4,520	391,004	55,293	1,739
Joypurhat	4,384	215,147	29,614	849
Habiganj	3,433	289,263	24,036	1,084
Netrakona	2,711	295,754	35,614	1,221
Rajshahi	2,385	192,650	17,612	1,012

IMPACT IN THE NATIONAL TERRITORY

Destroyed buildings (thousands)
Range: 95 – 3,708

Economic Losses (Billion USD)
Range: 9 - 127

Fatalities (thousands)
Range: 19 – 427

Displaced (million)
Range: 2 - 32

128 thousand
Fatalities

11 Million
Displaced population

1,032
Destroyed buildings

48 Billion USD
Economic losses

More information about the assumptions of the seismic scenario analysis can be found in the document 'Seismic Risk Assessment for the Republic of Bangladesh at Upazila level' (https://www.globalquakemodel.org/proj/Bangladesh).

Figure 8-4. Summary of risk results at zila and national level for the 1897 M8.7 Great Indian earthquake

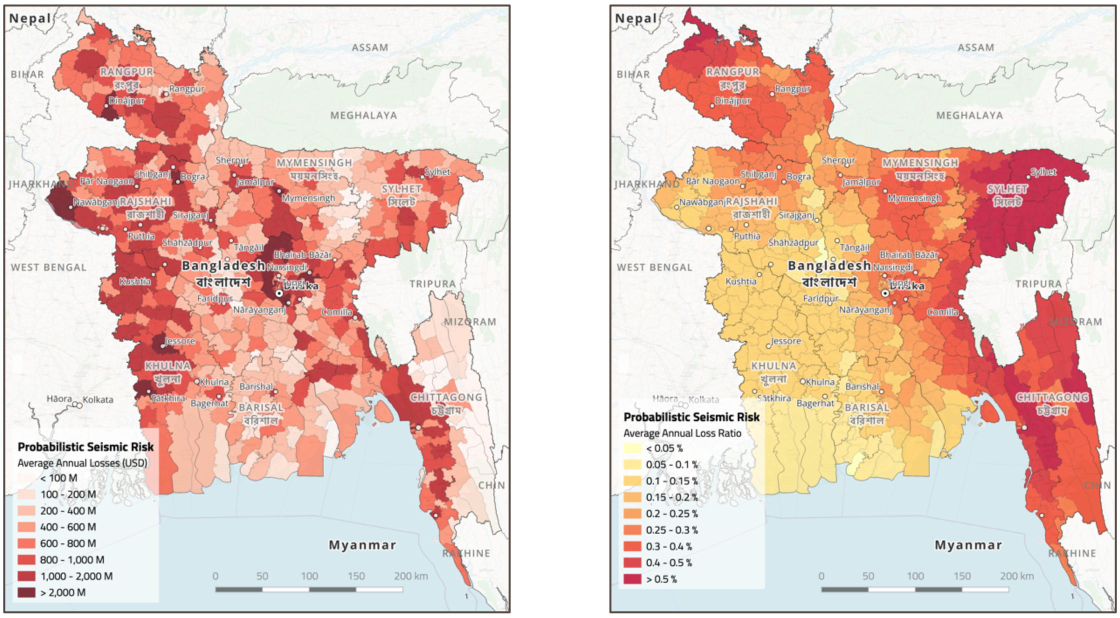
8.2 Probabilistic seismic risk assessment

Probabilistic Seismic Risk Assessment (PSRA) integrates seismic hazard analysis, which forecasts the intensity and frequency of potential earthquakes, with vulnerability assessments of the built environment and exposure analysis detailing the elements at risk, such as population, buildings, and critical infrastructure. PSRA calculates the probability of various levels of loss, from minor structural damage to economic impacts and human casualties, by considering all possible earthquakes and their corresponding likelihoods.

The strength of PSRA lies in its ability to provide decision-makers with detailed information about the relative risks associated with seismic activity throughout the territory of the country, without focusing on individual earthquake scenarios that might bias DRR financing decisions toward particular districts or subdistricts. This information is crucial for developing effective mitigation strategies, enhancing building codes, planning urban development, and preparing emergency response and recovery plans. PSRA is also instrumental in the insurance sector, where it helps in the accurate pricing of earthquake insurance and the management of financial reserves. By employing a probabilistic approach, PSRA acknowledges the inherent uncertainties in predicting earthquake characteristics and effects, thus providing a more comprehensive risk profile that supports resilience and preparedness initiatives. This comprehensive perspective is essential for regions prone to seismic activity, enabling them to prioritize investments in risk reduction and improve overall community safety.

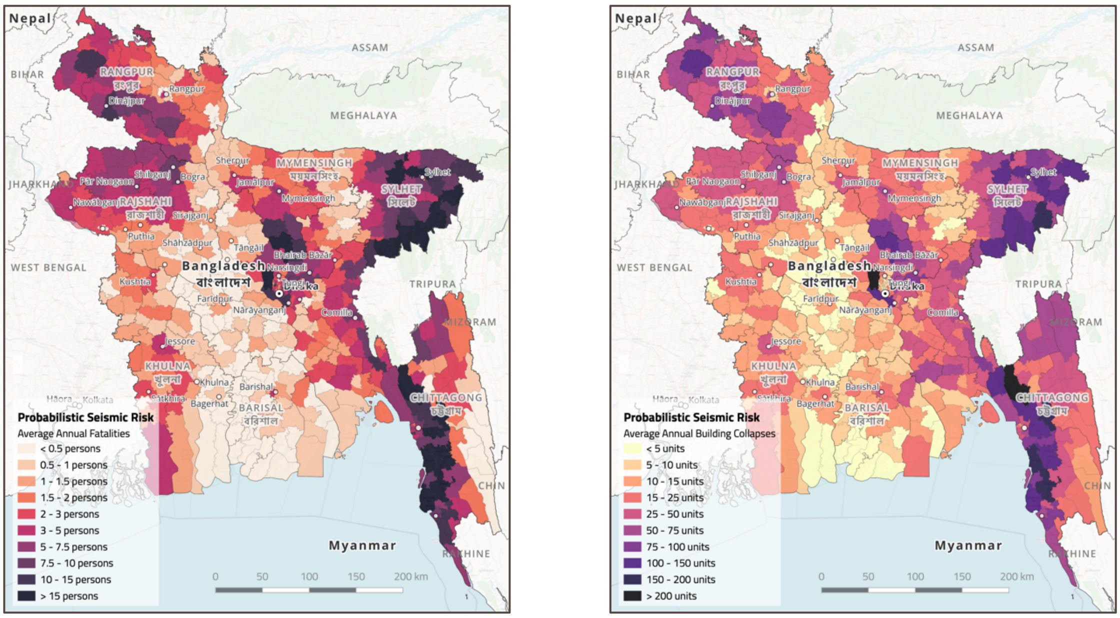
The estimation of the probabilistic seismic risk metrics in this project was performed using the stochastic event-based risk assessment calculator of the OpenQuake-engine. In this calculator, the previously described probabilistic seismic hazard analysis model is used to create an earthquake rupture forecast (i.e., a list of all of the possible ruptures that can occur in the region of interest with the associated probability of occurrence in a given time span), which is then employed to generate a stochastic event set (SES) spanning a long (say 100,000 year) period. Economic and human losses are calculated for every event in the SES, generating event loss tables (ELT) and year loss tables (YLT). These loss tables are then used for the calculation of various risk metrics, including exceedance probability curves and average annualised losses.

Fatality and injury estimates are based on human vulnerability models that are conditioned on structural collapse, and informed by human casualties reported in past earthquakes globally, but with particular weight given to developing countries in South Asia and Southeast Asia that have building stocks similar in structural characteristics to Bangladesh. All of the aforementioned risk metrics have been computed and tabulated at the national, divisional, district (zila), and subdistrict (upazila) levels. Four of these risk metrics computed at the upazila level are shown below in Figure 8-5, including the average annual economic losses (AAL), average annual economic loss ratios (AALR), average annual fatalities (AAF), and average annual number of building collapses.



(a) Average annual economic losses

(b) Average annual economic loss ratios

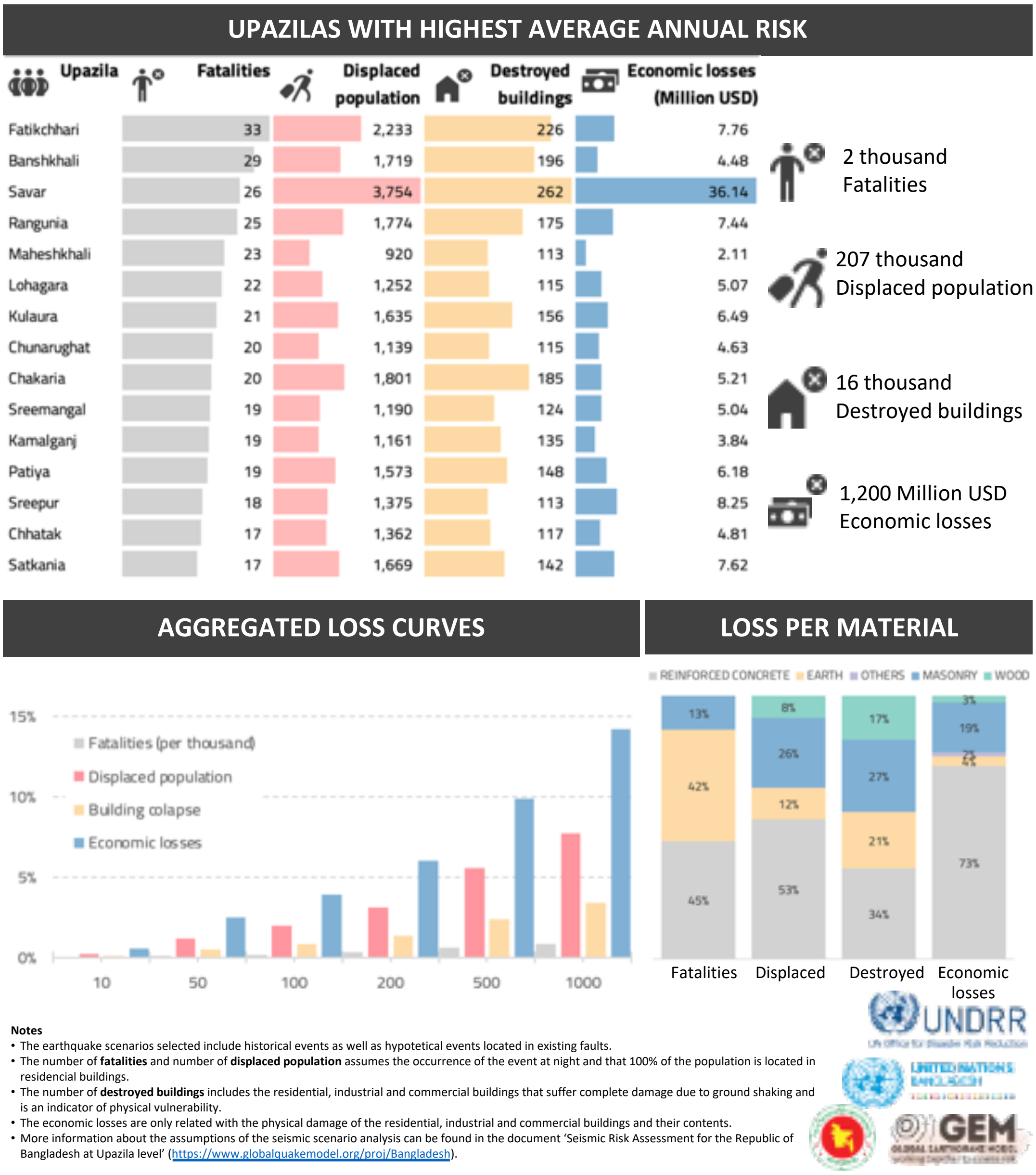


(c) Average annual fatalities

(d) Average annual building collapses

Figure 8-5. Probabilistic seismic risk results at the upazila level

Figure 8-6 provides a high-level summary of the probabilistic risk results at the upazila and national levels. We show the top 15 upazilas ranked according to the expected average annual fatalities due to earthquakes. Fatikchhari upazila and Banshkhali upazila in Chittagong district, followed by Savar upazila in Dhaka district are the top three upazilas in terms of expected average annual fatalities. At the national level, the total average annual economic loss for the country is expected to be around US$1.2 billion. Figure 8-6 also shows the loss exceedance curves for each of these four risk metrics at the national level. Loss exceedance curves graphically represent the probability that a given level of loss will be exceeded within a defined time frame. On the loss exceedance curves in Figure 8-6, the x-axis represents the return period of loss, while the y-axis displays different levels of potential loss or fatalities as a percentage of the exposed value. Finally, Figure 8-6 also shows the average annual risk contributions from the different primary construction types prevalent in Bangladesh.


UPAZILAS WITH HIGHEST AVERAGE ANNUAL RISK

Upazila	Fatalities	Displaced population	Destroyed buildings	Economic losses (Million USD)
Fatikchhari	33	2,233	226	7.76
Banshkhali	29	1,719	196	4.48
Savar	26	3,754	262	36.14
Rangunia	25	1,774	175	7.44
Maheshkhali	23	920	113	2.11
Lohagara	22	1,252	115	5.07
Kulaura	21	1,635	156	6.49
Chunarughat	20	1,139	115	4.63
Chakaria	20	1,801	185	5.21
Sreemangal	19	1,190	124	5.04
Kamalganj	19	1,161	135	3.84
Patiya	19	1,573	148	6.18
Sreepur	18	1,375	113	8.25
Chhatak	17	1,362	117	4.81
Satkania	17	1,669	142	7.62

2 thousand Fatalities

207 thousand Displaced population

16 thousand Destroyed buildings

1,200 Million USD Economic losses

AGGREGATED LOSS CURVES

LOSS PER MATERIAL

Notes

- The earthquake scenarios selected include historical events as well as hypotetical events located in existing faults.
- The number of **fatalities** and number of **displaced population** assumes the occurrence of the event at night and that 100% of the population is located in residencial buildings.
- The number of **destroyed buildings** includes the residential, industrial and commercial buildings that suffer complete damage due to ground shaking and is an indicator of physical vulnerability.
- The economic losses are only related with the physical damage of the residential, industrial and commercial buildings and their contents.
- More information about the assumptions of the seismic scenario analysis can be found in the document 'Seismic Risk Assessment for the Republic of Bangladesh at Upazila level' (https://www.globalquakemodel.org/proj/Bangladesh).

Figure 8-6. Summary of probabilistic risk results at the upazila and national levels

As with the scenario results, a full set of probabilistic risk results are being made available on the project website.

9 Technical panel engagement

The UN Resident Coordinator's Office in Bangladesh has helped identify key technical experts and stakeholders, who will form the technical panel. The panel will be headed by the Additional Secretary of the Ministry of Disaster Management and Relief (MoDMR) of Bangladesh, and includes representatives from the Department of Disaster Management (DDM), the Fire Service and Civil Defence of Bangladesh, the Ministry of Housing & Public Works (MoHPW), and the Statistics and Informatics Division (SID) of the Bangladesh Bureau of Statistics (BBS). The panel also includes national experts in seismic hazard and risk assessment from the University of Dhaka (DU), Bangladesh University of Engineering and Technology (BUET), and Jahangirnagar University (JU). The Geological Survey of Bangladesh, the Centre for Urban Studies (CUS), and United Nations Development Programme (UNDP) in Bangladesh are also represented on the panel of experts. Table 9-1 below lists the members of the technical advisory panel.

The technical advisory panel met four times between October 9th 2023 to January 31st 2024. Engagement with the panel began with an introductory meeting on October 9th, where UNDRR and GEM introduced the goals and objectives of the project, and the panel members introduced themselves and described their focus areas in the government, academia, or otherwise.

Table 9-1. Technical panel member list

Name	**Designation**	**Organisation**	**Contact**
Md. Hasan Sarwar	Additional Secretary	Ministry of Disaster Management and Relief (MoDMR)	rchmodmr@gmail.com
Kazi Wasi Uddin	Secretary	Ministry of Housing & Public Works	secretary@mohpw.gov.bd
Md. Asif Ahasan	Officer	Ministry of Housing & Public Works	a.ahasan75@gmail.com
Dr. Syed Humayun Akhter	Professor	Department of Geology, University of Dhaka	geology@du.ac.bd
Dr. Mehedi Ahmed Ansary	Professor	Department of Civil Engineering, Bangladesh University of Engineering and Technology	ansary@ce.buet.ac.bd

Dr. Raquib Ahsan	Professor	Department of Civil Engineering, Bangladesh University of Engineering and Technology	raquibahsan@ce.buet.ac.bd
Mohammad Elius Hossain	Director General (Additional Charge)	Geological Survey of Bangladesh	geologicalsurveybd@gmail.com
Brig. Gen. Nayeem Md. Shahidullah	Former Director General	Fire Service and Civil Defence	nayeem.shahidullah@gmail.com
Dr. Mohammad Shakil Akther	Professor	Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology	shakil@urp.buet.ac.bd
Sabbir Siddique	Technical Director and Bridge Design Engineer		sabbirsiddique@yahoo.com
Faria Sharmin	Bridge Design Engineer		fariasharmin07@gmail.com
Professor Mahbuba Nasreen	Professor & Co-Founder	Institute of Disaster Management and Vulnerability Studies, University of Dhaka	mnasreen@du.ac.bd
Professor Nazrul Islam, M.A.	Chairman	Centre for Urban Studies (CUS)	cus@dhaka.net
Prof. Dewan Mohammad Enamul Haque	Assistant Professor	Dhaka University	dewan.dsm@du.ac.bd

Dr. Khandakar Hasan Mahmud	Professor	Jahangirnagar University	khmmahmud@geography-juniv.edu.bd
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Netai Chandra Dey Sarker	Director (MIM)	Department Of Disaster Management, Govt of Bangladesh	dmim@ddm.gov.bd
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In depth technical discussions began with the second meeting, which was held on October 31st. The topics of discussion for the second session included the development of the probabilistic seismic hazard model for Bangladesh, and the development of the historical and hypothetical earthquake scenario set for Bangladesh presented by GEM. We also had two presentations from members of the technical panel in this session, including one on probabilistic seismic hazard assessment for Bangladesh by Prof. Dewan Mohammad Enamul Haque of Dhaka University, and the second by Mr. Sabbir Siddique and Ms. Faria Sharmin, also on the same subject.

The third session with the technical panel was conducted on November 30th, focusing on the development of the exposure and physical vulnerability models, and on socio-economic vulnerability modelling for Bangladesh. In this session, Mr. Dilder Hossain, project manager of the 2022 Population and Housing Census of Bangladesh, presented some of the key findings of the latest census that are relevant for the purposes of disaster risk assessment and mitigation efforts. We also invited Prof. Mahbuba Nasreen of Dhaka University to present some of her pioneering work on gender and social vulnerability in the context of disasters in Bangladesh.

A final online session with the technical panel was held in the last week of January, where we presented some of the preliminary results of the probabilistic seismic risk assessment at the upazila level, damage and fatality estimates for the scenario set, and earthquake-induced liquefaction hazard. Feedback and suggestions from the panel were continuously incorporated into the modelling workflows and outcomes of the project. The panel members were invited to participate in the final in-person workshops near the end of the project.

10 Dissemination and capacity building

In March 2024, with the support of UNDRR and the UN RC office in Bangladesh, we organized a series of meetings to present the findings of the earthquake risk assessment to a wide audience of different stakeholders. The initial two days were dedicated to introducing the project, its results, and objectives to key government stakeholders. These sessions covered a range of topics, including the tectonic setting and earthquake scenarios, probabilistic seismic hazard assessment and models, key insights from the 2022 national census, exposure of buildings and populations, social vulnerability modelling, and historical and potential future earthquake scenarios in Bangladesh.

Firstly, we presented a comprehensive overview of the project activities and key outcomes to the Ministry of Disaster Management and Relief. On the second day, we presented the outcomes of all components of the project to a wider audience of government officials, including representatives from the Geological Survey of Bangladesh (GSB), Ministry of Housing and Public Works (MoPHW), Urban Development Directorate (UDD), Bangladesh Meteorological Department (BMD), and Bangladesh Fire Service & Civil Defence (FSCD). Figure 10-1 below shows some pictures from the second day of presentations.

Figure 10-1. Pictures from Day 2 of the dissemination efforts

On the third day, a capacity development session was organized for thirty-five Ms and PhD students from the University of Dhaka (DU), Bangladesh University of Professionals (BUP), Bangladesh University of Engineering and Technology (BUET), and Jahangirnagar University. GEM provided technical training on the OpenQuake engine, which is crucial for modeling earthquakes and estimating damages, economic losses, and casualties. This session prepared the students with the necessary tools and knowledge for future academic and research endeavours related to earthquake risk reduction. Figure 10-2 below shows some pictures from the hands-on training workshop for university students on the third day.

Figure 10-2. Pictures from the hands-on training workshop for university students

The series concluded on the fourth day by presenting the findings to the humanitarian and donor communities, inviting their feedback and suggestions on using the data for preparedness strategies. The honourable Secretary of MoDMR, Mr. Md Kamrul Hasan NDC, delivering the opening remarks on this day (Figure 10-3), and WFP country director, Mr. Dom Scalpelli delivered a keynote introducing the context of the project on behalf of the UN Resident Coordinator (Figure 10-4).

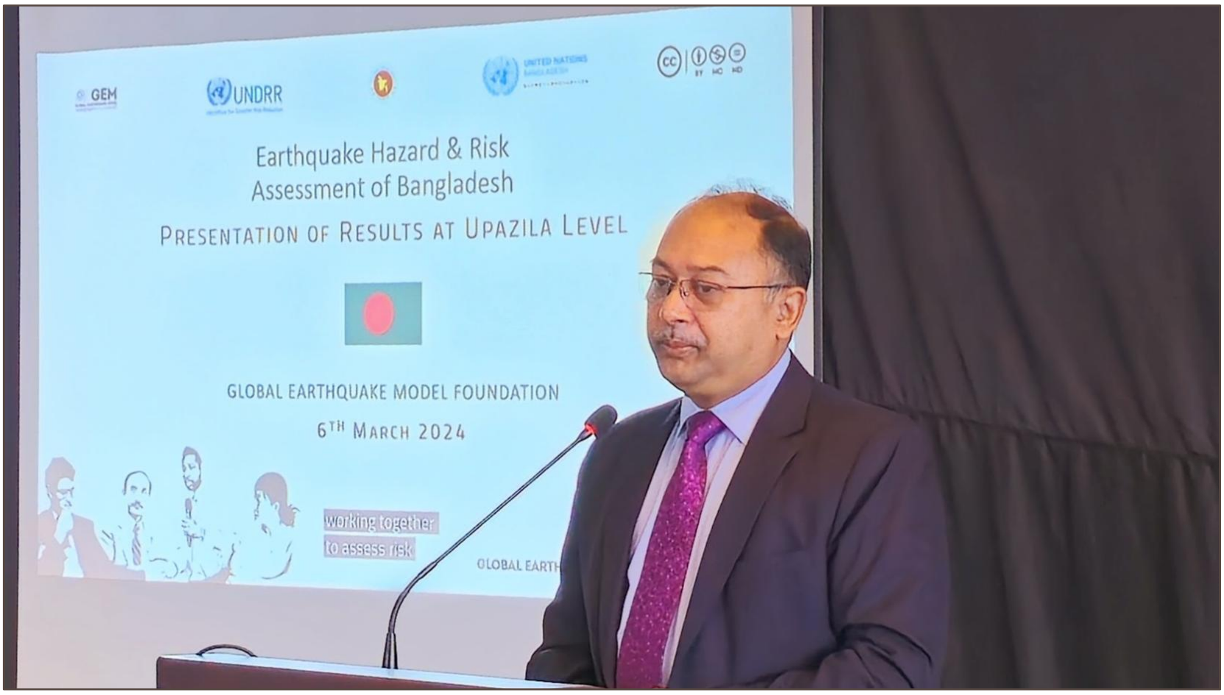

Figure 10-3. Secretary, MoDMR, Mr. Md Kamrul Hasan NDC, delivering the opening remarks on Day 4

Figure 10-4. Dom Scalpelli, WFP Country Director, delivering remarks on behalf of UN RC

Mr. Scalpelli's highly informative points regarding the importance of this work are printed below, as a fitting conclusion to this report:

Leveraging Sub-National Earthquake Risk Assessment for a Resilient Bangladesh

The sub-national earthquake risk assessment in Bangladesh holds immense potential as a cornerstone for informed decision-making across various sectors, bolstering the nation's preparedness and resilience.

Cultivating public awareness: The assessment will serve as a vital tool to educate the public and policymakers about potential earthquake severity, highlighting probable magnitudes, tremor frequencies, and worst-case scenarios, and empowering individuals and authorities to take preparedness measures.

Empowerment of land-use planners: The planners will receive a comprehensive understanding of earthquake-prone areas, empowering them to strategically distribute resources, prioritize community safety, and potentially restrict development in high-risk zones. Similarly, spatial planners can use this knowledge to design community layouts, ensuring critical facilities and structures are situated in less susceptible areas.

Strengthening existing infrastructure: The assessment will enable prioritization of retrofitting efforts for crucial buildings like hospitals, emergency response centers, and government offices, ensuring their operational continuity and easing swift recovery post-earthquake.

Strategic infrastructure investment: Investors can prioritize projects and distribute resources efficiently by pinpointing areas with lower seismic risks, contributing to the development of a more resilient infrastructure network.

Informed urban planning: Real estate development can be bolstered by incorporating earthquake considerations, informing the development of building codes emphasizing structural integrity, setting up designated emergency evacuation routes, and creating safe gathering spaces post-earthquake.

Sector-specific planning: The assessment's impact will extend beyond immediate measures, enhancing healthcare, education, and transportation planning, ensuring a more comprehensive and well-coordinated response to disaster events.

Earthquake preparedness extends beyond mitigation: This assessment will strengthen contingency planning by tailoring emergency response measures to find vulnerabilities, resulting in a swifter and more effective response, potentially saving lives. Search and rescue operations will become more efficient with insights from the assessment, directing valuable time and resources toward high-risk zones requiring immediate intervention.

Foster Improved Civil-Military Coordination: It will encourage a collaborative and effective response during emergencies by setting up a shared understanding of earthquake risks and using all available resources efficiently to minimize seismic event impact.