



Bhutan Earthquake Impact Planning (EquIP)

Modelling the impacts from potential future earthquakes



Executive Summary

The Himalayan region has amongst the highest earthquake risk globally, with recent moderate-sized events resulting in tens of thousands of casualties. Despite this, understanding of earthquake risk in the region is limited, particularly in Bhutan, where research on both past and future earthquakes is also limited. While recent work has clearly shown the potential for large earthquakes in the Himalayan region, the impacts from potential future earthquakes in Bhutan is entirely unknown. The Equip-Bhutan project provides the first ever model of impacts from potential earthquakes in Bhutan, accounting for multiple possible eventualities to inform government and humanitarian planning for a future event. In total, 110 different earthquake scenarios are considered, and the number of fatalities, serious injuries and displaced people are modelled.

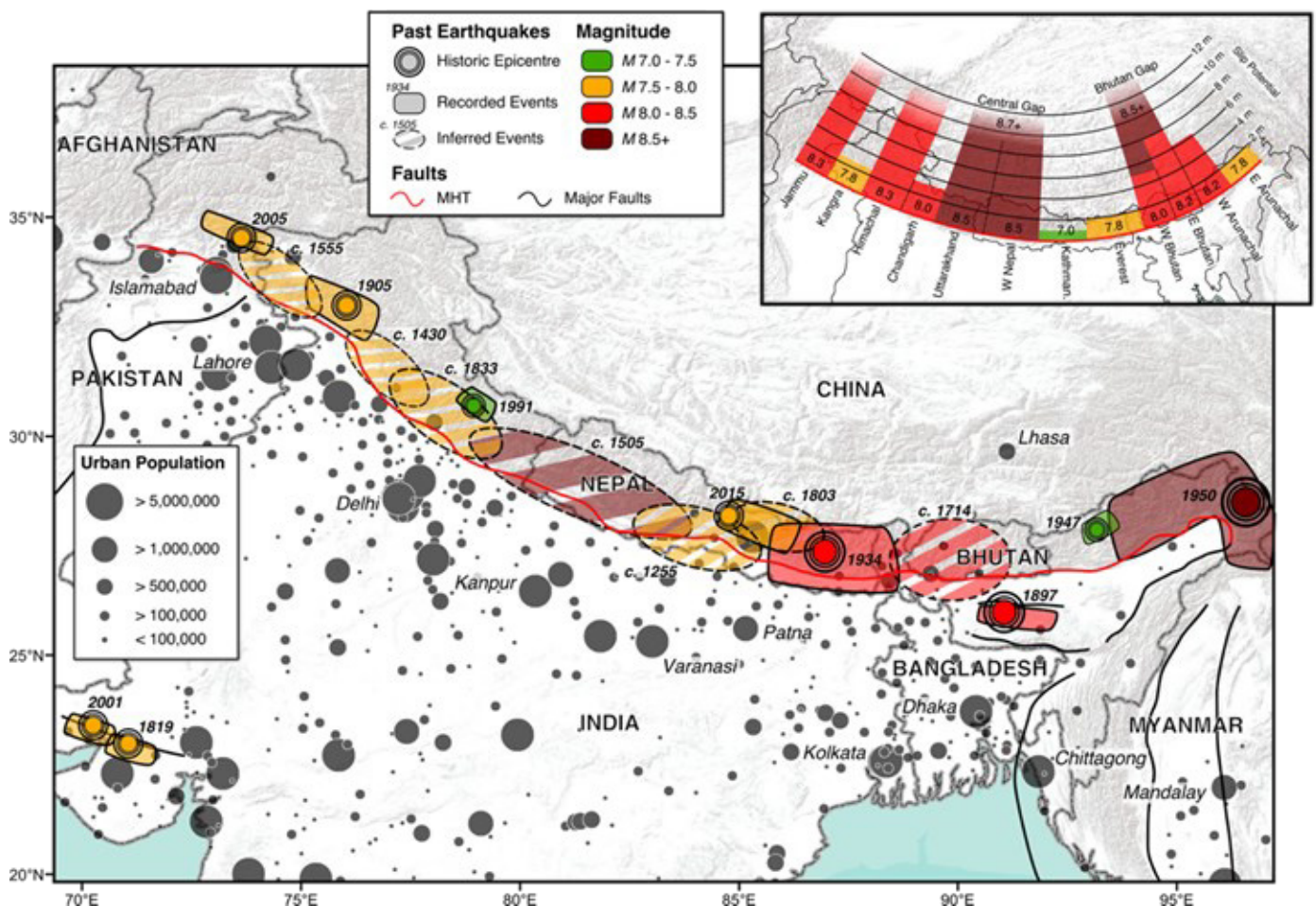
The results show that in the worst-case there could be more than 9000 fatalities, 10,000 serious injuries, and 45,000 displaced nationally. There are 5 different scenarios in which more than 5000 fatalities occur nationally, and 3 scenarios with more than 5000 injuries, but at least 13 scenarios with more than 10,000 displaced. Earthquake risk is heavily concentrated in the more populous Western Bhutan where impacts are typically 3x larger than in Eastern Bhutan. Wangdue Phodrang and Punakha Dzongkhags have the highest risk nationally since the majority of damaging scenarios result in more than 500 fatalities and 1000 displaced in each Dzongkhag. The amount of damage an individual Dzongkhag experiences is close to its maximum for M 7.5 earthquakes and stronger earthquakes do not produce significantly more damage within a Dzongkhag. However, nationally, stronger earthquakes impact bigger areas and therefore have much larger total impacts.

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I. Context

The Himalayan region is one of the most at-risk regions for earthquake disasters globally¹. During the last 1000 years, at least 15 large earthquakes have occurred in the region (Fig. 1)²⁻⁶. Several of these had magnitudes (M) > 8 making them at least twice as strong as the 2015 earthquake in Nepal; the largest was M 8.8, making it 32 times stronger than the 2015 earthquake⁷. While recent earthquakes have had comparatively moderate magnitudes, they have still resulted in tens of thousands of fatalities⁶, highlighting the risk from larger earthquakes in the region. Despite this, the risk is poorly understood compared to other earthquake-prone regions globally. This is especially true for Bhutan, where research on earthquake risk is notably sparse.

Figure 01: Previous earthquakes and (inset) the largest earthquake magnitude possible in different regions of the Himalaya



Whilst very large earthquakes have occurred elsewhere in the Himalaya, until recently there has been limited evidence of past large earthquakes in Bhutan. Moreover, today, the number of minor ($M < 4$) earthquakes are significantly lower in Bhutan compared to the rest of the Himalaya^{8,9}. As a result, it has been suggested that Bhutan is somehow safe from future large earthquakes. However, this is not the case. Recent work^{9,10} has shown two very large earthquakes occurred near Bhutan in 1714 and 1897 (Fig. 1), with the more recent event temporarily reducing the stress on faults in Bhutan, resulting in the low numbers of minor earthquakes today. Consequently, it is now understood that very large earthquakes can and have occurred in Bhutan. Yet despite this evidence, the potential magnitude, location, and impacts from a future earthquake remain unknown. The *EquiP-Bhutan* Project has therefore modelled the likely impacts that would result from a wide range of different earthquake scenarios affecting Bhutan in order to better understand the potential impacts of a large earthquake affecting the country and to help inform both the Royal Government of Bhutan and the humanitarian communities planning for such an event.

II.Approach

Using population and housing data from the *2017 Population and Housing Census of Bhutan*, the study modelled the number of building collapses, fatalities, serious injuries, and displaced persons. The number of building collapses is controlled by the construction method and wall material¹¹. Because there have been relatively few significant earthquakes in Bhutan over the last several decades, there are few records of building damage from earthquakes in Bhutan to base the study on. The study therefore used data from Nepal due to the markedly similar construction styles and the wealth of data on earthquake building damage¹¹, supplemented with global data from the USGS¹². Whilst building techniques in Nepal are similar to those in Bhutan, there are notable differences, and some building types in Bhutan are not commonly found in Nepal (e.g. rammed earth structures) meaning the results may not be entirely accurate for Bhutanese conditions. However, with limited local data, using data from Nepal provides the best current option.

Fatalities and serious injuries in collapsed buildings are also strongly influenced by the building's wall material, and records from fatal earthquakes around the world¹³ were used to provide broad-scale estimates of the fatality and injury rates for each building type. The study also considered the effect of time of day on the modelled losses since night-time earthquakes have been shown to be significantly more fatal^{14,15}. Estimates of the number of people indoors during the day and night were derived in consultation with various technical experts from the Royal Government of Bhutan and humanitarian community during a 1-day workshop.

Because the size, location, and type of earthquake that might affect Bhutan remains unknown, the study modelled a large range of different earthquakes in order to account for multiple scenarios. The study considered earthquakes ranging from *M* 7.0 (16 times weaker than the Nepal 2015 earthquake) to *M* 8.5 (11 times stronger), encompassing a wide range of realistic future scenarios. In total, both night and daytime impacts were modelled for 55 different earthquakes, giving 110 realistic possible future scenarios for Bhutan. From these, the study identified key statistics for both the whole country and individual Dzongkhags, such as the worst-case scenario and average impacts.

III.Key Findings

National-level findings:

- ◆ In the worst-case, there could be at least 9000 fatalities throughout Bhutan, with 10,000 serious injuries requiring urgent hospital care and 40,000 displaced people (Fig. 2). This scenario is for a night-time earthquake but if it occurred during the day, there would be half as many fatalities and injuries, but the number of displaced people would increase to 45,000 (Fig. 3).
- ◆ Of the 110 possible scenarios, 65 are large enough to cause at least 1 fatality in Bhutan but of these, 15 result in > 1000 fatalities and 5 result in > 5000 fatalities.
- ◆ There are 70 scenarios large enough to cause serious injuries and displaced people, with at least 17 scenarios resulting in > 1000 serious injuries and > 5000 displaced. However, there are 13 different scenarios that result in > 10,000 displaced people.
- ◆ Earthquakes that occur in Western Bhutan result in at least three times more damage than if they occurred in Eastern Bhutan. In fact, a moderate earthquake striking Western Bhutan may result in more damage than a much larger earthquake striking Eastern Bhutan. However, large earthquakes in Eastern Bhutan can still result in thousands of fatalities and serious injuries, and tens of thousands of displaced people.
- ◆ Earthquakes in Western Bhutan typically cause more fatalities than serious injuries (Fig. 3) due to the large number of adobe buildings in the region. These structures have extremely large fatality rates meaning most people inside these structures when they collapse would be killed leaving relatively few injured survivors.

Figure 02: The worst-case earthquake impacts for each Dzongkhag and Thromde*

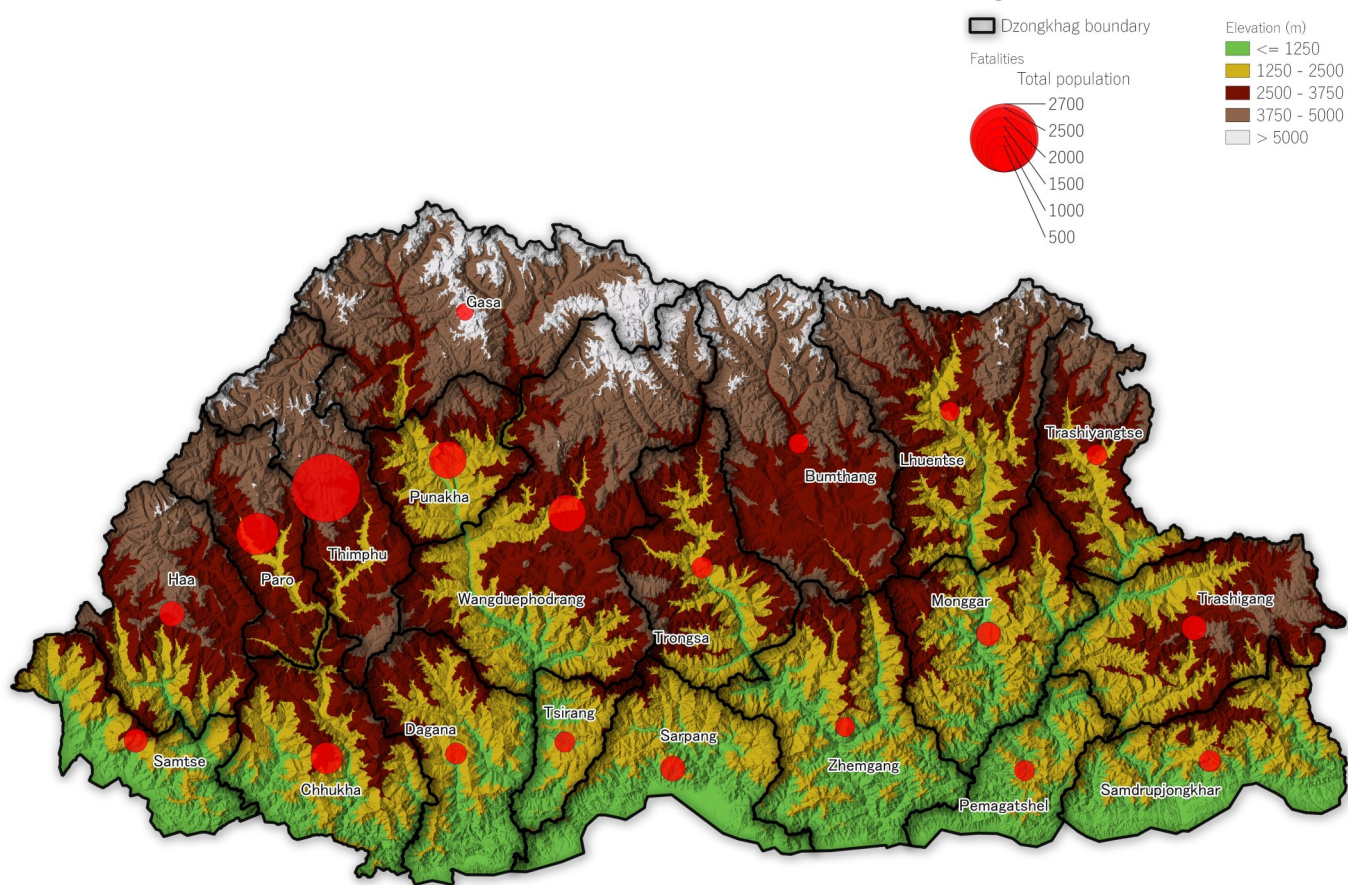
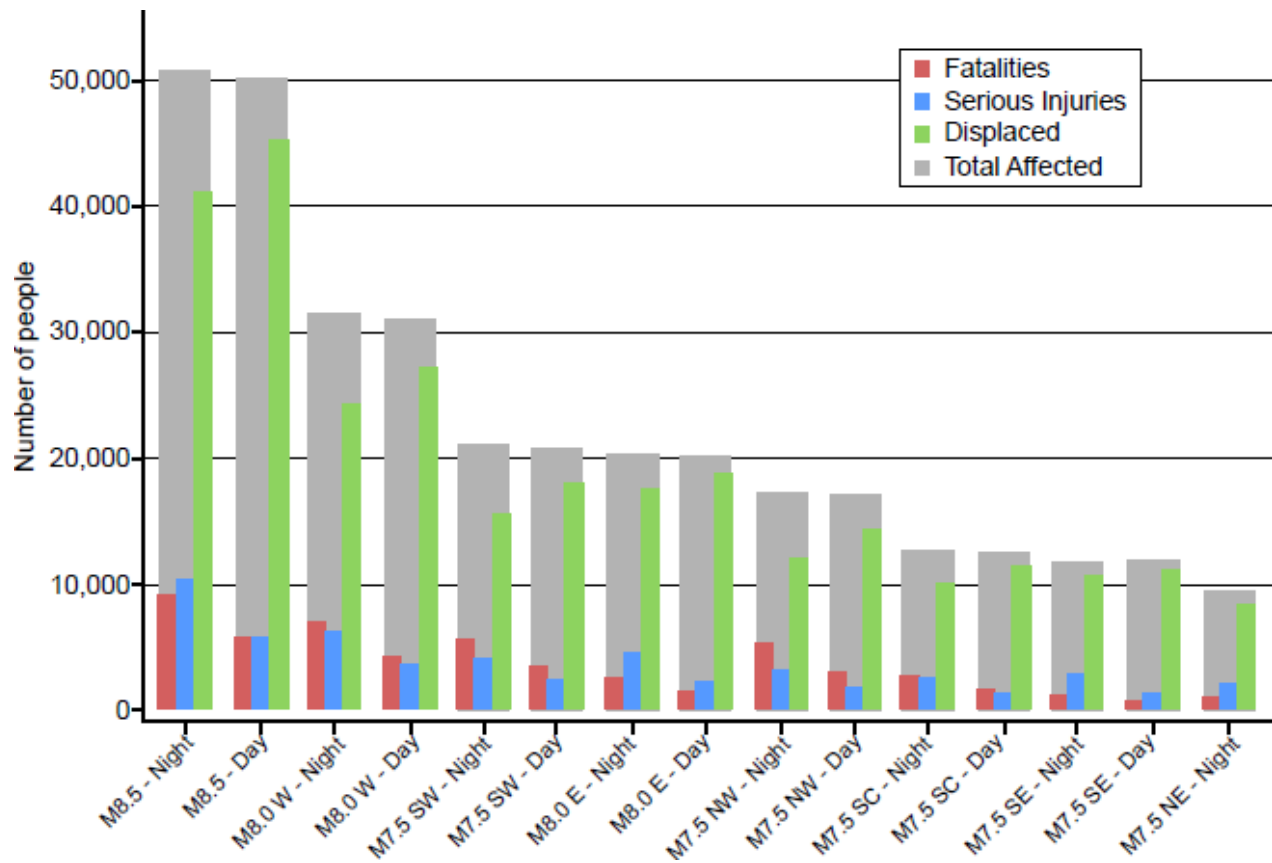


Figure 03: Summary of the impacts from the 15 scenarios with the largest number of total affected people, showing the numbers of fatalities,



* These numbers would not all occur together in the same earthquake.

Dzongkhag-level findings:

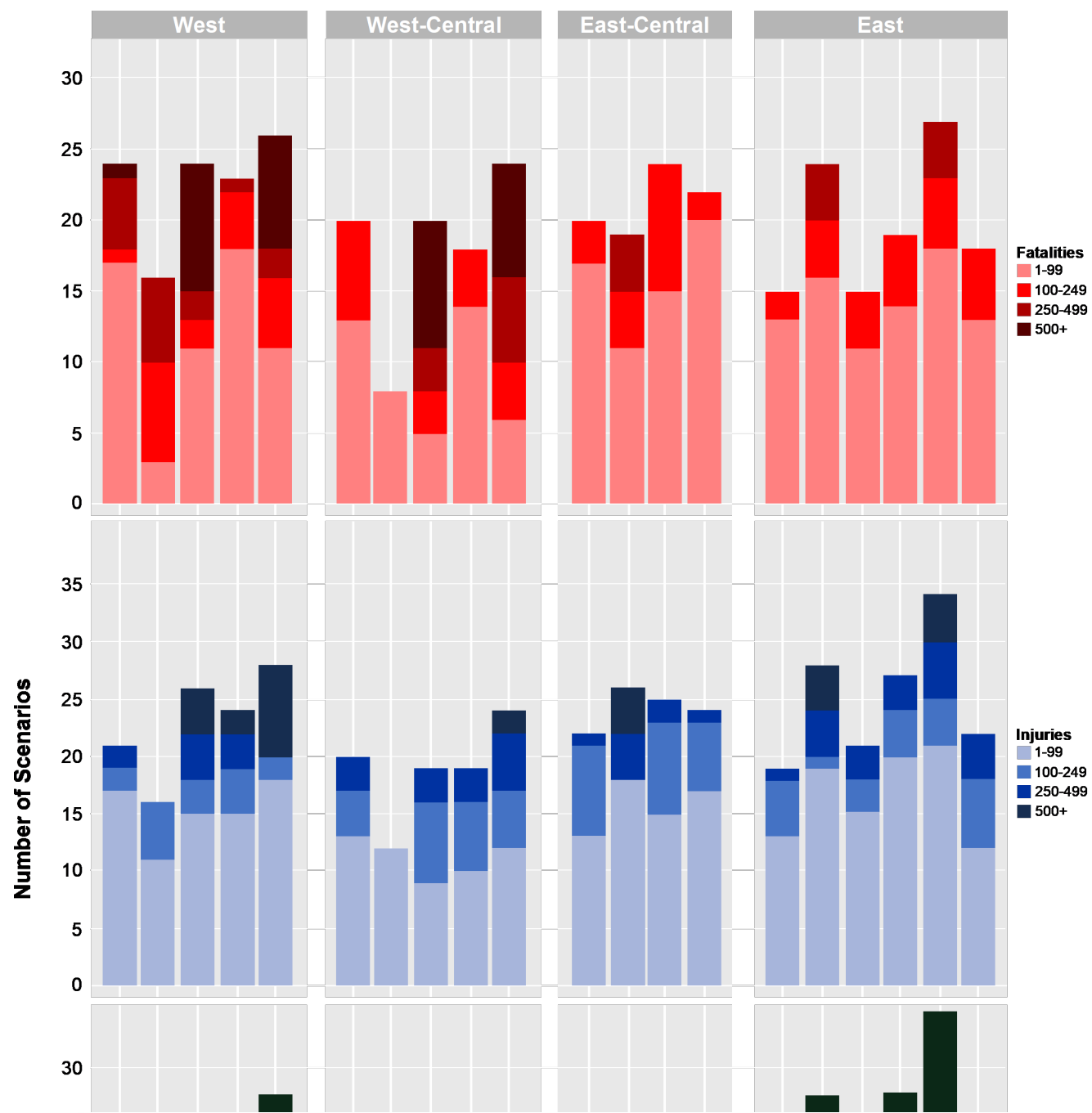
- ♦ Thimphu has the highest worst-case impacts of any Dzongkhag. In the worst-case, there could be at least 1500 fatalities, 1500 serious injuries, and 6500 displaced people (Fig. 2). However, there are just 28 scenarios that result in severe damage in Thimphu and the majority result in small numbers of fatalities, injuries, and displaced people (Fig. 4).
- ♦ However, despite not having the largest worst-case, impacts are most consistently high in Punakha and Wangdue Phodrang, where 45% of all damaging scenarios cause > 500 fatalities and > 1000 displaced people (Fig. 4). Serious injuries in both are comparatively low however, because the dominant building types have high fatality rates, meaning most exposed people are killed leaving relatively few survivors. Wangdue Phodrang and Punakha are therefore considered the highest risk Dzongkhags in Bhutan.
- ♦ Within each Dzongkhag, a nearby *M* 7.5 earthquake may result in almost as much damage as an *M* 8.5 earthquake despite being 32 times weaker (Fig. 5). Nationally, an *M* 8.5 earthquake causes far greater total damage because it impacts multiple Dzongkhags simultaneously. However, within each Dzongkhag, the amount of damage sustained does not increase substantially for earthquakes bigger than *M* 7.5 (Fig. 5).
- ♦ Within Bhutan, earthquake risk is most highly concentrated in Wangdue Phodrang, Punakha, Thimphu, and Paro Dzongkhags where 33 of the most at-risk Gewogs/Thromdes are located, comprising 35% of the national population.
- ♦ Within these four Dzongkhags, earthquake risk is most heavily concentrated in the urban Gewogs and Thromdes, particularly Thimphu Thromde, Wangdue Phodrang Town, Paro Town, and Punakha Town. The large populations mean these urban areas typically account for at least 20% of the entire Dzongkhag's impacts. Thimphu Thromde is at especially high risk, often accounting for > 70% of the fatalities, > 85% of the injuries, and > 80% of the displaced population across Thimphu Dzongkhag. However, Thimphu Thromde accounts for ~80% of the population of Thimphu Dzongkhag, highlighting that recent earthquake strengthening efforts in the city are reducing fatalities.



Photo 1: A house damaged by an earthquake

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Figure 04: Number of scenarios producing various scales of fatalities, severe injuries, and displaced people per Dzongkhag



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