# Bhutan Earthquake Impact Planning (EquIP)

**Modelling the impacts from potential future earthquakes**

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# 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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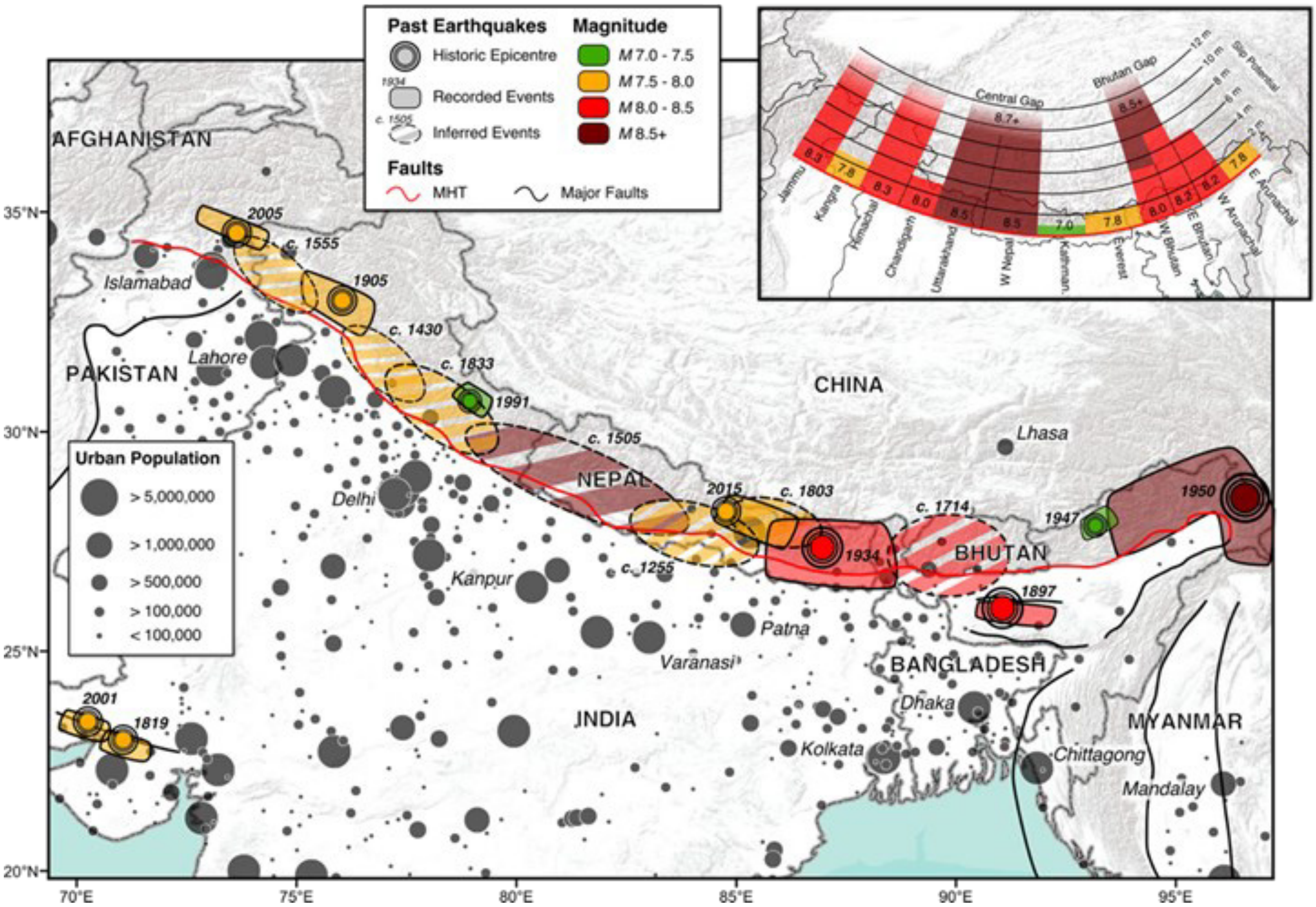
# I. Context

The Himalayan region is one of the most at-risk regions for earthquake disasters globally[1]. 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 earthquake[7]. While recent earthquakes have had comparatively moderate magnitudes, they have still resulted in tens of thousands of fatalities[6], 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 of 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 material[11]. 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 damage[11], supplemented with global data from the USGS[12]. 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 world[13] 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.

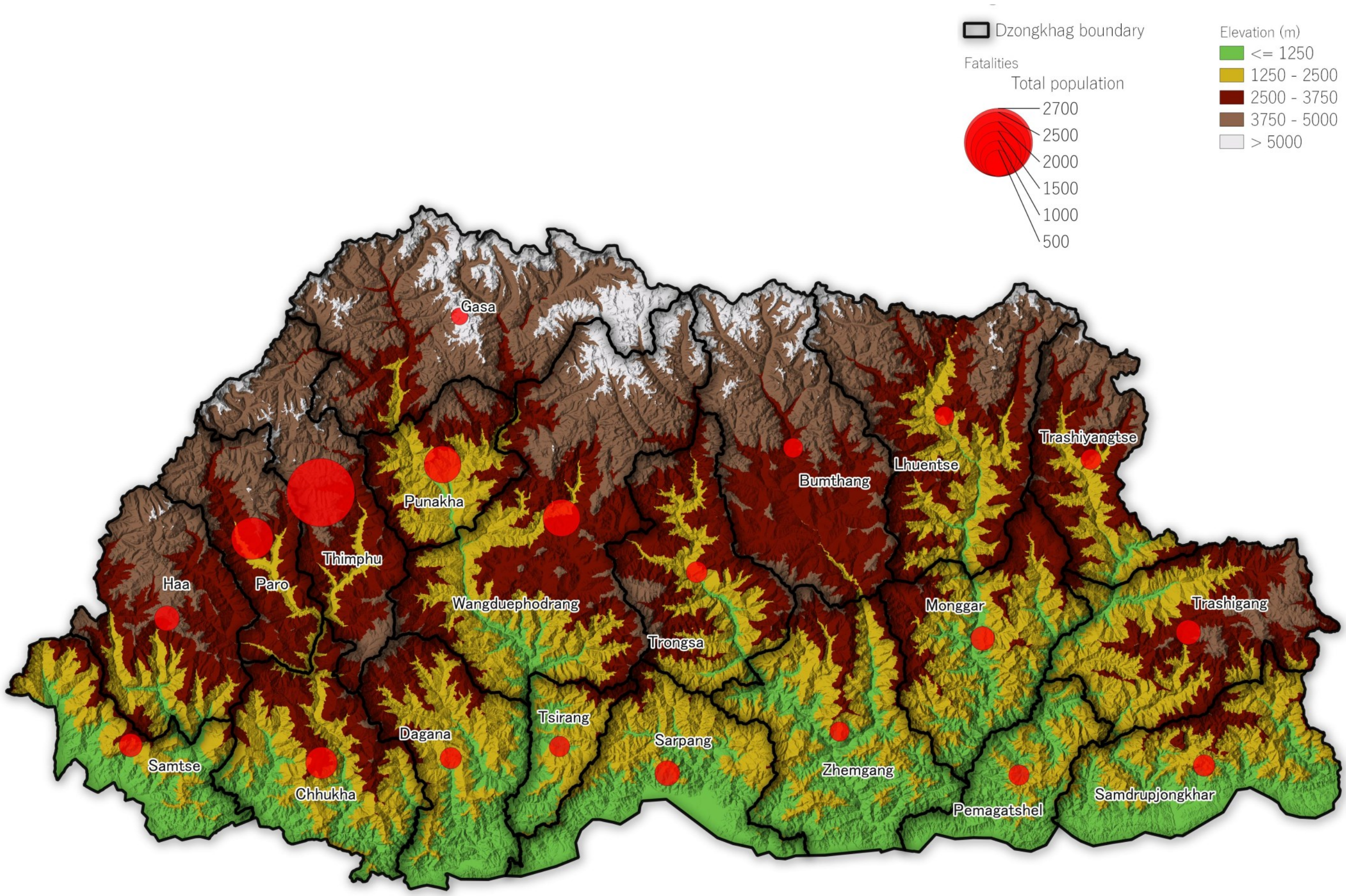
Because the size, location, and type of earthquake that might affect Bhutan remains unknown, the study modelled a large range of different earthquakes in order to account for multiple scenarios. The study considered earthquakes ranging from *M* 7.0 (16 times weaker than the Nepal 2015 earthquake) to *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

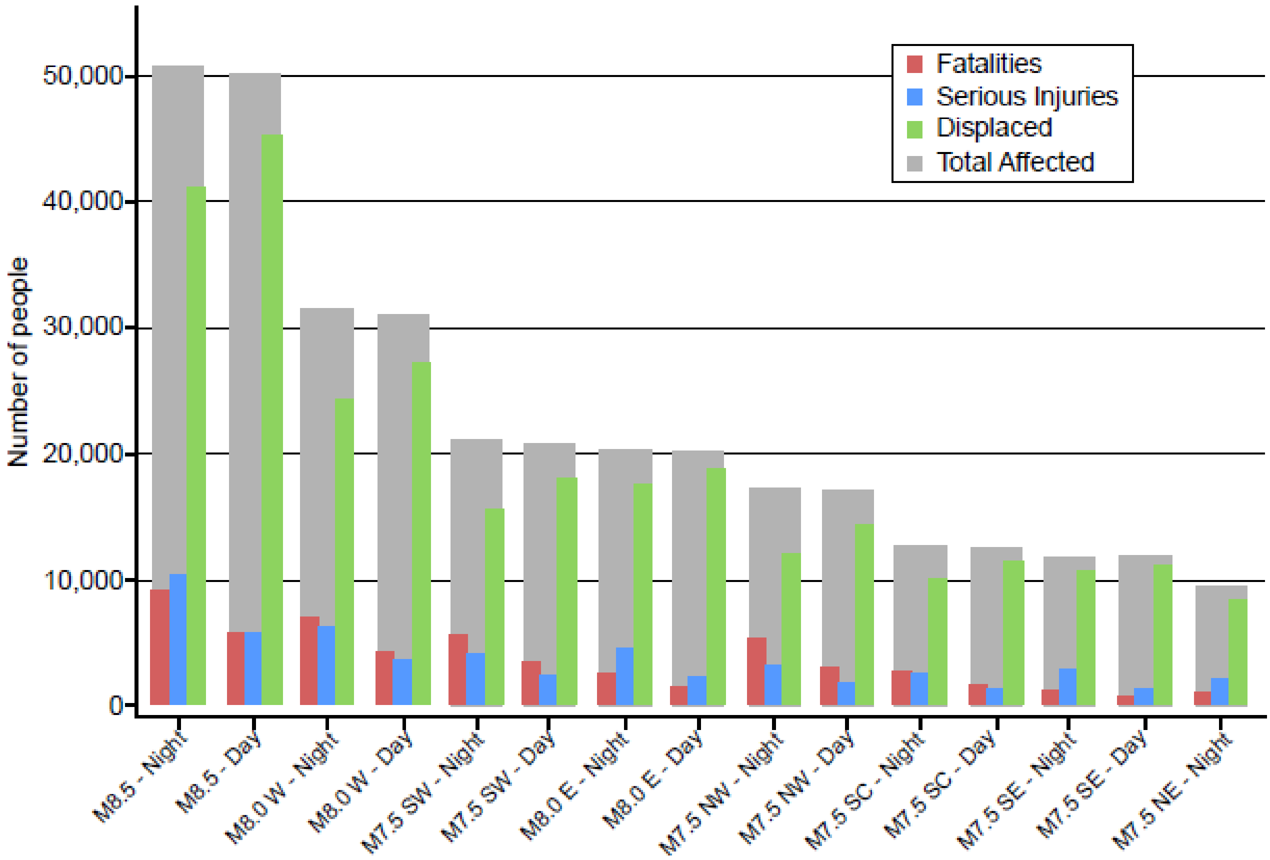
### *National-level findings:*

- 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**

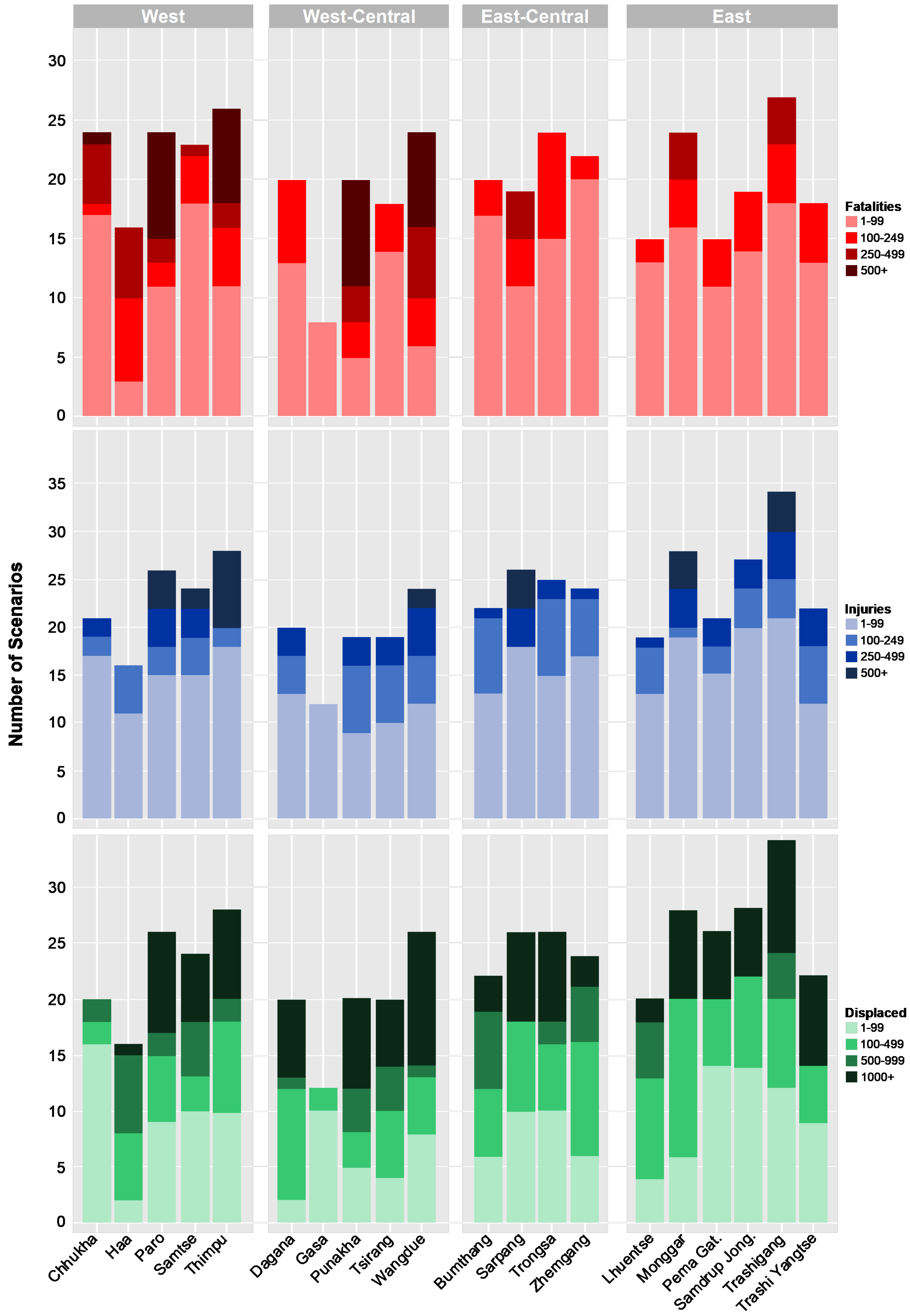
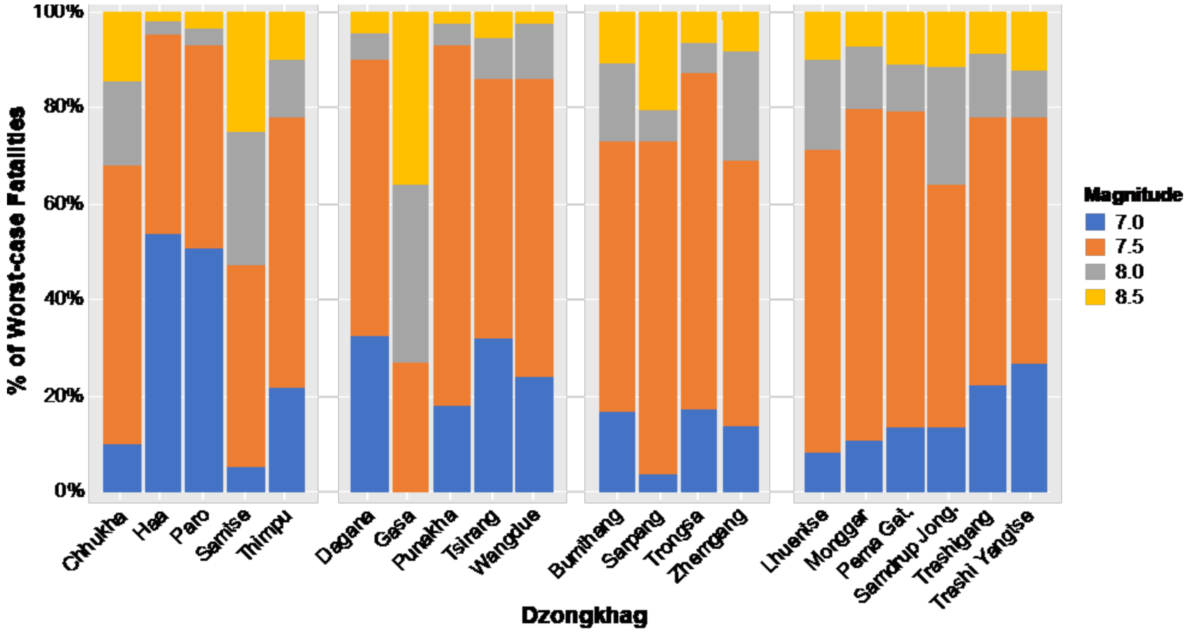


**Figure 05: Level of damage caused by different magnitude earthquakes for each Dzongkhag. The majority of damage is done by M 7.5 earthquakes (orange bars) with typically little extra damage being done by M 8.0 (grey) and M 8.5 earthquakes (yellow)**




# IV.Recommendations

The report and its findings lead to a series of recommendations which should be considered in order to both reduce the earthquake risk facing Bhutan and improve the general understanding of earthquake risk. The recommendations cover a broad range of topics and suggest ways in which the risk could most effectively be reduced. These are presented in no particular order but instead are grouped into key themes:

### *Emergency Preparedness and Response*

1. There is an important need to develop and practice response coordination amongst the humanitarian clusters through the use of periodic simulation exercises (SIMEX) to identify current gaps and to improve readiness for earthquake preparedness and response.
2. The study findings should serve as an important reminder of the need to continually update both individual sector and district disaster contingency plans.
3. There is an urgent need for the development of Standard Operating Procedures for a primarily air-based humanitarian response. In particular, there needs to be a focus on the development of a Humanitarian Staging Area at Paro International Airport along with Forward Logistics Bases throughout the country in order to effectively respond in different regions.
4. There should be greater planning for necessary early actions related to emergency facilities in the wake of an earthquake such as prepositioning of water storage, electricity supply, and food and medicine storage. Engaging with the Nepal National Reconstruction Agency to discuss key early actions following the 2015 earthquake would be beneficial.
5. Greater planning for the temporary shelter needs of tens of thousands of displaced people across Bhutan is urgently needed, with a particular focus on how the needs of these displaced people would vary with time of year (e.g. winter versus monsoon season). This is particularly important for urban areas such as Thimphu Thromde where large numbers of local displaced people are anticipated and where rural displaced people may migrate to following an earthquake as seen in other disasters in the region.

### *Public Awareness & Community Resilience*

6. Increasing public awareness and understanding of the earthquake risk in Bhutan is expected to be beneficial for both local resilience and preparedness. This could be undertaken via the DeSuung who are well placed to engage in community earthquake preparedness activities.
7. In line with (11) above, working to strengthen earthquake resilience among at-risk communities at the Dzongkhag- and Gewog-level is recommended. This could take the form of local emergency response plans, shelter planning, and/or community-based resilience actions but should be locally developed and appropriate.

### *Data Needs and Availability*

8. There should be continued collaboration efforts for the creation of comprehensive and consistent information systems on damage and societal responses in previous earthquakes to aid planning for future disasters.
9. Bhutan-specific data on earthquake hazard and building response to shaking is extremely limited and therefore current studies must rely on representative data from locations such as Nepal. A concerted effort to collect and/or create necessary data is essential for improved understanding of earthquake risk in Bhutan (see (1) above).
10. The present study only considers damage arising from ground shaking during an earthquake. However, earthquakes trigger many other hazards including landslides and Glacial Lake Outburst Floods (GLOFs). Continued research into the other hazards an earthquake may trigger, and their associated impacts, is essential to more fully understand the earthquake risk facing Bhutan.

### *Building Codes*

11. The lack of Bhutan-specific data on building performance during an earthquake limits the conclusions of this and future studies, which are currently based on data from Nepal. There is an urgent need for further detailed scientific and engineering studies into the specific performance of Bhutanese structures during earthquake shaking such as the 'Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan' project between JICA & the Department of Culture.
12. Efforts to reduce earthquake risk in Bhutan should prioritise reducing risk in the urban areas of western Bhutan, particularly Thimphu Thromde, Wangdue Phodrang Town, Punakha Town, and Paro Town. This would be most effectively accomplished by further increasing the resilience of new and existing buildings in these locations, especially adobe and reinforced concrete structures. Further efforts to reduce earthquake risk should also focus on reducing food insecurity in the more rural areas of Wangdue Phodrang Dzongkhag since this dramatically effects earthquake resilience here.
13. Continued development, refinement, and enforcement of the existing building codes in Bhutan is essential for mitigating the number of building collapses and consequent impacts in a future earthquake. The development of codes for the strengthening and retrofit of existing structures is also essential.
14. Further investment in research into earthquake-safe construction practices would be beneficial including research into design standards in other earthquake-prone nations. Engaging with the Nepal National Reconstruction Agency to discuss and understand their learnings from the 2015 earthquake would also help Bhutan prepare for a future earthquake.
15. There is an urgent need for a targeted assessment of the current condition of all essential buildings, such as schools and hospitals, in terms of their earthquake safety. Retrofitting those that do not meet current or future standards should be considered a national priority for earthquake risk reduction.
16. Greater investment in the training of local masons in retrofitting and 'build-back-better' techniques along with a series of information campaigns to inform the public of the benefits and often less-than-expected costs of retrofit could lead to far greater uptake of building retrofitting nationally.

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