UCLouvain
Institut de recherche santé et société

Centre for Research on the Epidemiology of Disasters
CRED

Fostering Hospital Resilience to Disasters

Lessons from a Tertiary Hospital in Nepal

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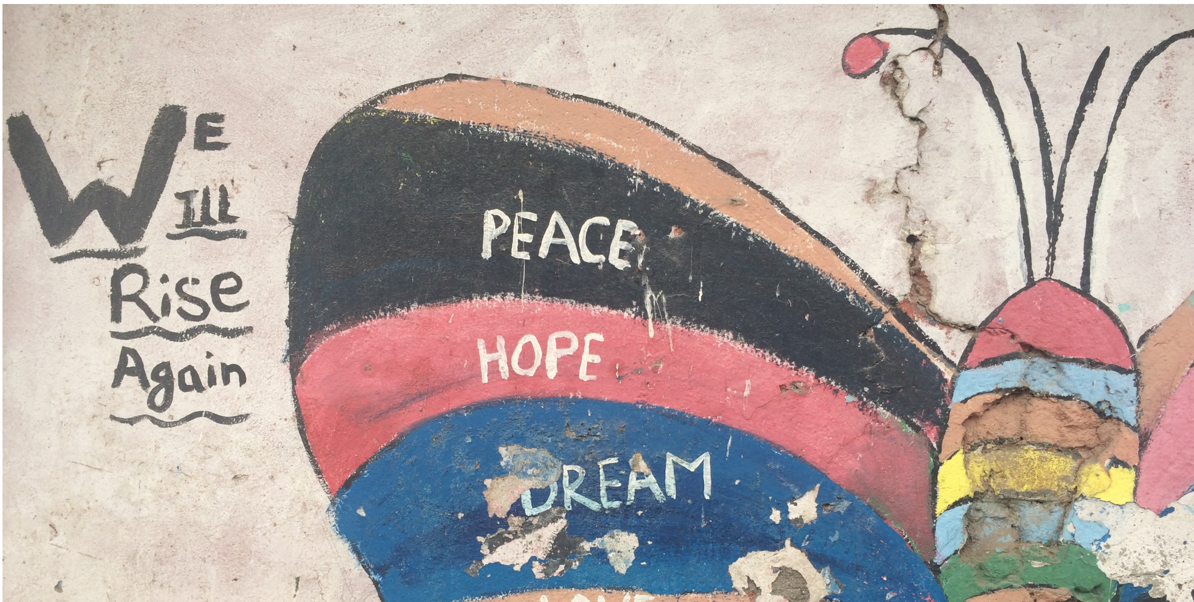
Février 2021

Thèse présentée en vue de l'obtention du grade
de docteur en sciences de la santé publique

Secteur des sciences de la santé



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Maria Moitinho de Almeida joined CRED in 2017 to start her PhD. She has a Medical Degree from the University of Lisbon, Portugal, and holds a joint Master's Degree in Public Health in Disasters from the Karolinska Institute and the University of Oviedo. Maria has worked as a general doctor in a hospital and as a public health medical resident in Lisbon. Her current research focuses on improving health resilience and response in humanitarian settings.

Les hôpitaux résilients sont essentiels pour réduire l'impact humain des désastres. Il y a peu d'évidence sur l'impact des désastres sur les hôpitaux, et la recherche sur leur résilience vient plutôt de contextes pré-désastres, ne capturant pas les réalités post-désastre. Cette thèse étudie l'impact d'un grand tremblement de terre sur un hôpital tertiaire au Népal et explore ses mécanismes de résilience, en utilisant une combinaison de méthodes quantitatives et qualitatives. Les conclusions majeures sont : i) le tremblement de terre a produit des hospitalisations prolongées; ii) la fonction de l'hôpital a été affectée et les soins programmés perturbés; iii) la résilience de l'hôpital était influencée par des adaptations émergentes et par la résilience de chaque travailleur, qui dépendait de trouver un sens à leurs expériences, de se sentir en sécurité, et d'un sens d'appartenance. Nous terminons cette thèse avec des recommandations pour améliorer la résilience des services de soins.

Resilient hospitals are essential to reduce the human impact of disasters. The evidence on the disaster impact on hospitals is limited, and research on hospital resilience is mostly from pre-disaster phases, and does not portray post-disaster realities. This dissertation investigates the impact of a high-magnitude earthquake on a tertiary hospital in Nepal and explores resilience mechanisms, using a combination of quantitative and qualitative methodologies. The key findings are: i) the earthquake produced resource-intensive conditions that required lengthy in-hospital treatment; ii) the hospital's function was affected and the provision of elective care was disrupted; iii) the hospital's resilience was highly influenced by emerging adaptations and on resilience of individual staff, which depended of meaningfulness, sense of safety, and sense of belonging. We finish the dissertation with recommendations to improve resilience of health facilities and reduce the human impact of disasters.

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Thesis submitted in fulfilment of the requirements for the degree of

Doctor in Public Health

Centre for Research on the Epidemiology of Disasters, CRED

Institute of Health and Society, IRSS

Université catholique de Louvain, UCLouvain

Brussels, Belgium

February 2021

"Après le tremblement de terre qui avait détruit les trois quarts de Lisbonne, les sages du pays n'avaient pas trouvé un moyen plus efficace pour prévenir une ruine totale que de donner au peuple un bel auto-da-fé; il était décidé par l'université de Coïmbre que le spectacle de quelques personnes brûlées à petit feu, en grande cérémonie, est un secret infaillible pour empêcher la terre de trembler."

Voltaire, in *Candide* (1759)

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To all the people who have suffered from disasters and conflicts,

To patients who have died in unfair suffering and in the absence of empathy,

And to students, who always teach me more than they learn from me.

Acknowledgements

This thesis exists thanks to the faith deposited in me by my promoters Prof. Debarati Guha-Sapir and Prof. Isabelle Aujoulat. Through her creativity and constant urge to challenge herself and others, Debby energized me to get out of my comfort zone and explore new topics, methods, and skills. Isabelle's work ethics and high scientific demands inspired me to ensure my project is meaningful not only to science but also to those who contributed or who benefit from it. Thank you, Debby and Isabelle, for your constant support, your admirable collaborative PhD supervision, and for encouraging me to work independently but value scientific collaborations – I will be forever grateful. I am also thankful to the steering committee and the jury members for their time and involvement in improving the quality of the thesis, and for enhancing my research skills: Prof. Niko Speybroeck, Prof. Jean Macq, Prof. Philippe Donnen, Dr. Joris van Loenhout, Prof. Ali Ardalan, and Prof. Johan von Schreeb. And thank you Prof. Jean-Marie Degryse, for your constructive insights during my confirmation meeting.

This dissertation would not have been possible without the admirable supervision from Prof. Deepak Mahara in Nepal, and the invaluable collaboration with Dr. Sunil Thapa and Mr. KC Kumar. They were extremely welcoming during my trips to Nepal, and never made me feel like a nuisance even if I took much of their time. Dr. Ravikant Singh was central to the success of this partnership, and working with him on different occasions was an amazing learning experience. I am also forever grateful for the support given by the administration and archiving teams in Nepal, as well as to all the staff who participated in the interviews. Namaste!

I am thankful to all CRED team members who made this PhD path much easier: Alexandria, Benjamin, Kirsten, Joris, Matthias, Max, Nima, Pascaline, Regina, Remi, Shivani, Tefera, Thomas, Valentin, Virginia, and Yasemin. I am especially indebted to Joris van Loenhout for his close support and guidance throughout the PhD, and for his kindness and dedication. Benjamin is also an excellent colleague and travel companion, and his thorough data management and analysis work greatly contributed to the quality of my research. Kirsten, Joris, and Thomas, thank you for revising the final draft of the thesis, and thank you Alexandria for your support in the writing process – including the organization of the writing sessions! #MerciCREDies for the unforgettable moments.

My CORSCIrss colleagues: Nora, Ségolène, Antoine, Olivier, Marie, Camille, Charlotte, Lucia and François-Xavier. Your dedication to improve the working environment for researchers inspired me to do the same. I am also thankful to Prof. Jean-Marie Degryse and Prof. Sandy Tubeuf for their efforts to improve the quality of the PhD training; and to the staff members and fellow researchers of the Institute of Health and Society, for their constant support and for ensuring nice working conditions. I'll dearly remember my discussions with P-O, Pierre, Hélène, Marie F, Afi, Luigi, Josephine, Angel, and the sweet support from Nathalie C, Nathalie M, Maria, Alaa, Valerie, Sophie, and Djamila.

My father, Crucas, and my mother, Teresa. The best friends one could have, the most loving and supportive parents in the world. Thank you for transmitting important values and for putting up with me and my restless mind. My siblings – Luis, Teresinha, Isabel – you are the best present our parents gave me (so much better than a flipper machine!). The babies of the family – Kika, Manel, Ro, Luisinho, and Domingos on the way – you fill our lives with joy. My grandparents, including those gone too soon, my cousins, my aunts and uncles – how amazing is it to have such a strong bond like we do?! #WeAreFamily

My friends in Brussels, you certainly made life cooler: Cath, Alex, Salomé, Lu, Rita, Eliana, Sara, João, Tia Sofia, Tia Eduarda, Tio Paulo… And my friends in Lisbon, Luxembourg, and those spread around the world, who always make me feel at home wherever we are: thank you! A special thought goes to the friends who led me to my future husband: Fred and Cunha.

Mathieu, thank you for making me feel the luckiest woman in the world since we met. I can't wait to spend the rest of my life with you.

Finally, I am grateful to the different organizations that funded my PhD and its fieldwork: the US Agency for International Development – Office for Foreign Disaster Assistance; the Education, Audiovisual and Culture Executive Agency of the European Union; UCLouvain Special Research Funds; and the Horlait-Dapsens Medical Foundation.

OBRIGADA!

Maria / Curi / Moitas

(Brussels, February 2021)

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List of Abbreviations

4R	Robustness, Rapidity, Redundancy, Resourcefulness (system resilience framework)
AKI	Acute Kidney Injury
CI	Confidence Interval
COREQ	Consolidated Criteria for Reporting Qualitative Research
COVID-19	Coronavirus Disease
CRED	Centre for Research on the Epidemiology of Disasters
DRR	Disaster Risk Reduction
EM-DAT	International Disasters Database (www.emdat.be)
EMT	Emergency Medical Team
EQ1	Acute Earthquake Period (April 25th 2015 – May 15th 2015)
EQ2	Post-Acute Earthquake Period (May 16th 2015 – June 5th 2015)
GDP	Gross Domestic Product
HDI	Human Development Index
HEPP	Health Facility Emergency Preparedness and Disaster Response Plan
HEOC	Health Emergency Operations Centre
HFA	Hyogo Framework for Action 2005-2015
HOPE	Hospital Preparedness for Emergencies
HR	Hazard Ratio
HSI	Hospital Safety Index
ICD-10	International Classification of Diseases, 10th revision
ICU	Intensive Care Unit
IDNDR	International Decade for Natural Disaster Risk Reduction
IRSS	Institute of Health and Society, Université catholique de Louvain
LOS	Length of Hospital Stay
MoH	Ministry of Health
M_W	Moment Magnitude
NDRF	Nepal Disaster Response Framework
NEOC	National Emergency Operations Centre
NGO	Non-Governmental Organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
ODVR	Original Discharge Victim Registry

OR	Odds Ratio
Post-EQ	Post-Earthquake Period (June 6th 2015 – August 17th 2015)
PPP	Purchasing Power Parity
Pre-EQ	Pre-Earthquake Period (March 15th 2015 – April 24th 2015)
PTSD	Post-Traumatic Stress Disorder
SAR	Search and Rescue
SARS	Severe Acute Respiratory Syndrome
SFDRR	Sendai Framework for Disaster Risk reduction
TDS	Teaching Disaster Survey
TUTH	Tribhuvan University Teaching Hospital
UCLouvain	Université catholique de Louvain
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
USD	United States Dollars
USGS	United States Geological Survey
WHO	World Health Organization

Summary

Large-scale disasters overwhelm a community's capacity and typically require external assistance. With increasing threats from climate change, rapid population growth, suboptimal urbanization, and poverty, the human impact of large-scale disasters will likely increase. "Resilient hospitals" have been increasingly recognized as a critical element of disaster reduction. While various frameworks of hospital resilience have been proposed, they mostly emerged from pre-disaster considerations, and have not incorporated evidence from post-disaster impact on hospitals and resilience mechanisms. This dissertation investigates the impact of a high-magnitude earthquake on a tertiary hospital in Nepal, and explores its resilience mechanisms. Given inherent challenges in data collection in disaster settings, this dissertation uses a combination of quantitative data from routinely generated hospital records and qualitative data from semi-structured interviews with hospital staff. Sequential analyses were conducted using a combination of advanced statistical methods and mixed deductive and inductive coding for the qualitative data. Many of the injured who made it to the study hospital required surgical interventions and long hospitalizations. Being a tertiary hospital, it also received referrals of more severe cases, which posed additional strains. For six weeks, the average number of daily admissions decreased. During this period, the share of injury-related admissions was particularly high, and such admissions were particularly long. Admissions due to other conditions relatively decreased and were shorter than usual. We found that the hospital's resilience was highly dependent on emerging adaptations in addition to pre-existing conditions. Operational aspects were major influencers of hospital resilience. Since they were highly dependent on human behaviour, individual resilience played a major role, and we found that hospital staff were conditioned by senses of safety, meaningfulness, and belonging. Hospitals should prepare resources and plan for their known disaster risks, but should also allow for a certain flexibility to innovative adaptions to emerging, unforeseen challenges. In addition, challenges faced by hospital workers should not be undermined, and supporting them will increase hospital resilience.

General introduction

Resilience, and the origins of this thesis.

Resilience and me

“It’s like a sponge: you squeeze it, hurt it, but it manages to gradually return to its original state. People, children, can be like that, societies can be like that”. The first time I heard about “resilience” was in my first week of Medical School, a word that has not ceased to intrigue me since. It recurrently resurfaced in different courses throughout my Medical degree. At the time, it felt intangible, abstract, impossible to conceptualize. What did they mean, “a sponge”? And why on earth would I need that to become a physician?

Little did I know that I would later pursue a professional path far from the obvious career track all doctors are expected to follow. During a residency in a central hospital in Lisbon, located in a decayed former monastery in a country still suffering from a violent financial crisis, I spent the little free time of my night shifts wondering “how are we supposed to manage if we have an earthquake like the one in 1755?”. Passionate about societal and organizational challenges to population health, I started to work in a public health department, and later received a European scholarship to pursue a master programme in public health in disasters.

And resilience came back at me through the sweet and funny accent of a shy teaching assistant. And it came to stay, to inspire me throughout the years to develop work that sheds light on this unique phenomenon (or should I say capacity? Or characteristic? We still don’t know, but this dissertation may contribute to ongoing debates). I was not afraid of working on a concept I did not fully understand, I was inspired to explore it. Go figure, I am even writing a PhD dissertation about it.

Resilience is an *experience*

As my lecturer in Medical School described, resilience started as a concept in material engineering, to refer to the “sponge-like” characteristic of absorbing energy and returning to the original state. The field of ecology later adopted the concept to describe systems’ capacities to maintain and/or recover functionality after disruptions, being associated with concepts of stability and sustainability. In medicine and psychology, a resilient individual is someone who can overcome life adversities and live in good physical and mental health. Quickly, resilience became widely used in a multitude of sectors in our societies, and vast amounts of research were produced to propose measurements of resilience and identify areas of improvement. While resilience was initially defined as a return to an original state, it became widely acknowledged that there is no return to the exact initial condition, but to a new "normal" and satisfying state that incorporates transformation. With the increasing awareness that un-resilient health systems and services could lead to additional deaths in the event of major disruptions like natural disasters, epidemics, or major economic crises; more and more health facilities are built with resistant infrastructure and incorporate plans on how to act in the event of emergencies. But in this urge to show visible actions, many have used elusive meanings of resilience and overlooked an essential aspect of the concept: resilience is ultimately experienced by individuals and societies *when* emergencies occur.

At present, our knowledge is insufficient to predict how resilient a health facility or a society will be in the event of a disaster. We can only look back at previous disruptions and understand what contributed to maintain function or recover quickly, what did not, and how that disruption influenced the current state of things. By accumulating evidence from the frontlines of different real-life events, we can ultimately increase our understanding of resilience as an experience, in contrast with producing theory from, well, theory.

A case-study and the bigger picture

This thesis explores a real-life disaster phenomenon in Nepal, by studying how a high-magnitude earthquake impacted the functioning of a tertiary hospital and by exploring the hospital's resilience mechanisms. To consider all the aspects at stake for this case-study, we begin Chapter 1 with a presentation of disaster and earthquake definitions, impacts, and trends, followed by an analysis of disaster management that outlines resilience as a major component, with a particular focus on hospital resilience theory and ongoing practices. This allows to position our case-study in the bigger picture of resilience studies, public health, and disaster management, and provides a good basis to understand how the findings can be transferable to other settings. Chapter 2 describes the country and local context of the case-study as well as the methodological considerations used throughout the dissertation, which is fundamental in the interpretation of the findings. Chapters 3, 4, and 5 consist of the three sub-studies that compose this thesis: Chapter 3 focuses on the profile of the earthquake victims who needed to be admitted in the study hospital; Chapter 4 analyses the impact of the earthquake on hospital admissions; and Chapter 5 explores how the hospital staff experienced the earthquake and hospital resilience. The findings of these three chapters are put in perspective with each other and with the literature in Chapter 6, followed by a reflection on their scientific and practical impacts considering the limitations. Chapter 7 ends this thesis with conclusions and directions for the future, with the purpose of setting an ambitious research agenda that will ultimately contribute to improve resilience and minimize the human impact of disasters.

Chapter 1
Large-scale disasters and their impact on hospitals

In this chapter, we first define disasters and introduce their human cost, and present particularities of earthquakes. We also explore the concept of hospital resilience and its relevance in disaster management, setting the theoretical framework in which we situate this study. We also review unmet needs in disaster and hospital resilience research, and discuss how addressing them would substantially mitigate the negative impact of disasters. Finally, we outline the aim and specific objectives of the thesis.

1.1. (Un)Natural Earthquake Disasters

Since the beginning of mankind, human populations have been faced with natural and man-made events that have caused widespread suffering. Such “disastrous events” were often perceived as inevitable or demonstrations of divine anger. But the perception of disasters changed substantially over time, and they are increasingly recognized as social phenomena, rather than natural [4]. The United Nations Office for Disaster Risk Reduction (UNDRR) states that disasters are events that seriously “disrupt the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts”. [5]

The impact of disasters depends not only on the hazard’s characteristics, but also on characteristics of the affected population that influence their vulnerability and coping capacity [6, 7]. An individual’s or a community’s vulnerability to disaster is mostly determined by physical, socioeconomic, and environmental characteristics [5, 8]. Vulnerability is increasing with rapid urban growth in poorly managed areas [8, 9], where overcrowding, poor socioeconomic development, and fragile constructions are powder kegs for disastrous events. Coping capacity, on the other hand, is the ability of communities to use strengths, assets, skills, knowledge, and resources to manage difficult conditions, risks, or disasters, and ultimately contribute to resilience [5]. As such, the impact of disasters can be conceptually presented with the formula:

$$Disaster = \frac{Hazard \times Vulnerability}{Coping\ Capacity}$$

1.1.1. Classification of disasters and global trends

Disasters can be classified according to the extent of their impact (small-scale versus large-scale disasters), the rapidity of their onset (slow-onset or sudden-onset) [5]or, more commonly, the hazard that originated the disaster. Broadly, disasters are differentiated into *natural* or *human-made/technological* [1]. "Complex disasters" refer to when the effect of human activity triggers or aggravates a natural event, or vice-versa [10].

The classification used in the International Disaster Database (EM-DAT), managed by the Centre for Research on the Epidemiology of Disasters (CRED) of the catholic University of Louvain (UCLouvain), divides natural disasters into six main groups: geophysical, meteorological, hydrological, climatological, biological, and extra-terrestrial [1]. Figure 1.1 presents the different hazards that belong to each group.

Geophysical	**Meteorological**	**Hydrological**	**Climatological**	**Biological**	**Extra-terrestrial**
• Earthquake • Vulcanic activity • Mass movement (dry)	• Storm (tropical, extra-tropical, convective) • Extreme temperature	• Flood • Landslide	• Drought • Wildfire • Glacial lake outburst	• Epidemic • Insect infestation • Animal accident	• Impact • Space weather

Figure 1.1: ***Classification of natural disasters***
This classification is the one used by EM-DAT (http://emdat.be ; [1])

The number of disasters captured in EM-DAT increased substantially in the end of the 20th century due to multiple reasons. First, data quality and coverage have improved since the 1960's with increased media coverage of global events, decrease of communication costs, and expansion of the internet [11]. Second, global population growth has increased the likelihood of hazards hitting human communities, and hence more disaster events are reported. Finally, an actual increase of hazards is also possible, especially as the consequences of climate change became more evident. Other conditions have aggravated the vulnerability

[1] note: even if, as demonstrated, disasters are social rather than natural phenomena, for readability concerns we will hereafter use the term "natural disasters" to refer to disasters caused by natural hazards

of populations in the end of the 20th century, continuing in the early 2000's: extreme poverty and rapid urban growth with suboptimal building standards [9].

In terms of geographic distribution, Asia has been disproportionately affected by natural disasters in the past 20 years. Not only was it the continent with the highest number of disaster occurrences, with nearly 40% of the events reported globally, but Asia also accounted for 59% of all natural disaster deaths that occurred in the world between 2000 and 2019 [1]. Asia is particularly exposed to a multitude of hazards and is particularly vulnerable due to a large population, development challenges, and rapid urban growth. Globally, floods are the most frequent type of natural disaster, followed by storms. While earthquakes were considerably less frequent, they were the deadliest disaster reported in EM-DAT.

1.1.2. Earthquakes: characteristics, patterns, and impact

The outer layers of the earth, consisting of the crust and the outer mantle, are divided in tectonic plates that move slowly in different directions. The boundaries of these plates are made up of faults, where most earthquakes strike. Earthquakes occur when two plates suddenly move in relation to one another, as energy is suddenly released from the faults due to abrupt, unpredictable movements. The hypocentre is the location below the earth's surface where earthquakes start, and the epicentre corresponds to the point on the earth surface vertical from the hypocentre. The shake felt at the surface of the earth results from the transmission of seismic waves, which eventually reach the surface and shake the ground and anything on it [12]. The main earthquake shock is always followed by smaller shakes – the aftershocks.

The magnitude expresses the "strength" of an earthquake, and is related to the energy released. It is determined by the measurement of seismic waves, and the existing scales are usually logarithmic. While the Richter Magnitude (M_L) scale is the best known, it is currently mostly used for small, localized earthquakes [13, 14]. The Moment Magnitude (M_W) is currently considered the most accurate to measure large earthquakes. In contrast to magnitude, the intensity of the earthquake is the measurement of shaking in each location where the earthquake is felt. It is traditionally a subjective measure that depends on human observations, felt shaking, and damages, and is mostly expressed in the Modified Mercalli Intensity Scale (Table 1.1).

Table 1.1: ***Modified Mercalli Intensity Scale***

Intensity	Shaking	Damage/Description
I	Not felt	Not felt except by very few under especially favourable conditions
II	Weak	Felt only by a few persons at rest especially on upper floors of buildings
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors. Many people don't recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed, walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Source: United States Geological Survey (USGS), [15]

Earthquake trends

Millions of earthquakes occur each year around the world, but only about 20,000 are large enough to be measured and located. Of those, around 1,300 have a magnitude greater than 5 and have potential to cause damage[16], but even these only become major disasters if they strike populated areas where buildings are not earthquake-resistant [11]. As shown in Table 1.2, earthquakes of magnitude higher than 8 are rare and usually occur only once per year. Earthquakes with magnitudes between 7 and 7.9 are more frequent, and can cause devastating damage if they hit vulnerable and unprepared communities.

Table 1.2: ***Number of global earthquakes per year, by magnitude, 2015-2019***

Magnitude	2015	2016	2017	2018	2019
8+	1	0	1	1	1
7-7.9	18	16	6	16	9
6-6.9	127	130	104	117	135
5-5.9	1419	1550	1455	1674	1492

Source: USGS [17]

Between 2000 and 2019, the international disaster database EM-DAT reported 552 earthquake events with human impact, defined as having caused at least 10 deaths, 100 people affected, a call for international assistance or a declaration of emergency. On average, 27.6 earthquake disasters occurred each year. Figure 1.2 shows the frequency of earthquake disasters and associated deaths. The average number of earthquakes per year slightly decreased from 2000-2009 (28.9) to 2010-2019 (26.3). Three major peaks in the number of deaths can be identified in 2004, 2008 and 2010. The 2004 peak is related to the South-East Asia Tsunami, which affected a multitude of countries. The 2008 peak corresponds to the Wenchuan Earthquake in China, and the 2010 peak relates to the Haiti earthquake, which killed more than 220,000 people [1].

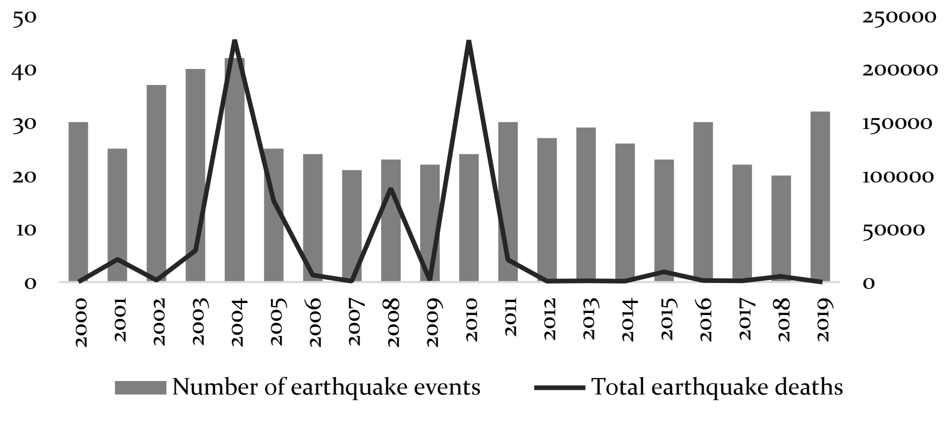

Figure 1.2: ***Number of global earthquakes and associated deaths, 2000-2019***
The disaster data was obtained from EM-DAT [1]. To be recorded on EM-DAT, a disaster event must meet at least one of the following criteria: (i) ten or more people reported killed, (ii) 100 or more people reported affected, (iii) a declaration of a state of emergency, and (iv) a call for international assistance. In EM-DAT, total deaths include persons confirmed dead and persons missing and presumed dead, excluding indirect deaths.

Asia hosted 370 earthquake events between 2000 and 2019, nearly two thirds of all events reported. The region of the Americas was hit by 85 earthquakes, counting for 15% of all earthquake events in the last 20 years. In terms of people affected, the Asian continent carries a disproportionately high burden: nearly 86% of all people affected by earthquakes in the world were living in Asia [1].

The health consequences of earthquakes

The destructive nature of earthquakes generates a multitude of potential health consequences to the affected populations. This impact depends on the earthquake characteristics and on the vulnerabilities and capacities of the affected communities. A major determinant of earthquake mortality is the building environment, such as the type of building material and the building density, as this influences the likelihood of building collapse. Although many deaths are immediate, several deaths occur hours and days after the shake if rescue services fail to reach the victims. Injuries to the head, chest, and abdomen are usually less survivable than orthopaedic injuries to the limbs [18], and elderly and child populations have increased risk of mortality [19].

In terms of morbidity, earthquakes produce substantive numbers of injuries. The average death to injury ratio is 1 : 2.7 in earthquakes meeting the EM-DAT criteria with deaths and injuries reported between 1990-2019[1]. The most common survivable injuries consist of fractures and soft tissue injuries in the extremities, and they occur more frequently in the lower limbs [18, 19]. Crush injuries are a common diagnosis in earthquake victims who need hospitalization [19], and they require particular medical attention to prevent the development of crush syndrome, a severe condition that can be fatal (box 1.1). Reports from the field suggest that the majority of injury-related healthcare needs are concentrated in the first days after the earthquake. This is followed by an increase of secondary complications caused by delayed initial injury treatment, and of infectious diseases associated with mass displacement conditions. Elective care is usually interrupted and medical care needs accumulate as conditions exacerbate; the restart of routine activities is challenged by the need to clear the backlog. (Figure 1.3).

Box 1.1 : Crush Syndrome [2, 3]

- Systemic manifestations resulting from crush injury due to disruption of skeletal muscle cell integrity, with release of their contents into the circulation
- Results in organ dysfunction, predominantly acute kidney injury (AKI). Multiorgan injury is also possible, and may lead to death.
- Deterioration typically occurs after the rescue, as the tension on muscle tissues is released. Reperfusion to ischemic damaged muscles disrupts cell wall integrity
- Hyperkalaemia due to release of potassium can result in ventricular fibrillation, which may kill within minutes of rescue
- AKI is related to the toxic effects of heme products in the kidneys, and obstruction of kidney tubules by myoglobin
- Early fluid resuscitation at the time of rescue is important to manage hyperkalaemia and prevent kidney injury in patients with crush injuries
- Dialysis is eventually required

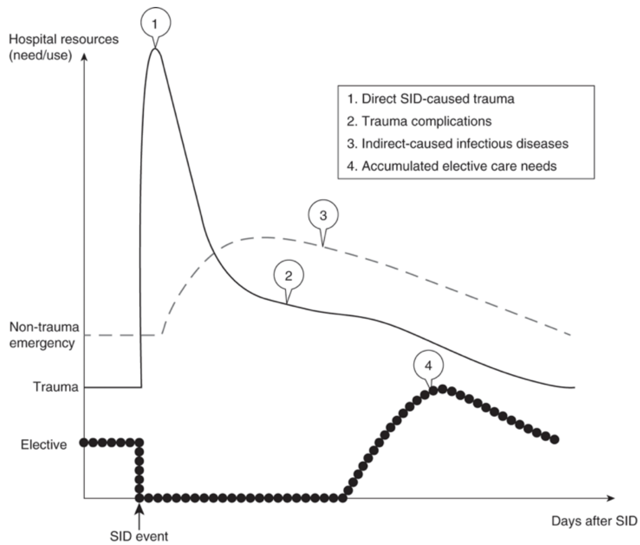

Figure 1.3: ***Conceptual model on hospital resource use after a sudden-onset disaster***
Reproduced from [20], with permission from Cambridge University Press.

In addition to injuries, earthquakes precipitate other causes of morbidity. For instance, the inhalation of particulate matters (which can be due to prolonged liquefaction explosion)[21] may increase the risk of respiratory conditions, including pneumonias and respiratory insufficiency, as previously reported in New Zealand and Italy [22, 23]. Earthquakes may also carry cardiovascular consequences. In the short term, hypothermia and constant stress may hyperactivate a patient's sympathetic nervous system [24]; there are descriptions of considerable blood pressure variability in the hours after an earthquake in patients with 24-hour blood pressure monitoring [25]. Because patients often lose their routine medications, exacerbation of chronic conditions may occur, including cardiovascular disorders [24]. However, an increase of cardiovascular diseases is not always visible in immediate health service use: a study in China showed that in the 60 days after the earthquake, hospitalizations due to ischemic heart disease were nearly 28% lower than would have been expected in a normal year [26]. But some studies have found a substantial long-term impact on cardiovascular diseases. In areas affected by earthquakes in Japan, mortality rates due to acute myocardial infarction significantly increased in the years after an earthquake, compared to unaffected areas [27]. A similar trend was identified in China five years after the Wenchuan earthquake, where the age-adjusted annual incidence of ischemic heart disease hospitalizations increased significantly and steadily in the area hard-hit by the earthquake [26].

The literature also reports prolonged psychological and psychiatric consequences of earthquakes. In Japan, increased cases of post-traumatic stress disorder (PTSD), depression, and cognitive disorder were identified in the elderly, as well as a worsening of psychological distress scores [24]. In China, prevalence rates of PTSD, anxiety and depression in the 3-4 months after the Wenchuan earthquake were 33.7%, 43.8% and 38.6%, respectively [28], and 26.3%, 49.8% and 49.6% after one year [29]. Common risk factors include being middle aged or elderly, having a bodily injury, and having experienced loss of livelihood. In Christchurch, at an unknown time after the February 2011 earthquake aftershock, a study detected a prevalence of 7.5% of major depressive disorder in earthquake-affected areas, compared to a baseline of 3.7%-5.1% [30]. Comparisons across studies are challenging as different measurement tools yield different prevalence rates, and the lack of standardized measurements hinders us from understanding the real impact of earthquakes, and any disaster, on mental health [31].

Earthquakes can displace large numbers of people, who often live in overcrowded temporary shelters, with poor sanitation and water supply. This is particularly challenging in low -income settings, where baseline infrastructure is already sub-optimal. In such poor environmental conditions, outbreaks of infectious diseases are commonly reported.

Finally, in addition to the direct earthquake impact on health, the complex disruption of health systems carries additional consequences. Earthquakes may severely compromise the existing health and transport infrastructure, thereby limiting access to care. Health workers may also be injured or unable to reach their workplace, and delivery of essential equipment becomes extremely difficult due to access constraints [32]. The impact is higher in countries with vulnerable health systems where physicians are scarce and communities are not trained for immediate search and rescue [19]. Because earthquakes are destructive and unpredictable disasters, an important step to reduce their human impact is to strengthen communities to manage disasters.

1.2. Disaster management in a nutshell

For centuries, disasters were typically perceived as "Acts of God" that could not be prevented [33]. This fatalistic view was questioned when the Lisbon Earthquake on November 1st 1755 killed the majority of those who attended church for All Saints' Day. In response to this historical disaster, new reconstruction measures were developed to resist seismic and fire events, such as the Pombaline cage [34], and disasters became perceived as "Acts of Nature". The late 20th century saw further developments, with the awareness of the influence of human populations in turning a hazard into a disaster [33].

This led to the conceptualization of disasters as a continuous cycle divided in four phases, highlighting that all communities are in at least one phase of the cycle at all times [33]: (i) mitigation, (ii) preparedness, (iii) response, and (iv) recovery (Figure 1.4). (i) Mitigation consists of policies and actions undertaken before a disaster to prevent or reduce its impact when it occurs, such as building codes and vulnerability analyses. (ii) Preparedness refers to the steps and measures planned for an identified disaster threat, in order to respond when a disaster occurs or is imminent. Examples include emergency exercises and early-warning systems. (iii) Response consists of the actions taken immediately after a disaster in order to minimize the impact, such as search and rescue and emergency medical services. Finally, (iv) recovery reflects the activities carried out after the crisis time response is over, like rebuilding of homes. This phase is increasingly aligned with the principles of "building back better" to prevent the occurrence of future disasters, and becomes part of mitigation, reinitiating the disaster cycle [5, 33].

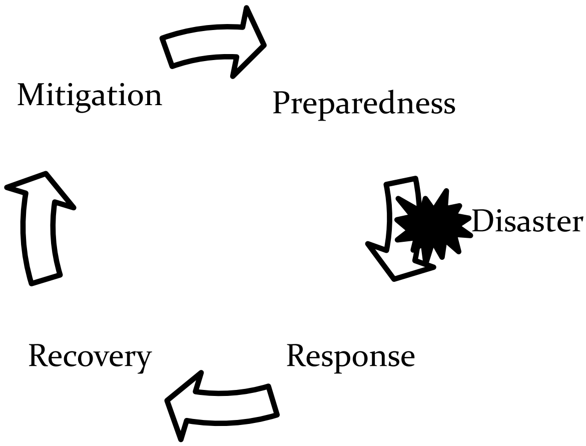

Figure 1.4: ***Disaster Cycle***

The conception of disasters as cycles has greatly influenced how disasters are managed. Disaster management includes the planning and implementation of measures needed at the different stages of the disaster cycle. While it does not completely remove the threats, disaster management contributes to reducing the impact of disasters. Increasingly, global policies and international development address international disaster management as an essential step to ensure sustainable development and cooperation. Nowadays, the activities conducted in pre-disaster phases are considered a major aspect of disaster management. Disaster Risk Reduction (DRR), includes strategies and policies aiming to reduce existing disaster risk and managing residual risk, ultimately strengthening resilience.

1.2.1. Global perspectives

Until the late 20th century, disaster management was typically reactive and fragmented. In a push for international coordination, the United Nations General Assembly declared the 1990's the international decade for natural disaster risk reduction (IDNDR). The IDNDR promoted coordinated efforts to reduce the human, material, and socioeconomic impact of natural disasters [35], and culminated with the development of the Yokohama Strategy and Plan of Action for a Safer World in 1994 [36], the first document to provide international guidelines for disaster management. The Yokohama Strategy consisted of ten core principles, and focused on improving coping and recovery mechanisms, and valuing the knowledge and experience of local communities [37].

With the end of the IDNDR, the UN secretariat for the International Strategy for Disaster Reduction[2] was created to institutionalize international collaborations to reduce vulnerability [38]. A strong shift of focus occurred in the following years, from coping capacities and relief interventions to risk preparedness and prevention, and from ad hoc fragmented activities to systemic approaches. The concept of Disaster Risk Reduction (DRR) became extremely popularized with the adoption of the Hyogo Framework for Action 2005-2015 (HFA). HFA was the first international document that described the detailed processes necessary to reduce disaster risks in various sectors and at different scales [39], and consisted of five priorities for disaster resilience:

1. Ensure that disaster risk reduction is a national and local priority with strong institutional basis
2. Identify, assess and monitor disaster risks and enhance early warning
3. Use knowledge, innovation and education to build a culture of safety and resilience at all levels
4. Reduce the underlying risk factors
5. Strengthen disaster preparedness for effective response at all levels.

The implementation of HFA revealed several weaknesses, including the lack of standardized definitions, measurable targets, and guidelines for implementation. These lessons learned were incorporated in a new agenda set in 2015. The Sendai Framework for Disaster Risk Reduction (SFDRR) reflected a renewed

[2] Now called the United Nations Office for Disaster Risk Reduction (UNDRR)

commitment to DRR in light of the recent societal, environmental and technological developments [40]. In addition to seven voluntary targets, the SFDRR outlines four priority actions:

1. Understanding disaster risk
2. Strengthening disaster risk governance to manage disaster risk
3. Investing in disaster risk reduction for resilience
4. Enhancing disaster preparedness for effective response, and to build back better in recovery rehabilitation and reconstruction.

The Sendai Framework identifies the importance of healthcare in reducing disaster risk and increasing resilience. This is reflected in priority 1 recommendations to develop effective campaigns on safe cities and hospitals; and in priorities 3 and 4 calls for resilience of national health systems and critical infrastructures. These highlight the importance of ensuring continuity of health facilities during and after disasters, to provide life-saving and essential services.

1.2.2. Hospitals: a cornerstone for disaster reduction

Disasters may lead to large numbers of people seeking medical attention, and health facilities play a pivotal role in disaster management. Earthquakes, in particular, generate several conditions that require specialized and emergency care [41, 42], and hospitals are essential to minimize the human impact of this sudden-onset disaster. Hospitals are complex: they require a large space, have specific construction and architecture approaches, require expensive medical equipment and qualified staff, and they constantly receive patients at high occupancy rates [43].

Earthquakes present diverse challenges for hospitals. A major threat is the eventual collapse of the hospital building, which not only endangers patients, staff and visitors, but also prevents the provision of a wide range of health services. This has received considerable scientific attention from the engineering sciences and substantial technological advances have been achieved [44-49] . Other threats include the effect on staff (who may be injured or unable to reach their workplace), the disruption of central electricity and water supply, damage to expensive and necessary equipment, access constraints, and a substantial increase of specific conditions that overwhelm the hospital's capacity [32].

Recognizing the importance of hospitals in disaster management, several initiatives have promoted disaster awareness in hospitals in the past decades [42]. From a focus on physical structures, increasing attention has been given to strengthening non-structural and functional components of hospitals, as evidence shows that the failure of hospital function in disasters is more often due to functional problems, rather than structural [50, 51].

The structural elements of a hospital refer to the essential construction that determines the overall safety, such as columns, walls, foundations, staircases, ceilings, and floors [51]. Non-structural elements consist of equipment and other installations (e.g. water heaters and storage tanks) that allow the hospital to operate, and can represent up to 80% of a hospital's total cost. Functional elements include activities such as contingency planning, implementation of disaster plans, training of staff, and emergency operations centre [50, 51]. A well-known example of a functional element is the incident command system, an all-hazards management approach that typically consists of five functions: Command, Planning, Operations, Logistics, and Financial/Administration [52].

Evaluating hospital safety and preparedness to disasters is challenging, as a multitude of tools exist, but few have been subject to validation. Two literature reviews have found diverse tools and checklists, which failed to reflect the different dimensions of hospital preparedness [53], focusing mostly on physical aspects rather than functional elements of preparedness [54]. The tools were also developed without following the instrument development guidelines, and there is little data to support their psychometric properties. The authors suggested that the lack of clear definitions of what such a tool is intended to measure is a major hurdle [54]. A commonly used tool is the hospital safety index (HSI), which assesses the level of structural, non-structural, and functional capacity. Each component has a check-list that is ranked as "high", "medium" and "low" [51], which can be quite subjective without clear thresholds.

The lack of standard definitions is a likely explanation for the absence of validated, robust tools to assess hospital preparedness to disasters. A recent systematic review identified 12 different definitions of preparedness, which provided little insight on how to operationalize this concept [42]. A hospital disaster preparedness framework emerged from this review, consisting of nine interdependent aims: continuity; knowledge and skills; safety and security; available equipment; available staff; plans and protocols; coordination; crisis communication strategies; and public engagement models. These aims could be strengthened through education, training, and exercises.

Assessing a hospital's level of preparedness before a disaster occurs is important to identify weaknesses and act upon them. But while related, the actual response performance may be substantially different from what the preparedness levels may have suggested [52, 55]. The understanding of post-disaster processes within a hospital merits scientific attention, and exploring these experiences through in-depth studies may unveil important aspects that need to be considered to mitigate the impact of future disasters.

1.3. Resilience: a trending concept in disaster management

The concept of resilience emerged in materials engineering, where it was defined as the ability of a material to absorb energy when deformed, and return to its original state. The field of ecology later described system resilience as a system's capacity to maintain or recover functionality in the event of disruption, and is associated with concepts of stability and sustainability [56, 57]. Resilience also became a common concept in medicine and psychology to describe the ability of individuals to overcome life adversities and maintain stable, healthy levels of psychological and physical functioning [58, 59]. Beyond domain specificities, resilience generally means that an individual, a community, or a system experiences a disruption and continues to function despite existing challenges, and is capable to adapt and learn from this. This is more comprehensive than the concept of preparedness, which focuses on strengths before a disaster occurs, even if it likely influences resilience. In recent years, resilience has received considerable scientific and policy attention, which has enriched the scope of the concept. However, this has also brought some confusion regarding basic terms and has led to a generalized and imprecise use of the word "resilience", further challenging scientists who want to study this phenomenon or decision-makers who want to strengthen resilience [60].

In disaster management, resilience describes the ability of a system or community to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through risk management. With regard to health, resilience is related to a community's or a system's capacity to cope with and manage health risks while maintaining essential functions of health systems [61]. Health systems are complex systems consisting of a multitude of actors that share the aim of improving, maintaining, and restoring the health of individuals and communities [62], and are highly vulnerable to external shocks that can severely disrupt their functioning. Such shocks include natural disasters or infectious disease epidemics, and are often presented as a four-stage cycle influencing health system resilience [60]:

1) System preparedness to shocks
2) Shock onset and alert
3) Shock impact and management
4) Recovery and learning.

Health system resilience is particularly complex because for a health system to be resilient, each of its subcomponents must be independently resilient as well. Critical health facilities are complex systems themselves, further adding to this complexity. Different resilience frameworks have been proposed for health facilities and health systems, but they have so far addressed these levels separately (Table 1.3). In addition, the parallel emergence of different frameworks further challenges the ability to operationalise resilience. The oldest resilience concept to emerge in the health system and health service sphere was Hospital Resilience, and is particularly important for sudden-onset, destructive large-scale disasters that precipitate large demand for hospital care, such as earthquakes.

Table 1.3: ***Overview of major resilience frameworks applied to health systems and/or health facilities***

Authors	**Health system component**	**Domains of resilience**
Bruneau et al, 2007 [63]	Hospital/ Acute healthcare facility	Means of Resilience: • Resourcefulness • Redundancy Ends of Resilience: • Rapidity • Robustness
Zhong et al, 2014 [64]	Hospital	Framework to evaluate hospital resilience: 1. Hospital safety 2. Command, communication, cooperation system 3. Disaster plan 4. Resource stockpile 5. Staff capability 6. Disaster training and drills 7. Emergency services and surge capability 8. Recovery and adaptation.
WHO, 2015 [61]	Health System	1. Context: the health system 2. Challenge / disturbance: shock, stress 3. Capacity to deal with disturbance 4. Choices and opportunities 5. Outcome options
Blanchet et al, 2017 [65]	Health System	Capacity to: 1. Absorb 2. Adapt 3. Transform Derived from the system's ability to manage: • Knowledge • Uncertainties • Interdependence • Legitimacy
Kruk et al, 2017 [66]	Health System	Resilient Health Systems are: 1. Aware: track threats, map weaknesses and strengths 2. Diverse: address a broad range of health issues 3. Integrated: cooperate with various sectors and involve the community 4. Self-regulating: contain threats; stability 5. Adaptive: respond to new challenges; rebound stronger than before

1.3.1. Hospital resilience

In contrast to preparedness and safety, the concept of hospital resilience includes the actual disaster scenario [67]. The engineering sciences were among the first to identify the need to ensure that constructions of critical care facilities resist to destructive earthquakes, marking the onset of hospital resilience studies [63, 68]. The same scientists rapidly identified the need to incorporate functional considerations to avoid substantial loss of function. The first conceptual frameworks for hospital resilience emerged based on a systems approach [45, 68]. Building on System Resilience theory, Bruneau and Cimellaro identified four dimensions to hospital resilience, known as the 4R resilience framework, which consist of "ends" of resilience – Robustness and Rapidity – and "means" of resilience – Redundancy and Resourcefulness. Redundancy can be described as the extent to which elements are substitutable, including the hospital itself if it establishes correct linkages. Resourcefulness is the ability to apply material and human resources in the process of recovery to meet established priorities and achieve goals. It also includes measures and procedures to improve coordination. Robustness is described as the strength to withstand a given level of stress without suffering degradation or loss of function. Rapidity entails that priorities are met and goals are achieved in a timely manner, in order to contain losses, recover functionality, and avoid further disruption [45, 63, 68].

While these concepts were thoroughly explored in the engineering sciences, they were considered difficult to use by hospital managers or health decision-makers [67]. In an extensive literature review, Zhong et al. found that a hospital's resilience depended on structural and non-structural components, as well as emergency medical functions and disaster response capacity [64]. According to their proposed definition (adapted from previous work [41, 45, 63]), a hospital's resilience consists of its "capability to resist, absorb, respond to the shock of disasters while still retaining [its] most essential functionality (e.g., prehospital care, emergency medical treatment, critical care, decontamination and isolation), then recover to its original state or a new adaptive state" [64].

Starting from the 4R dimensions, Zhong and colleagues developed the hospital resilience framework to make it more translatable into hospital management and decision-making [64]. They presented a conceptual chart showing the meaning of the 4R dimensions (Figure 1.5); and identified four primary domains where these dimensions could be applied: (i) hospital safety and vulnerability, (ii) disaster preparedness and resources, (iii) continuity of essential services, and (iv) recovery and adaptation. These would then be broken down in sub-domains and potential measurements. In another step of their research, Zhong and colleagues presented an assessment framework to a Delphi panel consisting of experts in China, with the purpose of evaluating resilience in Chinese hospitals. The final evaluation framework consisted of 17 subdomains, and 43 indicators categorized into eight domains [69]: (i) hospital safety, (ii) command, communication and cooperation system, (iii) disaster plan, (iv) resource stockpile, (v) staff capability, (vi) disaster training and drills, (vii) emergency services and surge capability, and (viii) recovery and adaptation. The resulting hospital resilience questionnaire was applied in 41 tertiary hospitals in China, with encouraging psychometric results [67]. A more recent systematic review identified a set of hospital resilience indicators built around three primary domains – constructive, infrastructural, and administrative resilience – which could also be linked to the 4R dimensions [70].

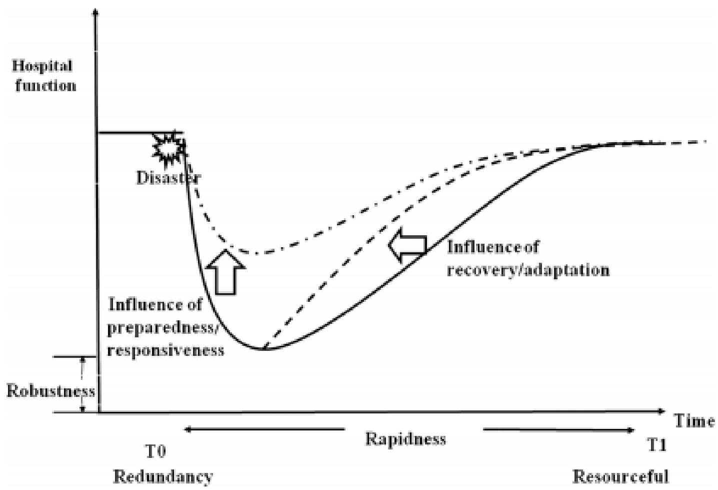

Figure 1.5: ***Relation between hospital function and the four resilience dimensions (4R)***
Reproduced from [64] with permission from BMJ Publishing Group Ltd.

However, two major shortcomings are hindering advances in improving hospital disaster resilience despite the existing tools. First, the present frameworks and measurement domains were built through a top-down approach, based on literature and expert views, not from actual data collection in post-disaster scenarios. Second, while some evaluation frameworks were empirically verified in non-disaster times, very few studies have ventured in applying them in a post-disaster context. A recent paper focusing on hospital staff experiences of resilience after Typhoon Haiyan in the Philippines highlighted the dynamic nature of hospital resilience to disasters, suggesting that current measurements fail to illustrate all the factors that influence sustained health service delivery in disaster aftermath [71]. As such, research from frontline hospitals' response to real disaster situations is critically needed to improve our understanding on the impact of disasters on hospitals and hospital resilience mechanisms.

1.4. Thesis aim

Disasters remain a serious threat to population health globally, but low- and middle-income countries are disproportionately affected by their consequences. Earthquakes are the most destructive type of natural disaster and heavily affect health systems, which are critical to minimize the direct and indirect human impact of earthquakes. The concept of hospital resilience has gained traction in the global disaster reduction spheres, but it remains elusive. The evidence of the earthquake impact on hospitals remains scarce, particularly in low-income settings, and resilience has not been appropriately studied in post-disaster contexts in front-line responders. Hence, evidence that can contribute to the improvement of hospital and community disaster plans is urgently needed, in order to improve resilience and reduce disaster-related mortality and morbidity.

Therefore, this dissertation investigates the impact of a high-magnitude earthquake on a tertiary hospital in Nepal, and explores its resilience mechanisms.

The thesis has the following specific objectives:

I. **To study the clinical and demographic profile of earthquake victims who were admitted in a tertiary hospital after a high-magnitude earthquake.** This objective is addressed in Chapter 3 ("Who needs hospital care?"). To achieve this objective, we retrospectively verified the files of 501 patients who were admitted at the Tribhuvan University Teaching Hospital. We studied their profiles through descriptive analyses and undertook a survival analysis to compare length of hospital stay between different patient groups, using Cox's regression and calculating hazard rations.

II. **To quantify differences in hospital admissions before and after the earthquake, and estimate the effect of the earthquake.** This objective is addressed in Chapter 4 ("How does an earthquake affect admission trends?"). We extracted hospital records from 9,596 admissions in a time interval of five months, which included the earthquake period. We divided the period under analysis in four sub-periods to make comparisons while keeping precision inherent to the critical weeks after the earthquake. We used negative binomial regressions to compare hospital length of stay across the periods, logistic regressions to compare probability of admission of different diagnostic groups, and Generalized Additive Model to model the difference of admissions compared to the baseline.

III. **To assess the impact of the earthquake on the hospital functioning, and explore hospital resilience as experienced by its staff.** This objective is covered in Chapter 5 ("How do hospital workers experience hospital resilience?"). We conducted 18 in-depth interviews with hospital workers from different professional and demographic categories. Using a questioning guide with open-ended questions, we explored their experiences at a personal, professional, and organizational level. We inductively created themes to describe the earthquake burden to the hospital, and to analyse individual resilience of hospital staff. We deductively documented the resilience of the hospital as a system, according to the system resilience dimensions: means of resilience (redundancy and resourcefulness), and ends of resilience (robustness and rapidity).

Using both quantitative and qualitative methodologies and a combination of inductive and deductive reasoning, these objectives complement each other to meet the general aim of this thesis. The work developed in this dissertation is expected to have not only a relevant scientific impact, but also to ultimately empower societies to become more resilient and reduce the human impact of disasters.

Chapter 2
Context and methodology

In this chapter, I present the setting of the study as well as its methodological approach. I describe the socioeconomic, political, and health profiles of Nepal, present the study hospital, and document the 2015 earthquake and associated response. This is followed by a description of the study design, and an overview of the data and the main analytical methods used in this dissertation.

2.1. Study setting

The 2015 earthquake in Nepal presented a unique opportunity to study in depth the disaster impact on a major hospital, and explore resilience. This was facilitated by the fact that Doctors for You, an Indian non-governmental organization (NGO) with whom CRED and myself had previously worked, contributed to the disaster response through close collaborations with the Tribhuvan University Teaching Hospital (TUTH). Another aspect that facilitated work at TUTH was its electronic health record system, enabling the possibility of extensive analyses beyond the period around the earthquake. This led to a fruitful TUTH-CRED collaboration and to the successful roll-out of this thesis.

2.1.1. Nepal country profile

Geography and population

Nepal is a landlocked country in South Asia, bordering China in the north and India in the east, west and south. It has a roughly rectangular shape with an area of 147,181 km² [72]. The distance between its southern and northern borders ranges from 145 to 241 km, yet topography changes drastically in this narrow distance: high-altitude mountains in the north known as the Himalayan mountain range, an intermediate region of mid-sized hills, and plains in the southern Terai region. Nepal is located above the boundary of converging Eurasian and Indian tectonic plates, which makes it prone to recurrent earthquakes [73].

The population of Nepal grew at an average rate of 1.11% between 2001 and 2011, and at a rate of 0.70% between 2012 and 2019 [74]. In 2019, Nepal had 28.6 million inhabitants, increasing from 26.9 million in 2014 – the year before the earthquake (Table 2.1)[74]. Emigration is a characteristic feature of Nepal's population: in 2011, the national census identified about 1.9 million absentees, the majority being male and employed in other continents [75], a possible explanation for a slower population growth [76]. Cultural and ethnic diversity also characterize Nepal's population: over 125 ethnic groups coexist as well as a wide range of religions, including Hinduism, Buddhism, Islam, Christianity, and other indigenous religions[75]. Most of the population is rural, but urban population is growing: in 2014, 18.2% of the population lived in urban areas, increasing to 20.2% in 2019 [74].

History and political context

The Kingdom of Nepal was founded in 1769 through the unification of multiple smaller kingdoms, and was ruled by the Shah dynasty until 2008. From 1846 until 1951, the monarchy held merely representative roles, as the ruling power was taken by a dynasty of Prime Ministers from the Rana family. After the first attempt of democratic elections in 1959, the ruling king Mahendra quickly dissolved Parliament to return to an absolute monarchy. The following parliamentary elections only took place in 1991 [77].

In 1996, a group of Maoist parties organized insurgencies against the monarchy and the elected government with the purpose of establishing a People's republic, leading to a 10-year civil war. The conflict ended with the signature of a peace agreement between the government and the Maoist groups. A Constituent Assembly was elected in 2008, abolishing the long-standing monarchy by declaring Nepal a Federal Democratic Republic, but a new constitution was only promulgated in September 2015 with the second Constituent Assembly [77, 78].

Since its new constitution, Nepal is a Federal Republic divided in 7 provinces and a total of 77 districts. The districts are further subdivided into urban or rural municipalities, which in turn are composed of wards, the lowest administrative unit. This new administrative division differs substantially from the previous one, which consisted of developmental regions and administrative zones instead of provinces, and of 75 districts instead of 77 [78].

Socioeconomic development

With a Gross Domestic Product (GDP) estimated at over 29 billion U.S. Dollars (USD) and an annual growth rate of 6.99% in 2019[74], Nepal is one of the fastest growing economies in the world. But with a Human Development Index of 0.579 in 2019, Nepal is among the 50 least developed countries in the world, ranking 147th out of 189. While substantial progress has been achieved in increasing literacy rate and access to electricity, poverty and development challenges continue, with the gross national income per capita at purchasing power parity (PPP) ranked 160th in the world in 2019 [79].

Nepal receives foreign aid and development assistance contributions from various countries and organizations, which were worth 1.45 billion USD in 2018[74]. Foreign remittances also play an important role in Nepal's economy: received remittances were worth 8.2 billion USD in 2019, the 19th largest in the world, representing 26.9% of Nepal's GDP [74].

Table 2.1: ***Population and development indicators in Nepal, selected years***

	2001	2014	2015	2018
Total population (millions)	24.35	26.91	27.02	28.09
Population growth (annual %)	1.68	-0.04	0.40	1.65
Urban population (% of total population)	13.95	18.18	18.56	19.74
Access to electricity (% of population)	24.6	84.9	85.24	93.92
Access to electricity, rural (% of rural population)	14.7	82.06	82.74	93.47
GDP (current USD, in millions)	6,007.06	20,002.97	21,410.84	29,173.51
GDP growth (annual %)	4.80	5.99	3.32	6.70
GDP per capita (current USD)	246.73	743.41	792.553	1,038.65
Literacy rate in adults (% of people ages 15 and above)	48.61	n.a.	n.a.	67.91

The data was obtained from the World Bank Development Data [74].
n.a.: not available

Health context

In the past 20 years, Nepal substantially improved key health indicators: life expectancy increased from 62.9 in 2001 to 70.5 years in 2018, lifetime risk of maternal death decreased from 1 in 46 in 2001 to 1 in 230 in 2017, and under-5 mortality rate halved to 33.2 deaths per 1,000 live-births (Table 2.2).

But several challenges persist. In 2018 Nepal only had 0.75 physicians per 1,000 population. Health expenditure represented only 5.6% of GDP in 2017, of which nearly 58% were out-of-pocket, increasing the risk of catastrophic spending for advanced care and associated impoverishment [74]. A large proportion of the total budget for health expenditure originates from foreign donations[80]. In addition, Nepal is experiencing a double burden of disease. Data from 2016 show that non-communicable diseases represent 66.2% of all deaths, and deaths due to communicable diseases and maternal, prenatal and nutrition conditions remain high with up to 25% of deaths. Injuries also represent a high burden, causing nearly 9% of all deaths [74].

Table 2.2: ***Nepal health indicators, selected years***

Indicator Name	2001	2014	2017	2018
Life expectancy at birth, total (years)	62.95	69.17	70.17	70.48
Lifetime risk of maternal death (1 in: rate varies by country)	46	170	230	n.a.
Maternal mortality ratio (modelled estimate, per 100,000 live births)	521	231	186	n.a.
Mortality rate, under-5 (per 1,000 live births)	76.5	37.9	33.2	31.9
Physicians (per 1,000 people)	0.05	0.60	0.91	0.75
Current health expenditure (% of GDP)	4.35	5.77	5.55	n.a.
Out-of-pocket expenditure (% of current health expenditure)	51.27	60.05	57.8	n.a.

The data was obtained from the World Bank Development Data [74].
n.a.: not available

Both public and private organizations provide healthcare services in Nepal, with a strong presence of national and international NGOs. Primary healthcare and delivery services are free of charge, as well as the provision of 40 essential drugs in hospitals with 25 beds or more. The remaining hospital services are only free for specific groups, such as people in verified poverty situations [81, 82].

In 2017, Nepal had 125 public hospitals and 198 primary health centres, and nearly 4500 other basic health centres [83]. While this represents a substantial increase from 2003 – when only 83 hospitals existed – Universal Health Coverage is still not ensured, particularly for vulnerable communities in mountainous and remote areas [80].

Nepal disaster profile

The INFORM risk index[3] [84] classifies Nepal at high risk for humanitarian crises and disasters, due to recurrent natural hazards like floods, landslides, and earthquakes, in combination with socioeconomic vulnerability and fragile institutional coping capacity.

Since 1980, Nepal registered 112 natural disasters with relevant human impact [1]. The yearly average of natural disasters between 1980-1999 was 2.5, increasing to 3.2 between 2000-2019. The average annual number of deaths increased from 433.3 to 680.2; and the annual number of people affected raised from 133,426 to 545,368. Between 1980-2019, floods represented 41% of all natural hazards (n=46), followed by landslides (19%, n=21); but earthquakes are by far the deadliest disaster in Nepal, with 9,785 deaths reported in only 6 occurrences. Floods caused 6,439 deaths in the same period, and the average number of deaths per event is one tenth of earthquakes' (139.9 versus 1630.8, respectively). Table 2.3 provides an overview of the five deadliest disasters; while Table 2.4 shows the top five disasters in terms of people affected.

Table 2.3: ***Five deadliest natural disasters in Nepal, 1980-2019***

Disaster type	Year	Number of deaths
Earthquake	2015	8831
Flash flood	1993	1048
Flash flood	1996	768
Earthquake	1988	709
Flash flood	1981	650

Source : EM-DAT [1]. Epidemics are excluded from the analysis.

[3] The INFORM global risk index is an open-source tool for risk assessment of humanitarian crises and disasters, led by the Joint Research Center of the European Commission in collaboration with a multitude of stakeholders. It evaluates risk according to hazard and exposure, vulnerability, and lack of coping capacity.

Table 2.4: ***Five natural disasters affecting most people, Nepal, 1980-2019***

Disaster type	Year	Total affected
Earthquake	2015	5,639,722
Flood	2017	1,700,134
Riverine flood	2004	800,015
Riverine flood	2007	640,706
Flash flood	1993	553,268

Source: EM-DAT [1]

Disaster risk reduction policies

A first milestone in DRR in Nepal was achieved in 1982, when a Natural Relief Calamity Act was adopted. This act focused only on the immediate response to disasters. An earthquake in 1988 led to the creation of the Nepal National Building Code in 1994, but this was barely enforced until the issuance of the Earthquake Risk Reduction and Recovery Preparedness Programme in 2007 [85].

The Hyogo Framework for Action in 2005 was adopted by Nepal and led to the National Strategy for Disaster Risk Management in 2009. It provided guidance to improve policy, legal environment and priority strategies for effective disaster risk reduction (DRR), which led to the subsequent formulation of national and local adaptation programmes of action to address climate change risks [85, 86].

Nevertheless, the complex political landscape in Nepal persistently delayed the setting of a legal framework for disaster management. This was only achieved with the Disaster Risk Reduction and Management Act in 2017, and the resulting national Disaster Risk Reduction Policy and Plan that provide the regulations and guidelines to enforce the Act [87].

Response capacity

The Nepal Disaster Response Framework (NDRF) was created after the National Strategy in 2009, and provides guidance for the coordination and implementation of response activities after a large-scale disaster [85]. A criticism was that it often attributed redundant roles to different agencies and authorities, including in low administrative levels [88].

In 2010, the National Emergency Operations Centre (NEOC) was created, under the direct influence of the Ministry of Home Affairs. It serves as a national coordination hub for organisations involved in disaster response, such as government agencies, multilateral organizations, and national and international NGO's. The NEOC has satellite centres at district level to improve coordination at local levels [85].

In addition, the Ministry of Health set up the Health Emergency Operation Centre (HEOC) in 2012 as a central coordination agency of health response. It is directly aligned with the NEOC, and coordinates with central and regional hospitals. It also coordinates health sector preparedness and response planning at different administrative levels in close collaboration with relevant disaster risk management structures.

In terms of health service response capacity in Nepal, existing regulations require all health facilities to have emergency preparedness and disaster response plans (HEPP). Institutions from Nepal were unique contributors to the international Hospital Preparedness for Emergencies (HOPE) initiative, a training course that addresses the structural, non-structural, organizational and medical concerns of health facilities in order to design and implement effective disaster response plans, and the programme had begun its roll-out in Nepal before the 2015 earthquake [89]. It was developed by the United States Agency for International Development in collaboration with John Hopkins University, the National Society for Earthquake Technology in Nepal, and a team of leading experts from throughout the Asia Pacific region. However, despite these regulatory and training measures to improve capacity, their implementation is difficult: in a survey in 2016, only a third of the hospitals actually had disaster plans in place.

2.1.2. The 2015 earthquake

Immediate and long-term impacts

On Saturday, April 25th 2015 at 11:56 am, an earthquake of moment magnitude 7.8 severely hit Nepal. The epicentre was located 80 km northwest of the capital Kathmandu, in Gorkha. This earthquake was followed by hundreds of aftershocks [90], of which the most powerful occurred on May 12th with a moment magnitude of 7.3 [91]. Out of the existing 75 districts in Nepal at the time, 14 were severely affected and were deemed a priority for rescue, relief and recovery efforts [92]. The earthquakes killed nearly 9,000 people, injured more than 22,000 [93], and destroyed or damaged 662 (83.5%) of the 793 public health facilities in the 14 most affected districts [92, 94]. The disaster also disrupted phone and road networks and widely destroyed buildings and monuments, generating a global movement of solidarity.

In addition to their immediate impacts, the earthquakes also carried long-lasting effects. Many of the affected people lived in temporary shelters for months or even years. Due to these living circumstances, they were also vulnerable to disease and extreme temperatures. A 4-month closure of the border with India in September further challenged the availability of fuel and medicines [90].

National coordination and response

Immediately after the earthquake, the Government of Nepal triggered its disaster response coordination mechanisms, in line with the NDRF. Central government authorities called for immediate search and rescue (SAR) activities, which were initially undertaken by the Nepal Army, the Nepal Police, Armed Police Force, and lay individuals from the communities [92].

The Prime Minister's Disaster Relief fund was unlocked, and several meetings with donors were organized to seek assistance for immediate relief. The Government of Nepal quickly activated an inter-agency cluster mechanism to address needs and coordinate response according to 11 different clusters [90, 92]: health, nutrition, emergency communication, camp management, education, food security, logistics, protection, shelter, water/sanitation, and early recovery. The health cluster was led by the Ministry of Health and co-led by the WHO, and received support from NGOs, academic institutions, private institutions, and freelance volunteers.

One hour after the earthquake, the Ministry of Health (MoH) activated the HEOC. Through its Health Information Management Unit, the HEOC received district-level information on a regular basis [94]. The MoH also activated hub-hospital systems, district hospitals, district/public health offices, and rapid response teams (responsible for outbreak response and control) at various levels. Hub-hospital systems consisted of a central, bigger hospital that coordinated with satellite hospitals to mobilize human resources and capacity [94]. All governmental, nongovernmental, and private hospitals were asked to provide free, 24-hour service to the earthquake victims, as well as free follow-up services for pre-existing chronic diseases [92]. Management of dead bodies was a joint responsibility of the Ministry of Health and the Ministry of Home Affairs.

International response and Emergency Medical Teams

The Government of Nepal made an official request for international assistance within hours of the earthquake [92]. A UN flash appeal for USD422 million was launched on 29 April to provide critical humanitarian support, of which 67% was met [95].

The first organizations to arrive in Nepal originated from India and included the Indian National Disaster Response Force, the Indian Air Force and the Indian Army Medical Corps. These organisations immediately assisted with SAR and, over time, a total of 134 international SAR teams from 34 countries participated in these efforts [92].

More than 36 national and 137 international Emergency Medical Teams (EMTs) from 36 countries were actively involved in health response activities [90]. Following the internationally acknowledged classification of EMTs (Table 2.5), nearly 50% of the international EMTs were fixed type-1 EMTs, and an additional 20% were mobile type 1. The share of type-2 EMTs was 15%, and 17% were specialized cells (surgery, epidemiology, maternal and child health, rehabilitation and microsurgery). The Israel medical team was the only type-3 EMT. To manage and coordinate international teams, the HEOC established a coordination team for international EMTs. Foreign teams could register directly with the HEOC upon arrival or, alternatively, they could register with the WHO before arrival, which then passed the information on to the HEOC [94]. To ensure uniformity in treatment and referral, all EMTs were asked to use national protocols while managing cases. Furthermore, they were instructed to maintain detailed documentation for trauma and amputation patients who required follow-up and rehabilitation, and reported daily to the Ministry of Health.

International EMTs were in principle deployed based on district needs, but reports show this was not always the case. Some EMTs proposed to intervene in particular districts they had previously chosen, and others were assigned locations on a first-come-first-served principle after registration. Most EMTs were deployed in Kathmandu (18%), which had the highest number of injuries (7,950), followed by Sindhupalchowk (18%), which had the highest number of deaths (3,570). EMTs arrived on average 4-5 days after the earthquake, and the majority of health facilities were not previously informed of their arrival, though some hospitals reportedly sought EMT support directly without consulting the HEOC [96].

Table 2.5: ***International classification of Emergency Medical Teams***

Type	**Characteristics**
EMT Type 1*	Outpatient emergency care of injuries and other significant health needs
EMT Type 2	Impatient acute care, general and obstetric surgery for trauma and other major conditions
EMT Type 3	Complex inpatient referral surgical care including intensive care capacity
Additional specialized care teams**	Additional specialized care cells within type 2, 3 or a local hospital

Adapted from the Health Cluster [97] and WHO/International Federation of Red Cross and Red Crescent Societies [98]
* Type 1 teams can be sub-classified as responding with a health facility (fixed) or without (mobile).
** e.g. rehabilitation, burn injuries, renal dialysis, epidemiology, specialist disease management teams such as for cholera or EVD

2.1.3. The Tribhuvan University Teaching Hospital (TUTH)

The Tribhuvan University Teaching Hospital (TUTH) is a major reference hospital in Nepal, located in Kathmandu. The hospital is under the responsibility of the Institute of Medicine of the Tribhuvan University and hence depends on the Ministry of Education [99]. TUTH was built in 1982 with donations from the Japanese Government and its construction used earthquake-resistant technologies. As a university hospital, TUTH contributes to training and education of medical and healthcare professions, in addition to providing tertiary and specialized care to the population of Nepal.

TUTH was part of the Hospital Preparedness for Emergencies (HOPE) initiative, as the head of its Trauma Centre had been a pioneer in introducing the programme in Nepal [100, 101]. Hence, at the time of the 2015 earthquake, TUTH had an emergency plan in place. Hospital staff were trained in the implementation of this plan through regular drills, and other physical measures were in place, such as supply and maintenance of emergency containers, electricity replacement, and fixing of objects to avoid uncontrolled movement or falls [89, 102].

TUTH was one of the only hospitals to resist to the 2015 earthquake [103], and was one of the seven hub hospitals in the Kathmandu valley that treated patients and coordinated with other health facilities [85]. TUTH's direction immediately activated the Incident Command System (Figure 2.1), and a triage system for mass casualty incidents was also immediately put in place. TUTH treated 1,723 victims and performed nearly 500 life and limb-saving surgeries [103, 104].

To prevent overcrowding and ensure the availability of care, TUTH coordinated with national and international NGOs to accommodate displaced patients who no longer needed hospital care elsewhere, such as in nutritional rehabilitation homes [103, 105]. In addition, TUTH organized outreach camps to bring healthcare to remote districts. These camps included teams from various departments who could treat minor cases at the location, and diagnose major situations and refer these to appropriate hospitals. Psychosocial counselling was also a component of these outreach activities.

Medical students also contributed to TUTH's disaster response. They were specifically responsible for conducting awareness campaigns with patients and visitors about hygiene, sanitation and epidemic prevention.

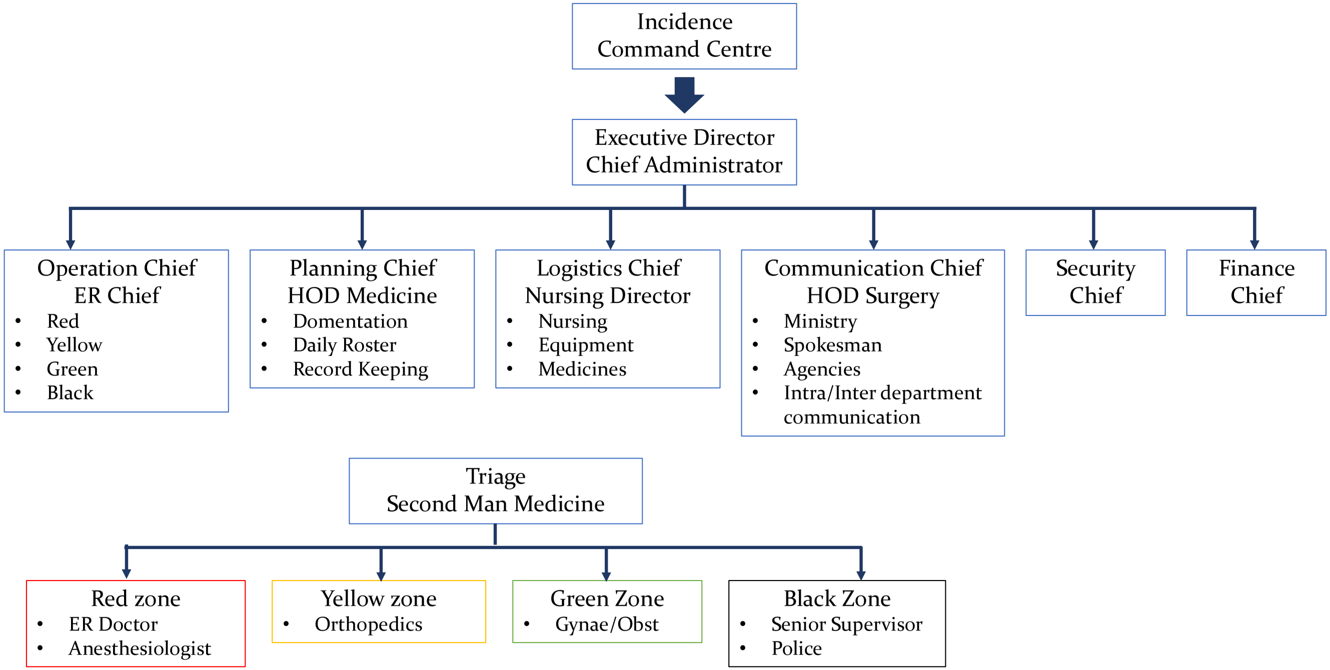

Figure 2.1: ***Organigramme of Incidence Command and Triage Systems at TUTH after the 2015 earthquakes***
Adapted from a presentation from TUTH [102]. ER: Emergency Room; Gynae/Obst: Gynaecology and Obstetrics; HOD: Head of Department.

2.2. Study design

2.2.1. Thesis structure

This thesis consists of an in-depth case-study, a useful approach to generate a comprehensive understanding of a complex issue in its real-life context [106]. It is composed of three studies that address specific objectives I, II and III (stated in Chapter 1), which complement each other to answer the general aim of the thesis. Figure 2.2 shows how these studies relate to each other and to the health system resilience shock cycle [60], and Table 2.6 describes and compares the three studies. Each study will be thoroughly presented in separate chapters, i.e. Chapter 3 (Study I), Chapter 4 (Study II), and Chapter 5 (Study III).

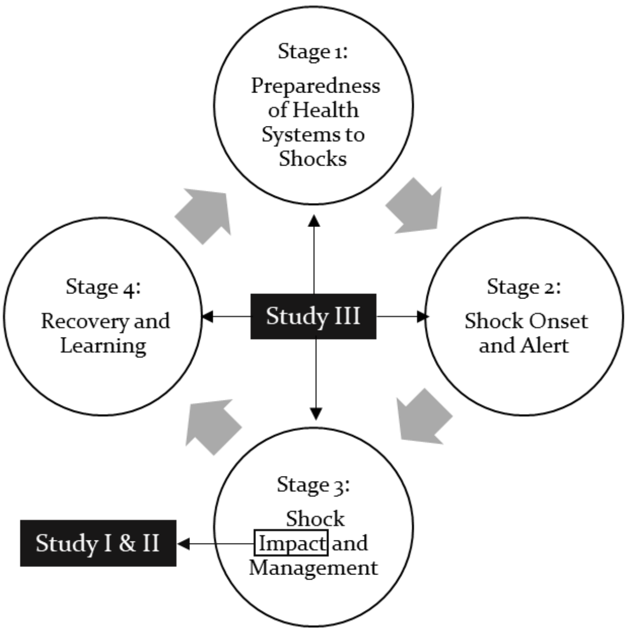

Figure 2.2: ***Relationship between the three studies and the shock cycle***

Table 2.6: ***Overview of the study components of the dissertation***

	Study I	**Study II**	**Study III**
Objective	Objective I: To study the clinical and demographic profile of admitted earthquake victims	Objective II: To quantify differences in hospital admissions before and after the earthquake.	Objective III: To explore the earthquake burden and the mechanisms of hospital resilience as experienced by its staff.
Data source	Hospital and government earthquake victim registries (ODVR and TDS) (secondary data)	Hospital admission and discharge registries, ODVR and TDS for earthquake victims (secondary data)	In-depth interviews with hospital staff (primary data)
Data collection / extraction period	February and May 2018	February and May 2018	May 2018
Data verification method	Hand search for inconsistencies	Hand search for inconsistencies for earthquake victims, accuracy check for impossible values	Interview transcript sent to interviewee for validation
Period of analysis	Period between first and last admissions: April 25th –October 2015	March 15th and August 17th 2015	From before the earthquake until time of the interview
Main analysis method	Time-to-event analysis of length of hospital stay – multivariate cox regression	Negative binomial regressions to compare length of hospital stay in different periods; logistic regressions to study changes in diagnostic categories; and Generalized Additive Models to model the difference in number of admissions compared to baseline.	Deductive coding for hospital system resilience themes, using the 4 R's framework, and inductive coding for burden and individual resilience.
Sample size	n=501	n= 9,596	n=18 (purposive sample)
Study population	Admitted earthquake victims	Hospital admissions	Hospital staff

ODVR: Original Discharge Victim Registry; TDS: Teaching Disaster Survey

2.2.2. Richness of data

In order to develop a thorough understanding of the disaster impact on hospital functioning and associated resilience mechanisms, we collected data from multiple sources of evidence, using a range of quantitative and qualitative techniques, including review of hospital admission records and conducting semi-structured interviews. The use of multiple sources of data (data triangulation), in this case different patient databases and narratives from hospital staff, is believed to increase the internal validity of a case-study, and it also helps develop a holistic picture of the topic under study [107]. In addition, mixed-methods are becoming increasingly popular in healthcare research and in humanitarian contexts, because they allow for a comprehensive view of complex issues and these settings usually challenge the conduction of classical epidemiological research.

2.2.3. The importance of field work

Since the research approach used in this dissertation requires an in-depth analysis of TUTH's earthquake response, a critical factor for success is the understanding of the context. While valuable information can be obtained remotely through document review, online search, conference calls, and examining pictures and videos, it does not enable the same contextual understanding that is inherent to field work and that can be gained through immersion, observations and interactions [108]. Some methodological approaches also advise for a balance between closeness and detachment to the study context, so the phenomenon being studied is assessed up close yet also from a distance [109]. Being an external researcher but with the possibility of multiple deployments to the field facilitated this balance. With this approach in mind, I deployed to Nepal for several weeks on different occasions, with the following purposes:

- Engage with the research team from TUTH, the central partners for this dissertation: Prof. Dr. Deepak Prakash Mahara, my local supervisor and executive director of TUTH; Dr. Sunil Singh Thapa, a talented orthopaedist and physician-scientist, and Mr. K.C. Kumar, the data manager and main advisor to the TUTH administration;

- Observe TUTH's organization and data management systems, verify and hand search patient files for data quality checks;
- Explore the feasibility of the proposed studies and submit the study protocols to the local Ethics committee;
- Engage with relevant stakeholders, including international and national NGO's (CARE Nepal, Humanity & Inclusion Nepal – formerly Handicap International, UMN/Indreni) and local research institutes (National Society for Earthquake Technology, Institute of Medicine);
- Conduct the semi-structured interviews, take field notes, and discuss findings and implications with partners;
- Immerse in the local culture through informal outings with colleagues and local acquaintances (e.g. yoga instructor), visits to historical landmarks and museums, and public transport trips.

2.3. Overview of the dissertation data

In this section, we present the main sources of data used for the completion of the dissertation.

2.3.1. Routinely generated health information

For the quantitative component of this thesis, i.e. Chapters 3 and 4, we extracted patient information from administrative data and patient records. This consisted of a total of four datasets (ODVR, TDS, Admissions, Discharge), which were later combined to generate the final datasets used for Studies I and II: the earthquake victim dataset and the hospital admissions dataset.

Table 2.7: ***Overview of datasets used in Chapters 3 and 4***

Dataset	Author	Unit of observation	Unique use / variables
Original Discharge Victim Registry (ODVR)	TUTH	Earthquake victims admitted in TUTH	detailed diagnosis
Teaching Disaster Survey (TDS)	Government	Earthquake victims admitted in TUTH	Mechanism of injury, outcome, detailed surgical intervention
Admissions	TUTH	All admissions	Panel data
Discharge	TUTH	All discharges	ICD-10 diagnosis

Earthquake victims dataset

As presented in Table 2.7, two distinct datasets contained data on earthquake victims admitted in TUTH: the Original Discharge Victim Registry (ODVR) and the Teaching Disaster Survey (TDS). The ODVR was created by hospital staff and compiled all information on patients with a clinical condition that could be linked to the earthquake. TUTH initially considered these patients as earthquake victims, and their records had a specific classification in order for TUTH to claim financial compensation from the government. The ODVR contains several columns where information was entered as free text, including detailed diagnostic information and residence. In parallel, the government of Nepal created a standardized matrix to ensure comparability among different hospitals. The dataset was posteriorly filled with TUTH patient information, resulting in the TDS. In TDS, the definition of earthquake victim was more conservative than ODVR, and excluded cases such as acute stress disorder, deprivation syndromes, or acute exacerbation of chronic diseases. The TDS also reported the mechanism of injury of the patient, and gave a detailed description of the surgical intervention.

The ODVR and TDS datasets were reviewed by two independent researchers, to identify duplicates and readmissions from both datasets. For our study on earthquake victims, we focused specifically on first admissions, because information on readmission was not exhaustive. Entries were only removed when both researchers agreed. We linked both datasets based on six variables: name, age, sex, living district, date of admission, and date of discharge. If there was a match in at least four out of six variables, we considered them the same subject. If there was a match in three of the six variables, we would verify the compatibility of diagnosis and treatment. If this was the same, we still considered the patient a match, otherwise not. Inconsistencies in variables between datasets (e.g. age, living district) were verified by hand search in patient records. If these records were not available, we prioritized information from ODVR. We included all victim admissions, including referrals from other hospitals, which occurred until October 2015. The main diagnosis for admission was entered as free text in ODVR, and two researchers independently coded it into the International Classification of Diseases, 10th revision (ICD-10). If the coding did not coincide, they would discuss in order to reach a consensus. Only the first and main diagnoses were considered. A final dataset with the minimum information required to reproduce the findings can be retrieved online [110].

Hospital admissions

To compare trends in TUTH admissions before and after the earthquake, we used a dataset directly produced by TUTH's information system. This dataset had panel data on admissions that occurred between March 15th and August 17th 2015, and included the date of admission and demographic information of the admitted patient. We merged this dataset with a dataset containing the discharges (organized by date of discharge) and the victim dataset retrieved from Study I, to have complementary information on diagnosis and date of discharge. We identified common admissions and merged the three datasets through deterministic linkages of identification number and name, and checked for consistency in sex, age, and date of admission. If these did coincide, we considered them the same admission. If not, we only considered the entry from the hospital admission dataset. In the discharge dataset, diagnosis was classified according to the ICD-10, until the third level (letter and two digits), and was entered directly by TUTH's administrative staff. In the earthquake victim dataset, diagnosis was originally entered as free text, and two independent researchers later codified it into ICD-10, as described in the previous section. The final anonymized dataset that was produced to analyse hospital admissions before and after the earthquake is also available online [111].

Diagnostic categorization: The International Classification of Diseases, 10th Edition (ICD-10)

To conduct thorough statistical analyses with clinical data, all variables need to be translated into a statistical code, meaning they are either numerical or categorical. Descriptions of medical diagnoses and procedures, which can be complex, should also be transformed into a usable classification that allows to compare between different institutions and different points in time.

The International Classification of Diseases (ICD) is a global tool that allows for international comparisons on health trends and statistics, and is the international standard for reporting diseases, health conditions, and causes of death [112]. Diseases, disorders, injuries, and other health conditions are listed in a hierarchical fashion. The ICD is used worldwide for morbidity and mortality statistics, reimbursement systems and resource allocation, health management, research, and quality guidelines. The first edition of the ICD was adopted in 1893. The World Health Organization (WHO) became responsible for the ICD in 1948 when it published its sixth edition. More editions have been issued, with the 10th revision of the ICD (ICD-10) being in place since 1992, though the WHO regularly releases minor updates.

The ICD-10 consists of 22 chapters, and the first character of its coding is a letter associated with each chapter (despite some exceptions for letters D and H). Four chapters use more than one letter in the first position of their codes. The following two characters of the ICD-10 code are numbers, and in the case of further detail being available (such as open/closed fracture), additional characters can be added after a dot. For most purposes, only the first letter and two digits are sufficient [113]. The latest small revisions to the ICD-10 were issued in 2019, 2016, 2015 and 2014, but an 11th revision of the ICD (ICD-11) was endorsed by the Member States in 2018 and is expected to be widely used in January 2022[112].

The TUTH administration routinely classifies the diagnoses of the admitted patients using the ICD-10 classification. The advantages of this classification are that it allows to conduct analyses at different levels of precision, and the way it is designed also enables quick recategorization. However, it is prone to bias as it is often used for reimbursement purposes and some codes are associated with higher reimbursement rates. Nevertheless, it is the most widely used diagnostic categorization tool in the world. In this dissertation, we used the ICD-10 categorization to allow for specific analyses on diagnosis or justification of admission in Chapters 3 and 4.

2.3.2. Semi-structured interviews

While the first studies give us quantitative insights on the burden and impact to the hospital, they fail to provide us with a picture of how the hospital was affected and how it managed the situation. The third study of this dissertation, presented in Chapter 5, explored the unique experiences of hospital staff after the earthquake, in particular their perceptions of the earthquake burden on TUTH and of hospital resilience.

For this purpose, we aimed to generate a rich and diverse set of narrative data that could later be analysed both deductively and inductively. As such, the research team decided to collect data using interviews from a diverse sample in terms of profession, function, gender, and seniority level with staff that was working at TUTH at the time of the earthquake.

In qualitative research, it is important to be aware of potential biases and assumptions of the interviewer and research team, and how this could have influenced data collection and analysis [114]. Hence, we report this specific methodology following the COREQ guidelines. As a non-Nepalese female with a Medical Degree, I conducted semi-structured interviews with 18 different hospital staff who were purposively selected to capture heterogeneous views on hospital resilience. The sample size had been estimated based on previous experience from the research team and according to time and resources available. During the field work, the sample size was confirmed to be sufficiently large: data saturation was reached in the 14^{th} interview, meaning that no new ideas or themes emerged afterwards [115]. The hospital director and/or the administrative chief invited interviewees to participate directly or through their direct supervisors, who had given them permission to participate during working hours. Participants had no previous contact with the interviewer.

The interviews were conducted following a guide with open-ended questions that focused on experiences before, during, and after the earthquake at personal, professional, and organizational levels, as shown in Appendix D. This guide was developed through iterative discussions between the research team, and aimed to avoid influencing responses. All interviews took place in May 2018 in a quiet room at TUTH. Eleven interviewees were comfortable in speaking English as it is their main working language (used in medical records and administration reports), and their interviews were conducted in English. For seven interviewees, an external interpreter facilitated communication and translated between the interviewee and interviewer. Interviews lasted on average 60 minutes, ranging between 40 and 100 minutes. At the start of each interview, study participants were informed about the researcher's background and the content of the research. They were given the opportunity to read the informed consent form before signing it. Upon participants' approval, all interviews were audio recorded, transcribed ad verbatim, and, if applicable, translated to English. Notes were taken during the interviews, and were incorporated in the initial coding. Interview transcripts were returned to participants, but no changes were requested.

2.4. Overview of data analysis

In this section, I expand on specific methodological decisions made for data analysis. All methodological decisions were taken in close collaboration with the research team. For a detailed explanation of all methodological steps, please refer to the specific Chapters 3, 4 and 5.

2.4.1. Length of hospital stay

Length of hospital stay (LOS) refers to the time a patient was hospitalized, from the day of admission to the day of discharge, death, transfer, or leaving against medical advice. It is usually calculated as the difference in days between discharge and admission. Length of hospital stay is often described as the result of complex interactions between patients, accompanying physicians, and hospital management characteristics [116, 117]. Past studies in disaster contexts suggest that it is a proxy indicator of resource use in hospitals rather than on severity of the underlying condition [118], and indirectly expresses the burden to the hospital.

In general, the distribution curve of length of hospital stay is right-skewed and does not meet assumptions of Normality. In addition, in-hospital deaths make it uncertain when the discharge would have occurred. As reported by Fenn and Davies [116] and Sá et al. [119], survival analysis is an appropriate method to study hospital length of stay as a dependent variable, particularly in small samples – which was the case in the study presented in Chapter 3. Here, in-hospital deaths were censored, and we first used the log-rank test to check for associations between length of hospital stay and demographic and clinical variables. Based on these results, we calculated individual hazard ratios for each category of variables that had a significant log rank test, and incorporated significant variables in a multivariate Cox regression.

Nevertheless, using survival analysis assumes that the probabilities of "survival" (in this case, not being discharged) and of the "hazard" (in this case, being discharged) are the same for subjects recruited in different time periods [120, 121]. Hence, to compare length of hospital stay in individuals admitted in different time periods, which was our aim in the study presented in Chapter 4, Poisson or negative binomial regressions are more suitable options. The negative binomial regression has the advantage that it can include overdispersion of counts [122]. We compared LOS in the four study periods using a negative binomial regression, and adjusted for age group, sex, and ICD-10 category. We also calculated LOS differences across the four periods for individual ICD-10 categories consisting of more than 10% of total admissions, adjusting for age group and sex.

2.4.2. Qualitative data analysis

Regarding the functioning of health services and the complexities that result from a large-scale disaster, qualitative research can provide rich and useful information. In this thesis, qualitative data analysis is considered "an ongoing, iterative process that begins in the early stages of data collection and continues throughout the study" [123].

This dissertation used an integrated approach to qualitative data analysis in the study presented in Chapter 5, employing both inductive and deductive coding. Inductive coding entails that the researcher avoids to "force" the data into any preconception, and concepts become apparent through an exhaustive review of the data [124]. With this approach, researchers commonly believe that the code structure, and subsequent themes and theories, more accurately reflect the ground experiences of participants [123].

On the other hand, a deductive approach defines codes before the data is reviewed, and then classifies the data into pre-defined categories [125]. Nevertheless, it is strongly advised not to force data into these categories, and leave the possibility to create new codes. Integrating both inductive and deductive approaches can help improve our understanding of complex, real-world phenomena, testing previous theories while also letting new concepts emerge. In this dissertation, this flexible approach allowed to empirically verify the suitability of a framework on hospital system resilience, enabling the possibility to incorporate new concepts that would enrich this framework.

The research team agreed that I, as the first author and author of the dissertation, should conduct the coding, as I was the only interviewer and was more familiar with the participants and their experiences. Before this study, I had attended two courses on qualitative research methods over two semesters. The main characteristics that may represent biases influencing the coding are the fact that I am a female Medical Doctor from Europe with clinical and public health experience in humanitarian and low-resource settings. The codes were then discussed with other members of the research team on different occasions.

The first analytical step after the data collection was immersion in the text, through transcription of the records and reading the translated transcripts. Each line was carefully read before any coding began. This helped me understand the different experiences and inductively identify emergent themes without losing connections with context and between concepts [126, 127]. Then, I inductively created codes to describe the earthquake burden to the hospital, as perceived by the respondents. This was a necessary step to have a broad understanding of the impact of the earthquake in the hospital functioning and better appreciate what the ensuing resilience mechanisms were addressing.

This was followed by a deductive analysis to document the resilience of the hospital, using the 4R framework (described in Chapter 1, section 1.3.1.) to define the starting codes [45]:

- Redundancy: the extent to which elements can be replaced;
- Resourcefulness: the ability to mobilize resources to meet priorities and achieve goals;
- Robustness: the strength to withstand stress without suffering loss of function;
- Rapidity: the ability to meet priorities in a timely manner to contain losses, recover functionality, and avoid further disruption.

This framework was selected for multiple reasons. First, it is the most widely used for system resilience across scientific disciplines. Second, it was the first to be applied to a hospital system, is more established in the scientific literature, and has also been the basis for subsequent frameworks, such as the one proposed by Zhong and colleagues [64]. However, it has so far not been used in a post-disaster setting, which questions its validity. Finally, it is a framework characterized by its simplicity. This facilitates the ability to allow new aspects to emerge.

Finally, it was evident from the text that individual experiences of interviewees influenced the hospital's own resilience. However, these could not fit the 4R framework since it is conceived for systems. Hence, we documented individual resilience of hospital staff as a separate theme, and coded it inductively.

2.5. Ethical considerations

The work developed for this thesis was approved by the Institutional Review Committee of the Tribhuvan University's Institute of Medicine, Kathmandu, Nepal (http://www.iom.edu.np/?page_id=67).

An informed consent was not required for the quantitative studies, which only used secondary data from routine health information. For the qualitative study, where I conducted semi-structured interviews with hospital staff, participants had to read and sign an informed consent form, available in English and Nepali, before the start of the interview. The risks of participating in the study were minimal, mostly related to (i) feelings of distress when recalling painful experiences, and (ii) breach of confidentiality. A referral to psychosocial counselling was planned in case participants demonstrated a need for such services. To ensure the data remained secure, all transcripts were pseudonymized, and only the lead researcher had access to the file linking a code with the respondent. This file and the transcripts were kept separately in secure folders protected by password. In addition, presentation of the data omitted any information that could enable identification. Research procedures in this dissertation adhered to the principles of the Declaration of Helsinki [128].

Chapter 3
Who needs hospital care?

This chapter is adapted from:

Maria Moitinho de Almeida, Joris Adriaan Frank van Loenhout, Sunil Singh Thapa, K. C. Kumar, Benjamin-Samuel Schlüter, Ravikant Singh, Xavier Banse, Dan Putineanu, Deepak Prakash Mahara, and Debarati Guha-Sapir. "Clinical and demographic profile of admitted victims in a tertiary hospital after the 2015 earthquake in Nepal." *PloS one* 14, no. 7 (2019).

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0220016

Abstract

Background: *Literature on earthquake victims in low and middle-income settings is scarce and originates mostly from foreign field teams who arrive with some delay after the disaster, failing to picture the victims who reach the local health services in the first days after the earthquake. In 2015, an earthquake killing 9,000 and injuring 22,000 people hit Nepal. The Tribhuvan University Teaching Hospital (TUTH), a reference tertiary hospital, was operational immediately after the earthquake. We studied the profile of earthquake victims admitted in TUTH and assessed what factors influenced hospital length of stay.*

Methods: *An earthquake victim dataset was created based on patient records, with information on sex, age, date of admission and discharge, diagnosis, and surgical intervention. After conducting initial descriptive analyses, we performed a time-to-event analysis to compare length of hospital stay in different patient groups, using log rank test and cox regression to calculate Hazard Ratios.*

Results: *There were in total 501 admitted victims, with the peak of admissions occurring on the fifth day after the earthquake. About 89% had injury as main diagnosis, mostly in lower limbs, and 66% of all injuries were fractures. Nearly 69% of all patients underwent surgery. The median length of hospital stay was 10 days. Patients with lower limb and trunk injuries had longer hospital stays than those with injuries in the head and neck (HR = 0.68, p = 0.009, and HR = 0.62, p = 0.005, respectively). Plastic surgeries were associated with longer hospital stays than orthopaedic surgeries (HR = 0.57 p = 0.006). Having a crush injury and undergoing an amputation also increased time to discharge (HR = 0.57, p = 0.013, and HR = 0.65 p = 0.045 respectively).*

Conclusions: *Hospital stay was particularly long in this sample in comparison to other studies on earthquake victims, indicating the high burden to TUTH. To strengthen resilience, tertiary hospitals should have preparedness plans to cope with a large influx of injured patients after a large-scale disaster, in particular for the initial days when external aid is limited.*

3.1. Background

Earthquakes are large-scale, sudden-onset disasters that cause widespread damage [5]. Between 2000 and 2019 there were 552 earthquake events worldwide, with more than two thirds having occurred in the Asian continent. Of these, 17 events killed more than a 1000 people, but only two occurred elsewhere than in Asia [1]. Health impacts of earthquakes depend not only on their magnitude and potential secondary effects, such as tsunamis or landslides [32], but also on characteristics of the community: built environment, time to rescue, availability of physicians and hospital beds, and prior training of lay uninjured survivors [19, 32].

Injuries are the most important cause of earthquake-related morbidity, consisting mostly of soft tissue and orthopaedic injuries, particularly fractures. These injuries are more frequent in the extremities, mostly lower limbs, and are also prone to wound infections [32]. Crush injuries are also a classic feature of earthquakes, and can develop into the potentially fatal crush syndrome [18, 19, 21]. Other causes of morbidity include respiratory diseases, usually related to inhalation of particulate matters [21], and cardiovascular diseases, such as hypertension and ischemic heart disease [25, 26]. Displacement-related outbreaks of communicable diseases and exacerbation of chronic conditions also contribute to earthquake morbidity [21]. Non-orthopaedic injuries to the head, chest, and abdomen have a lower likelihood of survival, and therefore they account for a minority of injuries treated in survivors [18]. Vulnerable groups like children, elderly, and people with disabilities are at higher risk of dying, as well as people with disabilities and comorbidities. Most deaths occur due to building collapse, and being indoors increases risk of death [19, 21].

The Gorkha earthquake in Nepal, which occurred on Saturday April 25th 2015, caused more than 22,000 injuries [92], 7950 of which in Kathmandu district alone[96]. Hundreds of aftershocks occurred thereafter, with the strongest one taking place on May 12th. The Tribhuvan University Teaching Hospital (TUTH), in Kathmandu, was an important actor during disaster response, as its structure was earthquake-resistant and previous preparedness programs prompted capacity to rapidly care for earthquake victims.

Understanding the profile of admitted earthquake victims is crucial to gain insight not only on health consequences of earthquakes, but also to understand what type of resources are mostly needed, for local health services to better prepare for such events. Literature on earthquake victims in low and middle-income settings is mostly from foreign field teams who only arrive some days after the disaster, failing to picture the victims who reach the local health services in the first days after the earthquake [20, 129]. Since Nepal is a highly earthquake-prone country, understanding the immediate post-earthquake reality in local hospitals is extremely important to improve future preparedness and response. The literature focusing on the earthquake victims treated within Nepal's healthcare system is limited [130-135], but studying patient profiles will improve our understanding of resource use and hospital burden after earthquakes.

In this study, we describe the demographic and clinical profile of earthquake victims admitted to TUTH after the 2015 Nepal earthquake, and study which characteristics were associated with hospital length of stay.

3.2. Methodology

3.2.1. Study data

As specified in Chapter 2, the data for this study resulted from the merging of two datasets on earthquake victims, one produced by the hospital (OVDR) and the other by the Government of Nepal (TDS). Some variables were reported in both datasets, but each dataset also contained unique information. In order not to lose this information, we linked both datasets based on six variables: name, age, sex, living district, date of admission, and date of discharge. If there was a match in at least four out of six variables, we considered them the same subject. If there was a match in three of the six variables, we would verify the compatibility of diagnosis and treatment. If this was the same, we still considered the patient a match, otherwise not. Remaining inconsistencies in variables between datasets were verified by hand search in patient records. If these records were not available, we used the information from the dataset generated by the hospital staff – OVDR – as it collected data at an earlier stage. We included all victim admissions, including referrals from other hospitals, which occurred until October 2015. Two researchers identified readmissions and duplications independently, and they removed those they agreed upon from the victims dataset, as our study only intended to look at first admissions.

Table 3.1 shows the variables in the original datasets that were used for this study. Age was categorized in four groups: 0–4; 5–14; 15–49; and 50 years or more. Delay of presentation was calculated as number of days between the first earthquake, on April 25th, and the admission. We computed length of hospital stay (LOS) by calculating number of days between admission and discharge. The main diagnosis for admission was entered as free text in the original files, and coded into the International Classification of Diseases, 10th revision (ICD-10), by two independent researchers. If the coding did not coincide, they would discuss in order to reach a consensus. Only the first and main diagnosis was considered. Diagnoses were also converted into additional categorical variables, such as location of injury, presence of fracture, presence of crushing injury. Main body region of injury was classified in head and neck, lower limb, trunk (including chest, abdomen, and pelvis), and upper limb. If a person sustained several injuries in one same region, the injuries would be classified under that region. The medical specialty performing primary surgery was classified from an open text into a categorical variable. We created a binary variable for amputations and in-hospital deaths.

Table 3.1: ***Overview of variables in the original datasets***

Variable	Type	Possible values
Name*	Open text	
Age	Continuous	
Sex	Categorical	Male / Female
Mechanism of injury	Categorical	Object fall on patient Trapped in rubble Fall from height Other
Date of Admission	Date	
Date of Discharge	Date	
Diagnosis	Open text	
Surgery Type	Categorical	Neurosurgery Orthopaedics surgery Plastic surgery Wound care Other
Surgery detail	Free text	
Comments on discharge	Free text	

* this variable was solely used for merging datasets, and removed immediately after

3.2.2. Data analysis

We first performed a descriptive analysis of selected variables, followed by a more thorough analysis of hospital length of stay. Statistical analysis of hospital length of stay is challenging, as the distribution curve is usually right-skewed and does not meet assumptions of Normality. In addition, in-hospital deaths make it uncertain when the discharge would have occurred. Time-to-event analysis, often known as survival analysis, allows inclusion of such cases [121], and is an appropriate method to study hospital length of stay as a dependent variable, particularly in small samples [116, 119]. We censored in-hospital deaths and used the non-parametric log-rank test to check for associations between length of hospital stay and the following variables: sex, age group, body region affected, surgery type, and the binary variables for fractures, amputations, and crush injuries. Based on these results, we calculated individual hazard ratios for each category of variables that had a significant log rank test. Finally, a multivariate Cox regression was computed, incorporating all covariates that showed significance in the previous steps. We checked for interaction between all variables, and performed regression diagnostics to the resulting model, using test of proportional hazards and a test of overall goodness of fit.

Data analyses were conducted using Stata 15.1 (StataCorp, College Station, Texas, USA). We considered a level of significance of $p < 0.05$.

3.2.3. Ethical considerations

The study we describe in this chapter only used secondary data. Identifiers were used for merging of databases and accuracy checks, but removed afterwards. Complying with local regulations, we submitted a protocol of this study to the ethics committee of the Tribhuvan University's Institute of Medicine. The ethics committee deemed that an informed consent was not necessary, and we received clearance to undertake this research (Ref. 381(6-11-E)^2/074/075).

3.3. Results

3.3.1. Descriptive overview

We included 501 earthquake victims in this study, with a mean age of 36.18 years (SD 21.58), ranging from 2 months to 87 years of age. Table 3.2 gives a descriptive overview of the included earthquake victims. Delay in presentation ranged between 0 and 166 days after the first earthquake on April 25th. The median was five days with an interquartile range of three to 15 days, and the peak occurred on the fifth day after the earthquake, with 77 admissions (Fig. 3.1). The mean length of hospital stay was 14.7 days (SD=15.2), with a maximum of 106 days. The median length of stay was ten days, with an interquartile range of five to 18 days (Fig. 3.2).

Table 3.2: ***Descriptive table of admitted earthquake victims***

	N(%)	Male, N(%)	Female, N(%)
Total admissions	501	242	254
Age group	495	242	253
0-4	18 (3.6)	10 (4.1)	8 (3.2)
5-14	67 (13.6)	30 (12.4)	37 (14.7)
15-49	266 (53.7)	139 (57.4)	127 (50.2)
>=50	144 (29.1)	63 (26.3)	81 (32.0)
Mechanism of injury	170	85	85
Fall from height	30 (17.7)	14 (16.5)	16 (18.8)
Object fell on patient	90 (52.9)	44 (51.8)	46 (54.1)
Trapped in rubble	33 (19.4)	19 (22.4)	14 (16.5)
Slipped/tripped	15 (8.8)	7 (8.2)	8 (9.4)
Other	2 (1.2)	1 (1.2)	1 (1.2)
ICD-10 groups	494	242	252
Injuries	438 (88.7)	219 (90.5)	219 (86.9)
Contact with health services	16 (3.2)	9 (3.7)	7 (2.8)
Neurological	11 (2,2)	5 (2.1)	6 (2.4)
Respiratory	5 (1.0)	2 (0.8)	3 (1.2)
Circulatory	4 (0.8)	2 (0.8)	2 (0.8)
Mental disorders	4 (0.8)	2 (0.8)	2 (0.8)
Pregnancy-related	4 (0.8)	0	4 (1.6)
Other	12 (2.4)	3 (1.2)	9 (3.6)
Location of injury	399	195	204
Head and neck	73 (18.3)	39 (20.0)	34 (16.7)
Lower limb	195 (48.9)	107 (54.9)	88 (43.1)
Trunk	80 (20.1)	29 (14.9)	51 (25.0)
Upper limb	51 (12.8)	20 (10.2)	31 (15.2)
Primary surgery	345	170	174
Orthopaedics	226 (65.7)	117 (68.8)	109 (62.6)
Neurosurgery	40 (11.6)	16 (9.4)	24 (13.8)
Plastic surgery	31 (9.0)	13 (7.6)	18 (10.3)
Wound care	19 (5.5)	10 (5.9)	9 (5.2)
Other	28 (8.1)	14 (8.2)	14 (8.0)

Column percentages within variables are shown. ICD-10 group names were simplified for clarity. Sums do not always add up to total admissions due to missing items.

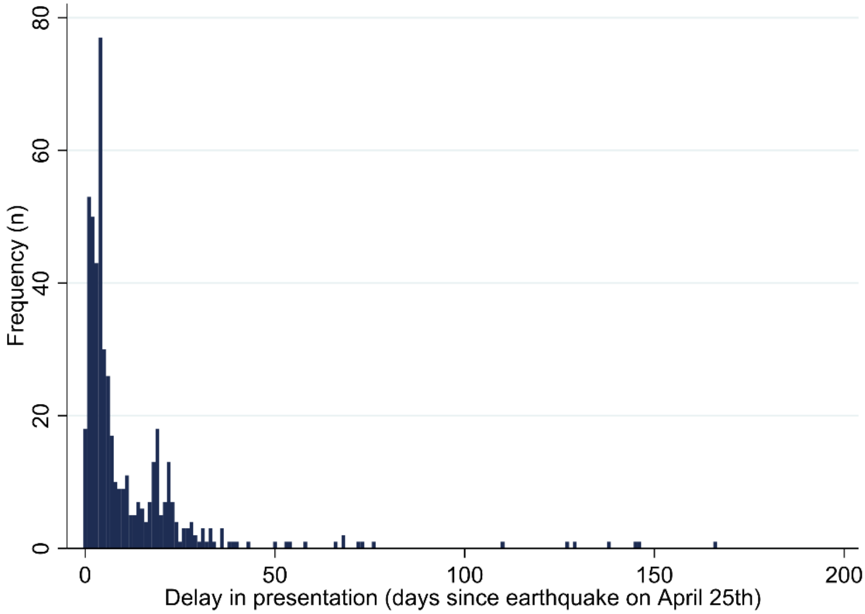

Figure 3.1: ***Distribution of delay in presentation, in days after the April 25th earthquake***

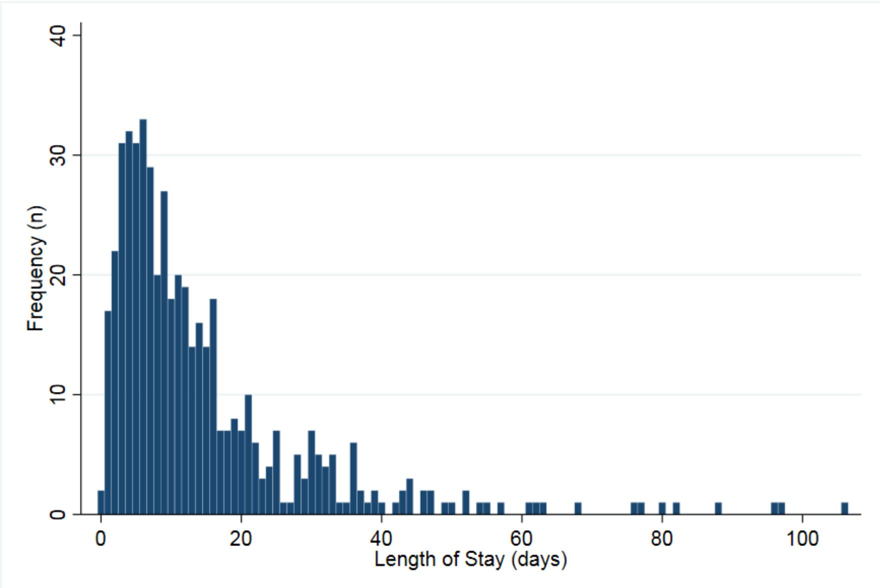

Figure 3.2: ***Distribution of length of hospital stay***

Length of Hospital Stay (LOS) corresponds to the number of days between the date of admission and date of discharge.

Of all 501 admitted victims, 494 had diagnostic information (Table 3.2). The majority (88.7%) had a diagnosis that fell in the “injury, poisoning and certain other consequences of external causes” group. Concerning third level ICD-10 diagnoses (letter and two digits), lower leg and femur fractures were the most common cause of admission, representing 26% of all diagnoses. These were followed by injuries to unspecified body regions and fractures of the lumbar spine or pelvis (Fig. 3.3). More specifically, the most common diagnoses were fracture of the femur shaft (6.8% of all injuries), multiple lower leg fractures (5.5% of all injuries), and unspecified fractures of the lower leg (4.8% of all injuries). When looking at conditions that were not part of the injury group (n=56), post-surgical states represent most cases (25% of all diagnoses not belonging to the injury group).

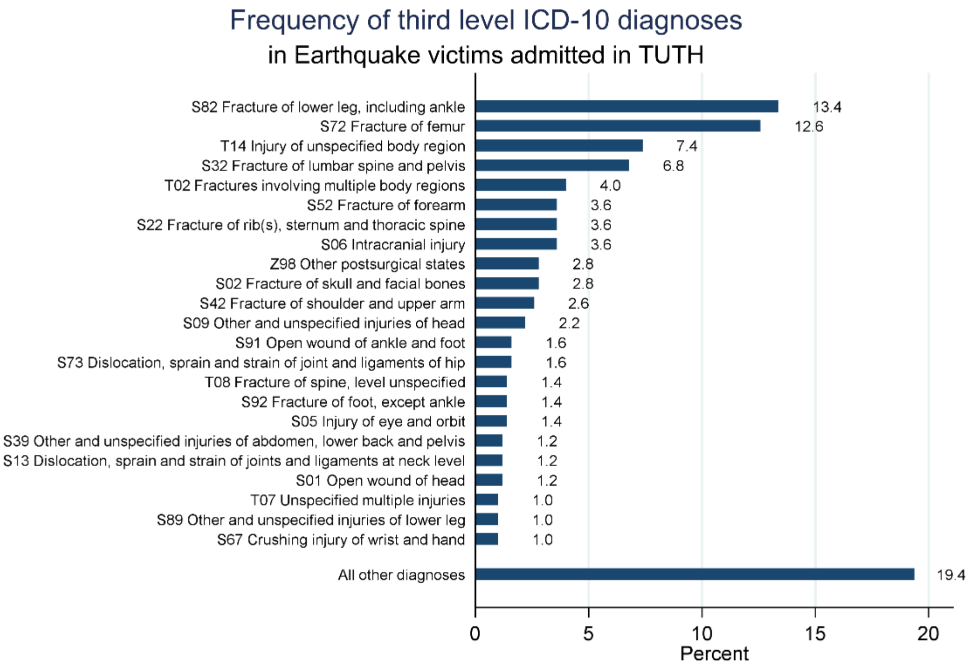

Figure 3.3: ***Frequency of primary diagnoses of admitted earthquake victims***
Only diagnoses with a frequency higher than 0.5% are shown, remaining are under “all other diagnoses

Fractures represented nearly two thirds of all injury cases (n=288, 65.8%), with 49 compound fractures (17% of all fractures). Crushing injury was primary diagnosis for 21 admissions. About a third of crushing injuries occurred in the upper limb (n=6), one third affected the lower limb (n=7), and one third occurred in an unspecified body region (n=8).

About 69% of all admitted victims underwent at least one surgery (n=345); this share was about 76% for fracture cases (n=218). Most surgical interventions were orthopaedic, followed by neurosurgery, and plastic surgery (Table 3.2). About 61% of all primary interventions were considered major surgeries (n=206), followed by intermediate surgeries (n=119, 35%). Minor surgeries represented 14% of all surgeries in admitted victims (n=15). Of all surgeries, 25 were amputations (7.3%).

In 37 cases (7%), death was reported as an outcome, of which 20 were males and 17 were female. Most people who died were admitted one day after the earthquake (n=10), and half were admitted within four days. Deaths occurred on average thirteen days after the admission, with a median of nine days. Among in-patient deaths, 14 had a lower limb injury, seven sustained a head and neck injury, six a trunk injury, and four an upper limb injury. One person had a postsurgical state (craniotomy), and two were due to earthquake-related diseases of the nervous system.

3.3.2. Time-to-event analysis

In the bivariate log rank tests, time to discharge was not associated with sex, age group, nor fracture. In contrast, it was significantly associated with main body region affected (p=0.0026), presence of crush injury (p=0.0093), having undergone an amputation (p=0.0361), and surgery type (p=0.0168).

Table 3.3 shows unadjusted individual hazard ratios (HR) for each category of variables that had a significant log rank test. Patients with injuries in lower limb and trunk had significantly lower hazards of discharge than head and neck, meaning they were hospitalized for a longer period. Plastic surgery was significantly associated with longer hospitalizations compared to orthopaedic surgery.

The four presented variables were incorporated in a multivariate model to calculate adjusted HR, which only included 291 observations due to missing values. The only significant finding was that injuries in the trunk region had lower hazards of discharge compared to head and neck (p=0.005). However, this model did not meet the proportional hazards assumptions (chi-square= 28.47, 9 df, p=0.0008), and there was significant evidence of a poor fit (p=0.047). We checked for interaction terms between all variables, but these models were not significantly better.

Table 3.3: ***Measures of association (unadjusted hazard ratios) of different characteristics with hospital length of stay***

Variable	*HR (95%CI)*	*Z*	*p*
Body Region			
Head and Neck	Ref		
Lower limb	0.68 (0.51-0.91)	-2.62	**0.009**
Trunk	0.62 (0.44-0.87)	-2.79	**0.005**
Upper Limb	0.99 (0.68-1.16)	-0.01	0.991
Crushing			
No	Ref		
Yes	0.57 (0.36-0.89)	-2.48	**0.013**
Amputation			
No	Ref		
Yes	0.65 (0.43-0.99)	-2.01	**0.045**
Surgery Type			
Orthopaedics	Ref		
Neurosurgery	0.90 (0.64-1.26)	-0.61	0.542
Plastic surgery	0.57 (0.38-0.85)	-2.76	**0.006**
Wound care	1.42 (0.87-2.34)	1.39	0.163
Other	0.84 (0.56-1.25)	-0.87	0.382

HR: hazard ratio (unadjusted); 95%CI: 95% confidence interval; Z: Z-score; p: p-value; Ref: reference category. Significant p-values (lower than 0.05) are presented in bold.

3.4. Discussion

A large share of the literature describing the profiles of treated victims from the Nepal earthquake is from foreign field teams, who usually arrive on site several days after the event [129, 136-138]. The experiences of such teams, albeit relevant, do not reflect the reality of the country's health system and services, and fail to report on the difficult conditions in which local health actors must act in the first days after an earthquake [20]. Our study shows how a local health service dealt with earthquake victims immediately after the quake, with no time for preparations or resource planning to pursue life and limb-saving activities. We found that the peak of victim admissions only occurred on the fifth day after the earthquake, an interesting feature for tertiary hospitals in seismic zones to consider when adapting and planning resources after such a disaster. Moreover, the date of admission of this sample had a wide range. A possible explanation is that some cases were referrals from other hospitals that were not able to provide the type of surgical care required. Secondly, in Nepal, access to surgical care was already challenged before the earthquake due to a poor road network and physical distance to appropriate health services. The earthquake worsened this situation by destroying paths up the mountain slopes, where the most severely affected villages were located [139], which could justify why many victims only reached TUTH after some days [140]. Regular aftershocks that followed the earthquake event, in particular the one on May 12th, probably caused additional waves of injury, which may have also caused some of the later admissions.

More than half of victims with a reported mechanism of injury were hurt by a falling object. As described in the literature, building collapse is associated with higher mortality, and such victims are hence less frequently admitted, as they often die before reaching a health facility [19]. Despite incompleteness of mechanism of injury data, our results suggest that survivable injuries are often related to non-structural components of housing, such as falling or moving objects. Implementing best practices on non-structural aspects should be applied in people's homes to avoid injury, although this finding requires more in-depth research.

In line with previous descriptions in the literature [18, 141, 142], the majority of earthquake victims were admitted primarily because of injuries, mostly orthopaedic, with fractures representing almost two thirds of all injuries. Lower limbs were the most common body location of injuries, and 17% of all fractures were compound. Fractures are conditions that allow patients to reach the hospital, and often justify hospital admission, since surgical intervention is usually warranted. Injuries that are non-orthopaedic, such as to the head, chest, and abdomen, are usually much more severe and deadly, and fewer individuals with such injuries reach health services – and will not be reflected in hospital admissions [18].

Children and adolescents under 15 years of age only accounted for 17.2% of admissions, a share lower than the country's age distribution in 2014, where they represented 33.4% of the population [74]. The earthquake occurred on a Saturday, a non-working day in Nepal, and during the day. Schools were closed and children were more likely to be outdoors, and were probably less severely affected than if the earthquake had occurred at night or on a school day. Also, children in general are less prone to fractures than adults due to the properties of growing bone and, in the event of a fracture, the healing process does not require surgical intervention as often as in adults [143]. For this reason, fractures in children are often managed in the emergency department, resulting in less frequent hospital admissions. It is possible, however, that some children were sent to other treatment centres specifically set up to provide care to paediatric patients, although there is limited available information to support this. A study in a tertiary paediatric hospital in Kathmandu only reported on admissions nine days after the earthquake, without providing information on whether it was functioning before this date [144]. Nevertheless, given the disruption of the health system in Kathmandu, we believe that children in need of higher levels of care did not deviate significantly from TUTH.

The mean and median length of hospital stay of earthquake victims in TUTH (14.7 and ten days, respectively) are particularly high. A study in a rural hospital in Nepal showed that earthquake victims had a median length of stay of eight days, as opposed to five days in non-earthquake patients. In another study comprising 1,878 admitted victims of the Wenchuan earthquake, their mean length of hospital stay was seven days, ranging from one to 120 days [118, 130]. On the other hand, a study with 171 admitted patients after the L'Aquila earthquake in Italy revealed an average LOS of 12.11 days, but the sample was particularly old (57% of patients were aged 60 or older), and LOS was associated with age [145]. Earthquake injuries are usually sustained by high levels of energy applied in the musculoskeletal system, which may increase injury severity and, in consequence, delay discharge. Moreover, since TUTH is a reference hospital in Nepal, we expect more complicated cases to be sent there, which would explain why the mean and median length of hospital stays are higher than in other hospitals that were functional after earthquakes. Another possibility that some patients were kept longer in the hospital as they had their homes destroyed or were from distant places with no available transport.

Our survival analysis indicates that trunk and lower limb injuries, crush injuries, undergoing plastic surgery, or undergoing an amputation were associated with longer hospital stays. A study in Italy identified a similar pattern, with fractures in lower limbs and in the spine and trunk associated with longer hospitalizations [145]. Injuries in the trunk region include pelvic and spine fractures, and such patients usually are more unstable and require definite treatment before being discharged. Lower limbs are relatively less vascularized than upper limbs [146], and need longer time to heal [147]. In addition, open fractures are more likely to occur in the leg, and such wounds have higher infection rates [148]. Besides, walking is more challenging for patients with lower limb injuries and this may have influenced discharges in the context of earthquake destruction. Crush injuries may develop into the potentially fatal crush syndrome, and are severe conditions requiring intense fluid therapy or even renal replacement therapy to ensure hydro electrolytic balance [149]. Since it is an expectable condition in the aftermath of earthquakes, hospitals should be prepared to treat such patients, who will require a considerable amount of resources and longer hospital stays. Finally, wounds that require plastic surgery interventions are prone to infection, particularly in earthquakes where open wounds can be left untreated and uncleaned for hours or days. Such infections may need intravenous antibiotic therapy, forcing patients to stay in hospital. Also, reconstructive surgery often requires reinterventions, which naturally increases length of hospital stay [150].

Length of hospital stay is often described as the result of complex interactions between patients, accompanying physicians, and hospital management characteristics [116, 117]. Our findings suggest that earthquakes add to this complexity, as they trigger several injury admissions, cause serious disruptions in the surrounding environment such as in infrastructure or other health services, and disturb the normal functioning of the hospital. A previous study on admitted earthquake victims in China showed that length of hospital stay was not an appropriate proxy indicator for severe injury, but rather for major non-orthopaedic surgery and blood transfusion [118], suggesting that length of hospital stay reflects hospital resource use after earthquakes.

3.4.1. Limitations

Data were collected in chaotic conditions, primarily aimed at reporting to the government for financial compensation. We limited our analyses to the most reliable information available, which underwent several verifications. Completeness was lower for some specific variables, decreasing the power of statistical tests, and preventing us from including additional information, such as subsequent surgeries or co-morbidities, which could have enriched our analyses. Furthermore, we only analysed the main diagnosis as reported in the patient records. Although some conditions could be jointly classified as one ICD-10 code (e.g. multiple fractures in upper limb), some were left out from the analysis due to limitations in categorization, which was done by two independent researchers. Hence, it is likely that a relevant share of injuries was not considered.

We included earthquake victims who were admitted at TUTH at any stage, and our analysis contains referrals from other hospitals. However, because this information was not systematically collected, we cannot be entirely certain of which individuals were referrals. It is also not possible to affirm with certainty which victims were affected during the first earthquake or in its aftershocks. In addition, we lacked reliable information on posterior readmissions, which would have provided more insights on the long-term consequences for patients.

3.5. Conclusions

Our study attempted to use existing data from a unique setting in the most efficient way possible, providing useful information for tertiary hospitals to improve earthquake preparedness and response. There was a high influx of earthquake victims coming to TUTH for several days, with the peak occurring on the fifth day. With an increased length of hospital stay for earthquake victims compared to other settings, and some conditions that specifically need higher levels of care requiring longer admissions, TUTH faced an extremely high burden after the 2015 earthquake. Understanding which patient, intervention, and hospital characteristics influence length of stay after earthquakes is important to better plan resource use in future events. To strengthen resilience, tertiary hospitals in countries with seismic risks should have preparedness plans to cope with large numbers of injured patients after earthquakes, anticipating that they will need considerable resources. A particular focus on the initial days following the disaster is needed, since there is a sustained influx of patients, but limited external aid.

Knowing the profile of the admitted earthquake victims helps in understanding the type of burden the earthquake caused on the hospital. However, it is not sufficient to understand how this affected the normal functioning of the hospital. The next chapter explores how hospital admissions were affected by the earthquake.

Acknowledgements

We thank Alexandria Williams for her language revisions and Tulsi Pandey for her support during the data verification process.

Chapter 4
How does an earthquake affect admission trends?

This chapter is adapted from:

Maria Moitinho de Almeida, Benjamin-Samuel Schlüter, Joris Adriaan Frank van Loenhout, Sunil Singh Thapa, K. C. Kumar, Ravikant Singh, Debarati Guha-Sapir, and Deepak Prakash Mahara. "Changes in patient admissions after the 2015 Earthquake: a tertiary hospital-based study in Kathmandu, Nepal." *Scientific reports* 10, no. 1 (2020): 1-9.

https://www.nature.com/articles/s41598-020-61901-7

Abstract

Background: *Large-scale, sudden-onset disasters such as earthquakes heavily disrupt the functioning of local health services, but the literature on their impact on hospital admissions is scarce, particularly in low and middle-income settings. Our aim was to study the pattern of admissions before and after the 2015 earthquake in a tertiary hospital in Nepal, in terms of length of hospital stay (LOS), diagnostic categories, and number of daily admissions.*

Methods: *We used routine hospital data from 9,596 admissions from six weeks before to four months after the earthquake, and defined four periods: pre-earthquake (pre-EQ), acute (EQ1), post-acute (EQ2), and post-earthquake (post-EQ). We compared LOS across the study periods using negative binomial regressions. Then, we conducted logistic regressions to study changes in probability of admission for different diagnostic categories, and used Generalized Additive Models to model the difference in number of admissions compared to the pre-EQ baseline.*

Results: *Average LOS was significantly longer in EQ1 than during pre-EQ (9.80 vs. 7.05, respectively, p<0.001), particularly for injury-related admissions, whereas LOS for respiratory diseases was significantly shorter. In EQ1, the odds of injury admissions increased (aOR=5.33, CI: 4.44-6.40), while they decreased for the majority of other diagnoses, with the odds of pregnancy-related admissions remaining low until post-EQ. The number of admissions dropped in EQ1 and EQ2, and returned to pre-EQ trends in post-EQ, accumulating 381 admissions lost (CI: 206–556).*

Conclusions: *Tertiary hospitals should prepare to shift their focus and resources to treat high numbers of injured victims after earthquakes, but also ensure a quick return to normality to prevent collateral negative health outcomes. Accessibility, in particular for pregnant women, should remain a concern even months after the occurrence of large-scale disasters.*

4.1. Background

Violent, sudden-onset disasters, such as hurricanes or earthquakes, cause considerable damage in communities and lead to widespread destruction [5]. While deaths and direct injuries are immediate and expectable consequences of such disasters, drastic changes in the surrounding environment may have longer-term health effects [20, 21, 26, 151-153]. These disasters heavily disturb health systems, which must provide healthcare in a context of sudden increase of health needs, radical change of priority conditions, infrastructural and material damage, and staff shortages [32]. While most of the victims in need of care during and after a disaster are managed in an outpatient basis at emergency departments, a considerable amount of people will require hospitalization [154], and influence the normal functioning of the hospital. However, we found inconsistent evidence on the impact on hospital admissions immediately after and in the months following violent, sudden-onset disasters [151, 155-157].

Earthquakes are the most destructive type of natural disaster, having killed more than 721,000 people globally between 2000 and 2019. Earthquakes are particularly deadly in Asia, where more than 490,000 people have died in the same time-period [1]. Rapid population growth, urbanization, poverty, and geological risks contribute to Asia's seismic vulnerability.

Nepal is located on the boundaries of two colliding tectonic plates, and is particularly vulnerable to large-scale seismic events, like the 2015 earthquake. The epicentre of the 7.8 moment magnitude earthquake was in Gorkha district, and it was followed by hundreds of aftershocks, with the strongest on May 12th. National health services were the only services available to treat the high number of injured victims in the first days, since external assistance arrived with a considerable delay [96]. The Tribhuvan University Teaching Hospital (TUTH) is a major tertiary hospital in Nepal, built with earthquake resistance standards, and was functioning immediately after the earthquake, having assisted many earthquake victims [158]. TUTH belonged to the Hospital Preparedness for Emergencies (HOPE) network since 2014 [89], and activated its disaster response plan after the earthquake, reorganizing its services and implementing a mass casualty triage system to categorize earthquake victims [103, 105].

The literature portraying how earthquakes affect health service outputs, such as hospital admissions, is scarce in lower income settings. Studies in Nepal either fail to show the consequences of the earthquake on hospital admissions on a longer term [130], or do not capture the specificities of the initial days after the disaster [144, 159]. Understanding the pattern of hospitalizations after earthquakes is essential to improve hospital preparedness and surge capacity in future disasters, and facilitates a quick return to regular activities.

We studied the pattern of hospital admissions at TUTH from six weeks before to four months after the 2015 earthquake, in terms of length of hospital stay (LOS), diagnostic categories, and number of daily admissions.

4.2. Methodology

4.2.1. Study data

Data on hospital admissions between March 15th and August 17th 2015 were collected from centralized hospital registries. We compiled three datasets: hospital admissions, hospital discharges, and admitted earthquake victims (the last described in section 3.2 in Chapter 3). The first dataset contained sociodemographic information and served as panel data for daily admissions. We linked it with the remaining datasets to include date of discharge and diagnosis. The victim dataset underwent hand verification in original patient files in case of missing data or inconsistent information. We identified common admissions and merged datasets through deterministic linkages of identification number, name, sex, age, and date of admission. If these did coincide, we considered them the same admission. If not, we only considered the entry from the hospital admission dataset.

Available variables were sex, age (continuous), date of admission, date of discharge, and diagnosis. In the discharge dataset, diagnosis was classified according to the International Classification of Diseases, 10th revision (ICD-10), until the third level (letter and two digits), and was entered directly by TUTH's administrative staff. In the earthquake victim dataset, diagnosis was originally entered as free text, and two independent researchers later codified it into ICD-10. If their coding differed, they would discuss and agree on a final code.

We classified age into four groups (0-4, 5-14, 15-49 and ≥50 years old), and used the 21 ICD-10 disease categories for our analyses. We calculated length of stay

(LOS) as the number of days between hospital admission and hospital discharge. We defined the following four study periods:

1. Pre-earthquake (pre-EQ): admissions from March 15th until April 24th 2015
2. Acute earthquake period (EQ1): admissions between April 25th (including) until May 15th 2015
3. Post-acute earthquake period (EQ2): admissions from May 16th (including) until June 5th 2015
4. Post-earthquake (post-EQ): admissions from June 6th until August 17th 2015

We determined a six-week critical period divided into two three-week sub-periods for multiple reasons. First, six weeks after the earthquake, national health actors considered the critical period to be over, and health services started shifting back to a regular system [96]. It was also the time period required for other public services, such as schools, to reopen [160]. But most earthquake-related hospital admissions occur in the first days following the disaster [20], and there were repeated aftershocks, the strongest on May 12th (within three weeks of the first earthquake). Hence, we divided the critical six-week period in two smaller time intervals to increase precision and capture these particularities.

4.2.2. Data Analysis

First, we made a descriptive overview of the variables and tested for bivariate associations between sex, age groups, earthquake periods, and ICD-10 category, using chi-square tests.

Length of stay (LOS)

Length of hospital stay (LOS) generally follows a right-skewed distribution curve. Negative binomial regression is suitable to analyse LOS, with the advantage over Poisson regression in case of overdispersion of counts [122], which was the case in our sample: the variance-to-mean ratio ranged from 9.77 in pre-EQ to 15.86 in EQ1. We compared differences in LOS in the four study periods using a Negative Binomial regression, and adjusted for age group, sex, and ICD-10 category. We also calculated LOS differences across the four periods for individual ICD-10 categories that represented more than 10% of total admissions, adjusting for age group and sex. Outliers, i.e. admissions with a LOS longer than six months, were removed from the analysis (n=4).

Association between EQ period and ICD-10 category

To evaluate how the probability of admission for a given ICD-10 category changed with earthquake period, in relation to all other ICD-10 categories, we carried out binary logistic regressions, adjusting for age group and gender. We assumed the outcome as a Bernoulli variable, where being admitted for a given ICD-10 category was a success and for any other ICD-10, a failure. We only included ICD-10 categories that followed the one in ten rule – in this sample, with a minimum of 70 observations – and each time we compared one category with all the others grouped. We tested for interaction terms between control variables.

Earthquake impact on hospital admissions

We calculated the median number of daily admissions for weekdays and Saturdays in the pre-EQ period, since Saturday is the only non-working day in Nepal, and considered these values as the baseline number of daily admissions. We computed the difference between this baseline and the actual number of daily admissions during the three following periods, and used Generalized Additive Models (GAM) to model these differences and to capture non-linear behaviour. We used a variable reflecting Saturdays, and linear B-splines with interior knots at transition dates between EQ1 and EQ2, and between EQ2 and post-EQ (May 16th and July 6th, respectively). Splines are more flexible around the knots and this allows to fully capture non-linear trends [161, 162]. We assessed the model's goodness-of-fit by visual inspection of its residuals, where a good fit means 95% of the deviance residuals are between –2 and 2 and no big outliers are present.

We used R software (version 3.5.0) to perform all analyses and considered α=0.05.

4.2.3. Ethical considerations

Personal identifiers were used solely in the data verification process, and removed immediately after. We submitted this research protocol to the Tribhuvan University – Institute of Medicine's ethics committee. Since this study used secondary data from routinely generated information, the Tribhuvan University – Institute of Medicine's ethics committee deemed that informed consent was not necessary, and they provided clearance to undertake this study (Ref. 381(6-11-E)²/074/075).

4.3. Results

4.3.1. Descriptive overview

We included 9,596 admissions occurring between March 15th and August 17th 2015. Appendix A provides an overview of missing data and show the number of observations included in each analysis. Although the number of daily admissions varied before the earthquake, they were lower in both EQ1 and EQ2, followed by a return to pre-EQ trends in the post-EQ period, as shown in Fig.4.1.

Table 4.1 shows admissions by earthquake period, diagnostic category, sex, and age group. The post-EQ period contained 49% of all admissions, followed by the pre-EQ period with 26%. Overall, the most common causes of admission were injuries, pregnancy-related conditions, diseases of the digestive system, respiratory diseases, genitourinary diseases, and factors influencing health status and contact with health services. In our sample, this category included a miscellaneous of conditions that (i) arise when a person encounters health services for some specific purpose, such as to receive limited care or service for a current condition, to donate an organ or tissue, or to receive follow-up care; or that (ii) influence the person's health status but are not in themselves an illness or an injury, such as the outcome of delivery or a postsurgical state. Women accounted for 56% of all admissions, while children and adolescents under 15 years of age represented 17% of all admissions.

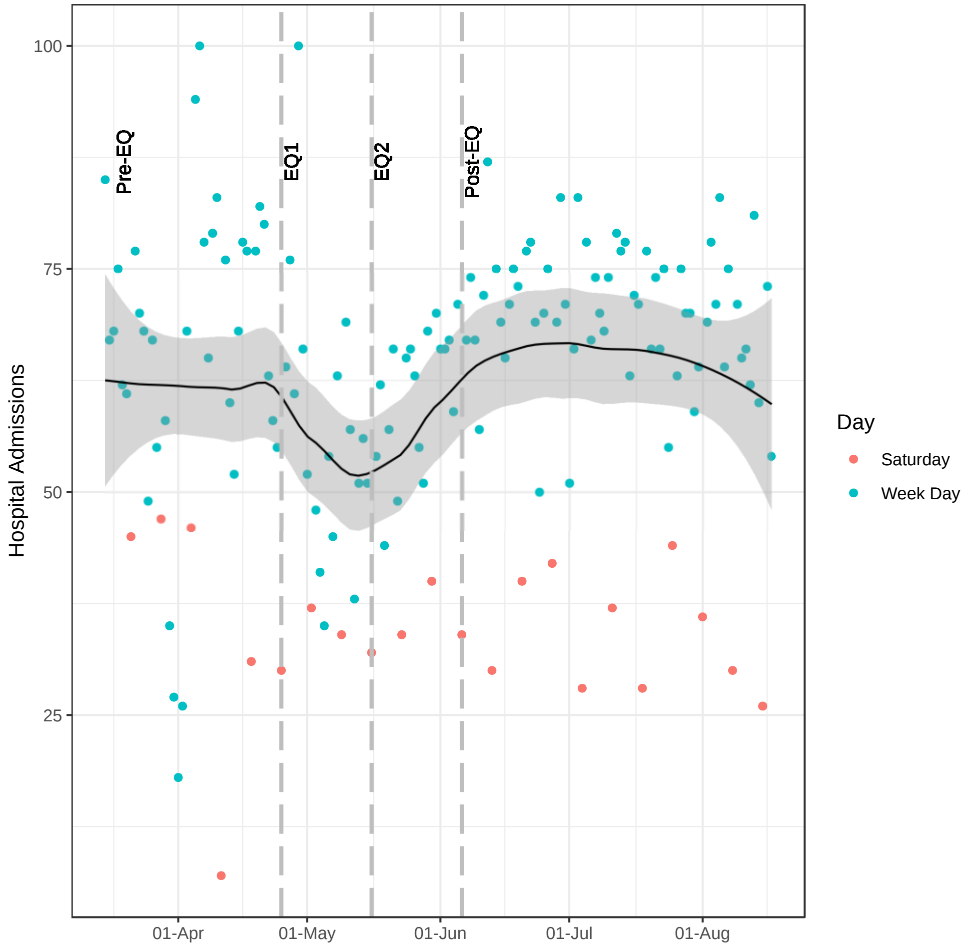

Figure 4.1: ***Evolution of number of admissions over time (smoothed)***
The smoothing curve is a local polynomial regression with span 0.5, where local regressions used to produce the curve incorporate 50% of the total nearest data points. The shaded area corresponds to the 95% confidence interval of the local polynomial regression. Red dots correspond to Saturdays, the weekly non-working day in Nepal. Dashed lines delimit different periods: pre-earthquake (pre-EQ), acute earthquake (EQ1), post-acute earthquake (EQ2), post-earthquake (post-EQ).

Table 4.1: ***Frequency of admissions by earthquake period, diagnostic category, sex, and age group***

	Total, N (%)	**pre-EQ, N (%)**	**EQ1, N (%)**	**EQ2, N (%)**	**post-EQ N (%)**
ICD-10 category					
Perinatal conditions	136 (1.5)	44 (1.9)	13 (1.2)	6 (0.5)	73 (1.7)
Infectious and parasitical diseases	352 (4.0)	89 (3.8)	22 (2.1)	46 (4.1)	195 (4.6)
Congenital conditions	110 (1.2)	20 (0.9)	3 (0.3)	10 (0.9)	77 (1.8)
Blood forming organ and immune system diseases	120 (1.4)	28 (1.2)	9 (0.9)	23 (2.0)	60 (1.4)
Diseases of the circulatory system	408 (4.6)	99 (4.2)	50 (4.8)	54 (4.7)	205 (4.8)
Diseases of the digestive system	954 (10.8)	266 (11.3)	58 (5.5)	136 (12.0)	494 (11.6)
Diseases of the ear and mastoid process	128 (1.4)	38 (1.6)	8 (0.8)	18 (1.6)	64 (1.5)
Genitourinary diseases	879 (10.0)	282 (11.9)	45 (4.3)	100 (8.9)	452 (10.6)
Musculoskeletal and connective tissue diseases	109 (1.2)	15 (0.6)	5 (0.5)	12 (1.1)	77 (1.8)
Neurological diseases	217 (2.5)	40 (1.7)	24 (2.3)	25 (2.2)	128 (3.0)
Respiratory diseases	899 (10.2)	297 (12.6)	78 (7.4)	115 (10.2)	409 (9.6)
Skin and subcutaneous diseases	123 (1.4)	47 (2.0)	5 (0.5)	17 (1.5)	54 (1.3)
Endocrine, nutritional and metabolic diseases	256 (2.9)	62 (2.6)	18 (1.7)	36 (3.2)	140 (3.3)
Contact with health services	902 (10.2)	210 (8.9)	125 (11.9)	119 (10.5)	448 (10.5)
Injuries and other external causes	1284 (14.6)	263 (11.1)	405 (38.5)	160 (14.2)	456 (10.7)
Mental and behavioural disorders	202 (2.3)	52 (2.2)	29 (2.8)	27 (2.4)	94 (2.2)
Neoplasms	424 (4.8)	107 (4.5)	21 (2.0)	64 (5.7)	232 (5.4)
Pregnancy, childbirth and the puerperium	1061 (12.0)	326 (13.8)	120 (11.4)	125 (11.1)	490 (11.5)
Other not elsewhere classified	186 (2.1)	56 (2.4)	14 (1.3)	21 (1.9)	95 (2.2)
Age group					
0-4 years	770 (8.0)	206 (8.7)	64 (6.1)	81 (7.2)	360 (8.4)
5-14 years	889 (9.3)	215 (9.1)	99 (9.4)	92 (8.1)	409 (9.6)
15-49 years	5555 (57.9)	1353 (57.3)	633 (60.1)	651 (57.6)	2512 (58.8)
≥ 50 years	2379 (24.8)	589 (24.9)	257 (24.4)	306 (27.1)	990 (23.2)
Sex					
Male	4178 (43.6)	1001 (42.4)	443 (42.1)	502 (44.4)	1864(43.6)
Female	5416 (56.4)	1362 (57.6)	610 (57.9)	628 (55.6)	2407 (56.4)
Total	**9596**	**2537**	**1128**	**1205**	**4726**

ICD-10 categories are simplified from their original designations for readability. Sums do not always add up due to missing values. pre-EQ: pre-earthquake period; EQ1: acute earthquake period; EQ2: post-acute earthquake period; post-EQ: post-earthquake period; ICD-10: international classification of diseases, 10th revision.

4.3.2. Length of Hospital Stay (LOS)

LOS ranged from 0 to 175 days, with an average of 7.7 days (SD 9.59), a median of 5 days, and an interquartile range of 3 to 9 days. Table 4.2 gives an overview of mean and median LOS in each study period. LOS was 19.7% longer during EQ1 than during the pre-EQ period (CI: 12.7-27.2; $p < 0.001$). There are no significant differences in LOS between any of the other earthquake periods.
In comparison to pre-EQ, LOS for admissions due to injury and due to contact with health services were 57.3% (CI: 37.0-80.7; $p<0.001$) and 21.0% (CI: 0.1-46.0; $p=0.046$) longer during EQ1, respectively. In contrast, LOS for admissions related to respiratory diseases decreased by 21.6 % in EQ1 (CI: 7.1-34.6; $p=0.008$).

Table 4.2: ***Central tendency and dispersion statistics for length of hospital stay, in days***

Period	Mean (SD)	Median	Range (minimum-maximum)	Interquartile range
Pre-EQ	7.05 (8.30)	5	0-110	3-8
EQ1	9.80 (12.46)	5	0-106	3-12
EQ2	7.49 (8.88)	5	0-87	3-9
Post-EQ	7.58 (9.58)	5	0-175	3-9

SD: Standard deviation.

4.3.3. Association between earthquake period and ICD-10 Category

In the bivariate analyses, earthquake period was significantly associated with age groups and ICD-10 categories (chi-square test, $p= 0.029$ and <0.001, respectively). The share of small children (0-4 years) was relatively low in EQ1, while the share of older people (50 years and older) relatively increased in EQ2 and post-EQ.
Table 4.3 presents the results of the logistic regressions, showing that the odds of admission due to injuries were significantly higher in EQ1 and EQ2, compared to pre-EQ. The odds for admissions due to contact with health services were higher

in EQ1, EQ2, and post-EQ. Pregnancy-related conditions and respiratory diseases had lower odds of admission in all study periods compared to pre-EQ. The odds of admission during EQ1 were significantly lower for infectious diseases, diseases of digestive system, diseases of ear and mastoid, skin diseases, and neoplasms, compared with pre-EQ. Genitourinary diseases had lower odds of admission during both EQ1 and EQ2. Congenital, neurological, and musculoskeletal diseases had increased odds of admission only in post-EQ. The most frequent conditions seen at TUTH for congenital diseases included congenital hydrocephalus, malformations of face and neck, and malformation of male organs. The most common neurological conditions included hemiplegia, para or tetraplegia, and other paralytic conditions. Musculoskeletal disorder-related admissions included mostly joint disorders and autoimmune diseases. We checked for interaction effects of earthquake period with age group and with sex, but these models were not significantly better, so we discarded them.

Table 4.3: ***Measures of association of ICD-10 Category and Earthquake period in relation to pre-EQ***

	EQ 1		EQ 2		post-EQ	
ICD-10 Category	**aOR (95% CI)**	***p***	**aOR (95% CI)**	***p***	**aOR (95% CI)**	***p***
Perinatal conditions	0.66 (0.35-1.23)	0.190	0.28 (0.12-0.66)	0.004**	0.91 (0.63-1.33)	0.642
Infectious and parasitical diseases	0.56 (0.35-0.89)	0.015*	1.09 (0.76-1.57)	0.643	1.22 (0.94-1.57)	0.135
Congenital conditions	0.36 (0.11-1.22)	0.099	1.11 (0.52-2.40)	0.781	2.16 (1.31-3.55)	0.002**
Blood forming organ and immune system diseases	0.71 (0.33-1.52)	0.379	1.74 (1.00-3.03)	0.051	1.19 (0.76-1.87)	0.456
Disease of the circulatory system	1.16 (0.81-1.65)	0.411	1.09 (0.78-1.54)	0.610	1.18 (0.92-1.52)	0.184
Disease of the digestive system	0.45 (0.34-0.61)	<0.001***	1.05 (0.84-1.31)	0.688	1.03 (0.88-1.21)	0.737
Diseases of the ear and mastoid process	0.46 (0.21-0.98)	0.045*	1.05 (0.59-1.85)	0.880	0.90 (0.60-1.35)	0.607
Genitourinary diseases	0.32 (0.24-0.45)	<0.001***	0.70 (0.55-0.90)	<0.001***	0.87 (0.74-1.02)	0.085
Musculoskeletal and connective tissue diseases	0.74 (0.27-2.04)	0.559	1.68 (0.78-3.61)	0.183	2.84 (1.63-4.94)	<0.001***
Neurological diseases	1.40 (0.84-2.33)	0.200	1.32 (0.80-2.20)	0.277	1.80 (2.26-2.58)	0.001**
Respiratory diseases	0.57 (0.43-0.74)	<0.001***	0.77 (0.61-0.97)	0.029*	0.73 (0.62-0.86)	<0.001***
Skin and subcutaneous diseases	0.23 (0.09-0.59)	0.002**	0.75 (0.43-1.31)	0.313	0.62 (0.42-0.92)	0.019*
Endocrine, nutritional and metabolic diseases	0.64 (0.38-1.10)	0.107	1.18 (0.78-1.80)	0.438	1.31 (0.96-1.78)	0.084
Contact with Health Services	1.47 (1.14-1.89)	0.003**	1.31 (1.02-1.69)	0.038*	1.23 (1.03-1.48)	0.024*
Injuries and other external causes	5.33 (4.44-6.40)	<0.001***	1.32 (1.07-1.64)	0.011*	0.94 (0.80-1.11)	0.456
Mental and behavioural Disorders	1.21 (0.76-1.92)	0.418	1.05 (0.65-1.68)	0.852	0.97 (0.69-1.37)	0.860
Neoplasms	0.43 (0.27-0.69)	<0.001***	1.22 (0.88-1.69)	0.225	1.26 (0.99-1.59)	0.060
Pregnancy, childbirth and the puerperium	0.74 (0.59-0.94)	0.012*	0.75 (0.60-0.95)	0.016*	0.77 (0.65-0.90)	<0.001***
Other not elsewhere classified	0.59 (0.33-1.06)	0.080	0.81 (0.49-1.34)	0.410	0.94 (0.67-1.32)	0.716

*p<0.05; **p<0.01; ***p<0.001. aOR: adjusted odds ratio; CI: Confidence Interval. Each ICD-10 category is compared to all other categories combined. Only ICD-10 categories with more than 70 observations are included. We removed the variable age group for perinatal conditions, and the sex variable for pregnancy-related conditions. The ICD-10 category names presented are simplified for readability, and we are not showing aOR for sex and age groups, although these variables have been adjusted for. A full table can be consulted in Appendix B.

4.3.4. Impact on total admissions

In the pre-EQ period, the median number of daily admissions was 68 on weekdays and 45 on Saturdays, which we considered the baseline for further analyses. As shown in Figure 4.2, the difference of hospital admissions was negative in both EQ1 and EQ2, meaning there were less admissions in these periods than in the pre-EQ baseline. While in EQ1, the number of daily admissions decreased, it had an ascending pattern in EQ2. In post-EQ, the difference of admissions has a tendency towards zero.

The model residuals do not show a particular remaining pattern although a big outlier is present on the fifth day after the earthquake (Appendix C) due to a peak of injury admissions, as shown in Figure 4.3. According to this model, the cumulative losses in admissions at the end of EQ1 reached 210 hospital admissions (95% CI: 112-307), whereas at the end of EQ2 they totalled 381 (95% CI: 206-556).

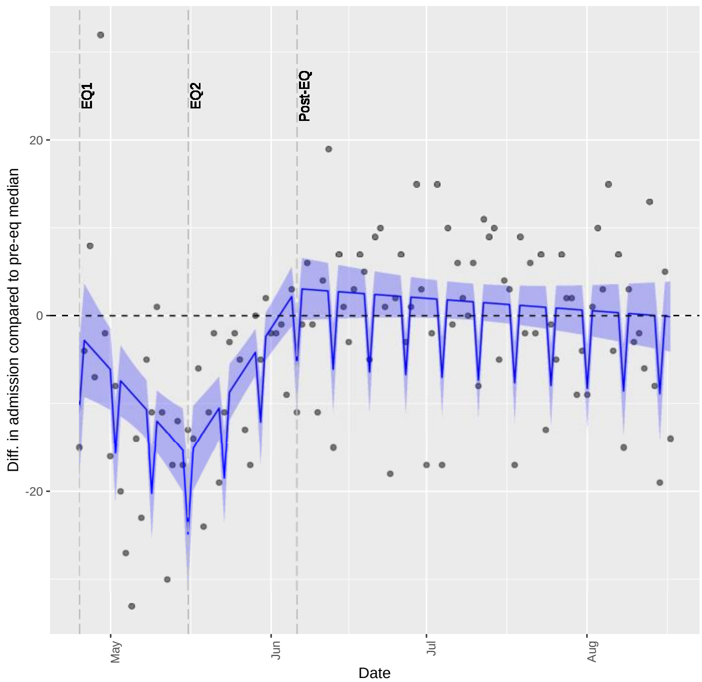

Figure 4.2: ***Difference of daily hospital admissions, compared to baseline pre-EQ median***
The line and shade represent the predicted values resulting from our model and their 95% confidence interval. Diff.= Difference; pre-eq= pre-earthquake period from March 15th to April 24th 2015.

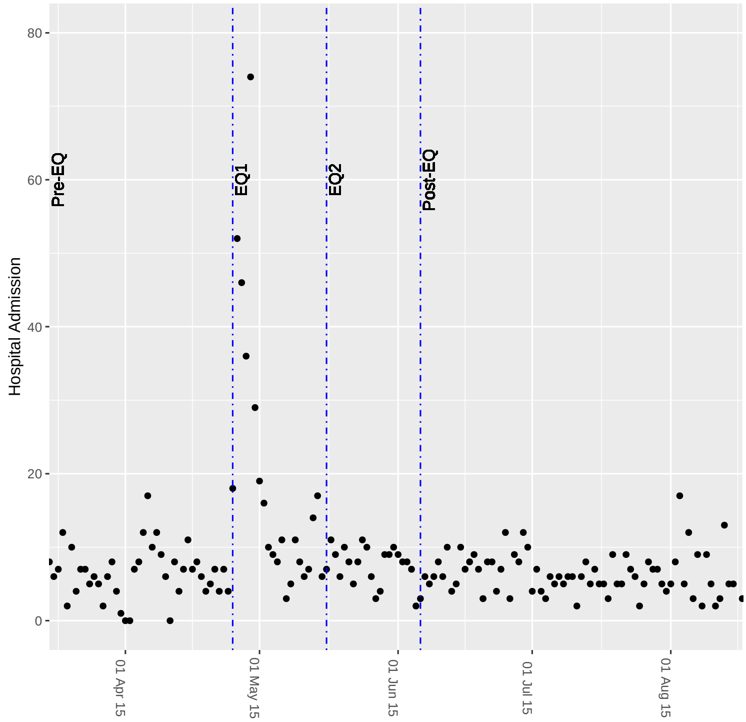

Figure 4.3: ***Daily admissions due to injury in all periods***
Dashed lines differentiate earthquake periods. pre-EQ: pre-earthquake period (from March 15th to April 24th); EQ1: acute earthquake period (from April 25th to May 15th); EQ2: post-acute earthquake period (from May 16th to June 5th); post-EQ: post-earthquake period (from June 6th to August 17th).

4.4. Discussion

Our results show that, in the aftermath of the 2015 earthquake, the pattern of hospital admissions varied with time. In the three weeks following the earthquake (EQ1), length of stay (LOS) for admissions was significantly longer than in other periods. This was mostly due to injury admissions, in which LOS highly increased. There were much higher odds of admission due to diagnostic categories “injuries” and “contact with health services”, compared with the pre-EQ period and relative to other admissions. There was also a significant relative decrease of admissions due to infectious diseases, neoplasms, pregnancy-related conditions, ear and mastoid diseases, digestive diseases, respiratory diseases, skin diseases, and genitourinary diseases. Finally, the overall number of admissions decreased significantly in EQ1 in comparison to the pre-EQ scenario, remaining significantly low in EQ2, and returning to pre-EQ trends in post-EQ.

The fact that injury admissions occurring in EQ1 were particularly long may relate to earthquake injury characteristics linked with severity and frequent complications [163], or because many severe cases were probably referred to TUTH since it is a referral hospital in Nepal that was functional after the earthquake [158]. A disrupted transport network, or destroyed housing, may have also delayed patient discharge until an improvement of the situation. Nevertheless, LOS for respiratory diseases substantially decreased in EQ1, probably because such admissions were shortened to increase patient turnover and ensure all earthquake victims in need were admitted and appropriately treated. These findings are in line with a study in a rural hospital in Nepal describing the patient load in the three weeks after the earthquake, which found that earthquake-related conditions had significantly longer hospitalizations compared to other non-earthquake related admissions [130]. Another study focusing on the L'Aquila earthquake in Italy had similar findings, with earthquake victims having significantly longer LOS than other patients [145].

There was a relative increase of admissions due to injuries and due to other factors influencing contact with health services in EQ1; while admissions due to other ICD-10 categories substantially decreased. Previous conceptual models have theorized that the need for hospital care due to earthquake injuries is concentrated in the days after the earthquake, while other elective and less urgent conditions are deferred [20]. Shortly after, there is a need for hospital care for trauma-related complications, which could explain why admissions due to "factors influencing health status and contact with health services" are high in EQ1 and EQ2. This was empirically verified in a study on the earthquake victims who were admitted in TUTH [158]. The high probability of admissions in this category in post-EQ may be due to an accumulation of interventions that re-started after weeks of being interrupted, such as the donation of organs and tissues by healthy donors. Admissions related to congenital diseases, musculoskeletal diseases, and neurological diseases increased in post-EQ, which could also correspond to an accumulation of elective care to clear the backlog caused by interruptions in EQ1 and EQ2. An interesting finding was the sustained decrease of respiratory conditions in post-EQ in comparison to pre-EQ, as the literature reports medium-term increases of respiratory diseases after earthquakes [21, 152]. The fact that our full study period corresponds to warmer months in Nepal, and that the population is relatively young, could be an explanation for this observation. Severe respiratory diseases requiring in-hospital treatment are less often expected, particularly because this earthquake was a relatively "dry" disaster, as opposed to hurricanes or earthquakes followed by tsunamis, characterized by an increase of pneumonia cases [151, 152, 164]. As such, most respiratory consequences of the 2015 earthquake would be reflected in outpatient care. A study in Patan Hospital, in the vicinity of Kathmandu, showed that there were significantly more emergency visits due to cardiovascular, psychiatric, respiratory, and hematologic conditions in the four months after the earthquake, compared to the same period one year before [159].

We also found that pregnancy-related admissions decreased immediately after the earthquake, and remained low in the long-term. A study following typhoon Haiyan also identified an immediate decrease of pregnancy-related admissions, suggesting that lack of access may have caused an increase in unsafe deliveries with lack of adequate care [151]. An ethnographic study in rural Nepal reported that, after the earthquake, several women preferred delivering at home rather than at a health facility, making it more difficult to refer to a hospital when needed [165]. The transfer from basic delivery facilities to higher levels of care was disrupted after the earthquake due to road destruction [165], which could further explain a sustained decrease in pregnancy-related admissions at TUTH. There are reports of operational mobile reproductive health clinics set up by the UNFPA and the Ministry of Health in the initial response phase to address specific maternal care needs [165], but information on long term changes in maternal health is scarce. Some admissions related to the outcome of delivery, however, are categorized under "factors influencing health status and contact with health services", which merits a more detailed examination combined with a more in-depth analysis of the category Pregnancy, Childbirth, and the Puerperium. In addition, more comprehensive studies can shed light on the external context's influence on maternal healthcare. Regardless of this, it is essential to ensure appropriate care for pregnant women in the months following a disaster.

It is well established that earthquakes cause a sharp increase of medical needs due to injuries, many of them requiring surgical and in-hospital treatment [18, 20]. Yet, we found that, despite an initial peak of admissions on the fifth day after the earthquake, the total number of admissions dropped in the weeks after the earthquake, and slowly increased back to baseline levels after six weeks. During this six-week period, our model estimates that there were 381 fewer admissions than if the pre-EQ trend had continued. TUTH was functioning immediately after the earthquake, with victims and visitors arriving within 20 minutes after the shake. The emergency department put in place its mass casualty triage system, and increased its space by using other buildings as specific triage colour areas. It is possible the emergency department treated many of the victims, who in normal circumstances would have been admitted, in an outpatient basis. Despite the lack of documentation to support this, probably only the most severe cases were admitted in the hospital, which themselves were very resource-consuming, suspending all other non-urgent admissions. This is supported by the fact that admissions occurring during EQ1 had higher LOS, but would benefit from more research exploring other contextual factors.

4.4.1. Limitations

Our study had some limitations, including that it used a large dataset from routine hospital activities, not created for research purposes, with a limited number of variables. There may have been a categorization bias in the diagnosis classification, since it often influences financial compensation. However, by using broad ICD-10 categories, we reduced this bias. Data from the earthquake periods may be less complete because of the hectic situation at the time, and it is possible that not all information was systematically registered. Since we completed and verified most of our findings with an additional earthquake victim dataset, which was verified with original patient files, we believe this is a minor issue. Our study compared the post-disaster situation with a relatively short baseline period, and did not take seasonality into account. Seasonality could partially have been overcome by using annual trends from previous years, but this information was not available. Nevertheless, in the post-EQ period, the number of admissions returned to baseline; suggesting a low seasonal variation of daily hospital admissions at TUTH in our study period. When we computed the baseline number of daily admissions, we differentiated for the only non-working day in Nepal. However, we could not capture variations related to festive holidays, strikes, or other events that may affect admission patterns. Finally, the results of this study do not consider external factors that can be potential confounders, such as access to care or other health services that may have drained patients who would have otherwise attended TUTH.

4.5. Conclusions

Large-scale disasters, such as earthquakes, heavily disrupt the functioning of tertiary hospitals. Our study provides useful information for tertiary hospitals in seismic and low-income settings. Because of the increase of injured patients with long admissions, hospitals should be prepared to quickly mobilize resources to treat high numbers of injuries in the event of an earthquake. However, the overall number of admissions decreased in the weeks following the earthquake, mostly due to a strong decrease of admissions due to other causes, which were also shorter than usual immediately after the earthquake. This loss of hospital function may carry additional negative health consequences. To avoid further morbidity and mortality associated with interruption of elective and specialised care, tertiary hospitals must ensure they remain accessible and capable of providing essential care to less urgent conditions. To avoid overloading tertiary hospitals, conditions that do not require specialized care should be treated in lower tiers of healthcare. In order to achieve this, it is essential to build capacity of peripheral health services that manage uncomplicated injuries and identify and refer severe cases.

Both Chapters 3 and 4 quantitatively describe the impact of the earthquake on the functioning of the hospital, either by presenting the profile of admitted earthquake victims or by studying changes in patient admissions. These findings outline unique challenges TUTH faced in the earthquake aftermath. However, we still lack a comprehensive understanding of other challenges, and how the hospital responded to them, in order to fully capture the drivers of hospital resilience.

Chapter 5
How do hospital workers experience hospital resilience?

This chapter is adapted from:

Maria Moitinho de Almeida, Joris Adriaan Frank van Loenhout, Sunil Singh Thapa, K C Kumar, Deepak Prakash Mahara, Debarati Guha-Sapir and Isabelle Aujoulat. “Hospital resilience after the 2015 earthquake in Nepal: results from semi-structured interviews with hospital staff”, accepted in *Frontiers in Public Health*, 2021.

https://www.frontiersin.org/articles/10.3389/fpubh.2021.602509/abstract

Abstract

Background: *Resilient hospitals are increasingly recognized as a cornerstone of disaster reduction in global policies such as the Sendai Framework for Action. However, current hospital resilience frameworks emerged from pre-disaster conceptualizations, and have not been verified in real-life disaster contexts in the frontlines. Our aim was to study a tertiary hospital's resilience after the 2015 earthquake in Nepal, as experienced by its staff.*

Methods: *We undertook a qualitative study in the Tribhuvan University Teaching Hospital (TUTH), where we conducted 18 semi-structured interviews with hospital staff. We inductively created themes to describe the earthquake burden to the hospital, and to analyse individual resilience of hospital staff. In addition, we deductively documented the resilience of the hospital as a system, according to the system resilience dimensions: means of resilience (redundancy and resourcefulness), and ends of resilience (robustness and rapidity).*

Results: *TUTH faced material challenges, as well as challenges to healthcare provision, to management and coordination, and to hospital staff. In terms of robustness, TUTH increased its capacity for earthquake victims as elective activities were temporarily interrupted and quality of care was not a priority. Three stages of rapidity were identified: critical rapidity to address immediate needs, stabilizing rapidity until the hospital re-started routine activities, and recovery rapidity. In addition to the disaster plan, emerging adaptations played a major role in redundancy and resourcefulness. We found that individual resilience depended on three determinants: safety, meaningfulness, and sense of belonging.*

Conclusions: *Hospital resilience results from a complexity of emerging and planned adaptations, as well as from interdependencies with individual resilience. Frameworks and plans to improve hospital resilience must reflect flexibility of response, and a concern for well-being of hospital staff is central for sustainable disaster response and improved resilience.*

5.1. Background

Disasters are events that lead to substantial losses and disrupt the functioning of a community beyond its coping capacity [5]. Large scale, sudden-onset disasters occur quickly or unexpectedly, cause widespread destruction, produce high numbers of deaths and injuries, and require external assistance [5]. Countries with increased vulnerability and weaker coping capacity are the most affected by the human consequences of such large-scale disasters, which heavily strain health systems by causing sudden material damages, increases in demand, or workforce disruptions [19-21, 32, 166]. Hospitals are critical in disaster response efforts to minimize loss of life, morbidity, and disability [64]. The role hospitals play in an effective community disaster response has been increasingly recognized [167], and resilient hospitals have become central in global disaster management initiatives. The Hyogo Framework for Action 2005-2015 [39] was the first international document to describe the processes needed to reduce disaster risks in various sectors, including the health sector. The more recent Sendai Framework for Action 2015-2030 [40] provides recommendations for safe cities and hospitals, and calls for resilience of national health systems and critical infrastructures.

Despite a growing recognition of its importance, the concept of hospital disaster resilience remains somewhat elusive [71]. Initially developed by engineering sciences, the concept of hospital resilience describes the "ability to overcome disasters with inherent capacity and adaptive flexibility, providing emergency medical services and responding to sudden increases in demand, while retaining essential functionalities" [64]. The four "resilience R's" framework of hospital resilience consists of "means" of resilience – Redundancy and Resourcefulness – and "ends" of resilience – Robustness and Rapidity. Redundancy is the extent to which elements are substitutable, including the hospital itself if linkages are in place. Resourcefulness is the ability to mobilize material and human resources to meet priorities and achieve goals, and includes coordination measures. Robustness is the strength to withstand stress without suffering degradation or loss of function. Rapidity entails that priorities are met and goals are achieved in a timely manner, in order to contain losses, recover functionality, and avoid further disruption [45].

Building on existing frameworks, instruments that assess hospital resilience have been recently developed, but they only consider pre-disaster states [69, 70]; it remains unclear whether they reflect processes in the context of actual disasters.

A recent paper attempted to use existing frameworks after an actual disaster, but it focused on experiences at managerial levels rather than from the frontlines [71]. However, frontline staff are confronted with difficult situations that are often not reflected in strategic level experiences, but greatly influence overall disaster response and, ultimately, disaster impact. Only by understanding experiences of hospital staff can we design plans that target them and increase overall hospital resilience. In this paper, we study a tertiary hospital's resilience after the 2015 earthquake in Nepal, as perceived by its frontline staff.

5.2. Methodology

As the concept of hospital resilience still is ill-defined and difficult to measure, a qualitative methodology can unveil important information that current quantitative approaches would not cover. In this study, the purpose was to explore how the hospital staff experienced and perceived hospital resilience. To capture a rich set of textual data, we conducted in-depth interviews with different hospital staff. The objective was to contribute to existing hospital resilience theories, while keeping an open-mind to avoid force-fitting the data into pre-conceived, static themes. Hence, we guided the analysis through a synthetic resilience framework – the 4R's – while allowing for new ideas to emerge.

5.2.1. Study setting

On April 25th 2015, a powerful earthquake hit Nepal killing nearly 9,000 people. It was followed by recurrent aftershocks, the strongest on May 12th [1, 92].

Our study focuses on a referral tertiary hospital in Kathmandu: the Tribhuvan University Teaching Hospital (TUTH). TUTH was established with donation funds from the Japanese government, has earthquake-resistant infrastructure, and is centrally located and easily accessible. Initially a 300 bed-capacity, it expanded over the years reaching 700 beds in 2018, but nearly a hundred additional beds were created after the earthquake in 2015 [103]. As a university hospital, TUTH contributes to training and education of medical and healthcare professions, in addition to providing tertiary and specialized care to the population of Nepal. TUTH was part of the Hospital Preparedness for Emergencies (HOPE) initiative, a training course that addresses the structural, non-structural, organizational and medical concerns of health facilities in order to design and implement effective disaster response plans [89]. At the time of the 2015 earthquake, TUTH had an emergency plan in place. Hospital staff were trained in the implementation of this plan through regular drills and additional physical measures had been implemented, such as supply and maintenance of emergency containers, electricity replacement, and fixing of objects [89]. TUTH was one of the seven hub hospitals in the Kathmandu valley treating earthquake victims and coordinated with other health facilities for referral. TUTH's direction immediately activated the Incident Command System, and a triage system for mass casualty incidents was put in place. TUTH treated 1,723 victims in total [104], having admitted more than 500, the majority with orthopaedic injuries and surgical needs [158]. Non-injury-related admissions were significantly lower in the weeks after the earthquake, as priority was given to resource-intense earthquake injuries [168].

5.2.2. Data collection

MMA, a non-Nepalese female Medical Doctor, conducted 18 semi-structured interviews with hospital staff to explore their experiences of hospital resilience after the earthquake. Interviewees were purposively selected to obtain a diverse sample in terms of profession, gender, and seniority. The sample size was estimated according to available resources, but data saturation was reached on the 14th interview, meaning that no new information emerged from the later interviews. The hospital director and/or administrative chief invited interviewees to participate directly or through their direct supervisors, who gave them permission to participate. Participants had no previous contact with the interviewer.

MMA developed an interview guide following iterative discussions with the research team. The final version was approved by all research team members and focused on experiences before, during, and after the earthquake at personal, professional, and organizational levels (Appendix D). Different probes were used to encourage interviewees to elaborate on certain aspects that merited to be explored more in-depth.

Interviews took place in May 2018 in a quiet room at TUTH during working hours. Eleven interviewees were comfortable in speaking English as it is their main working language (used in medical records and administration reports), and their interviews were conducted in English. For seven interviewees, an external interpreter facilitated communication and translated between the interviewee and interviewer. Interviews lasted on average 60 minutes, ranging between 40 and 100 minutes.

At the start of each interview, study participants were informed about the researcher's background and the content of the research. They were given the opportunity to read the informed consent form before signing it. Upon participants' approval, all interviews were audio recorded, transcribed ad verbatim, and, if applicable, translated to English. Notes were taken during the interviews, and were incorporated in the initial coding. Interview transcripts were returned to participants, but no changes were requested.

5.2.3. Analysis

Following recommendations for qualitative data analysis in health services research, we combined deductive and inductive thematic coding [123]. The first author coded the data, and themes were discussed among the research team.

We first inductively created themes to describe the earthquake burden to the hospital, as perceived by the respondents. Then, to document the resilience of the hospital as a system, we extracted parts of the data that thematically aligned with the four dimensions of hospital resilience, the theoretical framework that defined our starting codes: Redundancy, Resourcefulness, Robustness and Rapidity. Some hospital adaptations could be categorized in multiple dimensions. We followed the definitions proposed in the literature, but establishing clear distinctions was sometimes difficult. In such cases, we categorized the content under multiple dimensions, and we explained how it aligns with each.

Finally, we found that individual resilience of hospital workers was an important component of hospital resilience, but could not fit in the "4R's" since they are conceived for systems, not individuals. We undertook inductive coding to analyse individual resilience of hospital staff, and three themes emerged: safety, meaningfulness, and sense of belonging.

We handled and coded the data using NVivo software, 12th edition. In our results, we present quotations to support our statements, some of which were slightly modified for clarity. Because interviews were conducted in a unique hospital and touched sensitive issues, we present quotations without any participant information to prevent identification. To ensure maximum transparency and reproducibility of the findings, this study complies with the Consolidated Criteria for Reporting Qualitative Research (COREQ) [114].

5.2.4. Ethical considerations

This research was approved by the Ethics Committee of the Tribhuvan University's Institute of Medicine, case number 381(6-11-E)²/074/075. Interviewees provided written informed consent to participate.

5.3. Results

We interviewed 18 hospital staff of different functions and demographic characteristics, presented in Table 5.1.

Table 5.1: ***Characteristics of interviewees***

Characteristics	Number
Profession	
Medical Doctor (Departments: orthopaedics, gastroenterology, anaesthesiology, emergency department)	4
Nurse (Departments: intensive care unit, operation theatre, maternity ward, direction)	4
Physiotherapist	2
Pharmacist and Dietician	2
Radiology and Laboratory Technician	2
Security and Housekeeping	2
Finance and Administration	2
Gender	
Male	11
Female	7
Age Group (at the time of the interview)	
30-40	7
41-50	4
51-60	7

Based on the information collected in the interviews, we identified four types of burden to the hospital: material challenges, challenges to health service provision, challenges to management and coordination, and emotional and physical impact on individuals. Table 5.2 expands on these burdens, and presents adaptations at system level under "means of resilience", whereas the resulting robustness and rapidity are the "ends" of resilience. Table 5.2 also presents the main determinants of individual resilience.

To summarize system resilience at TUTH, Figure 5.1 illustrates how hospital functionality evolved with adaptations and over time. We briefly summarize the main findings on the ends of resilience (robustness and rapidity) in the following section, followed by a more expanded description of the means of resilience as well as individual resilience.

Table 5.2: ***Overview of earthquake burdens and system and individual resilience***

Burden	System resilience (the "4 R's")			
	"Means" of resilience		"Ends" of resilience	
	Redundancy	Resourcefulness	Robustness	Rapidity
<u>Material damages</u> **Structure** **Electricity** **Equipment and supplies**	• Offices in damaged area moved to resistant part • Electricity generator, fuel for 24 hours	• Pre-existing disaster plan: use of open-space • Army intervened for fuel supply • Rationing and reutilization of equipment • External donations BUT challenges (storage, validity)	• Structure resisted despite minor damages • Objects fell as fixing and retrofitting not systematic • Emergency activities continued	• Critical rapidity: Ability to function immediately • Challenges to critical and stabilizing rapidity: Management of equipment may have caused delays
<u>Health service provision</u> **Massive influx of earthquake victims** **Chronic disease patients** **Mental health (MH)**	• Linkages with other health services	• Emergency triage • Free healthcare for victims • Interruption of elective activities, early discharges • Rearrangement of surgical and ICU services • Long working hours	• Increased capacity for EQ victims • Decreased quality of care? • Health needs addressed	• Critical rapidity: Surgeries within 2h • Stabilizing rapidity: 2-3 weeks to address all victims
	• Task shifting of human resources			

<table>
<tr>
<td><u>Management and coordination</u>

Saturday and mostly junior

“Chaos”

Inflow of external organizations, with infiltration of thieves and fraudulent schemes in the crowd

Tension with foreign medical teams

Second earthquake</td>
<td colspan="2">• Establishment of assessment meetings and decision channels (although unclear for some)
• Unclear coordination
• Spontaneous individual decisions by individuals
• Transfer of burden to external actors
• Direct requests of foreign teams to the government

Second earthquake:
• Improved coordination
• Prepared staff</td>
<td>• Victims were assessed (triage) and surgeries occurred
• Hospital able to focus on core activities
• Decreased quality of care?
• Unclear if following disaster plan

Second earthquake:
• Improved response</td>
<td>• Benefits to critical and stabilizing rapidity: external support
• Challenges to critical rapidity: confusing decision-making and coordination

Second earthquake:
• Quicker response: limited impact on stabilizing rapidity</td>
</tr>
<tr>
<td rowspan="4"><u>Emotional and physical impact to individuals</u>

Concern with family

Feelings of “torture”

Exposure to suffering

Increased workload</td>
<td colspan="2">• Split groups so everyone had time to check on family</td>
<td>• Staff showed up and ensured continuous work</td>
<td>• Critical rapidity influenced by contact with family and private life adaptations
• Recovery rapidity influenced by personal experiences</td>
</tr>
<tr>
<td colspan="4">Individual resilience</td>
</tr>
<tr>
<td>Safety</td>
<td colspan="2">Meaningfulness</td>
<td>Sense of belonging</td>
</tr>
<tr>
<td>• Important to keep working despite aftershocks
• Absence of national policies and safety measures contribute to persistence of fear</td>
<td colspan="2">• Making sense of the tireless work and prioritizing it over family
• Dependent on job visibility</td>
<td>• Support from families, co-workers and communities
• Key to focus on work without concerns</td>
</tr>
</table>

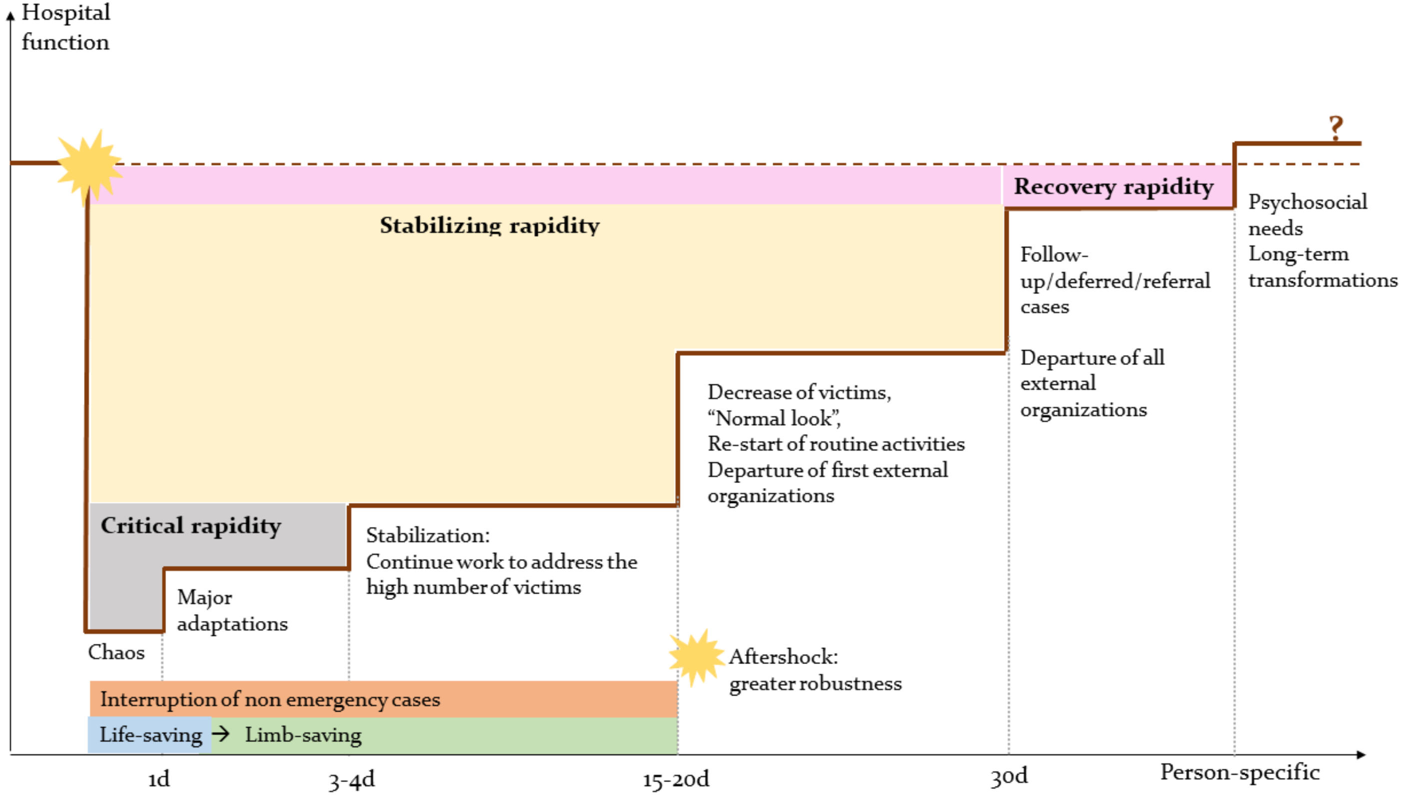

Figure 5.1: **Diagram relating hospital functionality, adaptations, and time, based on information from interviews**

5.3.1. Ends of system resilience at TUTH

In terms of hospital robustness, TUTH avoided total loss of function and maximized capacity to provide emergency treatment, though at the expense of routine activities and with potential collateral impacts: loss in quality of care and patients discouraged to travel to TUTH even after re-start of routine services. For instance, deliveries at TUTH reportedly decreased with the earthquake and remained low, possibly because women preferred closer health facilities.

During that time, we were not focusing on quality of care. (…) We had a lot of wound infections, we were not taking care of sterility properly… We just needed to provide care, we were focusing on life-saving and limb-saving activities.

In our analysis of hospital rapidity, we identified three major types of rapidity, as TUTH regained different functions at different times:

- Critical rapidity: the time needed to start essential work and assist injured victims while also self-organizing. At TUTH, the first surgeries started two hours after the shake, but more days were needed to optimize coordination, since being a Saturday challenged critical rapidity as most senior staff was absent.

  We tried to manage the pharmacy without a software system, but for two days, we failed. We were almost out of stock after two days. Then we started to ask for medicine supply from different agencies, from the government…

- Stabilizing rapidity: the new rhythm after critical reorganizations to address earthquake-related surges, until the hospital re-started routine activities and reobtained a "normal look". The major aftershock seemed to have had limited impact.

  (…) That made us feel like "ok we are back into function": no patients treated on the ground, all patients treated in the wards.

- Recovery rapidity: After the situation was stabilized and the hospital re-started routine activities, time was needed to end the phase - and feeling – of emergency, which was very subjective. Administrative staff and those caring for earthquake victims reported longer times to recovery. Although they often mentioned it, interviewees struggled to elaborate on the concept of "recovery" – some even referred that they were "*still recovering, and not recovered*"

5.3.2. Means of system resilience at TUTH

Redundancy

TUTH found suitable alternatives to disrupted elements. While redundancies to certain challenges were established prior to the earthquake, others emerged as new problems arose.

<u>Redundancy to material challenges</u>

Services from slightly damaged facilities moved to earthquake-resistant areas, and the fuel-supplied generator provided electricity after the earthquake disrupted central supply. However, it only had a 24-hour autonomy. After the first day, a fuel shortage in Kathmandu threatened TUTH's energy supply. To solve this, the hospital coordinated with the army to ensure fuel supply (which demonstrates resourcefulness – see further).

For the generator to run, we had a back-up of 24 hours, but after the first 24 hours, there was no fuel. (...) So, our administration had to go to the army, they have a petrol pump.

<u>Redundancy to health service provision</u>

After the earthquake, "step-down centres" were established to rehabilitate or care for patients no longer requiring hospital care. TUTH staff actively looked for patients they could transfer in order to accommodate more victims, and a mobile team ensured patient follow-up outside the hospital.

This is how concept of step-down centre came immediately. Second or third day we started sending the patients. (...) We used to go on a vehicle take a round of all patients. "This patient is serious, we can bring back to our hospital, we take care. This patient is good, please carry on"

Reports regarding referrals from TUTH to other hospitals at the time of the earthquake were conflicting: some denied their existence while others affirmed they were in place, although patients were reluctant to move to unsafe buildings.

This hospital wants to refer, and those doctors they want to take the patient. But due to the structure, these patients said "oh that structure is so scary, we don't want to go to that hospital"

Staff conducted tasks that differed from their usual work or qualifications. Task shifting could be considered a feature of both redundancy and resourcefulness; we considered redundancy when hospital workers explicitly switched tasks to replace overwhelmed colleagues.

The surgeons were limited in number, they had to go to the OT, they had to go to emergency. There were not enough surgeons. So, we did the dressing and all. And we were helping them, in a way keeping the records, and discharging the people…

Resourcefulness

TUTH showed resourcefulness in mobilizing external and internal resources. Some aspects were specified in the disaster plan, but many adaptations were spontaneous, compensating for a perceived lack of coordination.

Resourcefulness to material challenges

Despite having emergency containers, TUTH faced shortages of essential supplies. Interviewees reported rationing and reusing equipment, but also that such strategies could be harmful. Fortunately, external donations flew in. Even if storage was initially challenging, TUTH handled donated surgical and rehabilitation equipment easily; donated medicines were more complicated to manage due to validity. Charity groups prepared meals to distribute among staff, patients and patient families, removing a substantial burden from TUTH.

Resourcefulness to health service provision

TUTH immediately started mass casualty triage, consisting of four categories: green (minor injuries), yellow (patients who did not require admission), red (severe injuries), and black (deceased). Only red cases received immediate and/or surgical care.

Elective services were halted, stable patients were discharged earlier than in normal circumstances, operation theatres were continuously functioning, and care for earthquake victims was free of cost. Neurosurgery and orthopaedic surgery monopolized operation theatres, and post-operative rooms were rearranged to accommodate more intensive care beds. Staff reorganized duties and worked longer hours to ensure uninterrupted services.

We categorized task shifting as resourcefulness when staff adapted tasks to address new health needs or high patient numbers. For instance, non-medical staff performed first aid, applied plasters and even resuscitated patients; and doctors and nurses conducted psychological counselling during unrelated consultations when they identified mental health needs.

Interviewees were satisfied with volunteer work from patient relatives, local communities, and students. Proximity to the university facilitated the integration of students in hospital work, but this required additional supervision. Nevertheless, foreign surgical teams from western countries were unwelcome, since their presence was felt as undermining TUTH's competence, and interviewees felt they were rather needed in places without health facilities. To handle the inflow of foreign teams, TUTH's administration requested that they first registered with the government. Nevertheless, foreign teams who supported in psychosocial counselling were perceived as useful and well-accepted.

We told them "we have our own doctors, we have our own nurses, we are enough already here. You are needed somewhere else. (….) Where the incident took place, there are no medical facilities, you are needed there". (…) We said "Enough right now. If you want to serve, you have to come through the government".

I'm thankful to these volunteers who came from abroad. One young doctor came from Canada and she went to different schools to give psychosocial counselling. Psychosocial skills and counselling were very important.

<u>Resourcefulness to management and coordination</u>

Some interviewees believed the day of the earthquake was well managed, despite reports of "chaos". After the first day, the director's team held assessment meetings twice per day, and gave instructions to different departments. The presence of external donors and volunteers also strained TUTH as it led to accountability issues, overflow of supplies, abuse of charity, and theft. Hence, coordination was essential. Most interviewees underlined the importance of having, or finding, a role after the earthquake, but not all were familiar with the disaster plan or aware of pre-earthquake drills. Those without assigned roles often acted spontaneously, and those unaware of decision-making systems made more spontaneous decisions.

At a disaster time, everyone needs to know their job. But I did not know my job: the scenario drove me to that job.

Resourcefulness to challenges to individuals

As staff adapted to the new context, they divided teams in shifts, allowing everyone to visit relatives without interrupting services.

We divided our group into two groups to cover days and nights. (…) One team would come in the daytime, do the cases, go home, and another team would come in the night-time.

5.3.3. Individual resilience

Staff were essential to TUTH's adaptive capacity, but were constantly exposed to suffering and living a work-family dilemma. Interviewees recalled feeling fear, worry, and sorrow, sometimes even reporting "mental instability" and "depression"; but also reported feeling pride and love for TUTH, and even recalled feeling "extra powers" to work. Inactivity or difficulties in contacting relatives often promoted negative thoughts and emotions, and "overworking" was a frequent strategy to avoid this.

You try to compensate with overworking or doing something else, so that you do not feel yourself depressed or you know, bad.

Some interviewees were trying to forget their experiences or denying the possibility of future events, but did not elaborate on this during the interviews despite different probes. Such interviewees had apparently implemented fewer adaptations at home, and were less confident about their experiences.

This type of disaster is not happening again and again. I pray the god. Because that time was terrible, everyone was panicking, crying, things were destroyed…

Determinants of individual resilience

We identified three major determinants of hospital staff resilience: safety, meaningfulness, and sense of belonging.

<u>Safety</u>

Feeling safe helped managing negative feelings: for instance, knowing TUTH was earthquake-resistant and safe allowed staff to continue working despite recurrent aftershocks. At home, interviewees reported improving safety by retrofitting and preparing emergency bags. The absence of safety and disaster prevention measures on a national level contributed to a persistence of fear, and challenged recovery.

We were terrified, but we knew that we were safe in ICU because that building was safe.

Now at this moment I can't say I am fully recovered. Because I feel scared of the roads, because roads are not properly constructed.

<u>Meaningfulness</u>

Many interviewees felt their work was essential and contributed to a selfless aim. Meaningfulness helped making sense of the tireless work, the putting family second, the constant fear. Interviewees alienated from this meaning often felt trapped in their jobs and frustrated with the administration. Professional visibility seemed to influence this. Technicians often felt overlooked and questioned the sense of their dedication, while those who directly cared for victims, or who had been recognized by the hospital, more often found their experiences meaningful.

One of my cousins, (…) he was found dead. It was pain. I couldn't even get there to say a few words on their sorrow and grief. What sort of job I have, I am even not free to go there and express my sorrow to them!

Now they have understood our importance. If there is work to do, they call us. If there is a meeting (…), they call us. Before, they never cared.

Sense of belonging

In order to focus on work without feeling guilty, hospital workers often left loved ones with extended families, or friends' and colleagues' families – often described as a relief. Interviewees were proud of the family cohesiveness in Nepal, which they thought largely contributed to success. Extended community support also contributed to an inspiring sense of belonging. Another example was team spirit, as co-workers comforted each other, and organized shifts so all could spend time with their families.

After the second day I shifted my family to uncle's house (...).They had like a family get-together. And I was free to work.

(...) In my house, there were 3-4 families ; doctors from this hospital, whose house had been damaged, they were in my house. We were like in a big hostel. (...) So, time passed gossiping (...), it was an enjoyable time actually.

5.4. Discussion

Our study was among the first to apply a hospital resilience framework in a post-disaster setting to analyse staff experiences. We illustrated how the earthquake generated a complexity of events that challenged a tertiary hospital in Nepal, many of which were addressed with emerging adaptations. We found that functional challenges, not material, were major disruptors of hospital resilience, and because they are highly dependent on human behaviour, hospital staff resilience plays a major role.

Our analysis captured a richness of experiences that did not exactly fit in the proposed definitions of the "4R" dimensions. The theoretical and empirical literature regarding hospital system resilience has been mostly developed in pre-disaster contexts, and has barely been validated by field evidence from disaster settings [71]. Although established plans did influence TUTH's resilience, our results emphasize the important role of emerging adaptations in the overall performance of the hospital, but the 4R framework does not differentiate emerging adaptations from pre-disaster preparedness, even if they are the only solutions as new, unforeseen problems arise. While more recent hospital disaster resilience frameworks recognize the importance of "adaptive flexibility" [67] or "adaptive capacity" [169], these concepts remain vaguely defined in the scientific literature, as they are mostly developed for the purposes of preparedness and do not include actual experiences from real disasters.

But, even if spontaneous adaptations are inevitable, it is important that they do not substantially reduce quality of care. Crises understandably lead to altered standards of care, but decision-making should be based on harmonized strategies [170], not on individual assumptions. We found that professionals with managerial roles or closer to the administration were more familiar with the disaster plan. The design of new disaster plans should be fed from the earthquake experiences of hospital staff, the frontline workers who will be executing the plan in the event of a disaster. Training all the staff on a regular basis should also be foreseen in such plans, to ensure everyone is familiar with the organizational procedures and knows the decision-making processes.

International Emergency Medical Teams were sometimes perceived as an invasion undermining local capacity, but they were also useful to fill specific gaps. In Nepal, the Health Emergencies Operations Centre under the Ministry of Health coordinated the activities of international teams, and they followed the classification and standards set by the World Health Organization [94]. To ensure uniformity in treatment and referral, all EMTs were asked to use national protocols while managing cases. Furthermore, they were instructed to maintain detailed documentation for trauma and amputation patients who required follow-up and rehabilitation, and reported daily to the Ministry of Health. A report on the effectiveness of these teams in Nepal highlighted a weak coordination and lack of needs-based deployment. The coordination of international Emergency Medical Teams, in Nepal and elsewhere, should avoid overlap with local capacitated teams, and should ensure a real discussion of needs and strategies with the local health service administrations [96].

Finally, we demonstrated the importance of staff in ensuring continuity and quality of services. Previous studies have shown that hospital workers undergo a double burden during disaster response, and struggle between responsibilities towards their family and hospital duties [166, 171]. We found that interviewees were generally more positive when they felt safe, attributed a meaning to their experiences, and felt a sense of belonging to a supportive community. A previous study with hospital staff after Typhoon Haiyan also had identified the importance of feeling safe and feeling committed towards the patients for staff to continue working; an interesting difference was the consistent reference to faith as a coping mechanism, which was absent in our sample [166]. Other qualitative studies have shown the importance of making sense of a difficult experience to believe efforts were worthwhile [172]; and the feeling of safety is a recurrent need expressed by health and humanitarian workers in times of emergencies [173-175]. According to the Sense of Coherence, when an individual perceives a difficult situation as meaningful, he/she will feel it is worth the commitment, rather than a burden [172].

Our findings suggest that hospital resilience and individual staff resilience are interdependent, as the conditions at the hospital affect the individual, and the individual's performance influences the effectiveness of adaptations. Strategies that contribute to staff wellbeing in times of disaster response contribute to hospital resilience. International initiatives such as the "Hospitals Safe from Disasters" Campaign [51] or the HOPE network [89] should make this explicit, and this should also be translated in hospital disaster plans in Nepal and beyond, as the ongoing Coronavirus Disease (COVID-19) pandemic showed these issues are present across different types of health services and different types of countries. One possible way to improve adherence to and effectiveness of hospital disaster plans and training exercises is to include different professions, seniority and functions of staff in their design, which also promotes disaster government at local levels and contributes to local community empowerment [176]. Contributions of young people also can be promising and forward looking when regarding disaster resilience, and could be a valuable asset in the design of local hospital plans [177]. Finally, co-design of strategies that help individuals make sense of difficult experiences, like organizing debriefing sessions, is a promising solution [173]. Staff should also be given the space to work as it may be a coping strategy that empowers them and helps make the most of their competences and capacities.

5.4.1. Limitations

A selection bias may be present, since interviewees were contacted by the hospital director and administrative chief. This may have also inhibited interviewees to fully express themselves. Because interviews were conducted three years after the earthquake, testimonies are subject to recall bias, but we believe its influence was minimal given the magnitude of the event. In addition, language and cultural biases may have influenced the interpretation of certain expressions. We had planned to validate our results through a participative approach through Focus

Group Discussions with hospital staff, but the COVID-19 pandemic prevented this. Finally, TUTH has a Japanese-donated earthquake-strengthened structure and is a tertiary, university hospital, and findings must be handled carefully before generalizing to other settings. However, we have applied common strategies that improve transferability to other settings, including a rigorous and transparent methodology, and allowing unexpected issues to emerge rather than force fitting them in theoretical frameworks [106].

5.5. Conclusions

Hospital resilience results from a complexity of emerging and planned adaptations that prevent substantial loss of function and promote a quick re-start of interrupted activities. Frameworks and plans to improve hospital resilience must reflect flexibility of response. Individual resilience of hospital staff and hospital resilience are interdependent. In emergencies, concern for hospital staff welfare is central for sustainable disaster response and improved resilience.

Acknowledgements

We thank Surya Gaire for his support during the interviews in Nepali and for translating the recordings, Dr. Kirsten Vanderplanken for her insights and support in optimizing the use of NVivo, and all the hospital staff who participated in the interviews.

Chapter 6
Discussion: What does all this mean?

In this chapter, I summarize the findings of the dissertation and discuss how they complement each other and relate to the literature. I also present the implications of these findings to national and global policies and practices, and dissert on the scientific impact of this work. I end this chapter with a reflection on the strengths and limitations of this thesis.

6.1. Findings in perspective

My thesis aimed to investigate the impact of a high-magnitude earthquake in a tertiary hospital in Nepal, and to explore its resilience mechanisms. I wanted to examine how the profile of admitted victims presented a burden to the hospital; I also intended to evaluate how the pattern of hospital admissions changed with the earthquake. Finally, I aimed to explore how the hospital staff experienced the hospital's earthquake response and resilience, and assessed the suitability of the 4R resilience framework [45], with the flexibility to incorporate new concepts that could enrich it.

With the support of my colleagues, I analysed the profile of 501 earthquake victims who were admitted in TUTH, and found that the peak of admissions occurred on the fifth day, with 77 admissions, and that many of the admitted victims required surgical interventions and particularly long hospitalizations. The average number of daily admissions decreased in the six weeks after the earthquake, with 381 admissions less (CI95%: 206-556) when compared to the pre-earthquake baseline. The share of injury-related admissions was particularly high in the three weeks after the earthquake (aOR=5.33, CI95%: 4.44-6.40), and such admissions were particularly long, with an increase of 57.3% (CI95%= 37.0-80.7) in length of hospital stay compared to the baseline. Admissions due to other conditions decreased and were shorter than usual. Finally, we found that the hospital's resilience was highly dependent on emerging adaptations, in addition to pre-existing plans. Functional aspects were major influencers of hospital resilience. Since they were highly dependent on human behaviour, individual resilience played a major role in the resilience of the hospital as a whole; we found that staff were conditioned by a sense of safety, meaningfulness, and belonging.

6.1.1. Connecting the dots: linking findings to each other and to the literature

Long stays

In our study, earthquake victim admissions were particularly long (mean= 14.7 days; median= 10) compared to studies in other hospitals, either in Nepal [130] (median= 8 days for earthquake victims) or in Wenchuan hospitals in China after the 2008 earthquake [118] (mean= 7 days). A study in Italy after the L'Aquila earthquake in 2009 found that the average length of hospital stay (LOS) of admitted earthquake victims was 12.11 days; LOS was significantly associated with age, in a sample where 57% of patients were older than 60 years [145]. In our sample, only 29% of patients were older than 50 years, and age was not associated with length of stay, suggesting a different cause for the long hospitalizations. Results in Chapter 4 show that in the three weeks after the earthquake, injury admissions were significantly longer than before the earthquake. This long LOS is probably related to the fact that TUTH is a reference hospital and received more severe cases, and that people from remote districts reached the hospital with considerable delay, and therefore with further complications or more advanced conditions. A paper analysing hospital admissions after the Wenchuan earthquake found that length of hospital stay was associated with the level of resource use [118]. In line with this, our findings suggest that earthquake admissions at TUTH were particularly resource-intensive. Results focusing on length of hospital stay in Chapters 3 and 4 contrast substantially with reports from hospital staff presented in Chapter 5. Hospital staff perceived that admissions were shortened to increase turnover, but the findings from Chapters 3 and 4 suggest that this was only the case for non-earthquake related admissions, which were shorter in the three weeks after the earthquake. These findings are in line with a study in a rural hospital in Nepal that found that earthquake-related admissions were significantly longer than non-earthquake admissions [130].

Overwhelmed?

The overwhelming burden to the hospital, described by hospital staff during the interviews analysed in Chapter 5, is not reflected in the total number of admissions, which decreased in the six weeks after the earthquake. Even if a peak of earthquake-related admissions occurred five days after the earthquake, it is estimated that up to 381 admissions were lost in the 6 weeks following the earthquake.

This means that, in absolute terms, TUTH's inpatient burden was not higher after the earthquake. However, we can assume that pressure points were elsewhere, which may not be reflected in hospital admissions. First, people with less severe injuries and conditions, who usually represent most earthquake injuries, were treated at the emergency department in an outpatient basis: of the total 1,723 injured victims reportedly treated at TUTH [103, 104], less than a third were admitted. Second, the type of admissions changed substantially: from a share of 11.1% of all admissions in the pre-earthquake period, injuries represented 38.5% of all admissions in the 3 weeks after the earthquake (aOR=5.3, $p<0.001$). The average length of stay also significantly increased during the same period, and mostly due to injury-related admissions, which were significantly longer. Third, the majority of admitted earthquake victims required a surgical intervention (69%, n=345), with many needing reinterventions. Staff reported that operation theatres were constantly occupied with earthquake-related surgeries, mostly with orthopaedic and neurosurgery teams. Teams from non-surgical medical specialties were mobilized to support surgical and orthopaedic wards, as surgeons were always in the operation theatres. Finally, the existing Intensive Care Units were not sufficient for the number of victims that required intensive care, and new units had to be set up.

As such, to deal with this sudden increase of a specific demand for surgical and orthopaedic services, TUTH had to sacrifice its capacity for non-urgent activities, cancelling routine services like outpatient consultations and elective interventions. As explained in a conceptual model by von Schreeb et al., the need for hospital care due to injuries is concentrated in the days after a sudden-onset disaster, while other elective and less urgent conditions are deferred [20]. As we lack data on the precise activities that were cancelled or postponed, we do not know how many of these corresponded to time-sensitive conditions, such as oncological situations. However, given the description of the chaotic conditions in the first weeks, we can assume these also did not take place, aggravating the deleterious impact of the earthquake. The ongoing COVID-19 pandemic and related lockdowns have demonstrated the problems of prolonged interruption of elective care, with models estimating that clearing the backlog would take up to 45 weeks if the normal surgical volume increased by 20% [178].

Where are the pregnant women?

Chapter 4 shows that pregnancy-related admissions decreased immediately after the earthquake, and remained low for months after. This was confirmed by perceptions of hospital staff, presented in Chapter 5, who believed this reduction was due to insufficient delivery beds and preference of pregnant women to use services closer to their residence, some of which were likely set up after the earthquake. An ethnographic study in rural Nepal also showed that, after the earthquake, women preferred delivering at home rather than at a health facility, making it more difficult to refer to a hospital in case of complicated labour [165]. This finding is not unique to the Nepal earthquake context. A study following typhoon Haiyan also identified an immediate decrease of pregnancy-related admissions, suggesting that reduced access to hospitals may cause an increase in unsafe deliveries with lack of adequate care [151]. Reports from after the 2004 Tsunami in South-East Asia suggested that, because many mid-wives had died, a large number of deliveries occurred without a skilled attendant and used potentially harmful techniques [179]. In the United States of America, significant increases in the percentage of inadequate prenatal care were detected after Hurricane Katrina (2005), and a criticism at the time was that most preparedness plans did not have specific provisions for women and children [180].

The missing pieces of Hospital Disaster Resilience

The study presented in Chapter 5 is one of the first to use the well-established 4R system resilience framework as a starting point to explore mechanisms of hospital resilience in a post-disaster setting, as experienced by its staff. We captured a richness of experiences and complexity of events that the 4R framework failed to reflect. The theoretical and empirical literature regarding hospital system resilience has been mostly developed in pre-disaster contexts, and has barely been validated by field evidence from disaster settings [71]. Although established plans did influence TUTH's resilience, our results emphasize the important role of emerging adaptations in the overall performance of the hospital. These were the only solutions as new, unforeseen problems arose. While more recent hospital disaster resilience frameworks recognize the importance of "adaptive flexibility" [67] or "adaptive capacity"[169], these concepts remain vaguely defined in the scientific literature, as they are mostly developed for the purposes of preparedness and do not include actual experiences from real disasters.

Moreover, while previous studies have demonstrated the important role of staff experiences in hospital disaster response [166, 171], ours is the first to identify individual resilience of hospital staff as an important contributor to hospital resilience. In our study, we identified three major determinants of hospital staff resilience: meaningfulness, sense of safety, and sense of belonging. A previous study with hospital staff after Typhoon Haiyan also had identified the importance of feeling safe and feeling committed towards the patients for staff to continue working; an interesting difference was the consistent reference to faith as a coping mechanism, which was absent in our sample [166]. Other qualitative studies have shown the importance of making sense of a difficult experience to believe efforts were worthwhile [172]; and the feeling of safety is a recurrent need expressed by health and humanitarian workers in times of emergencies[173-175].

6.1.2. Framing this case study in the Nepal Earthquake context

The earthquakes in Nepal reportedly injured 22,000 people, the majority located in Kathmandu district (n= 7,950, or 36.1% of all victims reported) [96]. One study estimated that a total of 1,723 victims were treated at TUTH both in inpatient and outpatient care [103, 104], which would represent about 21.7% of Kathmandu's injured, and 7.8% of Nepal's injured. This is a substantial share, considering that in theory not all 22,000 injured needed hospital care. Bambarén and colleagues [154] modelled the demand for hospital care after an earthquake, based on an extensive review of the available evidence. They estimated that up to 26% of injured earthquake victims would need hospital care and, of these, 20-68% would need to be hospitalized (Fig 6.1). This would mean that, in Nepal, up to 5,720 people were treated at a hospital, and between 1,144 and 3,890 people were hospitalized. Considering 501 earthquake victims were admitted in TUTH, this would mean that TUTH treated between 12.9-43.8% of all earthquake victims who needed inpatient care in Nepal. However, these calculations assume that the estimate of 22,000 injured victims includes cases that did not require any medical or paramedical attention. This figure is repeatedly reported in different institutional and scientific documents, and probably has specific definitions set by the Government of Nepal, but unverified situation reports from the time of the earthquake response place the number of victims at higher levels [181].

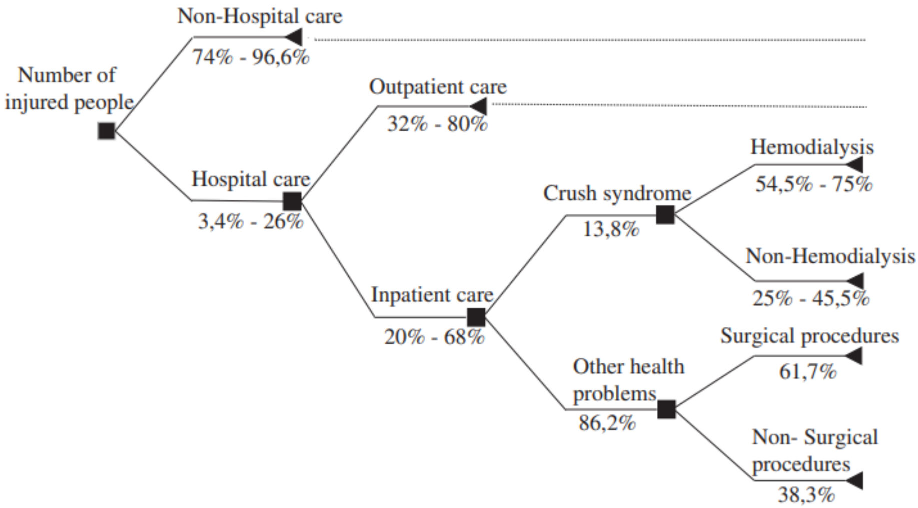

Figure 6.1: ***Estimates of demand and need for hospital care after an earthquake***
Reproduced from [154], with permission from Cambridge Univerisity Press.

6.2. Importance of the findings

6.2.1. Implications for TUTH and Nepal

Although a participatory approach would have been the optimal solution to design recommendations based on this dissertation (see section 6.3.2), the available evidence and contextual information allow us to outline major implications of our findings.

Considering the particularities of Nepal's topography and seismic risk, earthquake victims in remote areas are likely to receive medical care too late. We established that the peak of admissions in TUTH occurred on day 5 after the earthquake, different from the usual 48-72 hours reported in the literature. This is likely influenced by the fact that TUTH is a reference hospital, and referrals contributed to the overall number of admissions. To save more lives and to preserve health of rural communities in Nepal, efforts to strengthen capacity in decentralized health services are crucial. This will ease the burden on TUTH – which took over many resource-intensive earthquake admissions at the expense of other conditions that needed specialized care – and other tertiary hospitals in future disasters.

Improved capacity in peripheral health services can also improve the likelihood of timely life and limb saving activities. In this sense, the Ministry of Health should ensure that the current national Disaster Risk Reduction policies and strategic actions are implemented at local levels, and that health services are resistant to high-magnitude shocks. Strengthening capacity in peripheral health services would also ensure continuity of care for pregnant women, which can easily be disrupted during disasters.

Our findings have established that the lack of engagement of part of the staff caused nuisances not only on the individual but also on TUTH as a whole. Individual and spontaneous decisions can decrease quality of care [170]. It is hence of utmost importance that TUTH and other hospitals in Nepal ensure harmonized approaches that allow for flexibility and provide guidance for emerging adaptations. Co-design of strategies that help individuals make sense of difficult experiences, like organizing debriefing sessions, is a promising solution. Staff should also be given the space to work, in order for them to make the most of their competences and capacities, and to feel empowered.

International Emergency Medical Teams could be perceived as an invasion and an insult to local capacity, but they were also seen as useful to fill specific gaps. A report on the effectiveness of these teams in Nepal highlighted the weak coordination and lack of needs-based deployment. The coordination of foreign teams should be handled carefully, in order to avoid overlap with local capacitated teams, and should ensure a real discussion of needs and strategies with the hospital administration [96].

The Government of Nepal obliges all health facilities to have a hospital and health facility emergency preparedness and disaster response plan (HEPP) in place, in coordination with the local disaster management authorities. These plans should include provisions to ensure continuity of maternal healthcare in case of a disaster. Data from 2015/2016 suggested that only 30 out of 85 hospitals had emergency preparedness plans, including TUTH. Enforcing adherence to legislation requiring hospitals to have HEPP is challenging, but the earthquake in 2015 probably raised awareness for the issue and highlighted the need for such plans. While some disaster plans are only known to some professionals with managerial roles, the design of new disaster plans should be fed from the earthquake experiences of hospital staff, the frontline workers who will be executing the plan in the event of a disaster. Training all the staff on a regular basis should also be foreseen in such plans, to ensure everyone is familiar with the organizational procedures and knows the decision-making processes.

We also found that hospital staff perceived a need for psychosocial counselling in earthquake victims. Hospital staff, particularly doctors and nurses, spontaneously integrated psychosocial counselling in their activities. While this was important, it would merit from a more coherent and systematic approach foreseen in disaster plans. Packages for psychosocial support in emergencies exist, and could be integrated in hospital disaster preparedness plans. Hospitals in Nepal should also provide key people with the appropriate training for mental health and psychosocial support in emergencies, who would then be able to support patients, families, and staff.

The recommendations of this dissertation contribute to operationalize the Nepal Post-Disaster Recovery Framework [182], in particular its core health sector strategies: strengthening existing structures and retrofitting of equipment in all hospitals and health posts; involving different stakeholders in the building of institutional and community capacity for disaster preparedness; and using the lessons learned from the earthquake to apply disaster risk reduction strategies in reconstruction. Moreover, we cannot isolate a hospital system from the health system it belongs to. A stronger health system throughout the nation will reduce the burden to individual health facilities in times of disasters, and will improve the quality of response. Our recommendations, if applied, also yield positive consequences even in non-disaster times – what is called the "resilience dividend"[183, 184]. For example, ensuring efficient referral systems for disasters will also improve referrals in general, which strengthens access and quality of care and reduces overall morbidity and premature mortality. Engaging stakeholders in the process of designing and implementing disaster plans, especially those who are typically overlooked, can empower individuals and improve everyday performance at work. Investing in resilience ultimately contributes to stronger, healthier communities, even if disasters do not happen.

6.2.2. Global implications

The findings of this dissertation can make substantial contributions to current practices in disaster and hospital management at a global level.

Countries at risk of natural disasters

For countries with seismic risk, the resilience of health services should not be limited to structural resistance to powerful shakes. Hospitals and health services should have strategies that ensure sufficient equipment for high numbers of orthopaedic injuries and related surgeries, possibly through centralized dispatching or agreements with neighbouring countries, and surgical capacity should be strengthened in peripheral services. Tertiary hospitals should provide advanced care to earthquake victims, but efforts are needed to minimize disruption on the provision of specialized care to non-earthquake conditions. The need for stronger health services in the periphery is especially accentuated in countries where baseline topography and transport networks already challenge access.

All countries need to promote disaster preparedness plans that include provisions for women and children, ensuring that maternal healthcare can be continuously provided in the event of an emergency. These should be incorporated at all levels, from local communities and health facilities to regional and national institutions. This is even more critical in contexts where maternal mortality and morbidity are still high and adherence to antenatal care is fragile.

In all countries facing disasters, victims, relatives, and frontline staff experience great levels of suffering and stress that can seriously impact their mental health [31, 174] and ability to reach their full potential in the future. Emergency packages for mental health and psychosocial support exist, but they are usually rolled out by external organizations to specific communities or individuals [185]. But the need for this kind of support often presents spontaneously during a medical encounter, and the medical worker may not always be sensitized to the issue. Moreover, this type of service is rarely provided to local frontline staff after a disaster. Hospital disaster plans should include basic training on psychosocial support for all the staff, and should also have specific provisions to ensure appropriate and skilled support to their own staff.

Strategies that contribute to staff wellbeing in times of disaster response contribute to hospital resilience. International initiatives such as the "Hospitals Safe from Disasters" Campaign [51] or the HOPE network [89] should make this explicit, and this should also be translated in hospital disaster plans. If hospital workers do not feel safe at work, if they do not feel appreciated and supported by their community, or if they do not see a purpose in their tireless efforts, the performance of the hospital as a whole is threatened. One possible way to improve adherence and effectiveness of hospital disaster plans and training exercises is to include different professions, seniority and functions in their design.

COVID-19 pandemic

In 2020, the world was hit by a pandemic disease caused by a novel coronavirus resembling the one that caused the Severe Acute Respiratory Syndrome (SARS) epidemic in 2003. In early December 2020, the COVID-19 pandemic had infected more than 65 million people and killed 1.5 million [186]. Faced with an unprecedented surge in cases and with collapse of health services in rich and poor settings, many countries imposed lockdowns, sometimes even on multiple occasions.

The catastrophic situation in critical care units and emergency wards in countries around the world highlighted the difficult working conditions of frontline workers such as hospital staff. The narratives that arose from this unprecedented episode reiterated the importance of our findings. First, the initial lack of sufficient personal protective equipment challenged the feeling of safety of hospital staff [175]. This may have, even if unconsciously, decreased their ability and willingness to monitor patients closely. The fear of infecting loved ones because of their work may have aggravated this. Second, global movements of solidarity towards healthcare workers reminding them of the importance of their work could help them find their experiences meaningful and feel community support. Initiatives such as giving them priority in supermarkets were visible demonstrations of community support. However, the gains achieved with these measures are fragile in prolonged situations. The resurgence of second waves through Europe related to so-called "pandemic fatigue" can dangerously make frontline staff lose the feeling of community support and meaningfulness, as their efforts seem to be in vain if populations do not do their part.

6.2.3. Scientific impact

This dissertation contributes to scientific advances in the fields of disaster medicine, disaster epidemiology, disaster management, and resilience studies.

It empirically supports conceptual models of disaster impact on hospital care proposed by von Schreeb et al. [20] and Zhong et al. [64], and shows concrete, measurable changes, some of which may seem counter-intuitive: the overall decrease in admissions, the long hospitalizations of earthquake victims, and the sustained reduction of pregnancy-related admissions.

A major contribution of this dissertation is the further verification of the suitability of the 4R framework through empirical post-disaster data collection and analysis. This framework was only applied in the evaluation of resilience in pre-disaster times, as well as other related resilience frameworks, and focused mostly on preparedness and simulation exercises. But resilience is only evident after a disaster has occurred. Our findings show that the 4R framework failed to reflect the spontaneous, unplanned adaptations as well as the importance of individual resilience in the overall hospital. This explains why hospital safety checklists and disaster plans often overlook measures to improve staff welfare or to ensure coherence and quality in spontaneous initiatives. Having resilience frameworks and assessment questionnaires that foresee the unpredictable is extremely challenging and counter-intuitive, but not acknowledging the possibility of spontaneous adaptations is a missed opportunity. An important step to move forward would be to better define these spontaneous adaptations with more field research and complementing them with literature including from other research domains.

The ongoing COVID-19 pandemic has shown the importance of staff wellbeing to ensure continuity of life-saving activities [175]; highlighting the importance of our findings beyond Nepal and an earthquake scenario. A study in the early stages of the pandemic identified five requests from healthcare professionals to their organization: “Hear me, Protect me, Prepare me, Support me, Care for me”; highlighting the desires to be heard in times of drastic change, to be safe and having health risks reduced, to be able to provide high-quality care, and to feel supported in times of extreme work and distance from the family. This is in line with the broad themes identified in this dissertation: meaningfulness, sense of safety, and sense of belonging. These findings can contribute to the development and refinement of salutogenic theories applied to health workers and disasters [173, 174].

Another scientific impact of this study is the spotlight given to routine health information systems as an important data source to advance the field of disaster epidemiology. However, we have shown that using this data alone can lead to misinterpretations, and the best approach is to complement it with additional data sources and qualitative information. Nevertheless, the quality and comprehensiveness of these information systems must be improved and prepared for disasters [187], which will also be useful for non-disaster times.

6.3. Strengths and limitations of the dissertation

To interpret the findings of this dissertation, they must be considered in light of the strengths and limitations of this research.

6.3.1. Reflections on the sources of data

The studies presented in Chapters 3 and 4 used routinely generated data, a specific type of data that presents benefits and disadvantages, as shown in Table 6.1 In disaster settings, they are a valuable source of information as they are produced independently of research activities. However, precisely for this reason they present limitations that influence their interpretation, such as selection bias, limited information available, and uncertain validity [188]. The research community has increasingly advocated for strengthening Routine Health Information Systems to support disaster response and research [187]. One option to strengthen the usefulness of this type of data is to complement it with additional event-specific data. This dissertation benefited from the fact that several datasets were used and verified, that a specific system was used for earthquake victims, and that qualitative data provided more contextual information to facilitate interpretation. However, additional sources of data would have contributed to an even more thorough and broader picture, such as information from primary healthcare centres and from the emergency department, or the perspectives of patients or NGO representatives.

Table 6.1: ***Benefits and limitations of routinely collected data for health research***

Benefits	**Limitations**
Population reach: Power to identify even marginal shifts in practice	Event based (hospital episode, death): Selection bias
Longitudinal	Uncertain validity: Correct information must be available for data entry Correct value must be entered
Avoids nonresponse, attrition and reporting bias	Limited data items: Incomplete list of confounders
Cost-effective	Linkage error (likely non-random)
Real world: Allows to evaluate the impacts of policies or events rolled out in a nonrandomized manner	Lack of metadata

Table adapted from Jorm, 2015 [188]

6.3.2. The missed opportunity of participatory research

In the work conducted for this dissertation, we were unable to incorporate the views of hospital staff and stakeholders about what the research results mean and how they could be used for practical and strategic improvements.

Participatory research methods seek to actively engage the beneficiaries of the research and empower them, transferring the power of controlling and generating knowledge to the study participants. Using this approach usually yields more sustainable results and increases the translation of research into effective strategies and interventions. It is a method that is well-appreciated in development settings, post-disaster recovery, and humanitarian crises [189, 190].

Under this dissertation, I had planned to present the results of Chapters 3-5 to the hospital staff, and organize focus group discussions to explore the meaning of these results and to jointly build recommendations for the future. A restitution workshop was scheduled in March 2020 and support for organization of Focus Groups was agreed with TUTH and with the National Society for Earthquake

Technology from Nepal. We had planned for three distinct groups, and participants had already agreed to participate: Doctors, Nurses, and Administrative and Technical Support staff. Unfortunately, the COVID-19 pandemic and related travel and meeting restrictions prevented these from happening. The English version of the Focus Group Discussion protocol and questioning route is available in Appendix E.

Nevertheless, more efforts could have been done to ensure a higher participation from the research community in Nepal. A major shortcoming of this dissertation is the absence of a researcher from Nepal as a formal member of the jury. A healthy partnership with the local research team was essential for the success of this dissertation, culminating in co-authored publications. However, it did not replace the formal participation in annual steering committee meetings to guide the direction of the thesis based on a lived experience from the field. This fails to serve the purpose of "decolonising global health" [191], but was mostly due to logistical and resource constraints: in the beginning of my PhD, steering committee meetings were in-person. The current COVID-19 pandemic has unleashed the potential for virtual meetings with members from different geographies, and Doctoral Schools in the Global North should be flexible and raise awareness for the importance of including jury members from the study countries in global health dissertations.

6.3.3. Reflections on the case study approach

In-depth case studies contribute to generate a comprehensive understanding of a complex issue in its real-life context. As we have already established, very few studies explore hospital resilience in a real post-disaster scenario, and the case-study approach can provide unique insights on under-studied research areas. But this approach also has shortcomings. A major shortcoming of the case-study approach is the difficulty in making generalisations to other settings [106, 192].

Another concern is the non-random selection of site. But as disasters do not strike randomly, and disaster impact is not randomly distributed, there is little option but to choose a convenient event [193, 194], with the caveat that conclusions must be drawn carefully. Another aspect is the nuance between statistical generalization and analytical generalization: the goal of the case-study is to extend and generalize theories, and not to calculate indicators that can be extrapolated to the entire population [194].

Some strategies can be used to improve the transferability of findings, such as an in-depth immersion in the theoretical and empirical literature to support conclusions, ensuring methodological rigour and transparency, and allowing for unexpected issues to emerge and not force fit them in theoretical frameworks [106].

The contextual information gathered from the literature and presented in Chapter 2, together with the perspective gained in section 6.1. in this chapter, provides robust support to the conclusions generated for Nepal. In addition, the field work conducted and inherent immersion in the context were key to gain contextual insights. Being an external researcher but with the possibility of deploying to the field on multiple occasions allowed me to find a balance between closeness and detachment to the study context [109].

The in-depth analysis of current theories on hospital response and resilience to earthquakes and large-scale disasters (Chapter 1), put in perspective with the empirical literature, also allows for practical and theoretical generalizations.

Moreover, this dissertation exhaustively reports on the methods used, with the purpose to be as transparent as possible. A methodological strength is the richness of data used for this dissertation, and the synergies of using both quantitative and qualitative approaches.

Chapter 7
So what?
Conclusions and future directions

In this chapter, I present the main conclusions of this dissertation, reflect on its scientific contributions, and set an agenda for future studies.

7.1. Conclusions and scientific advances

The findings of this dissertation, interpreted in light of the scientific literature and the methodological strengths and limitations, allow us to generate the following conclusions:

- The 2015 earthquake precipitated specific conditions that required hospital treatment at a major tertiary hospital and were resource-intensive.
- The hospital's function was affected and the provision of elective care was seriously disrupted, which may have carried additional consequences on morbidity and mortality.
- This tertiary hospital faced unique burdens after such a large-scale disaster. Its structural resistance was essential for it to provide emergency care, but equipment and functional aspects also played a major role.
- The hospital resilience was highly dependent on emerging adaptations, in addition to pre-existing plans.
- Since functional aspects are highly dependent on human behaviour, individual resilience of hospital staff influences hospital resilience. In the Nepal context, it was important that staff felt safe and had a sense of meaningfulness and belonging.

This dissertation represents several contributions to the advancement of science. We have demonstrated the importance of synergizing routine health information with additional sources of data and qualitative information to advance the field of disaster and resilience studies. Our findings also empirically support conceptual models of disaster impact on hospital care and show concrete, measurable changes: the overall decrease in admissions, the long hospitalizations of earthquake victims, and the sustained reduction of pregnancy-related admissions. Finally, this is the first research work to further explore the suitability of the 4R framework on hospital disaster resilience through empirical post-disaster data collection and analysis. We highlight that resilience is only evident *after* a disaster occurs, when unplanned adaptations emerge and individual staff face unique challenges.

7.2. Future directions

One of the first of its kind, this dissertation paves the way for future research in the fields of public health, disaster, and resilience studies. In general, more insights are needed to improve our understanding of how large-scale disasters and health emergencies impact critical health services. We also need more insights on how resilience is experienced in health facilities and communities affected by disasters.

Specifically, additional case-studies are needed to (i) quantify the short and long-term impacts of other types of disasters on hospitals, in different contexts, and to (ii) better describe hospital resilience and identify the main concepts that can be measured and used to predict resilience before a disaster happens. By producing evidence from different events and contexts, we will be able to differentiate contextual factors that influence resilience from other factors that can be easily modifiable. These factors could then be validated through co-construction of a hospital resilience assessment tool by different stakeholders, which would then follow standard steps of tool development and refinement.

In addition, little is known about the actual mental and physical impact of working in disaster and health emergency situations on frontline staff, and which characteristics, measures and behaviours are considered protective or harmful. The current pandemic situation provides a unique opportunity to monitor this effect through quantitative and qualitative approaches, and such studies can contribute to the development and refinement of salutogenic theories applied to health workers and disasters.

The potential and hidden impact of disasters in the utilization of and access to maternal healthcare is of major concern and merits an integrated scientific approach. A global analysis of trends of maternal health indicators before and after disasters can already shed light on this issue, but it should be complemented by further community and country-level studies. These would help understand changes in offer and demand for maternal health services, and provide guidance on how to prevent avoidable morbidity and mortality.

Finally, hospital resilience is impossible to isolate from the wider, more complex health system resilience. The protracted COVID-19 pandemic has revealed how hospital resilience was greatly influenced by external factors, including failure to stock sufficient protective equipment at the national level, the fragile disease surveillance and response systems, the often uncoordinated links between primary and hospital care, or the difficulty of governments to assume leadership and communicate clearly in times of uncertainty. A clear and consistent definition of health system resilience still is lacking, and existing measurement tools need refinement. The link between hospital and health system resilience remains difficult to establish, as the empirical evidence is scarce. More in-depth analyses from disaster settings will elucidate the nature of this relationship.

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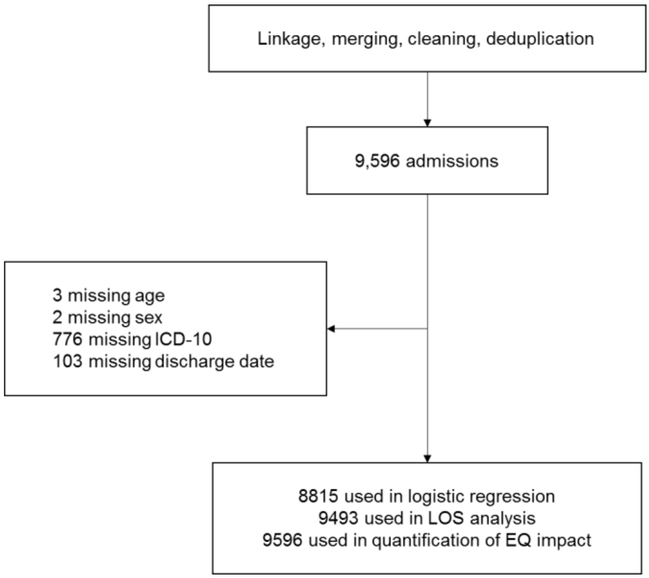
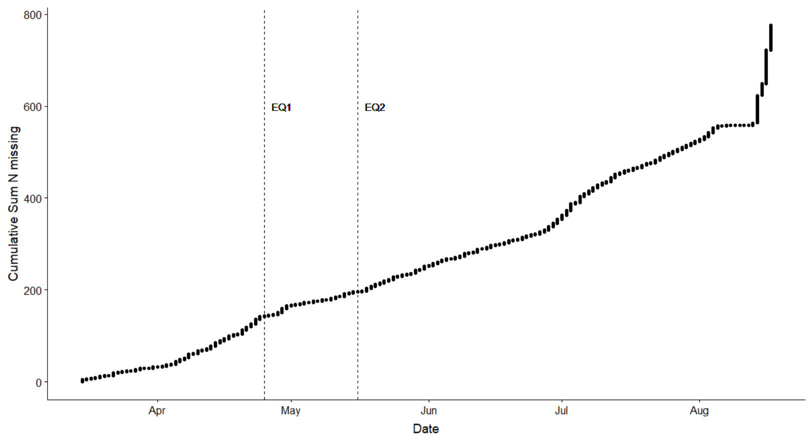
Appendix A
Overview of missing data in Chapter 4



A.1.: Flowchart of total observations, missing values, and observations used in different analyses.

ICD-10: International Classification of Diseases, 10th edition. LOS: Length of hospital Stay. EQ: Earthquake.



A.2.: Cumulative sum of missing ICD-10 values over time of analysis

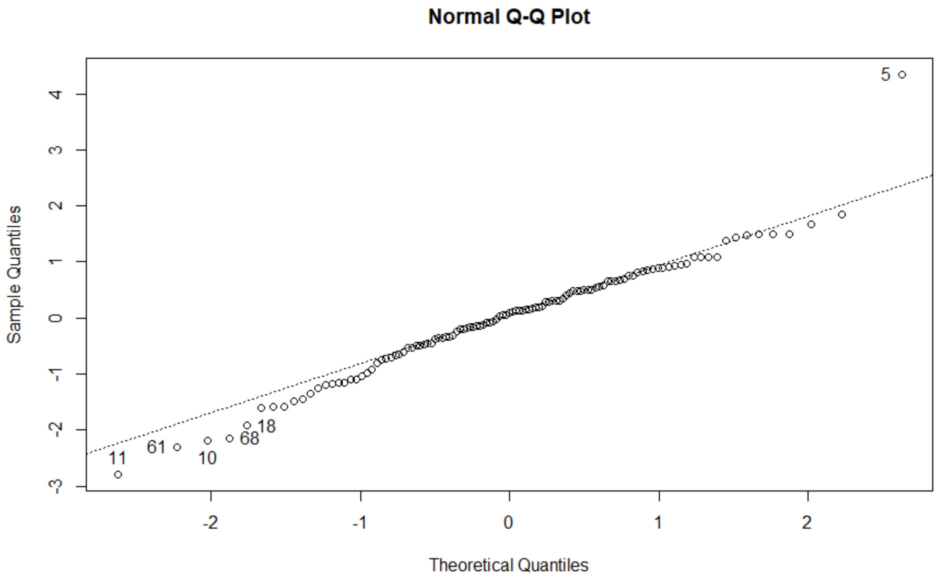
Appendix B
Complete logistic regressions conducted in Chapter 4

ICD-10 category	Earthquake Period						Age Group (years)						Sex	
	EQ 1		EQ 2		Post EQ		<5		5-14		>=50		Female	
	aOR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value	aOR (95% CI)	P-value
Perinatal conditions	0.66 (0.35 - 1.23)	0.190	0.28 (0.12-0.66)	0.004**	0.91 (0.63 - 1.33)	0.642	N/A		N/A		N/A		0.85 (0.61-1.19)	0.349
Infectious and parasitical diseases	0.56 (0.35 - 0.89)	0.015*	1.09 (0.76-1.57)	0.643	1.22 (0.94 - 1.57)	0.135	1.75 (1.25-2.47)	0.001**	1.61 (1.16-2.24)	0.005**	1.07 (0.82-1.40)	0.627	0.58 (0.47 - 0.73)	<0.001***
Congenital conditions	0.36 (0.11-1.22)	0.099	1.11 (0.52-2.40)	0.781	2.16 (1.31-3.55)	0.002**	4.55 (2.83-7.31)	<0.001***	2.69 (1.58-4.56)	<0.001***	0.58 (0.30-1.11)	0.099	0.62 (0.42 - 0.92)	0.017*
Blood forming organ and immune system diseases	0.71 (0.33 - 1.52)	0.379	1.74 (1.00-3.03)	0.051	1.19 (0.76-1.87)	0.456	0.86 (0.39-1.90)	0.710	2.20 (1.31-3.71)	0.003**	1.26 (0.81-1.96)	0.302	1.27 (0.87-1.85)	0.220
Disease of the circulatory system	1.16 (0.81-1.65)	0.411	1.09 (0.78-1.54)	0.610	1.18 (0.92-1.52)	0.184	1.00 (0.63-1.60)	0.996	0.80 (0.50-1.30)	0.371	3.86 (3.10-4.82)	<0.001***	0.75 (0.61 - 0.92)	0.006**
Disease of the digestive system	0.45 (0.34 - 0.61)	<0.001***	1.05 (0.84-1.31)	0.688	1.03 (0.88 - 1.21)	0.737	0.66 (0.49 - 0.89)	<0.001***	1.07 (0.84-1.35)	0.605	1.53 (1.31-1.79)	<0.001***	0.59 (0.51 - 0.67)	<0.001***
Diseases of the ear and mastoid process	0.46 (0.21 - 0.98)	0.045*	1.05 (0.59-1.85)	0.880	0.90 (0.60-1.35)	0.607	0.43 (0.16-1.19)	0.104	5.67 (3.86-8.32)	<0.001***	0.22 (0.09-0.50)	<0.001***	0.72 (0.50-1.04)	0.080
Genitourinary diseases	0.32 (0.24 - 0.45)	<0.001***	0.70 (0.55-0.90)	<0.001***	0.87 (0.74 - 1.02)	0.085	0.56 (0.41-0.77)	<0.001***	0.82 (0.63-1.06)	0.127	1.06 (0.90-1.25)	0.487	0.85 (0.74 - 0.98)	0.030*
Musculoskeletal and connective tissue diseases	0.74 (0.27 - 2.04)	0.559	1.68 (0.78-3.61)	0.183	2.84 (1.63-4.94)	<0.001***	0.53 (0.21-1.34)	0.183	2.04 (1.22-3.39)	0.006**	0.85 (0.52-1.39)	0.512	0.60 (0.40 - 0.89)	0.011*

Neurological diseases	1.40 (0.84 - 2.33)	0.200	1.32 (0.80-2.20)	0.277	1.80 (2.2 6-2.58)	0.001**	2.19 (1.44-3.33)	<0.001***	1.77 (1.16-2.70)	<0.001***	1.38 (0.98-1.92)	0.061	0.69 (0.52 - 0.91)	0.009**
Respiratory diseases	0.57 (0.43 - 0.74)	<0.001***	0.77 (0.61-0.97)	0.029*	0.73 (0.62 - 0.86)	<0.001***	1.85 (1.46-2.33)	<0.001***	1.41 (1.11-1.79)	0.004**	1.68 (1.42-1.98)	<0.001***	0.54 (0.46 - 0.62)	<0.001***
Skin and subcutaneous diseases	0.23 (0.09 - 0.59)	0.002**	0.75 (0.43-1.31)	0.313	0.62 (0.42 - 0.92)	0.019*	0.81 (0.38-1.70)	0.572	2.04 (1.24-3.36)	0.005**	1.07 (0.69-1.67)	0.766	0.57 (0.39 - 0.83)	0.004**
Endocrine, nutritional and metabolic diseases	0.64 (0.38-1.10)	0.107	1.18 (0.78-1.80)	0.438	1.31 (0.96-1.78)	0.084	0.88 (0.47-1.66)	0.698	0.78 (0.41-1.46)	0.435	4.02 (3.06-5.29)	<0.001***	1.21 (0.93-1.56)	0.156
Contact with Health Services	1.47 (1.14-1.89)	0.003**	1.31 (1.02-1.69)	0.038*	1.23 (1.03-1.48)	0.024*	0.16 (0.10-0.27)	<0.001***	0.08 (0.04 - 0.16)	<0.001***	0.07 (0.04-0.10)	<0.001***	12.42 (9.21 - 16.76)	<0.001***
Injuries and other external causes	5.33 (4.44 - 6.40)	<0.001***	1.32 (1.07-1.64)	0.011*	0.94 (0.80-1.11)	0.456	1.04 (0.82-1.32)	0.720	2.08 (1.72-2.51)	<0.001***	1.02 (0.87-1.19)	0.824	0.47 (0.41 - 0.53)	<0.001***
Mental and behavioural Disorders	1.21 (0.76-1.92)	0.418	1.05 (0.65-1.68)	0.852	0.97 (0.69-1.37)	0.860	0.39 (0.21-0.76)	0.005**	0.45 (0.26-0.79)	0.005**	0.49 (0.34-0.71)	<0.001***	0.32 (0.24-0.43)	<0.001***
Neoplasms	0.43 (0.27 - 0.69)	<0.001***	1.22 (0.88-1.69)	0.225	1.26 (0.99 - 1.59)	0.060	1.35 (0.90-2.04)	0.146	0.44 (0.24-0.81)	0.009**	3.94 (3.17-4.89)	<0.001***	0.96 (0.79-1.18)	0.711
Pregnancy, childbirth and the puerperium	0.74 (0.59 - 0.94)	0.012*	0.75 (0.60-0.95)	0.016*	0.77 (0.65 - 0.90)	<0.001***	0.07 (0.04-0.13)	<0.001***	0.01 (0.01-0.03)	<0.001***	0.01 (0.01-0.03)	<0.001***	N/A	
Other not elsewhere classified	0.59 (0.33 - 1.06)	0.080	0.81 (0.49-1.34)	0.410	0.94 (0.6 7-1.32)	0.716	4.53 (3.03-6.78)	<0.001***	3.19 (2.08-4.89)	<0.001***	1.54 (1.04-2.28)	0.031*	0.75 (0.55 - 1.02)	0.062

Reference categories: Pre-EQ (Earthquake Period); 15-49 (Age group); Male (Sex)
*p<0.05; **p<0.01; ***p<0.001. aOR: adjusted odds ratio; CI: Confidence Interval; NA: not applicable. Each ICD-10 category is compared to all other categories combined. Only ICD-10 categories with more than 70 observations are included. We removed the variable age group for diagnostic category "perinatal conditions", as it only included children aged 0-4 years, and the sex variable for pregnancy-related conditions, as it only consisted of females. The number of observations included was n=8817. The ICD-10 category names presented are simplified from the original denomination for readability.

Appendix C
Residuals distribution for Model developed in Chapter 4



Residuals distribution from the proposed model of differences of hospital admissions in EQ1, EQ2 and post-EQ with the median of admissions in the pre-EQ period.

We used Generalized Additive Models to model these differences and capture non-linear behaviour. The baseline of comparison was the median of admissions on week days and Saturdays in the pre-EQ period.

A big outlier is present on the fifth day after the Earthquake that occurred on April 25th 2015. This correspondents to the highest peak of injury admissions.

Appendix D
Interview Guide used in Chapter 5

Initials: ________________ Date: ___________________

Start time: _______________ End time: ________________

My name is Maria Moitinho de Almeida, I am a public health researcher working in Belgium. Based on previous research, my team understood that it is important to get an insight/better understanding of the impact of the 2015 Earthquake at a personal and work level.

I would like to ask you questions related to your personal experience in this hospital after the earthquake. We would like to record the interview if that is fine with you, which will only be used to help us remember all that you said.

Please read carefully the following consent form, and if you agree, you can sign and we can start with the interview.

Feel free to share any related idea that you may find important. Let's start.

Personal information

- Sex : F / M / ....
- Age : ....
- What was your work at TUTH during/after the earthquake ?

  ....

I will now ask you some questions about your experience after the earthquake on a personal, professional and organizational level.

<table>
<tr><th>Main questions</th><th>Additional questions</th><th>Clarifying questions</th></tr>
<tr><td>Can you recall the time of the earthquake, and what it was like for you?
(Day of the earthquake and time immediately after)</td><td>Where were you on the day of the earthquake?
How did this event affect you emotionally / affect your life?
How did you experience your professional obligations?
How did you perceive your ability to work after the Earthquake?
What were the personal working conditions like?
How did your situation at home affect your ability to work?
How did you feel the hospital was functioning? What were the main challenges and difficulties you witnessed?
How do you think the quality of care was influenced in your department/hospital?</td><td rowspan="6">Can you expand a little on this?

Can you tell me anything else?

Can you give me some examples?</td></tr>
<tr><td>If you think about the time between the earthquake and now, can you explain what were your main experiences?
(Transition)</td><td>How has your personal situation evolved since then?
How has your performance at the hospital evolved?
Can you recall main challenges and strategies to cope with a return to a routine?
How has hospital performed/functioned since then?</td></tr>
<tr><td>How do you feel the situation is now?
(Now)</td><td>How has this earthquake experience influence your personal and professional life?
How has your experience changed your current work behaviour?
How do you feel the hospital is functioning now?
What are your impressions on the current situation now, compared to before?</td></tr>
<tr><td>During this interview, some of the strong points were .... (Short summary)
What are your impressions on the current situation, compared to before the Earthquake?
(Before)</td><td>Were you prepared to face such a disaster before the earthquake occurred? How do you feel now? (Personal and professional)
What were the main differences in the functioning of the hospital compared to now?</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Are there any other issues regarding your experience in the hospital after the earthquake that we have not discussed but you would like to share?
OR
Do you want to add anything regarding your experience during the response and recovery phases?</td></tr>
</table>

Appendix E
Protocol for Focus Group Discussions

Note: While these Focus Group Discussions were planned and scheduled, they were cancelled due to the COVID-19 pandemic.

1. Information to conduct Focus Group Discussion

We are planning 3-4 Focus Groups in March 2020. In the TUTH premises, with a maximum of 8 participants per group. Groups will be formed according to professional groups. One group will consist of doctors (some of them may accumulate managerial positions), another one of nurses (idem), another group administrative, and if feasible a group with technicians/technologists. Maria Moitinho, will be assisted by Manisha Pantha, a Registered Nurse from the National Society on Earthquake Technology (NSET), who works in topics related to emergency health response. Language barriers are greatly expected in the last group, and may also be partly present in the nursing group, but all physicians speak good English. We will start with the physician Focus Group, so Manisha is more at ease, continue with the nursing, and finish with the administrative group, where Manisha will play a bigger role to communicate with participants and translate findings. An ethical clearance was obtained in May 2018.
The Focus Groups will clarify and explore collective views on findings from previous studies. We would also like to discuss and make recommendations for future improvements.

2. Focus Group Questioning route

We are public health researchers working in Belgium and Kathmandu, our names are Maria Moitinho de Almeida and Manisha Pantha. Based on previous steps of this research, we would like to know your views on main lessons learned from the Earthquake in 2015, and recommendations for future improvement.

We would like to generate discussion between participants of this group, introducing some questions and topics related to your views based on your experience in this hospital after the earthquake. Please note that the point of this work is not for you to reach consensus, but openly express your thoughts even if they differ from others'.

We would like to record this discussion if that is fine with you, which will only be used to help us remember all that was discussed. Please read carefully the following consent form, and if you agree, you can sign and we can start with the discussion.

Feel free to share any related idea that you may find important within this discussion.

Introductions + start with 15-20 min presentation of results

Questions 1) Clarify, know their thoughts on findings

- *Many interviewees referred they did different tasks from their routine work, even tasks they are not allowed to do normally. What are your thoughts about it?*

  Try:
  - *What are the lessons learned?*
  - *Did they receive any authorization; was it expected, etc?*
  - *Explore the concept of role in the disaster plan, whose roles are clear, whose roles should be specified, etc.*
  - *Explore the shift of leadership*
- *Many interviewees had trouble describing what it was like for them to return to routine work at the hospital, and at home. What are your thoughts about this?*
- *For doctors only: Foreign Medical Teams were unwelcome if wanted to perform surgery, but less clear if they came for psychosocial counselling. Can you elaborate on this?*
  - *Clarify also TUTH's outreach activities after the earthquake*
- *The workload and adaptations may have affected quality of care. What are your thoughts about this?*

  Clarify:
  - *Differences between emergency and routine*

  Explore:
  - *Change of standards is part of resilience, but to what point?*
  - *Again, who confirms it is ok?*

"Prompt" questions when necessary [ask more directly at level of authorities]

- *When you did this, was it your initiative or was it fixed in the plan?*
- *Do you feel the lessons learned with your experience should shape new recommendations for a future disaster plan?*
- *Could you elaborate how the disaster plan was created, and how it was applied during the earthquake response?*

  Try to clarify:
  - *By whom and when was it created?*

- *What happened with modifications not foreseen in the disaster plan?*
  - *Clarify if emerging adaptations were foreseen in the plan?*

<u>Intermediate</u>

- *What has changed in the disaster plan and hospital policies since the earthquake?*
  - *If so: by whom? How? When?*

<u>Round 2) Way forward</u>

- *We present a table (see below) with problems and solutions that arose from the interviews with hospital staff. We would like you to discuss these but also add any solutions that you want to propose.*

  Discuss:
  - *Priority?*
  - *Are these suitable? Why or why not?*
  - *Realistic?*
  - *Barriers to implement?*
  - *What's different then and now?*

<u>Closing</u>

- *How do you think you and the hospital would handle a new earthquake now, compared with 2015?*

- *We wanted you to help us understand Hospital and individual experiences from the TUTH earthquake response, to know how to improve it for the future. Is there anything that we missed? Is there anything you wanted to say but haven't had the chance to?*

Notes:

- Always ask for concrete examples
- Bring a "moving forward" perspective, ask what they would do differently, etc.

Problem	Solution proposed	Potential outcome	Discussion points
Insufficient equipment if sudden mass casualty	Purchase 1-2 more X-ray machines, or 1 CT Scan	*It would be easier not only for day-to-day basis, also for casualty time*	
Influx of Foreign Medical teams	Make a rule plan to look at competence and only allow to work under supervision	?	But psychosocial counselling?
Misinformation, rumours, and supply of inappropriate items	- Volunteers to disseminate information of what is needed - Social media should be provided with right information of what is needed	*With right information, we can provide right service to the people immediately*	
?	Build community capacity and teach basic first aid (wound management, immobilization, CPR)	*When they learn they can also do, this is how it is transferred.* *At disaster situation such small support can be huge*	
Fragmented disaster policies in hospitals and pre-hospital settings.	*There should be a form of networking system between the hospitals and ambulances…* *the government should work to make a strong disaster network team*	*So that they can be controlled during the time of a disaster… that will mobilize all the ambulances or other healthcare workers during disaster*	
Simulations now: not everyone included…	?	?	Who should be included and why? And what do you do with people you exclude?
	Proposals from the group		

Appendix F
Scientific Curriculum Vitae

MARIA MOITINHO DE ALMEIDA has been working as a research associate at the Brussels-based Centre for Research on the Epidemiology of Disasters since 2017. Maria obtained a Medical Degree at the University of Lisbon, Portugal, and holds a joint Master's Degree in Public Health in Disasters from the Karolinska Institute and the University of Oviedo. Maria has worked as a general doctor in a hospital in Lisbon and as a public health medical resident in a primary healthcare cluster in Lisbon South Bay. She has medical and public health experience in Portugal, Germany, Mozambique, India, and Brazil, and is also a Red Cross delegate on Community-based Surveillance. Her research interests focus on improving health resilience and response in humanitarian settings. Maria is also a regular guest lecturer at the Institute of Tropical Medicine in Lisbon and at the Medical School of the University of the Algarve.

Publications

- **Maria Moitinho de Almeida**, Joris Adriaan Frank van Loenhout, Sunil Singh Thapa, K C Kumar, Deepak Prakash Mahara, Debarati Guha-Sapir and Isabelle Aujoulat. Hospital resilience after the 2015 earthquake in Nepal: results from semi- structured interviews with hospital staff. Accepted in Frontiers in Public Health, 2021. doi: 10.3389/fpubh.2021.602509

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- Alexandra Moraru, **Maria Moitinho de Almeida**, Jean-Marie Degryse. PALTEM: What Parameters Should Be Collected in Disaster Settings to Assess the Long-Term Outcomes of Famine? International journal of environmental research and public health 05/2018; 15(5):857. doi: 10.3390/ijerph15050857

Presentations

- **Maria Moitinho de Almeida**, Isabelle Aujoulat, Deepak Mahara, Debarati Guha-Sapir: Fostering Hospital Resilience to Disasters: Lessons from a Tertiary Hospital in Nepal. Presented at the "16th Academic Surgical Congress", 2021, on-line.
- **Maria Moitinho de Almeida**, Joris van Loenhout, Deepak Mahara, Debarati Guha-Sapir, Isabelle Aujoulat: Not without the staff: Hospital Resilience after a large-scale disaster. Poster presented at the virtual conference "World Congress of Public Health", 2020, on-line.
- **Maria Moitinho de Almeida**, Joris van Loenhout, Deepak Mahara, Debarati Guha-Sapir, Isabelle Aujoulat: Hospital resilience to earthquakes: preliminary results from semi-structured interviews with hospital staff in Nepal. Presented at the "Doctoral Day", 2019, Louvain-la-Neuve, Belgium.
- **Maria Moitinho de Almeida**: (Near) Future challenges for Public Health Professionals in Germany. Key note presentation at the "20. Jahrestagung der Akademie für öffentliches Gesundheitswesen", 2019, Düsseldorf, Germany.
- **Maria Moitinho de Almeida**, Joris van Loenhout, Ravikant Singh, Deepak Mahara, Debarati Guha-Sapir: Impact of the 2015 earthquake on hospital admissions in Kathmandu. Presented at the conference "Doctoral Day", 2018, Liège, Belgium.
- **Maria Moitinho de Almeida**, Benjamin-Samuel Schlüter, Kathy Buelens, Xavier de Bethune, Debarati Guha-Sapir: Clinical Characteristics of Refugees in Greece. Presented at the "Migration Conference", 2018, Lisbon, Portugal.
- **Maria Moitinho de Almeida** & Johan von Schreeb: Human stampedes: what do we know today? Presented at the "World Congress of Disaster and Emergency Medicine", 2017, Toronto, Canada

Grants, Prizes and Awards

- Laureate, Horlait-Dapsens Medical Foundation, 2020
- Best oral presentation, Doctoral Day Louvain-la-Neuve, 2019
- Personal PhD grant, UCLouvain Special Research Funds, 2018
- Grant for Erasmus Mundus Master Programme, European Commission, 2015
- Personal grant for laboratory research, GAPIC / Portuguese Foundation for Science and Technology, 2009

Appendix G
Statement of personal contributions and conflicts of interest

MARIA MOITINHO DE ALMEIDA conceived this dissertation under the supervision of Profs. Debarati Guha-Sapir and Isabelle Aujoulat, and in close collaboration with Prof. Dr. Deepak Prakash Mahara. MMA verified and managed the secondary data provided by TUTH with support from the local research team and CRED colleagues, and collected the qualitative data used in Chapter 5. MMA led the data analysis in Chapters 3 and 5 and co-led the analysis with Benjamin-Samuel Schlüter in Chapter 4. MMA interpreted the data, prepared the manuscripts of all the scientific papers resulting from this PhD project, and wrote this dissertation.

MMA and the co-authors involved in the scientific outputs of this thesis have no financial conflict of interests to declare.