Human Casualties in Earthquakes

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Progress in Modelling and Mitigation

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Foreword

Natural disasters are one of the last remaining public safety issues for society to manage. Over the past centuries, the big killers of disease and accidents have gradually been tamed, and the causes of premature death are constantly being reduced by medical and technological advances.

In the modern world it should not be possible, or acceptable, for large numbers of people to die in the occurrence of geological processes like an earthquake, a volcanic eruption or a landslide. These are well understood phenomena and the science has existed for some time for us to understand their mechanisms, geography and temporal patterns. And yet sudden manifestations of these forces of nature continue to kill thousands of people, and in some cases tens of thousands and even hundreds of thousands of people, at a time.

The forces wreaked by nature are formidable, and yet there are ways that these forces can be understood, withstood, and accommodated. There are success stories where the infrastructure has been built strongly enough to withstand the energy unleashed on it, and the preparation has been sufficient to organise people to protect themselves when it has happened.

The protection of societies from these forces needs considerable forethought and planning. It needs a collective effort of will to recognise the threat, and to organise our social systems to meet this threat. We have to agree to invest in resilient infrastructure that has redundant capacity to withstand forces beyond those required for everyday needs. We have to divert resources to cope with exceptional requirements. We need a coordinated effort to build our buildings strong enough, and to provide planning resources to prepare for the severity of the extreme threats of nature.

And all this requires a political consent to invest in the safety standards required for social resilience.

But most importantly of all, we need to understand how casualties occur in these natural disasters. The underlying science needs to be firmly in place to show how best to prepare and to combat the destruction and social disruption that can ensue from geological events.

These collected papers are a welcome compilation of some of the groundbreaking science in understanding and combating casualties from natural hazards. They represent a wide range of studies in different countries, and different events and many different aspects of the causes of human death and injury.

The studies in this book provide a long-overdue re-examination by some of the world's leading practitioners in mass-casualty risk management. The contributors to this compendium have established a road map for the science, and set the challenge for society to follow to eliminate the risk of big death tolls from natural disasters in the years ahead.

Risk Management Solutions, Inc. Dr. Andrew Coburn

Acknowledgements

During the development, writing, and editing of this book, we called upon many friends and technical experts for input. We are deeply grateful to all of them, and would like to take this opportunity to thank especially Professor Yutaka Ohta for his encouragement and to Dr Andrew Coburn for his guidance and for kindly writing the preface for the book.

This book is the outcome of two fruitful International Workshops on Disaster Casualties. We are grateful to the sponsors of the meetings, CAR Ltd., RMS and Willis Re and to the contributors who so generously gave their time to ensure the success of these events, Maria Sylvester, Dr Keiko Saito, Dr Susanna Jenkins and Daniel Brown.

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Chapter 2
Earthquakes, an Epidemiological Perspective on Patterns and Trends

D. Guha-Sapir and F. Vos

Abstract The unpredictable nature of earthquakes and the vast impact they can have makes them one of the most lethal kinds of natural disaster. Earthquakes have claimed an average of 27,000 lives a year since 1990, according to the data on reported deaths compiled by the EM-DAT International Disaster Database, which is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University in Louvain, Belgium. The consequences of earthquake disasters vary around the globe, depending on the region and its economic development. Data shows that the number of earthquakes causing significant human and economic loss has increased since the 1970s, endorsing research into individual risk patterns which can provide important information for community-based preparedness programmes. Epidemiological analysis of earthquake impact data can be useful for evaluating impact patterns over space and time. However, the lack of standard definitions of exposure to risk of death or injury from earthquakes is an ongoing methodological obstacle and contributes to inaccuracies in calculations of rates and ratios for comparison purposes. Standardised definitions of deaths and injuries from disasters would improve understanding of earthquake-related risks.

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2.1 Introduction

Earthquakes can have devastating impacts in a matter of seconds. Their unpredictable nature and the potential scale of their impact make them one of the most lethal of all disasters, claiming an average of 27,000 lives a year worldwide since the 1990s. If we look at the science behind the death tolls, earthquakes are caused by faulting, a sudden lateral or vertical movement of rock along a rupture surface. Accumulated strain in the earth along faults is released, resulting in radiation of seismic energy and ground shaking. Earthquakes can also be triggered by volcanic or magmatic activity or other sudden stress changes in the earth (Stein and Wysession 2003; Bolt 1988). There are more than 1.4 million earthquakes a year around the planet, an average of almost 4,000 per day.[1] And yet, of course, if earthquake phenomena occur in uninhabited areas where they do not have any human impact, they remain hazards rather than disasters. If, on the other hand, they strike urban areas with high population density or communities where buildings are not earthquake-resistant, there is the potential for major disasters with large-scale human loss, especially in the case of larger earthquakes.

Scientists and researchers have increasingly focused their attention beyond seismology and the physics of the earth's structure and interior, to look at real-time earthquake damage estimation. It is possible to estimate the seismic hazard or how much an earthquake could potentially shake the ground in an area by looking at local seismicity and seismotectonics and from records of strong-motion accelerographs (Berckhemer 2002). Computer simulations and experimental designs have been used to investigate the dynamic response of technical construction elements. Seismic building codes provide a basis for recommending earthquake-resistant construction. Much has been written on this (Kanamori and Brodsky 2001; Chen and Scawthorn 2002; Bullen and Bolt 1985; Coburn and Spence 2002; Aki and Richards 2002; Scholz 2002; Lay and Wallace 1995). However, in this paper we focus on the human impact of disasters. As a result, we restrict our discussion to analysis of relevant earthquake statistics in the EM-DAT International Disaster Database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium.

The aims of this paper are to display and analyse the global data on earthquakes held by CRED's EM-DAT database, the reference source for systematic global disaster data, from an epidemiological perspective. Following this introduction, Section 2.2 provides an overview of the methodological parameters that guide the way natural disasters are recorded in EM-DAT. It will also discuss the challenges thrown up by potential ambiguities in disaster data collection. This is followed in Section 2.3 by a description of global patterns and trends in earthquake occurrence and their human impact. Finally, in Section 2.4 we will offer some conclusions and suggestions for future research in this area.

[1] http://earthquake.usgs.gov/learn/faq/?faqID=69, accessed on 1 December 2009.

2.2 Recording Natural Disasters in EM-DAT

In this section, we will describe the methodological procedures and parameters used in the CRED EM-DAT International Disaster Database, which is a unique public source of information used by a wide variety of scientists, policy makers and operational organisations.[2] We will also outline some of the methodological challenges encountered in disaster data collection.

2.2.1 EM-DAT: Objectives and Methodology

CRED provides standardised data on disaster occurrence and loss around the world.[3] Its wider goal is to contribute to information dissemination for disaster management in order to enhance regional, national and local capacity to prepare for, respond to, and mitigate disaster events. CRED has maintained EM-DAT since 1988 with the initial support of the U.N. World Health Organisation (WHO), the U.N. Disaster Relief Organisation (UNDRO) and the Belgian government, and since 1999 with the sponsorship of the Office of Foreign Disaster Assistance at the United States Agency for International Development (OFDA-USAID). The main objectives of the database are to:

- Assist humanitarian action at both national and international levels
- Rationalise decision-making for disaster preparedness
- Provide an objective basis for vulnerability assessment and priority-setting

Historical disaster data can help to determine the characteristics of disaster risks and analyse trends in them. EM-DAT contains essential core data on the occurrence and impact of more than 18,000 natural and technological disasters around the world from 1900 to the present. The database is compiled from various sources,[4] including U.N. agencies, governmental and non-governmental organisations, insurance companies, research institutes and press agencies. The data inserted in EM-DAT

[2] See also: www.emdat.be

[3] See also: www.cred.be

[4] This includes U.N. bodies (Food and Agriculture Organisation – FAO, Integrated Regional Information Networks – IRIN, Office for the Coordination of Humanitarian Affairs – OCHA, U.N. Environment Programme – UNEP, World Food Programme – WFP, WHO, World Meteorological Organisation – WMO, Economic Commission for Latin America and the Caribbean – ECLAC), U.S. governmental bodies (Centers for Disease Control – CDC , Federal Emergency Management Agency – FEMA, National Oceanic and Atmospheric Administration – NOAA, OFDA, Smithsonian Institution), official agencies (Asian Disaster Risk Reduction Center – ADRC, Caribbean Disaster Emergency Response Agency – CDERA, national governments), NGOs and humanitarian organisations (International Federation of Red Cross and Red Crescent Societies – IFRC), reinsurance companies and magazines (Lloyd's Casualty Week, MünichRe, SwissRe), inter-governmental organisations (World Bank), press agencies (AFP, Reuters), and other specialist sources (Dartmouth Flood Observatory – DFO, U.S. Geological Survey – USGS). This is not an exhaustive list.

follows a strict methodology using standardised definitions, and the validation procedure is intensive. Validated data are uploaded to the EM-DAT website at three-month intervals, and economic loss data are cross-checked and completed with data from MünichRe NatCat[5] and SwissRe Sigma databases.[6]

For the purposes of EM-DAT, a disaster is defined as: "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering". For a disaster to be entered into EM-DAT, it must fulfil at least one of the following criteria:

- Ten or more people reported killed
- 100 or more people reported affected
- A declaration of a state of emergency
- A call for international assistance

Each EM-DAT disaster entry conforms to a set of fields that is uniform throughout the database (Table 2.1).

Table 2.1 Overview of main parameters included in EM-DAT

Field name	Content of field
DISNO	Eight-digit disaster ID composed of year + sequential number (e.g. 2009-0037)
Country	Country of disaster occurrence
Disaster group	Natural/technological disasters
Disaster sub-group	Geophysical, meteorological, hydrological, climatological or biological disasters
Disaster type and sub-type	Description of the disaster according to a pre-defined classification
Date	Start/end date of disaster
No. people killed	Persons confirmed as dead and persons missing and presumed dead
No. people injured	People suffering from physical injuries, trauma or an illness requiring medical treatment as a direct result of a disaster
No. people homeless	People needing immediate assistance for shelter
No. people affected	People requiring immediate assistance during a period of emergency, including displaced or evacuated people
Total no. affected	Sum of injured, homeless and affected people
No. victims	Sum of killed and total affected people
Estimated damage	Estimated economic damage in US$ × 1,000 (reported values)
Geographical information	Location, latitude and longitude
Additional fields	E.g. scale/magnitude of disaster, international status, aid contribution, affected sectors

[5]See also: www.munichre.com/en/ts/geo_risks/natcatservice/default.aspx

[6]See also: www.swissre.com

2.2.2 Finding the Right Definitions and Terminology

One of the major challenges in the field of disaster data today is finding a way to overcome the limitations that result from not having standardised definitions. The lack of universal definitions leads to inconsistencies in reported disaster figures and makes it extremely hard to compare and exchange data between multiple disaster data compilation initiatives. In response to this, CRED and MünichRe have recently led a collaborative initiative on a Disaster Category Classification for Operational Databases in order to come up with standardised terminology for global and regional databases on natural disasters (Below et al. 2009). This initiative is an important step towards standardising disaster databases worldwide, which should help to improve the quality and interoperability of disaster data.

2.2.3 Challenges in Disaster Data Collection

All global datasets have inherent limitations on their data, and this is certainly the case for global disaster data sets. Information sources reporting data on disasters have different objectives, so data may not be gathered and communicated specifically for statistical purposes. This means that the quality of disaster statistics depends to a large extent on the reporting sources. There are ambiguities in the definitions and criteria used to describe the human impact of disasters. Up until now, there has not been any commonly applied definition of 'people affected by a disaster'. The numbers reported for disaster-related deaths sometimes include the missing, but sometimes do not, so if the reporting is not clear it is easy for mortality figures to be inflated or deflated.

Likewise, economic losses are often loosely reported or even missing altogether, because of the complexity of assessing damages. In EM-DAT, economic loss data are cross-checked with other specialist sources, such as reinsurance companies. While no database can capture complete information on all events, the statistics compiled in EM-DAT provide an insight into trends which can be used to appreciate the direction and comparative impact of different disasters. On a positive note, consensus has been reached in recent years on definitions and thresholds in reporting disaster statistics, which makes global data more consistent and easier to compare.

2.3 Global Patterns and Trends in Earthquake Occurrence and Human Impact

Earthquake disasters are distributed through time and over space with a wide range of potential consequences. First, we will look at the trends in natural disasters that we can identify in the EM-DAT database from 1900 until the present day. After this, we will draw on the improved quality of data reporting and better coverage of global events to do further analysis of earthquake disasters between the first day of 1970 and the end of 2008. We will only include disasters that meet the EM-DAT criteria as described in Section 2.2.1.

2.3.1 Long-Terms Trends in Natural Disasters

EM-DAT has a record of more than 11,000 natural disasters dating back to 1900. Of these recorded events, 85% took place since 1970. One of the main factors contributing to this apparent increase in natural disasters is improved reporting, influenced by the launch of OFDA-USAID in 1964 and CRED in 1973.

The data represented in Fig. 2.1 might lead one to believe that disasters occur more frequently today than in earlier decades. However, it would be wrong to reach such a conclusion based solely on this graph. When interpreting disaster data, one has to take into account the inherent complexity of disaster occurrence and human vulnerabilities, as well as how statistics are reported and registered. Furthermore, developments in telecommunications and media, increased humanitarian funding and improved international cooperation have all contributed to better reporting of disasters, particularly the smaller-scale ones.

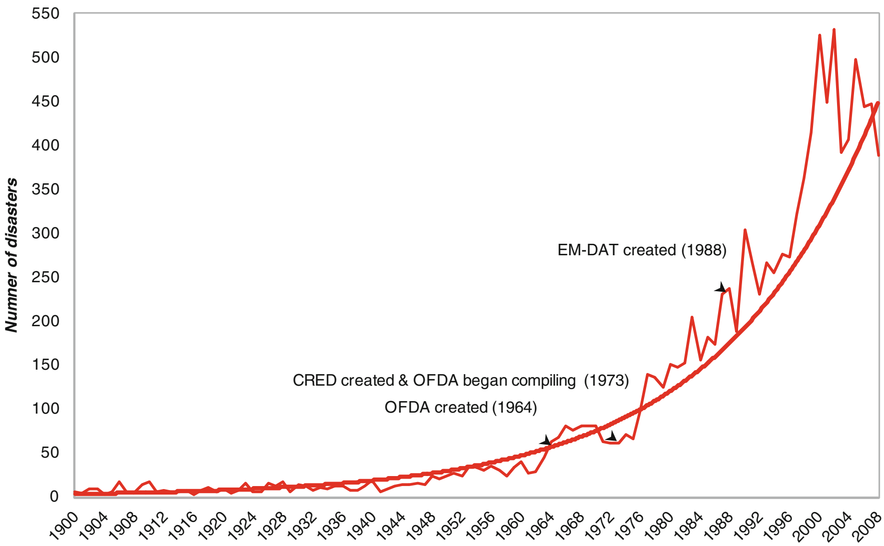


Fig. 2.1 Reported natural disaster occurrence in EM-DAT (1900–2008)

2.3.2 *Earthquake Disasters: Patterns and Trends from 1970 to 2008*

In recent decades, data quality and coverage have vastly improved. Media coverage of global events has expanded widely, and telecommunication costs have decreased. The increased use of internet and email correspondence has also improved the timeliness and quality of disaster reporting. In this section we look at some patterns and trends in the earthquake data since 1970.

An annual average of 21 earthquake disasters has been reported over the last 39 years, according to EM-DAT criteria (see Section 2.2.1). But over the last 9 years, this average has increased to 30 earthquakes per year. Figure 2.2 shows the frequency of seismic shocks with significant human impact. The three peak years for high numbers of earthquake disasters were 1990, 2003 and 2004. In 1990, both Asia and Europe experienced frequent seismic activity with significant human consequences. In that calendar year, 13 earthquakes – ranging from 5.8 to 7.7 on the Richter scale of magnitude – hit Asia, and 12 earthquakes occurred in Europe with magnitudes ranging from 4.7 to 6.8 on the Richter scale. The rest of the world also experienced several major earthquakes. By far the most lethal earthquake in 1990 was the earthquake which hit Iran on June 21 with a magnitude of 7.3 on the Richter scale. It struck Manjil-Rudbar at 00:30 local time, killing 40,000 people and affecting more than 700,000 others. In the same year, a 7.7-magnitude earthquake struck the densely populated island of Luzon in the Philippines on July 16, killing 2,400 people and affecting more than 1.5 million others.

In 2003, 29 earthquakes occurred in Asia, of which 11 were in China and five in Iran. The destructive 6.6-magnitude Bam earthquake, which struck Iran on December 26, 2003 at 05:26 local time, killed 27,000 people and affected 270,000 others.

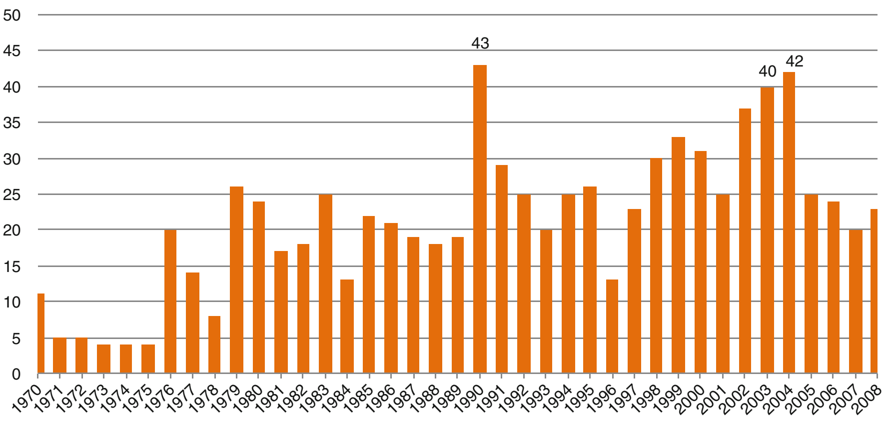


Fig. 2.2 Number of earthquakes with human impact according to EM-DAT criteria (1970–2008) (Tsunamis included)

Fig. 2.3 Earthquake occurrence (%) by continent 1970–2008

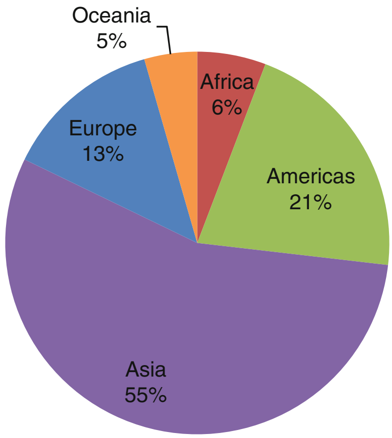
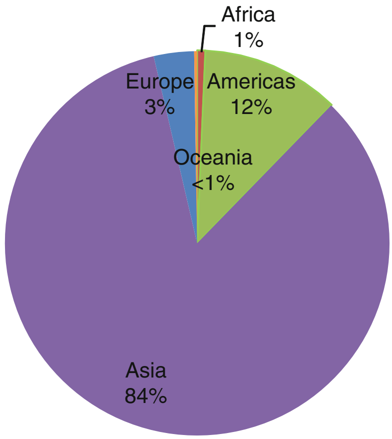


Fig. 2.4 Earthquake fatalities per continent (%) 1970–2008



A 6.0-magnitude earthquake struck the Yunnan province of China on July 21, 2003 at 23:16 local time, affecting over 1.3 million people.

Asia was struck again by a series of earthquakes in 2004. In that year, Indonesia (six) and China (five) were the two countries with the highest individual contribution to the continent's total of 26 earthquakes. On the other hand, a single massive event, the devastating Sumatra-Andaman earthquake and tsunami of December 26, affected 12 countries, increasing the annual total of human disaster earthquakes in the region. It killed more than 226,400 people, with a total of 2.4 million affected, and inflicted damage costing US$10 billion.

Profiles of earthquake occurrence and their impact differ between continents (Figs. 2.3–2.6). During the past 39 years, Asia is the continent with the highest number of earthquakes (with an average of 55% of each year's share), followed by the Americas (21%). When we look at the human impact, over 80% of earthquake victims are in Asia. Damage costs from earthquakes are also highest in Asia, partly due to the high frequency of earthquakes in relatively wealthy Japan and the widespread scope of damage in India. Despite relatively low earthquake numbers,

Fig. 2.5 Earthquake victims per continent (%) 1970–2008

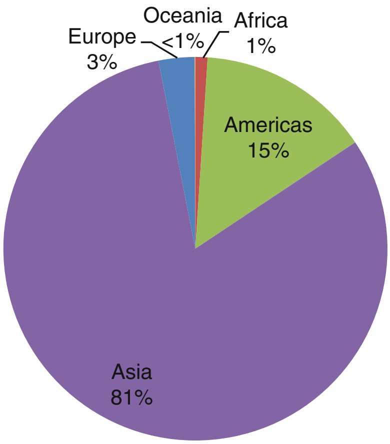
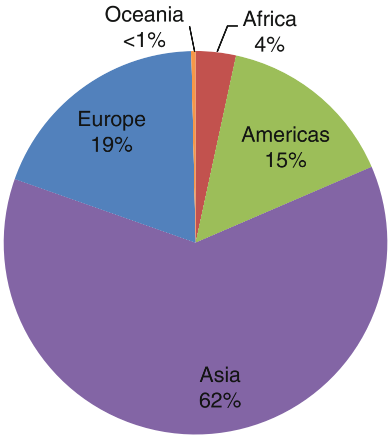


Fig. 2.6 Earthquake damage costs (%) by continent 1970–2008



Europe accounts for nearly 20% of damage costs, compared to the Americas – another relatively high-income region – which remain at 15%.

Finally, if we look at how the share of victims has changed over time, Asia's burden has increased substantially in recent decades, as shown in Fig. 2.7. The two peaks in this figure represent the 1988 earthquake which hit India and Nepal at a magnitude of 7.0 on the Richter scale, with over 20 million victims, and the 2008 Sichuan earthquake in China (magnitude 7.9), which claimed more than 46 million victims. Victims, according to EM-DAT terminology, include both the dead and affected.

If we rank individual countries by the number of earthquakes that occurred in them over the last 39 years, China tops the list, experiencing a total of 99 earthquakes that had major human impact. Indonesia comes second, with 80 earthquakes during this same period. Although China and Indonesia are relatively big countries, a larger surface area is not necessarily associated with a higher frequency of disastrous earthquakes. Other larger countries, such as Brazil, Russia or India, do not experience more earthquakes due to their size, since earthquake occurrence is not randomly distributed across the globe. Table 2.2, which compiles the top ten countries

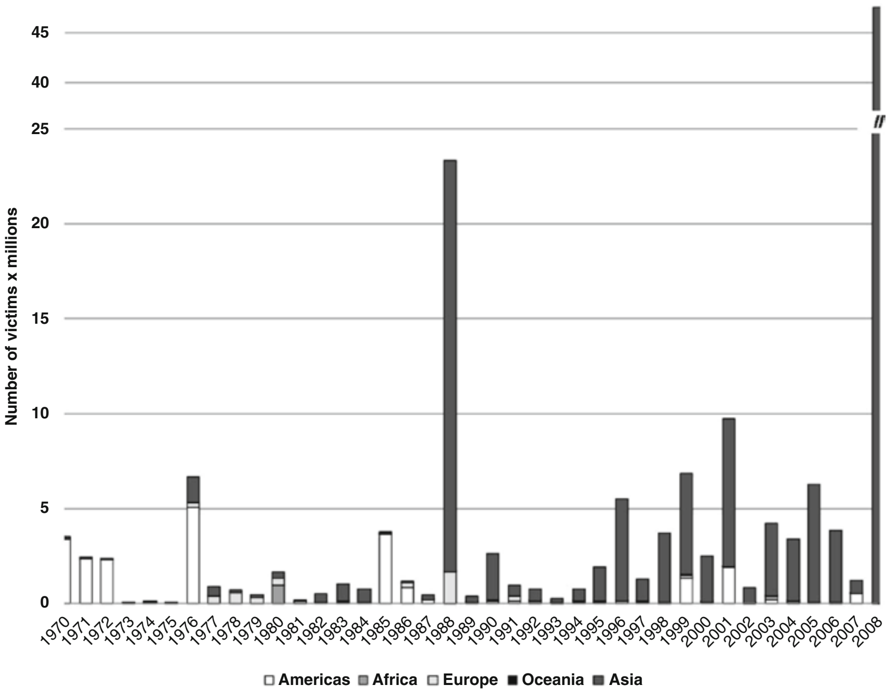


Fig. 2.7 Trend in number of earthquake victims per continent 1970–2008

Table 2.2 Top ten countries with highest number of earthquakes 1970–2008

Country	No. earthquakes
China	99
Indonesia	80
Iran	74
Turkey	42
Japan	34
Peru	27
Afghanistan	25
United States	24
Italy	23
Greece, Mexico	22

with the highest number of earthquakes, highlights countries located in high-risk geographical locations, such as the Pacific's Ring of Fire.

If we look at the ten most fatal earthquakes of the last 39 years, low- and middle income countries top the list (Table 2.3). When earthquakes strike, the human impact can be enormous, killing hundreds of thousands of people in a few seconds. Earthquake risk increases with population growth and urbanisation, as well as with poverty. Low-quality building construction and inadequate spatial planning put people in danger, and we often find that earthquake damage is particularly destructive

Table 2.3 Top ten most destructive earthquakes in terms of human impact (1970–2008)

Date	Country	Richter	Killed (× 1,000)	Total affected (× 1,000)
27 Jul 1976	China	7.8	242	164
26 Dec 2004	Indian Ocean tsunami[a]	9.0	226	2,432
12 May 2008	China	7.9	88	45,977
08 Oct 2005	Pakistan, India, Afghanistan[b]	7.6	75	5,285
31 May 1970	Peru	7.8	67	3,216
21 Jun 1990	Iran	7.3	40	710
26 Dec 2003	Iran	6.6	27	268
07 Dec 1988	Armenia	6.9	25	1,642
16 Sep 1978	Iran	7.7	25	40
04 Feb 1976	Guatemala	7.5	23	4,993

[a] Affected countries: Bangladesh (two killed, zero affected), India (16,400 killed, 654,500 affected), Indonesia (165,700 killed, 532,900 affected), Kenya (one killed, zero affected), Malaysia (80 killed, 5,100 affected), Maldives (102 killed, 27,200 affected), Myanmar (71 killed, 15,700 affected), Seychelles (three killed, 4,800 affected), Somalia (298 killed, 105,100 affected), Sri Lanka (35,400 killed, 1,019,300 affected), Tanzania (ten killed, zero affected), Thailand (8,300 killed, 67,000 affected)

[b] Pakistan (73,300 killed, 5,128,000 affected), India (1,309 killed, 156,600 affected), Afghanistan (one killed, zero affected)

in countries with developing economies. Poor people are most vulnerable, being forced to settle on steep hillsides, flood-prone alluvial land, low elevation coastal zones and valleys at risk of landslides, or to develop their livelihoods around terraced agriculture. However, the extent to which each of these factors play a role is not yet well understood.

The ratio of people killed (mortality) to injured (morbidity) by earthquakes can provide information that is useful for planning the type and amount of supplies and personnel needed in a disaster relief effort (Lechat 1979). Earlier research has estimated a ratio of one person killed for every three people injured by earthquakes measuring 6.5–7.4 in magnitude on the Richter scale (Alexander 1985; De Ville de Goyet et al. 1976). The magnitude of the earthquake is one of several determinants of the consequent mortality or morbidity. Many factors in addition to earthquake severity influence the human consequences. These include the time of the day the event occurred, distance from the epicentre, secondary events triggered by the earthquake, urbanisation grade, building standards and regulations, and access to medical care, as well as social and behavioural customs (Ramirez and Peek-Asa 2005; Chou et al. 2004; Liang et al. 2001; Armenian et al. 1992). Unravelling which of these factors played the predominant role in determining the level of loss is complicated without extensive data on the affected community both before and after the event. Even more fundamentally, methodological problems faced in comparative analysis of earthquake morbidity and mortality are the lack of standardised concepts and definitions for the number of ‘injured’ and ‘affected’ people. Furthermore, estimating the size of the population at risk is challenging due to poor census data and movement of citizens and relief personnel from and towards the disaster site. Under- or overestimation of the number of earthquake-related injuries and deaths influences the determination of the magnitude of the health impact in the population. The relationship between causal factors and their outcomes is difficult to determine, since information on risk factors and injury data are incomplete and often completely lacking. On a positive note, in the recent years, the importance of reliable data is increasingly recognised and there are efforts to improve organised surveillance of injuries and collection of data at medical treatment sites. Useful analyses from the Sichuan earthquake in 2008 as well as the Kashmir earthquake in 2005 based on field data are being published (Zhang et al. 2009; Wen et al. 2009; Xie et al. 2008; Mulvey et al. 2008), contributing to the evidence base on risk factors for human impact of earthquakes.

2.4 Conclusions

Annually, since 1970, numbers of earthquakes with major impact on human populations have increased. Increasing population growth in zones of high seismic risk or decreasing quality of physical structures may transform a less significant quake to a major disaster. For example, Asia faces an increasing number of earthquake events and associated victims and structural losses. The extent to which this vulnerability is due to population pressures, unbridled urbanisation and inadequate housing requires special study. Globally, risk factors that expose a population to loss of life or major injuries remain inadequately understood whereas, without this knowledge, it is difficult to put in place an effective preparedness or prevention plan.

Long experience with the EM-DAT international disaster database has convinced us that standardised definitions for human impact indicators – such as people injured or people affected – would be a significant step forward in improving understanding of earthquake-related risk. Key concepts such as definitions, even conventional, that describe the population exposed to death and injury from earthquakes have yet to be established. As a result, not only are results from different studies not comparable, denominators are inadequate even within a study, making rates and ratios suspect.

It is now widely recognised that the distribution of deaths and injuries caused by earthquakes varies greatly according to the region and the economic development of the community in which it occurs. However, individual risk patterns can reveal information that could contribute to improving community-based earthquake preparedness programmes. Statistical analysis of earthquake impact data can be useful for evaluating impact patterns over space and time. Besides, well-designed case-control studies and, more ideally, cohort studies could significantly contribute to generating evidence on risk factors for earthquake mortality and morbidity.

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