Chapter 2

Global disaster risk: patterns, trends and drivers

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The chapter was developed in collaboration with the UNDP led Global Risk Identification Programme (GRIP), the World Bank Global Facility for Disaster Reduction and Recovery, UNEP/GRID Europe PREVIEW (Project for Risk Evaluation Vulnerability Information and Early Warning), the Norwegian Geotechnical Institute and the Earth Institute at Columbia University. Close coordination was maintained with a study on Risk Assessment and Mitigation Measures for Natural- and Conflict-Related Hazards in Asia–Pacific, undertaken by the United Nations Office for Coordination of Humanitarian Affairs (OCHA), Regional Office for Asia and the Pacific. Both that study and the present analysis are underpinned by common hazard data sets, in order to avoid duplication and enable comparability.

The mortality risk analysis was developed and coordinated by Pascal Peduzzi and the economic loss risk analysis by Uwe Deichmann. The advisory group included: Maxx Dilley and Carlos Villacis (UNDP/BCPR); Hy Dao (UNEP/GRID-Europe); Oddvar Kjekstad and Farrokh Nadim (Norwegian Geotechnical Institute); Art Lerner-Lam and Brad Lyon (Earth Institute at Columbia University); Uwe Deichmann, Andrew Maskrey and Pascal Peduzzi.

The population distribution (1975–2007) used in this chapter was prepared by Hy Dao, based on the Landscan™ population model, kindly provided by the Oak Ridge National Laboratory[1]. The GRUMP population distribution was also tested. It was generated by Greg Yetman (Columbia University) and used to compute the GDP raster distribution (1975–2007) prepared by Uwe Deichmann, Siobhan Murray and Mahyar Eshragh-Tabary (World Bank).

Social and economic indicators were compiled by Hy Dao, Andrea De Bono (UNEP/GRID-Europe) and Uwe Deichmann. The historical disaster loss data used was from EMDAT: the OFDA/CRED International Disaster Database. Munich Reinsurance provided economic loss data aggregated at the country level. Maryam Golnaraghi and Jean Baptiste Migraine (WMO) coordinated the scientific peer review of the hazard models for tropical cyclones, floods and droughts. Badaoui Rouhban, Takashi Imamura and Juliana Chaves Chaparro (UNESCO) coordinated the scientific peer review of the hazard models for landslide, earthquake and tsunami.

The tropical cyclones hazard model was developed by Bruno Chatenoux (UNEP/GRID-Europe) and Pascal Peduzzi, based on previous work by Christian Herold, Frédéric Mouton, Ola Nordbeck and Pascal Peduzzi (UNEP/GRID-Europe). Events in the EMDAT database were geo-referenced by Andrea De Bono and human and economic asset exposure was calculated by Bruno Chatenoux. The cyclone storm surge hazard model was developed and exposure calculated by Andrea De Bono. The vulnerability and risk analysis and models were done by Pascal Peduzzi (for human losses) and Uwe Deichmann (for economic losses) with Michael M. Lokshin (World Bank). Scientific peer review of the hazard models was carried out by Koji Kuroiwa and Taoyong Ping (WMO) with Jim Davidson (Bureau of Meteorology, Queensland, Australia), Woo-Jin Lee (Korean Meteorological Administration) and Linda Anderson-Berry (Bureau of Meteorology, Melbourne, Australia).

The hazard model for floods was developed by Christian Herold and Frédéric Mouton (University of Grenoble, Institut Fourier) with code contributed by James and Kristin Verdin (US Geological Service). All information associated with flood events was processed by Christian Herold based on floods detected by remote sensing by Bob Brackenridge and his team at the Dartmouth Flood Observatory. Disaster losses and exposure were geo-referenced and calculated by Christian Herold. The vulnerability and risk analysis and models were done by Pascal Peduzzi (for human losses) and Uwe Deichmann (for economic losses). Advice on development of the flood hazard model was given by James and Kristin Verdin, Bob Brackenridge and Wolfgang Grabs (WMO). Scientific peer review of the hazard models was carried out by Ayinash Tyagi (WMO) and Wolfgang Grabs with Zhiyu Liu (Bureau of Hydrology, Ministry of Water Resources, China).

The hazard model for drought was developed by Brad Lyon, Greg Yetman, Maria Muniz, Liana Razafindrazay and Vilentia Mara (Columbia University). Drought exposure was calculated by Gregory Guiliani (UNEP/GRID-Europe) and Andrea De Bono. Scientific peer review of the hazard model was carried out by Mannaya Sivakumar and Robert Stefanski (WMO) with Simone Orlandini (Department of Agronomy and Land Management, University of Florence, Italy), Harlan D. Shannon (US Department of Agriculture, World Agricultural Outlook Board), Mark Svoboda (National Drought Mitigation Center, School of Natural Resources, University of Nebraska-Lincoln, USA) and Orivaldo Brunini (Instituto Agronomico, Sao Paulo, Brazil).

The landslide hazard model was developed by Helge Smebye and Bjorn Kalsnes (International Centre for Geohazards, Norwegian Geotechnical Institute, Norway) and Pascal Peduzzi calculated exposure. The vulnerability and risk analysis and models were done by Pascal Peduzzi (for human losses) and Uwe Deichmann (for economic losses). Scientific peer review of the hazard models was carried out by Kyoji Sassa (University of Kyoto, Japan), Nicola Casagli (University of Firenze, Italy), Lynn Highland (USGS), Dwikorita Karnawati (Gadjah Mada University, Indonesia) and Alexander Strom (Institute of Geospheres Dynamics, Russia).

The intensities and spatial extent of past earthquake events were compiled from the ShakeMap Atlas[2] developed under the auspices of the US Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER)[3], kindly provided for the project by USGS. Losses were geo-referenced by Andrea De Bono. Human and economic exposure was computed by Bruno Chatenoux. The vulnerability and risk analysis and models were done by Hy Dao and Pascal Peduzzi (for human losses) and Uwe Deichmann (for economic losses). The global intensity hazard earthquake distribution was developed by Arthur Lerner-Lam and Liana Razafindrazay. Scientific peer review of the hazard models was carried out by Avi Shapira (Israel Geophysical Institute), Kunihiko Shimazaki (University of Tokyo, Japan), Giuliano Panza (University of Trieste, Italy) and Mihail Garevski (Institute of Earthquake Engineering and Engineering Seismology, Former Yugoslav Republic of Macedonia).

The tsunami hazard model was developed by Finn Løvholt, Natalia Zamora, Sylfest Glimsdal and Helge Smebye (International Centre for Geohazards, Norwegian Geotechnical Institute, Norway) with Greg Yetman. Exposure was calculated by Hy Dao. Scientific peer review of the hazard models was carried out by Jörn Behrens and Alfred Wegener (Institute for Polar and Marine Research, Germany), Stefano Tinti (University of Bologna, Italy) and Kenji Satake (University of Tokyo, Japan).

The study on economic resilience was carried out by Felipe Barrito, Werner Corrales and Tanya Miquelena (independent consultants).

Introduction

An observation of disaster risk patterns and trends at the global level allows a visualization of the major concentrations of risk described in the previous chapter and an identification of the geographic distribution of disaster risk across countries, trends over time and the major drivers of these patterns and trends.

The analysis presented in this chapter, developed by a large, interdisciplinary group of researchers from around the world, makes global disaster risk more visible – a key step towards mobilizing the political and economic commitment needed to reduce it.

Given the growing influence of climate change, the centrepiece of this chapter is an analysis of the mortality and economic loss[4] risk for three weather-related hazards: tropical cyclones, floods and landslides. In addition new insights have been gained into other hazards such as earthquakes, tsunami and drought.

Summary of findings

1. Risk concentration

Disaster risk is geographically highly concentrated. A very small portion of the Earth's surface contains most of the risk and most future large-scale disasters will occur in these areas. Risk will increase further if exposure continues to increase, for example in tropical cyclone prone coastal cities.

2. The uneven distribution of risk

Disaster risk is very unevenly distributed. Hazards affect both poorer and richer countries. For example, tropical cyclones hit both Japan and Bangladesh. Severe earthquakes occur in the United States and in India. However, for hazards of a similar severity, countries with higher incomes and, importantly, higher human development levels generally experience lower mortality and smaller losses when measured against the country's total wealth. In absolute terms economic losses are higher in richer countries, but less so once they are seen as a share of overall wealth.

3. Risk drivers

In addition to hazard severity and exposure a range of other risk drivers related to economic and social development play a crucial role in the configuration of disaster risk. These include not only income and economic strength, but also governance factors such as the quality of institutions, openness and government accountability. Income is a driver in its own right, but also conditions other drivers. Wealthier countries tend to have better institutions, more effective early-warning, and disaster preparedness and response systems, and more open government that tends to be more supportive of disaster risk reduction.

4. Disaster risk is increasing

Risk levels for most of the hazards are increasing over time, even assuming constant hazard frequency and severity. Economic loss risk is increasing faster than mortality risk. These increases in risk are being driven by the growing exposure of people and assets, for example through rapid economic and urban growth in cyclone prone coastal areas and earthquake prone cities. Vulnerability decreases as countries develop, but not enough to compensate for the increase in exposure.

5. Climate change

Weather-related hazard is critically important in the configuration of global risk patterns. Two of the principal global datasets on disaster losses[5] agree that more than two thirds of the mortality and economic losses from internationally reported disasters is associated with meteorological, climatological and hydrological hazard.

The IPCC has confirmed that the geographic distribution, frequency and intensity of these hazards is already being altered significantly by climate change[6]. Changes are already occurring in the amount, intensity, frequency and type of precipitation. This is associated with increases in the extent of the areas affected by drought, in the numbers of heavy daily precipitation events that lead to flooding, and increases in the intensity and duration of certain kinds of tropical storms.

Individual events, such as recent large tropical cyclones in the United States and Myanmar, cannot be attributed to climate change. However, given the concentration and uneven distribution of risk described above, the impact of any increases in weather-related hazard will be highly asymmetric. Poorer countries that concentrate most existing risk will be disproportionately affected by climate change.

6. Economic resilience, vulnerability and development constraints

A group of developing countries, including many SIDS, LLDCs and others with small and weak economies are particularly vulnerable to economic loss, have low resilience to that loss and are particularly exposed to climate change. Disaster impacts compromise their prospects for economic growth, poverty reduction and development at large, to the extent that the capacity of the most vulnerable countries to benefit from their insertion in the global economy is severely constrained.

2.1 Method and data[7]

Improvements in methodology and data now enable a much more accurate characterization of disaster risk than was possible when comprehensive global assessments were published by the UNDP and the World Bank[8] five years ago. Several factors have contributed to these improvements, outlined in Box 2.1.

Box 2.1: Innovations in data and methodology

Improved estimates of global disaster risk have been made possible by:

- Higher resolution and more complete data on geographic and physical hazard event characteristics, especially for floods, tropical cyclones and earthquakes.
- Improved high resolution exposure data on population and economic assets (sub-national GDP).
- Enhancements in geographic and physical modelling of hazard extent, frequency and severity – especially for floods, landslides and tsunamis – allowing hazard intensity or severity to be calculated.
- Explicit linking of hazard event outcomes (i.e. losses) with the geographic and physical characteristics of the event. This permits *event-level* analysis of the influence of exposure, vulnerability and hazard severity and the imputation of disaster losses for events for which no loss data were recorded.
- Incorporation of new global data sets on social, economic and other vulnerability factors, such as governance and corruption.

Following the basic risk model that guides this Report (Box 1.1), disaster risk for a given location is determined by the probability that a hazard event of a given magnitude will occur, the number of exposed people or the value of exposed assets, and the level of vulnerability. The latter refers to characteristics of the exposed population, public infrastructure and economic assets that increase or decrease the likelihood of damages when a hazard event occurs, as well as factors such as effective governance and higher levels of social coherence, which influence and condition those characteristics.

Analysing the mortality and economic loss experienced in past disasters permits an assessment to be made of the role played by each of the three main risk factors – hazard event characteristics, exposure and vulnerability – in configuring risk. With data for each of these risk factors for many individual disaster events, their relative importance can be statistically analysed. For instance, controlling for the magnitude of a tropical cyclone and the size of the population or economy in the affected area, it is possible to measure how vulnerability factors (such as a country's institutional quality) affect mortality or the size of economic losses. Box 2.2 presents the methodology that was followed for each hazard type.

Box 2.2: Risk analysis procedure

The application of the risk model involved the following steps for each hazard type:

1. Compile geographical and physical information on specific hazard events such as tropical cyclone track data, areas of flood extent, or earthquake location and magnitude.
2. For each hazard event, determine the footprint or area of impact, such as the area where a tropical storm exceeded tropical cyclone-force wind speed. See Figures 2.1, 2.2 and 2.3.
3. For each impact area, compute exposure as the number of people and economic assets within that area.
4. Link available loss information for each hazard event (sourced from EMDAT) to the hazard event information (hazard severity and exposure).
5. Add information on vulnerability. Since global data on direct vulnerability factors such as building quality are unavailable, this analysis uses country-level indicators for the year in which the event occurred, such as government accountability or per capita income.
6. Estimate empirical loss functions that relate event mortality or economic losses to risk factors (hazard characteristics, exposure and vulnerability) using statistical regression techniques.
7. Derive an estimate of expected average annual losses and exposure. The estimated loss functions are used to impute disaster outcomes for all recorded events, whether or not a loss estimate is available in EMDAT or not. This is done using data on exposure and vulnerability for 2007 such that annualized average estimates reflect current conditions.
8. Apply estimates to all pixels in a geographic grid. The loss estimates are aggregated at different levels (1 km x 1 km cells; sub-national administrative areas; countries) allowing the identification of geographic concentrations of risk. Mortality risk is classed in deciles using a logarithmic index with values ranging from 1 = negligible to 10 = extreme risk (see below). Economic loss risk is calculated for World Bank regions and country income groups.

Classes	Absolute risk (average killed per year)	Relative risk (killed per million peryear)	Mortality Risk Index (average of both indicators)
10	>3 000	>300	Extreme
9	1 000–3 000	100–300	Major
8	300–1 000	30–100	Very High
7	100–300	10–100	High
6	30–100	3–10	Medium high
5	10–30	1–3	Medium
4	3–10	0.3–1	Medium low
3	1–3	0.1–0.3	Low
2	0.3–1	0.03–0.1	Very Low
1	>0–0.3	>0–0.03	Negligible
0	0	0	Unknown exposure

9. The above procedure differed slightly between hazards. A full description of the methodology is given in Appendix 1, Technical Note 1.1: Methodology.

While understanding of disaster risk has increased steadily, data limitations combined with the unpredictable and unique nature of hazard mean that much uncertainty remains. Rapid increases in vulnerability and in the exposure of population and economic assets, as well as the possibility of shifting climatic conditions affecting hazard location, frequency or magnitude, imply that risk cannot be modelled deterministically. Despite improvements in disaster reporting, loss information for individual events is incomplete and suffers from inconsistent measurement of damages and broader losses, particularly in the case of economic losses. Box 2.3 illustrates the difficulties in obtaining accurate data. While disaster mortality data are considered to be better recorded and more robust than economic loss data, uncertainties still exist.

Sub-national data on the exposure of economic assets and vulnerability factors are scarce or non-existent, meaning that proxies have to be used. Higher resolution data on disaster impacts that capture smaller-scale events and locally specific hazards are not globally available. Steady improvements in data collection will address these shortcomings and national data collection efforts will filter up to provide better global information, but these processes will take time.

Figure 2.1: Multi-hazard map of Africa

Data sources: Tropical cyclones: UNEP/GRID-Europe; Floods: UNEP/GRID-Europe + observerd from Dartmouth Flood Observatory and frequency from Flood PREVIEW UNEP/GRID-Europe; Droughts: IRI, Columbia University; Landslides: Norwegian Geotechnical Institute; Earthquakes: GSHAP transformed into MMI by IRI, Columbia University; Tsunami: compiled from various sources by the Norwegian Geotechnical Institute; *Cartography:* P. Peduzzi, UNEP/GRID-Europe, 2009.

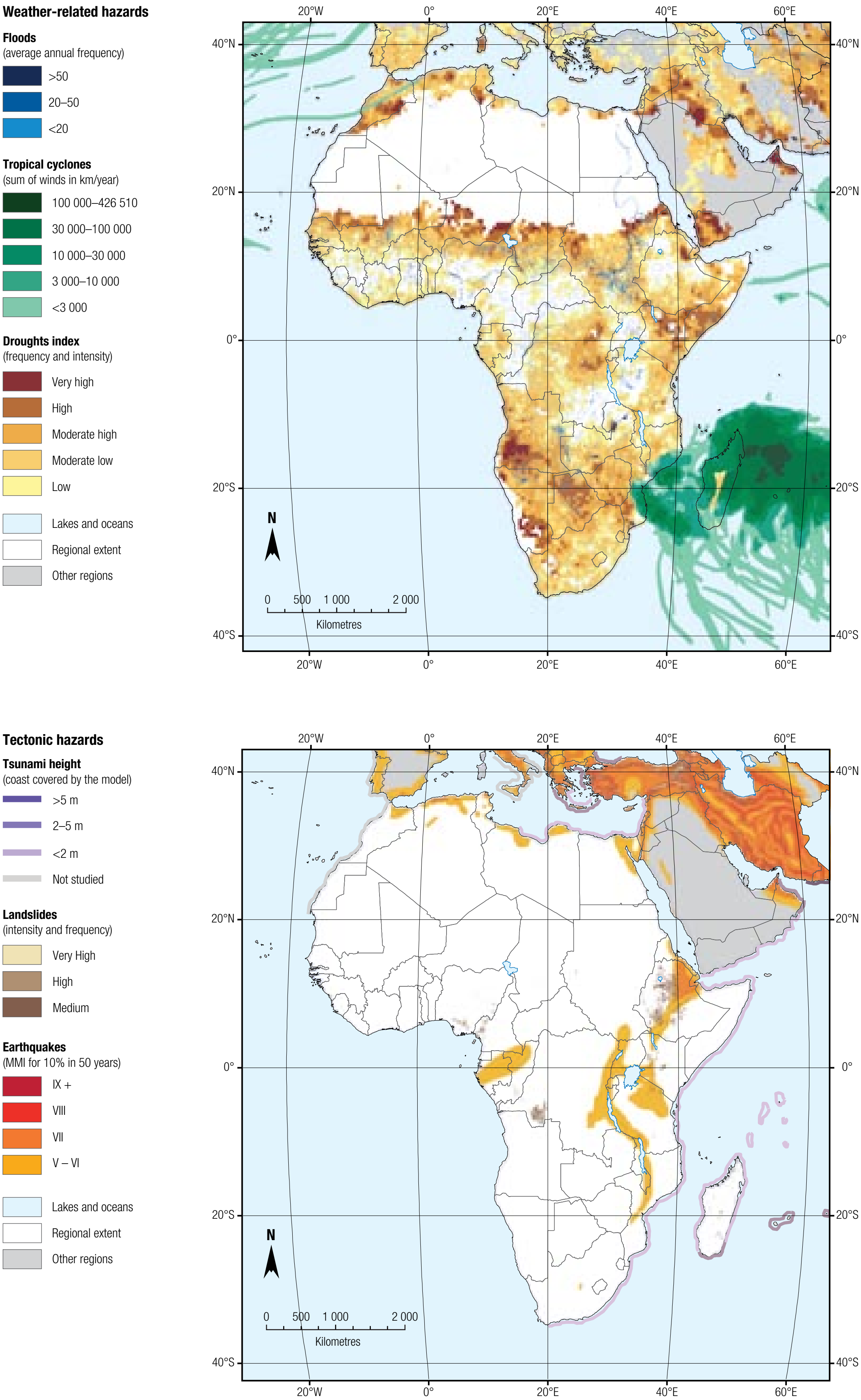
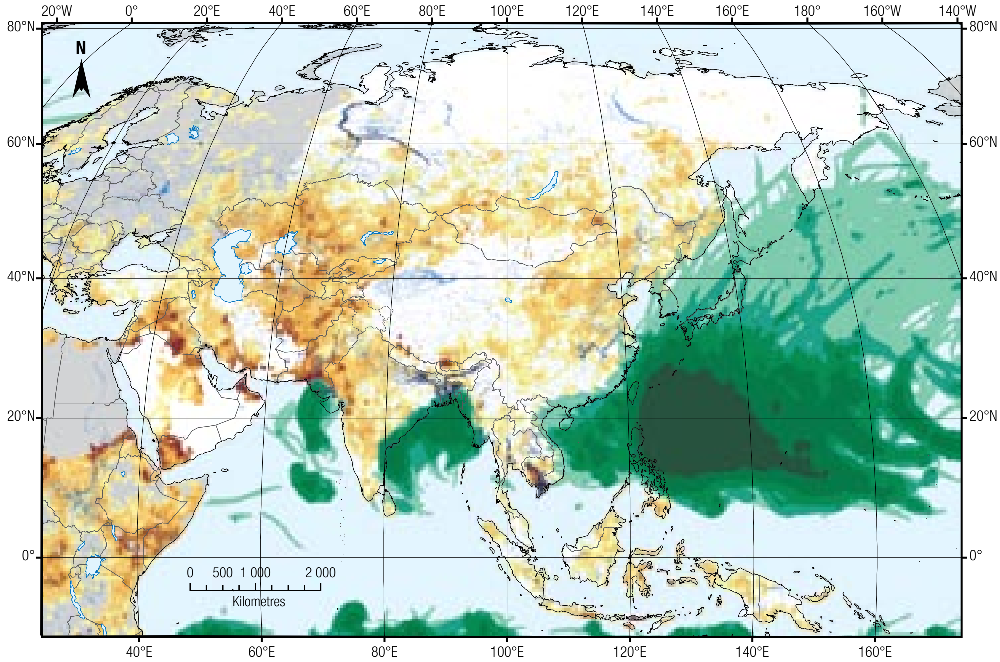


Figure 2.2: Multi-hazard map of Asia

Data sources: Tropical cyclones: UNEP/GRID-Europe; Floods: UNEP/GRID-Europe + observerd from Dartmouth Flood Observatory and frequency from Flood PREVIEW UNEP/GRID-Europe; Droughts: IRI, Columbia University; Landslides: Norwegian Geotechnical Institute; Earthquakes: GSHAP transformed into MMI by IRI, Columbia University; Tsunami: compiled from various sources by the Norwegian Geotechnical Institute; *Cartography:* P. Peduzzi, UNEP/GRID-Europe, 2009.



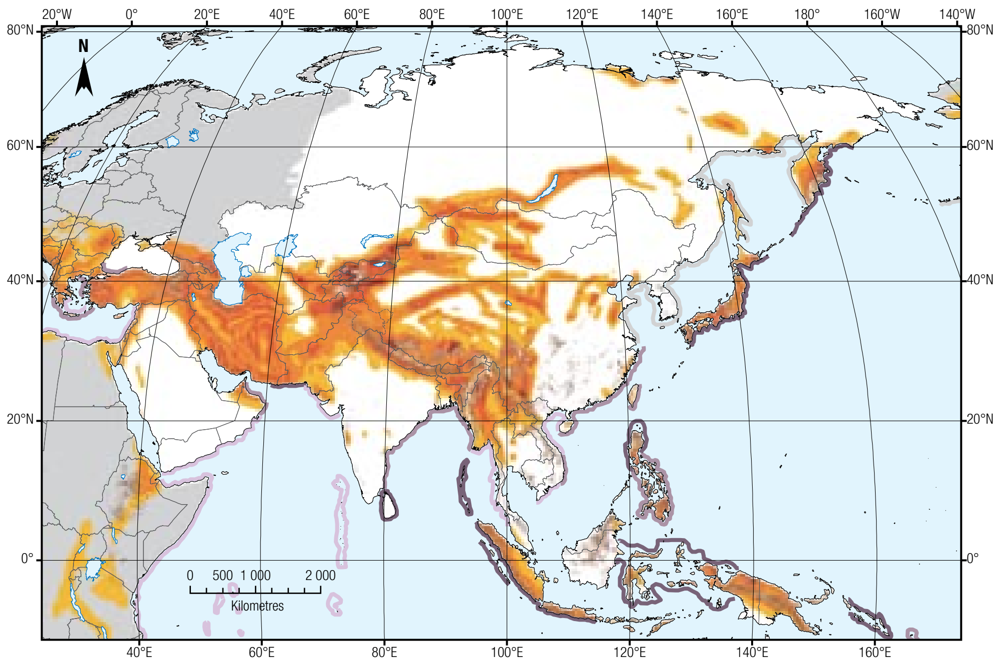
Weather-related hazards

Droughts index (frequency and intensity)
- Very high
- High
- Moderate high
- Moderate low
- Low

Tropical cyclones (sum of winds in km/year)
- 100 000–426 510
- 30 000–100 000
- 10 000–30 000
- 3 000–10 000
- <3 000

Floods (average annual frequency)
- >50
- 20–50
- <20

- Lakes and oceans
- Regional extent
- Other regions



Tectonic hazards

Earthquakes (MMI for 10% in 50 years)
- IX +
- VIII
- VII
- V – VI

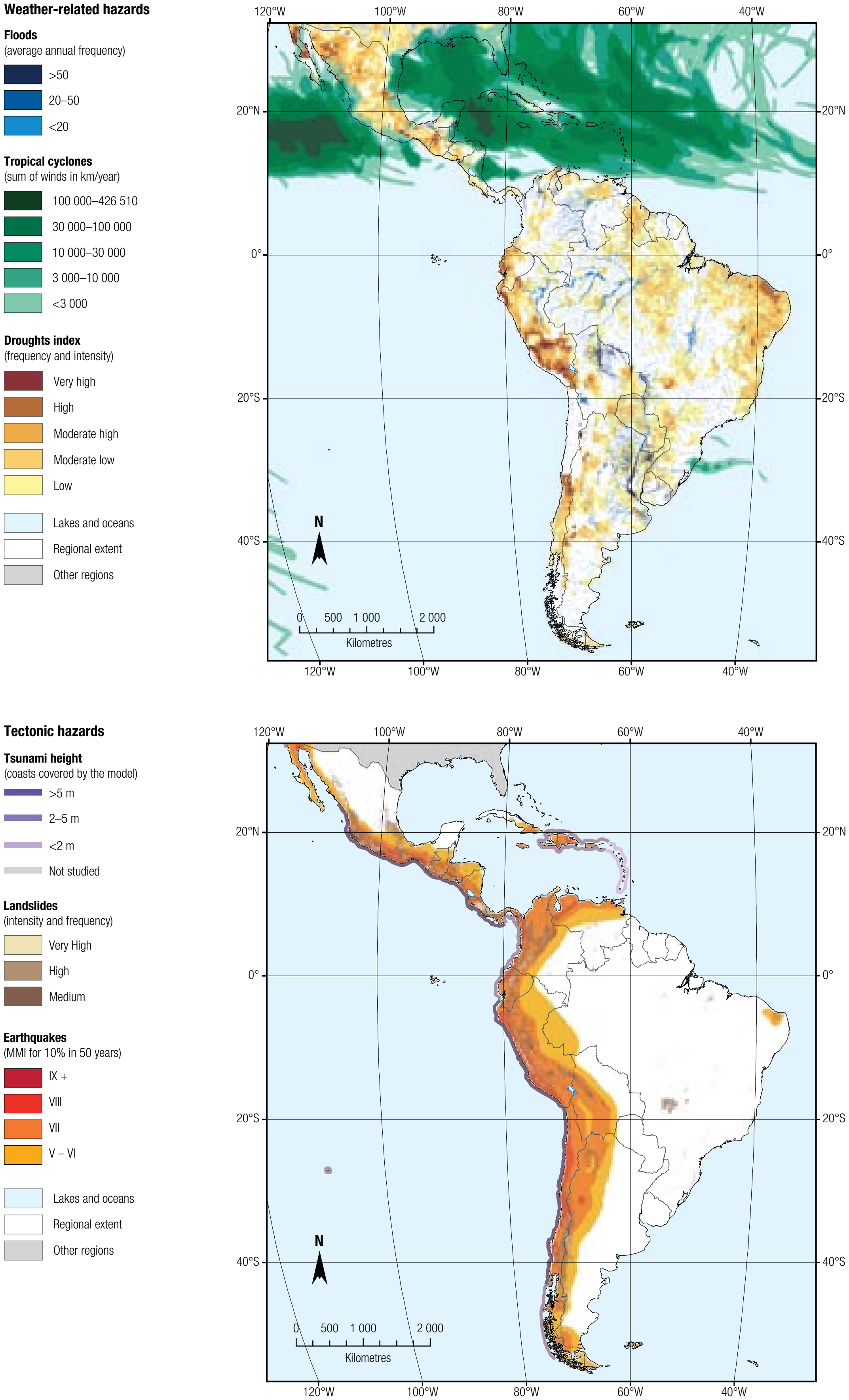
Landslides (intensity and frequency)
- Very High
- High
- Medium

Tsunami height (coasts covered by the model)
- >5 m
- 2–5 m
- <2 m
- Not studied

- Lakes and oceans
- Regional extent
- Other regions

Figure 2.3: Multi-hazard map of Latin America and the Caribbean

Data sources: Tropical cyclones: UNEP/GRID-Europe; Floods: UNEP/GRID-Europe + observerd from Dartmouth Flood Observatory and frequency from Flood PREVIEW UNEP/GRID-Europe; Droughts: IRI, Columbia University; Landslides: Norwegian Geotechnical Institute; Earthquakes: GSHAP transformed into MMI by IRI, Columbia University; Tsunami: compiled from various sources by the Norwegian Geotechnical Institute; *Cartography:* P. Peduzzi, UNEP/GRID-Europe, 2009.



Box 2.3: Disaster mortality data – when the dead go missing

In 2000, the World Bank, describing the impact of natural catastrophes in 1999, stated that *"the landslides in Venezuela alone caused 50,000 fatalities"*[9]. The EMDAT database records 30,000 deaths due to the same set of floods, mudslides and landslides, which occurred in December 1999 and affected 11 states of Venezuela, mostly the State of Vargas but also Miranda and the country's capital, Caracas.

Research by anthropologist Rogelio Altez[10] of the Universidad Central de Venezuela puts forward a very different picture. After a forensic investigation into the deaths occurred in Vargas state, Altez documented a total of only 521 corpses attributed to the disaster, including 290 that had never been identified. In addition only 331 people had been reported missing. Given the likelihood that some of those reported missing were amongst the 290 unidentified corpses, Altez concluded that *"the total number of deaths does not exceed 700"*.

After flying over the affected area, the then Secretary General of the International Federation of Red Cross and Red Crescent Societies (IFRC) had declared that Venezuela's disaster was *"certainly at least two or three times worse than Mitch as far as the death toll is concerned"* and that *"as many as 50,000 people may have been killed"*[11]. According to Altez, statements of this kind began to be quoted as objective data and later became accepted international statistics.

The key message from Altez's study is that there are still major deficiencies in the way corpses are dealt with after many large natural disasters around the world, with documented cases of mass cremations and burials without an adequate process of identification or even quantification of the victims, often due to unjustified fear of epidemics. While the Venezuelan case may be unique, it does highlight the need for a critical approach when dealing with disaster mortality data.

Common statistical techniques, as employed in this study, are suitable for estimating average patterns and trends but are not able to predict extreme events, given the data limitations described (in particular limitations in the use of country-level vulnerability indicators) and the unpredictability of individual hazard events. This means that if the models in this analysis predict an annual average of 1,000 people killed by a given hazard type globally, there could be one event killing 10,000 people followed by 9 years of almost no casualties.

A number of hazard types have been left out or covered less comprehensively in this global analysis. Most importantly, although new indicators of drought occurrence have been developed and are discussed, the analysis did not yield sufficiently accurate estimates of global risk. This is a significant gap especially for sub-Saharan Africa, where drought is a major hazard facing rural populations. As a slow onset hazard, drought impacts are very different from those in sudden impact disasters such as earthquakes or storms. Many droughts with very severe social and economic consequences do not, in fact, show recorded mortality in international disaster databases[12].

The Report looks briefly at forest and other biomass fires, which account for a mere 0.1% of the fatalities recorded in EMDAT, but have major impacts on climate change, deforestation, soil productivity and biodiversity. This hazard is both exacerbated by and influences climate change, and is the second largest source of human-related greenhouse gas (GHG) emissions.

Given these limitations and uncertainties the estimates of exposure and risk provided can only be taken as indicative. They do not describe and cannot predict disaster risk in specific locations. As such, while many of the results can be displayed at quite high geographic resolutions, these should not be used for planning or decision making at the national or local levels. The purpose of this global risk analysis is to decipher global patterns and trends in risk and it does not and cannot substitute for detailed national and local-level risk assessments.

2.2 Weather-related disaster risk

2.2.1 Tropical cyclones

Tropical cyclones, also called typhoons and hurricanes, are powerful storms generated over tropical or sub-tropical waters. They have multiple impacts including extremely strong winds, torrential rains leading to floods or landslides, high waves and damaging storm surge, leading to extensive coastal flooding. Tropical cyclone risk has been modelled using the procedure described in Box 2.2 and further elaborated in Appendix 1.

Disaster risk for tropical cyclones has been calculated taking into account hazard associated with both wind speed and storm surge for different categories of cyclones on the Saffir–Simpson scale.

Figure 2.4 shows the geographic distribution of mortality risk for 10 km × 10 km squares in Asia, Africa and the Americas. Figure 2.5 shows the distribution of both absolute and relative mortality risk from all categories of tropical cyclones aggregated at the country level. Absolute risk is the average annual expected mortality; relative risk describes the average annual expected number of deaths as a proportion of national population. The statistical level of confidence in the model is good, particularly for Category 4 and 5 cyclones[13]. However, these are average annual estimates and cannot be used to predict specific events.

The top ten countries on the Mortality Risk Index and their respective values are Bangladesh (8.5), the Philippines (6.5), India (6), Madagascar (6), the Dominican Republic (6), Haiti (6), Myanmar (5.5), Vanuatu (5.5), Mozambique (5) and Fiji (5).

Geographically, tropical cyclone mortality risk is highly concentrated. For example, 75.5% of the expected mortality is concentrated in Bangladesh and 10.8% in India. There are also large differences in risk between different groups of countries. Relative mortality risk is approximately 200 times higher in low-income countries than in OECD countries and approximately 30 times greater in low human development countries than in high human development countries.

Economic loss risk due to tropical cyclones can be estimated using a model similar to that for mortality. However, the results tend to be less reliable because loss estimates are available for fewer events. There are also difficulties in defining and estimating losses, and there is an incentive to exaggerate damages in anticipation of greater external support. Because of these data constraints this chapter reports economic loss risk aggregated by broad regions and categories of countries.

As Table 2.1 shows, OECD countries including those prone to tropical cyclones such as Japan, the United States of America and Australia, account for almost 70% of estimated annual economic losses in absolute terms, followed by East Asia and the Pacific, and Latin America and the Caribbean. Sub-Saharan African countries, such as Madagascar and Mozambique, suffer the highest relative economic loss risk as a proportion of the size of the affected economy. Across all regions, estimated economic losses are highly concentrated in a few countries. The top five countries account for 80% of all estimated losses, with the remainder spread over more than 50 countries and areas.

When expressed as a proportion of exposed GDP, estimated losses in East Asia and the Pacific, Latin America and the Caribbean, and South Asia are between 5 and 7 times higher than those of the OECD countries, indicating a far higher vulnerability of their economic infrastructure.

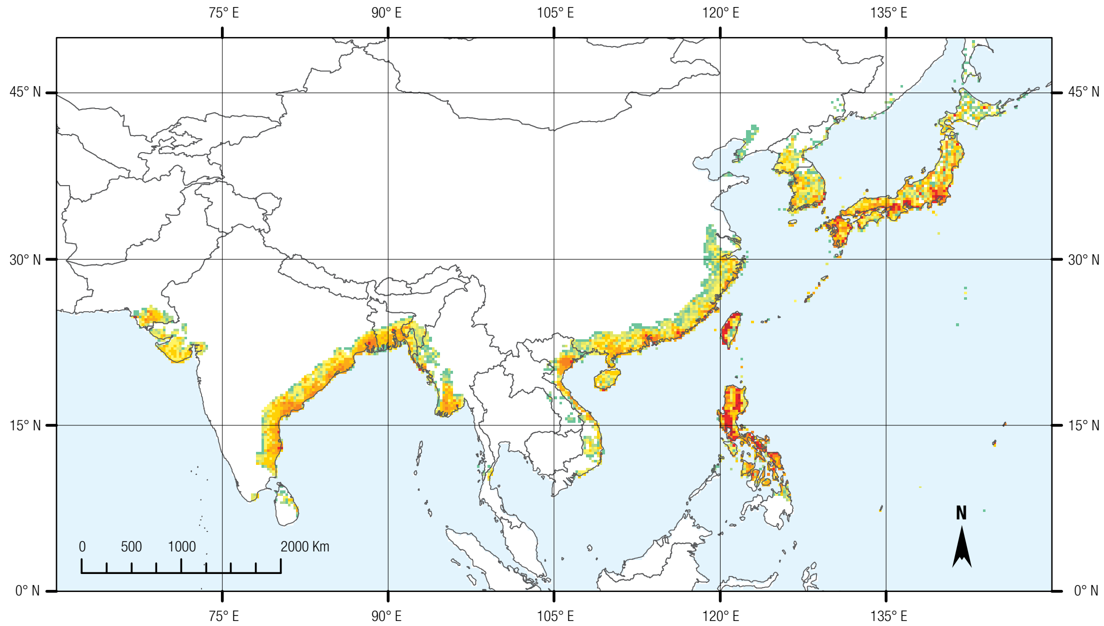
Risk drivers and vulnerability factors

Tropical cyclone hazard (for each category of cyclone) is shown for each region in the regional multi-hazard maps presented presented in Figures 2.1, 2.2 and 2.3.

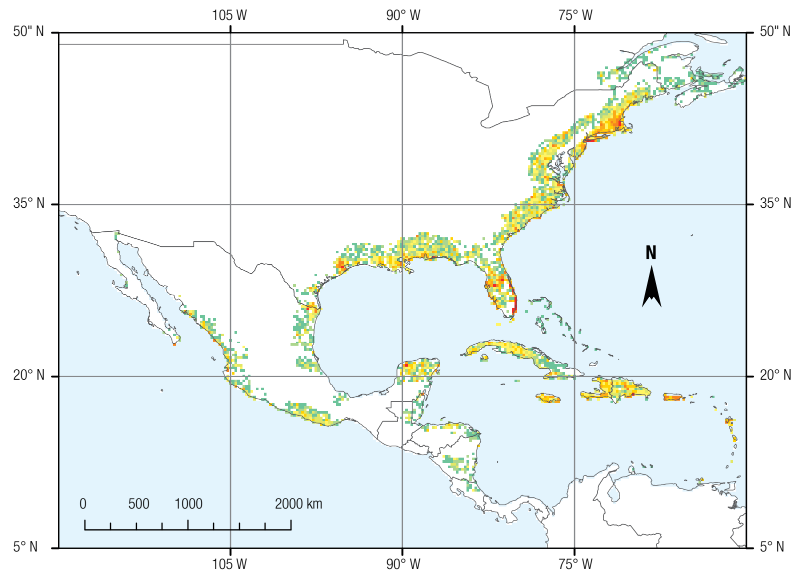
Figure 2.4: Distribution of mortality risk associated with tropical cyclones (10 × 10 km)

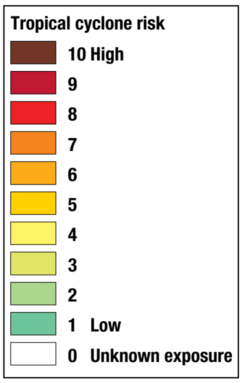
GIS and cartography: P. Peduzzi, ISDR, UNEP/GRID-Europe, 2009.

Tropical cyclones risk in North Indian and North West Pacific Oceans



Tropical cyclones risk in North Atlantic and North East Pacific Oceans





Tropical cyclones risk in South Indian Ocean

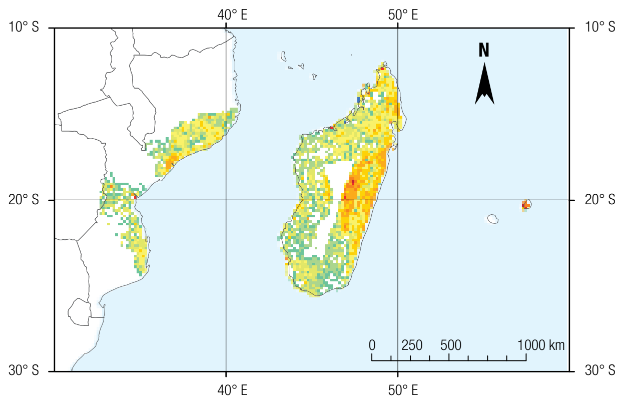


Figure 2.5: Absolute and relative mortality risk for tropical cyclones

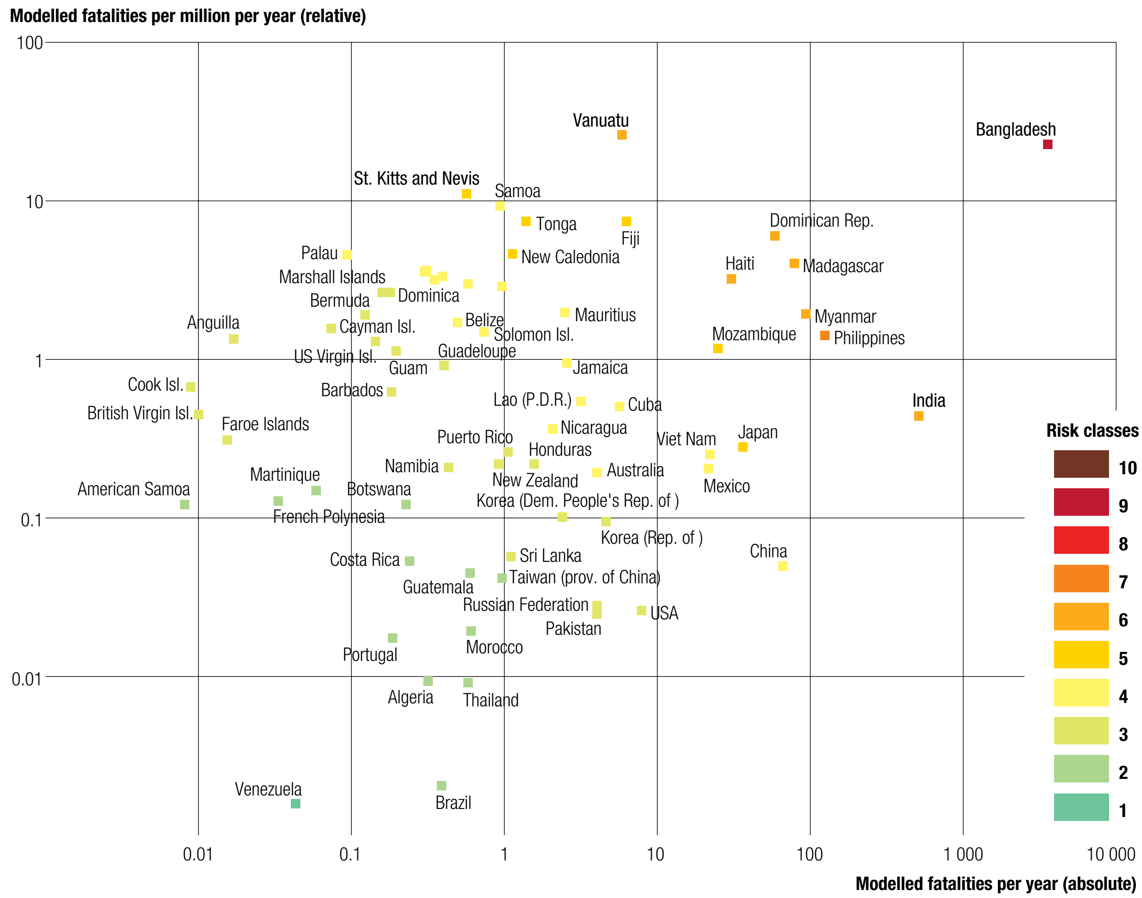


Table 2.1: Summary of predicted losses from tropical cyclone events[14]

*insufficient observations

Region	Average annual number of reported tropical cyclones 1975–2007	Average annual estimated economic loss (million constant 2000 US$)	Average annual GDP exposure (million constant 2000 US$)	Percent of global total economic loss	Estimated average annual economic loss as % of GDP in affected countries	Ratio of economic loss to GDP exposure (global mean = 100)
East Asia and Pacific	8.8	5,835	44,136	15.1	0.22	438
Europe and Central Asia*	–	–	–	–	–	–
Latin America and Caribbean	3.2	2,465	14,656	6.4	0.13	557
Middle East and North Africa*	–	–	–	–	–	–
South Asia	1.2	1,054	8,380	2.7	0.11	417
Sub-Saharan Africa	1.9	306	3,467	0.8	0.55	292
OECD	11.1	27,451	1,060,431	71.2	0.13	86
Other high income countries	3.5	1,434	176,010	3.7	0.19	27
Total	**29.7**	**38,545**	**1,307,080**	**100**		

Table 2.2 shows the number of people and GDP exposed to tropical cyclones and related storm surge hazards, for different tropical cyclone categories. An average of 78 million people worldwide are exposed each year to tropical cyclone wind hazard and a further 1.6 million to storm surge. Asian countries have the largest absolute population exposed, while SIDS have the highest proportion of their population exposed. In particular, SIDS have a far greater relative exposure to highly destructive Category 3 and 4 storms than larger countries. Some countries, such as the Philippines have a very high absolute and relative exposure.

In terms of economic exposure, an annual average of US$ 1,284 billion of GDP is exposed to tropical cyclones. The country with the highest absolute exposure is Japan. The countries with the highest relative exposure, however, are almost all SIDS.

The strength of a tropical cyclone and the number of people or exposed economic assets in the area affected explain a large part of the risk (see Figures 2.7, 2.8 and 2.9). However, even for comparable storms and exposure, large differences persist between countries (also see Box 2.4 for unexpected events).

Box 2.4: Unexpected risks: tropical cyclone Catarina, 2004

For the first time since monitoring of tropical cyclones began a tropical storm in the South Atlantic reached a force of Category 1 on 26th March, 2004 (Figure 2.6). By the 28th it had strengthened to Category 2, when it reached Santa Catarina Province of Brazil. Even though it weakened somewhat before landfall, it caused US$ 350–425 million damage [15], killing 4 people and injuring 518 others [16].

It was commonly thought that tropical cyclones could not be generated in the South Atlantic Ocean. Today there is still no scientific agreement on the cause of the Catarina cyclone, but it provides a clear demonstration that unexpected events can occur in places where they have not happened before. Longer-term changes in the Earth's oceans and atmosphere may bring more such surprises.

Figure 2.6: Tropical cyclones over a 30-year period

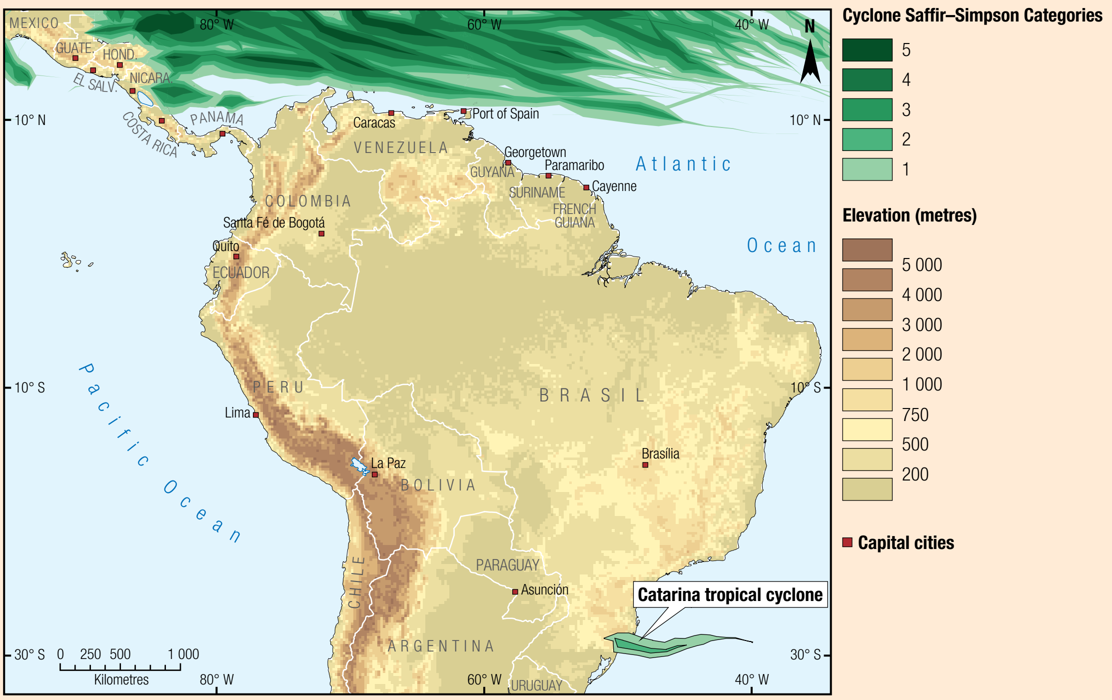


Table 2.2: Annual exposure to tropical cyclones by classes of intensity (Saffir–Simpson)*

Source: Adapted from the U.S. National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center (NHC)[17]

* Modelled

Cyclone category	Annual population exposure (millions)	Annual GDP exposure (US$ millions)
Category 1: Winds (Km/hour) 118–153, Surge: less than 2 m	57.8	942,300
Category 2: Winds (Km/hour) 154–177, Surge: 2–3 m	13.5	229,025
Category 3: Winds (Km/hour) 178–210, Surge: 3–4 m	5.5	100,684
Category 4: Winds (Km/hour) 211–249, Surge: 4–5 m	0.8	11,623
Category 5: Winds (Km/hour) more than 249, Surge 5–10 m	0.2	824
Total	**77.7**	**1,284,456**

Figure 2.7: People exposed to tropical cyclones (wind speed categories)

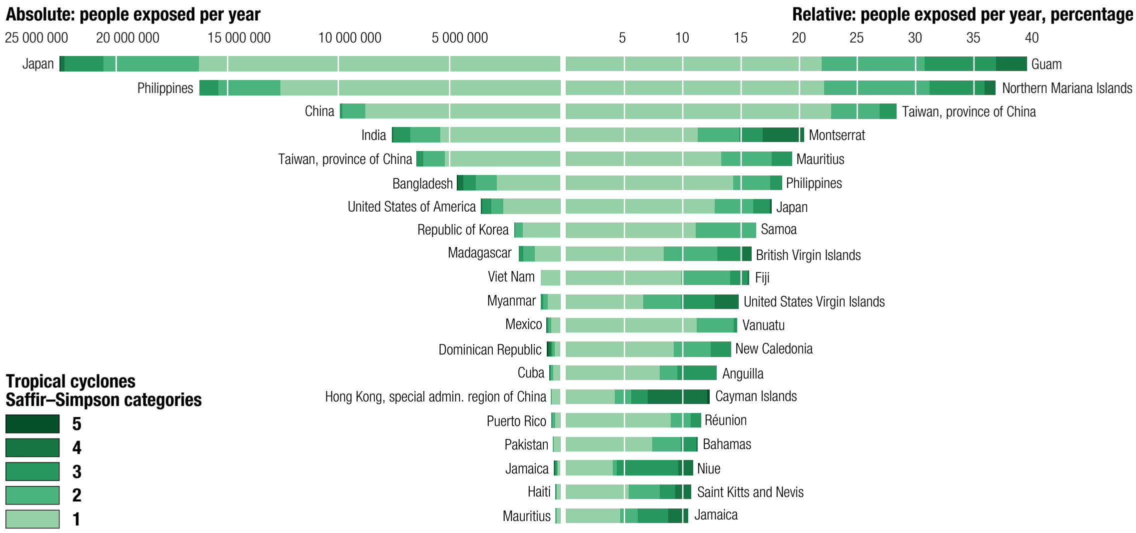


Figure 2.8: People exposed to storm surge for all categories of tropical cyclone

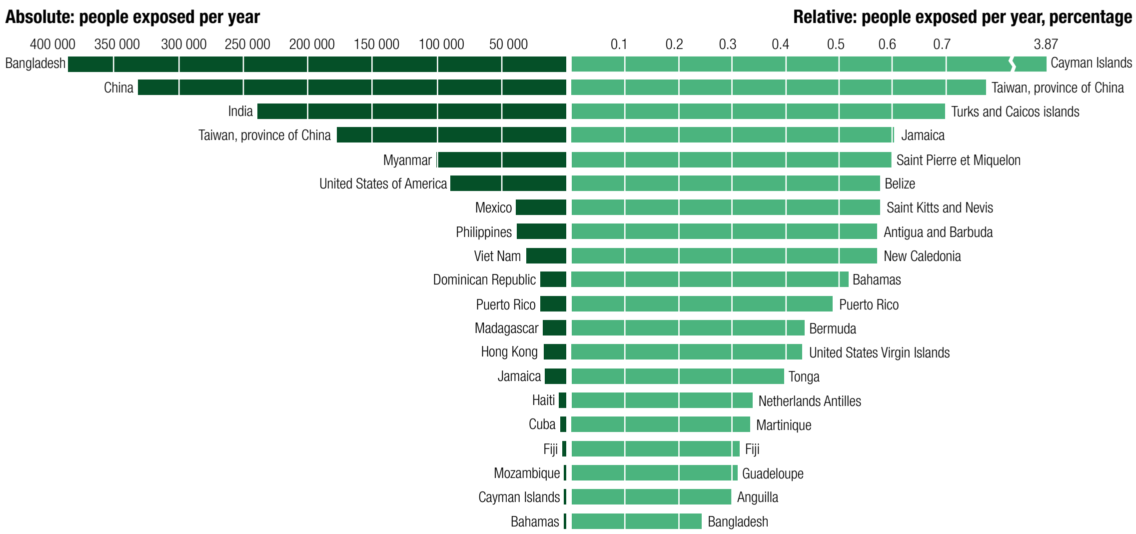


Figure 2.9: GDP exposed to tropical cyclones

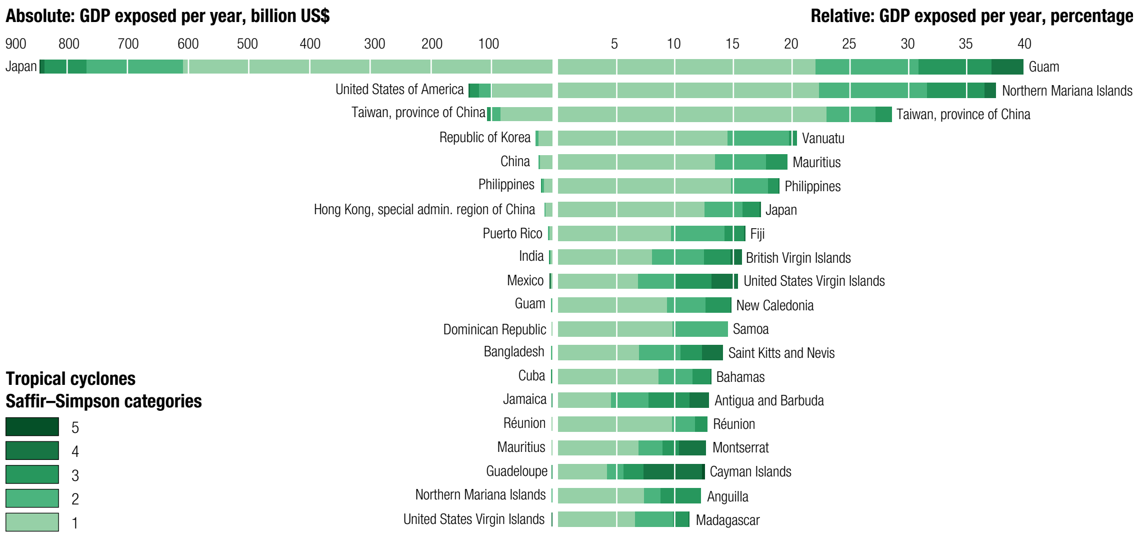


Figure 2.10 shows that in general, low-income countries are far more likely to suffer mortality for a given number of people exposed and, in particular, for powerful Category 3 and 4 tropical cyclones. Similarly, lower-middle income countries are much more likely to suffer economic loss across all categories of cyclone intensity.

The key vulnerability factors that contribute to mortality risk are low GDP per capita and remoteness. As exposure increases and income decreases there is a greater risk of tropical cyclone mortality. Areas that are remote with respect to the main administrative and economic centre of the country, tend to suffer more. The case of tropical cyclone Nargis in Myanmar in 2008 is an example. Densely populated, very poor remote rural areas were devastated by a Category 4 tropical cyclone and associated storm surge.

In the case of economic losses, well-governed countries seem to experience lower damages in comparable tropical cyclones with similar magnitude and exposure, than poorly governed countries. In contrast, income inequality is associated with higher levels of damage. To illustrate the effect of these variables, the economic risk model suggests that if Bangladesh had the significantly higher institutional quality and lower levels of inequality found in Japan, its annual economic loss from tropical cyclones could be about 60% lower, even if exposure and hazard severity remained unchanged.

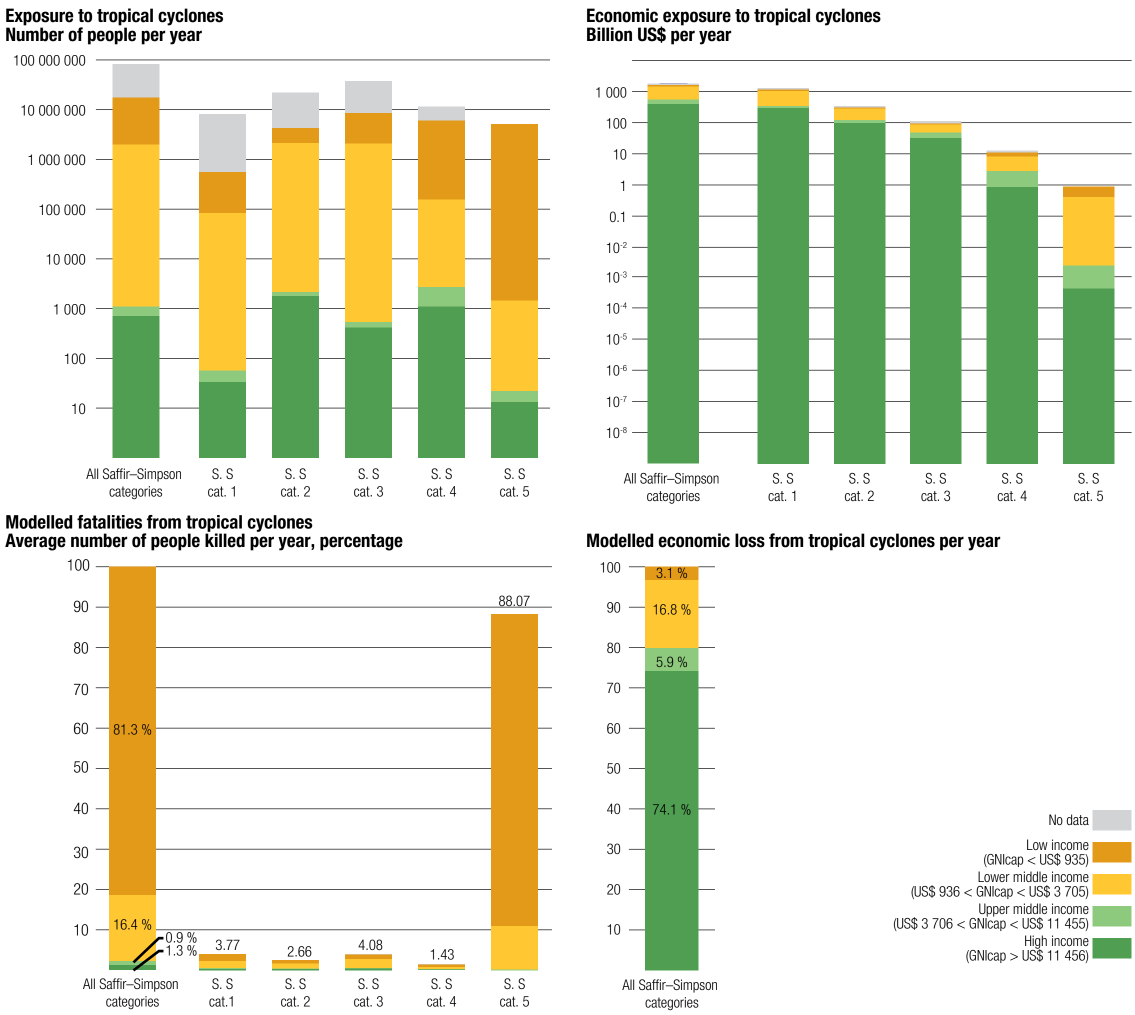
Finally, even after controlling for population size, SIDS generally experience greater economic losses.

2.2.2 Floods

Disaster risk for floods has been calculated for large rural flood events. The risk calculations do not include flash floods or urban flooding from inadequate drainage.

Figure 2.11 shows the geographic distribution of mortality risk for 10 km × 10 km squares of the Earth's surface. Figure 2.12 shows the distribution of both absolute and relative mortality risk for floods aggregated at the country level. As with cyclones, absolute risk is the average annual expected mortality, while relative risk is measured as the average annual expected number of deaths as a proportion of national population. The geographical distribution of flood mortality risk mirrors that for exposure. It is heavily concentrated in Asia, especially in India, Bangladesh and China. Between them these countries concentrate 75% of the modelled annual global mortality. Viet Nam also has high absolute and relative flood risks. The top ten countries on the Mortality Risk Index for floods and their respective values are India (7.5), Bangladesh (6.5), China (6), Viet Nam(6),

Figure 2.10: Mortality and economic loss from tropical cyclones compared to exposure for income classes



Cambodia (6), Myanmar (5.5) Sudan (5.5), Democratic People's Republic of Korea (5.5), Afghanistan (5), Pakistan (5).

The regional distribution of economic loss risk is shown in Table 2.3. Severe flooding affects more countries than tropical cyclones[18]. Flood losses are also somewhat less concentrated across countries than tropical cyclone losses. The top five countries account for 68%, and the top 10 for 78%, of total modelled economic losses. By region, OECD countries (especially the United States of America and Germany) account for the largest share of average annual modelled damages. But the East Asia and Pacific region and South Asia experience almost similar levels of losses. China, Indonesia and Thailand combined account for 25%, as do India, Pakistan and Bangladesh. By far the largest economic losses in relation to the size of economies occur in South Asia, followed by sub-Saharan Africa and East Asia.

The ratio of losses to GDP exposure in the OECD countries is far higher than in Latin America and the Caribbean, or South Asia. This probably indicates the differential impact of flooding on primary sector activities, such as agriculture and fishing in the latter two regions, compared to the impact on industry and services in the OECD.

Figure 2.13 illustrates why global hazard identification cannot be used for local risk mapping. In August 2008, a dyke breach led to a large flood in Bihar, India. The red areas are those that actually flooded, while the blue areas

Figure 2.11:
Distribution of mortality risk associated with floods (10 × 10 km)

GIS and cartography: C. Herold, P. Peduzzi, UNEP/GRID-Europe, 2009

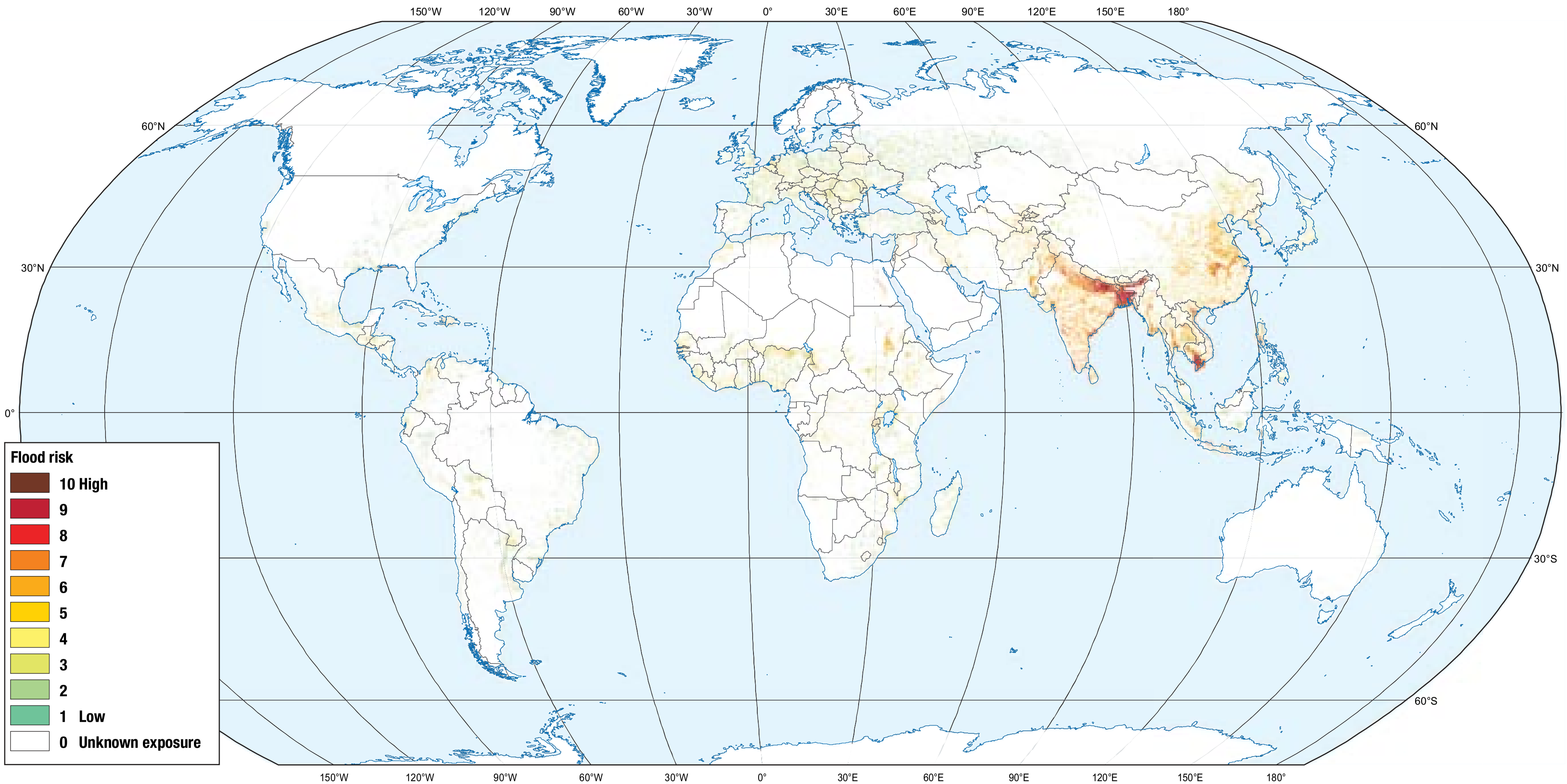


Figure 2.12: Absolute and relative mortality risk for floods

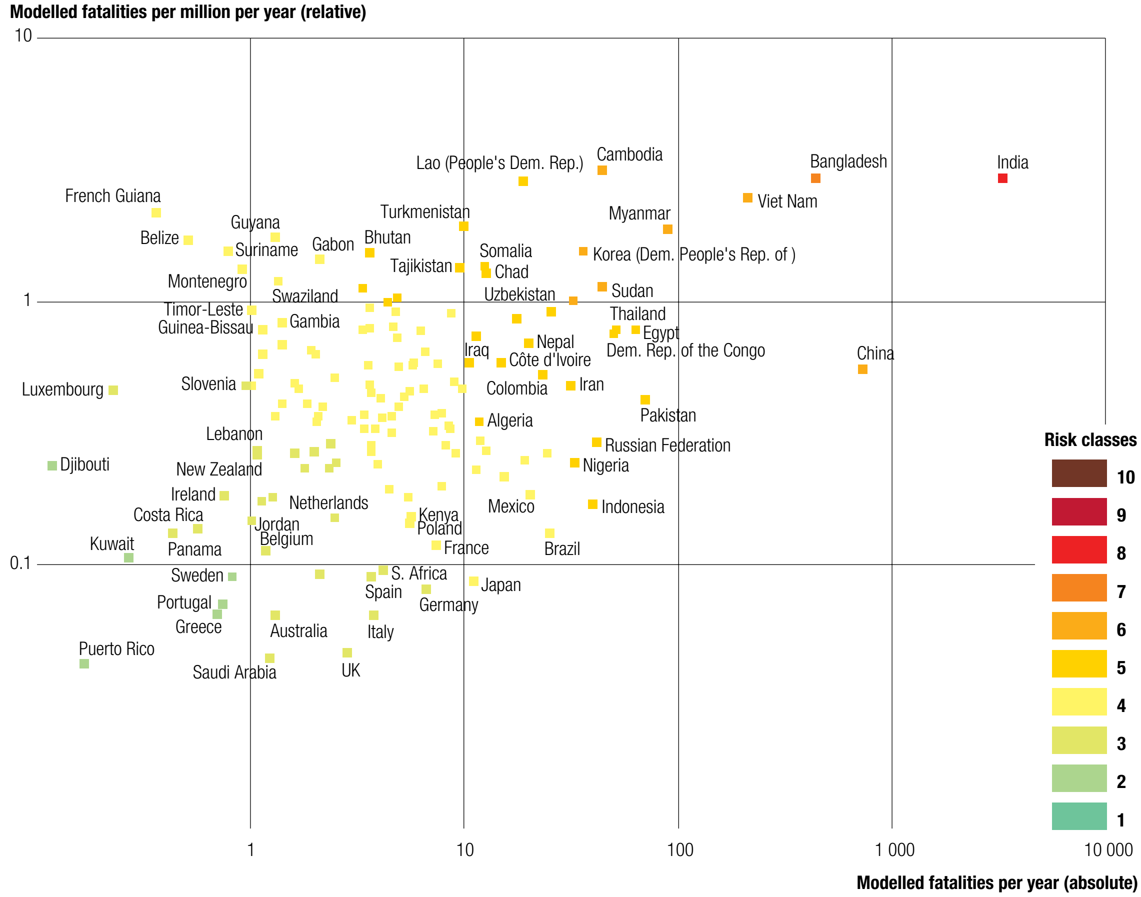


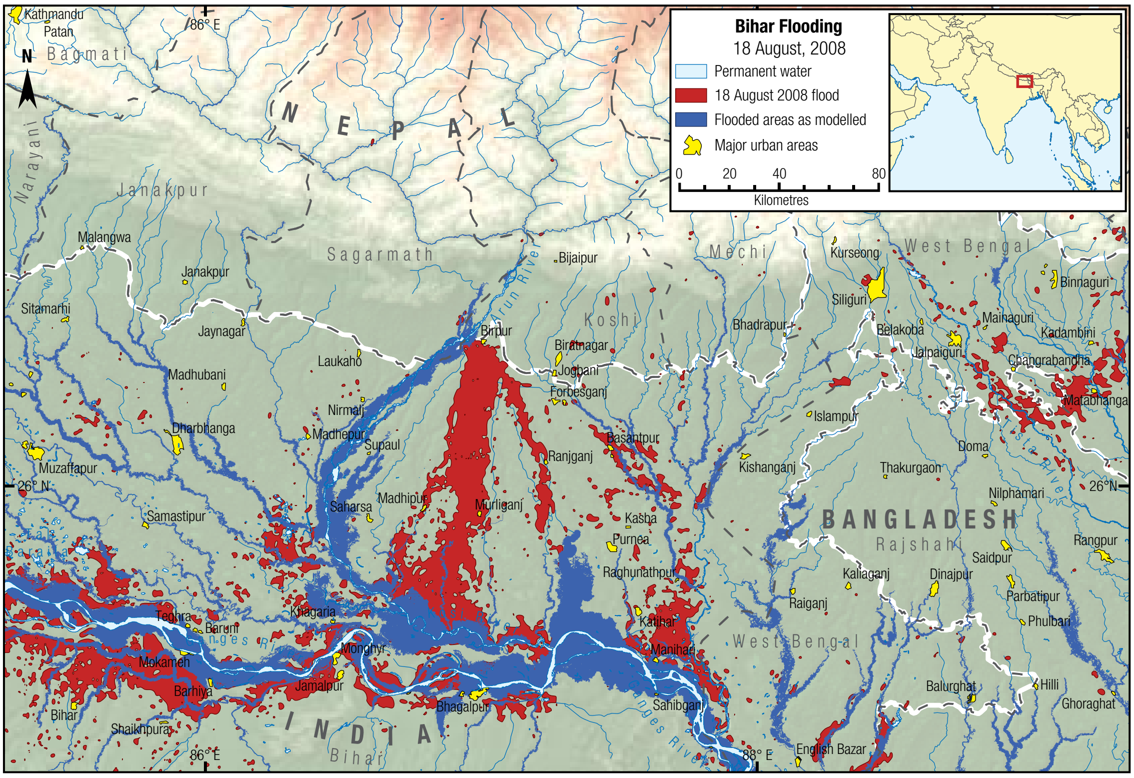
Table 2.3: Summary of predicted losses from flood events

*insufficient observations

Region	Average annual number of reported floods 1999–2007	Average annual modelled economic losses (million constant 2000 US$)	Average annual GDP exposure (million constant 2000 US$)	Percent of total global economic loss	Modelled average annual economic loss as % of GDP in affected countries	Ratio of economic loss to GDP exposure (global mean = 100)
East Asia and Pacific	4.0	4,935	8,707	27.4	0.16	128
Europe and Central Asia	4.9	1,382	3,156	7.7	0.11	99
Latin America and Caribbean	3.2	470	1,818	2.6	0.02	59
Middle East and North Africa*	–	–	–	–	–	–
South Asia	5.7	4,807	13,817	26.7	0.49	79
Sub-Saharan Africa	8.6	767	867	4.3	0.19	201
OECD	4.2	5,536	12,113	30.7	0.03	104
Other high income economies*	–	–	–	–	–	–
Total	**30.6**	**17,897**	**40,478**	**100**		

Figure 2.13: Example of one limitation of the model

Cartography and GIS analysis: UNEP/GRID-Europe
Data source for detected Bihar flood event: courtesy of Dartmouth Flood Observatory.



represent modelled flood hazard. The global model cannot take into account locally specific risk factors, such as the strength of dykes, even though these have a critical influence on the distribution and magnitude of losses.

Risk drivers and vulnerability factors

Flood hazard is shown for each region in the regional multi-hazard maps presented in Figures 2.1, 2.2 and 2.3.

As Figure 2.14 shows, human exposure to floods is heavily concentrated in Asia. The top ten most exposed countries – in absolute and relative terms – are in South and South-East Asia, where a number of heavily populated river deltas and watersheds are located. GDP exposure is also heavily concentrated in Asia (see Figure 2.15). However, developed countries such as the United States of America, Germany, Japan and France also have high absolute GDP exposure, while African countries, such as Benin, the Sudan and Chad have high relative GDP exposure.

Compared to their exposure, lower-middle income countries have higher mortality rates and higher levels of economic loss (Fig. 2.16).

Mortality from flood events [19] is closely associated to the size and growth rate of exposed rural populations. Lack of voice and accountability were also identified as significant factors. Flood mortality risk is thus highest in heavily populated rural areas in countries with weak governance.

In the case of economic risk, smaller, more concentrated floods appear to cause relatively greater economic damages than floods with a larger extent. The former may affect areas with higher population density more severely, while the latter might mostly impact relatively lower value agricultural lands. The effect of a country's wealth is much less pronounced for floods than for other disaster types. While mortality is concentrated in developing countries, significant economic damages from floods also occur regularly in North America and Central Europe, for instance.

Figure 2.14: People exposed to floods

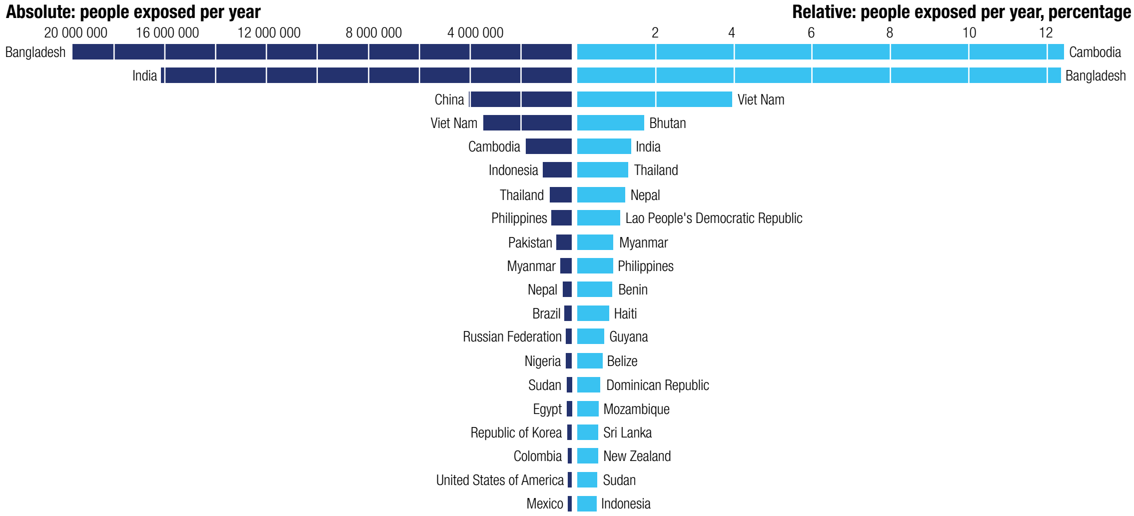


Figure 2.15: GDP exposed to floods

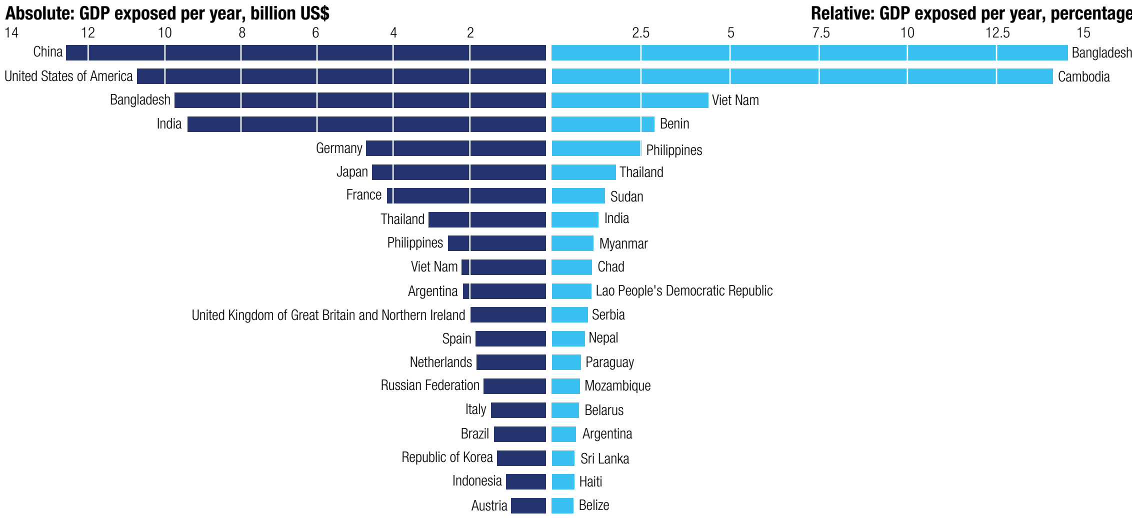
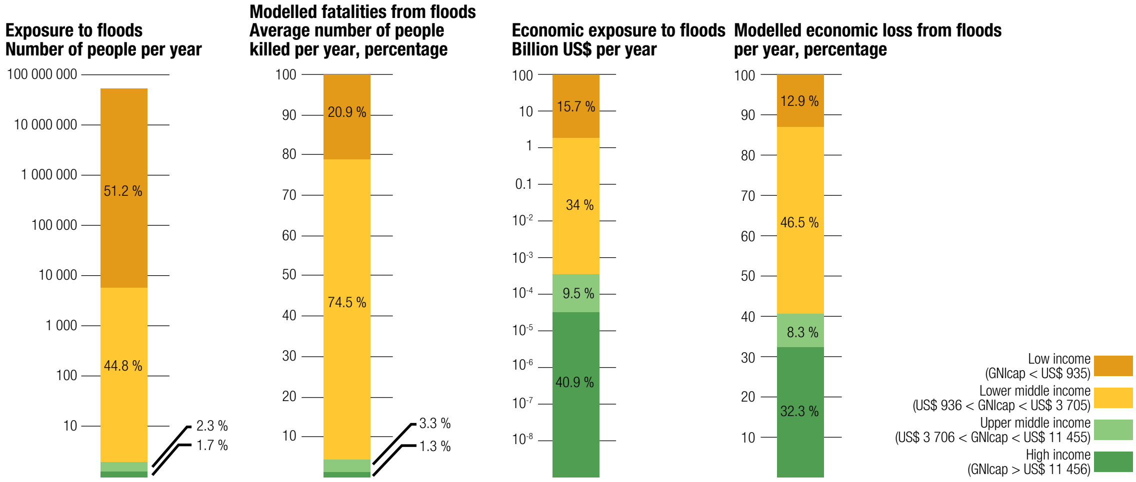


Figure 2.16: Exposure, mortality and economic loss to floods by income class



2.2.3 Landslides

Observed mortality in landslides triggered by high precipitation is approximately six times higher than in landslides triggered by earthquakes. The risk model therefore focuses on precipitation triggered landslides (Fig. 2.17). Exposure, however, has been calculated for both kinds of landslide.

Figure 2.18 shows absolute and relative mortality risk for precipitation triggered landslides. Countries with very high absolute and relative risk include Guatemala, Nepal and Papua New Guinea. Compared to other hazards, global landslide mortality risk is relatively low, although many small landslide events causing deaths are not internationally reported. The predicted mortality risk, even in very large countries such as India or China, is less than 100 deaths per year. Absolute mortality risk is highest in countries such as Ethiopia, Indonesia and India. Relative mortality

Figure 2.17: Distribution of mortality risk associated with precipitation triggered landslides (10 × 10 km)

GIS and cartography: P. Peduzzi, ISDR, UNEP/GRID-Europe, 2009.

Mortality risk distribution for landslides triggered by precipitation

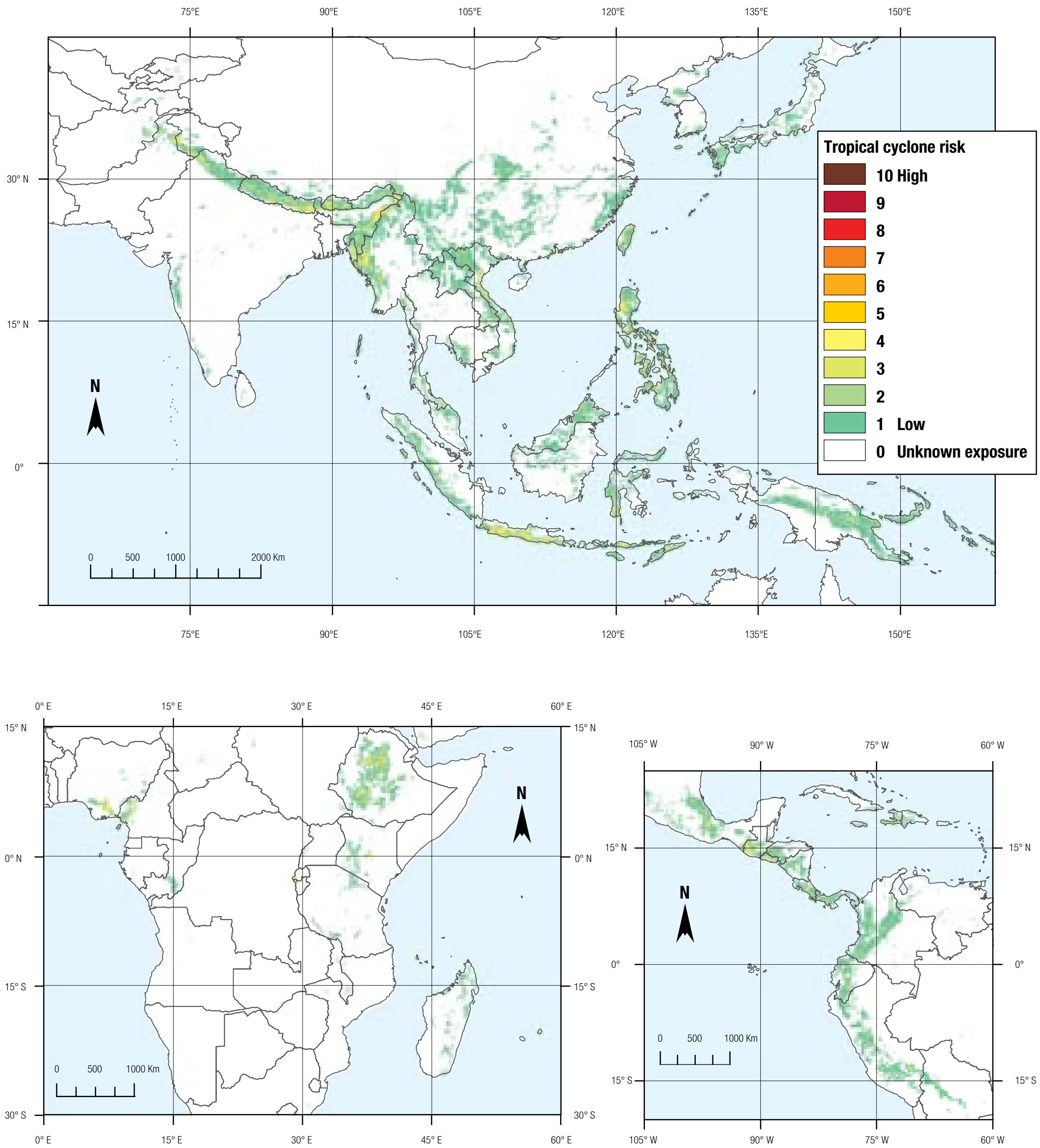
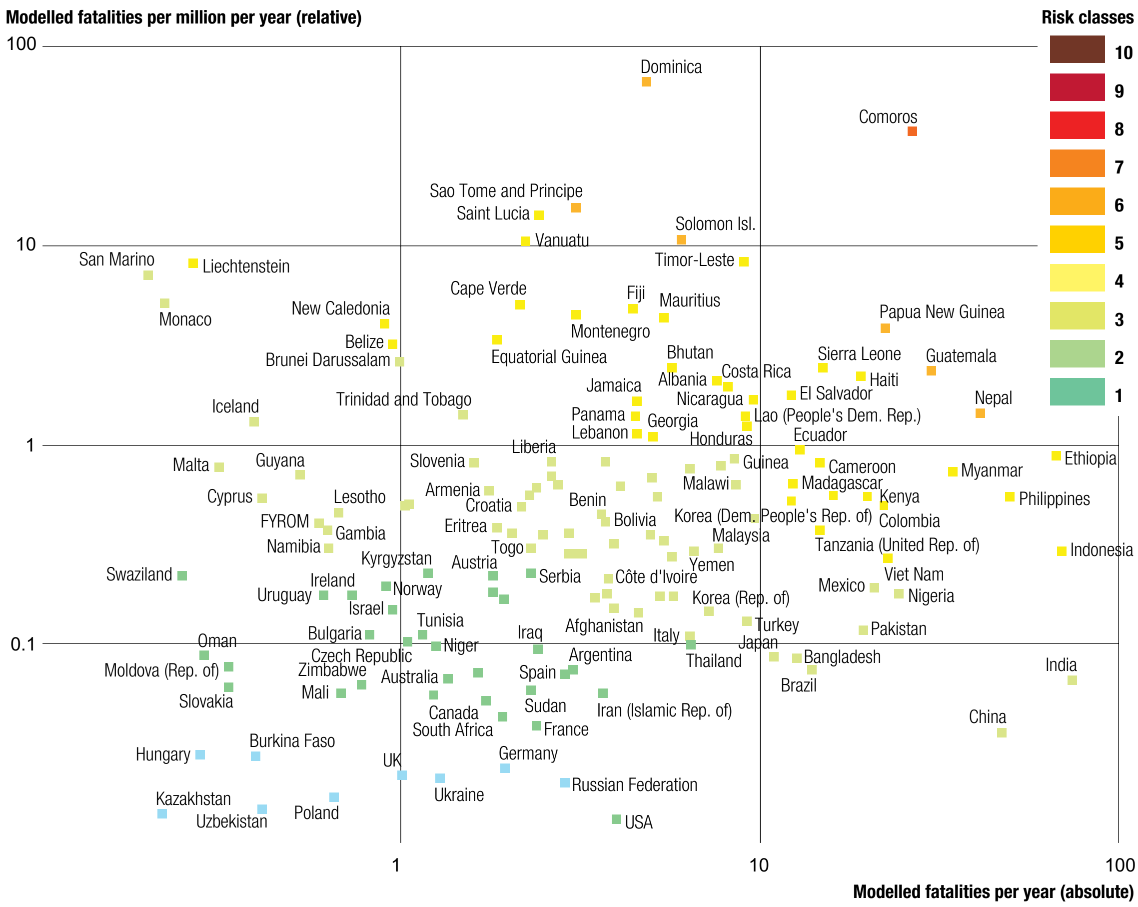


Figure 2.18: Absolute and relative mortality risk for precipitation triggered landslides



risk is highest in small islands, notably in Dominica and the Comoros. Approximately 55% of mortality risk is concentrated in 10 countries, which also account for 80% of the exposure. The top ten countries on the Mortality Risk Index for landslides and their respective values are Comoros (6.5), Dominica (6), Nepal (5.5), Guatemala (5.5), Papua New Guinea (5.5), Solomon Islands (5.5), Sao Tome and Principe (5.5), Indonesia (5), Ethiopia (5), and the Philippines (5).

Risk drivers and vulnerability factors

Landslide hazard is shown for each region in the regional multi-hazard maps presented in Figures 2.1, 2.2 and 2.3. Figures 2.19 and 2.20 illustrate the relative and absolute exposure of people and GDP to both earthquake and precipitation triggered landslides. Approximately 2.2 million people are exposed to landslides worldwide. In absolute terms, exposure is very high in a number of large Asian countries, especially India, Indonesia and China. Relative exposure is highest in small countries with steep terrain including a number of small island nations. The relative importance of the triggering mechanism varies widely among countries.

Taiwan, Province of China, has the highest absolute GDP, as well as the highest relative GDP exposure, both due to earthquake triggered landslides. As illustrated in Figure 2.21, lower-middle income countries in general experience greater mortality with respect to the population exposed.

This is confirmed by the identification of vulnerability factors. Precipitation triggered landslide mortality is best explained by the exposure of the population and by local GDP per capita. As in the case of tropical cyclones, poor countries have significantly more landslide mortality than wealthier countries.

Data limitations prevent the analysis of economic losses due to landslides.

Figure 2.19: People exposed to landslides triggered by precipitation or earthquake

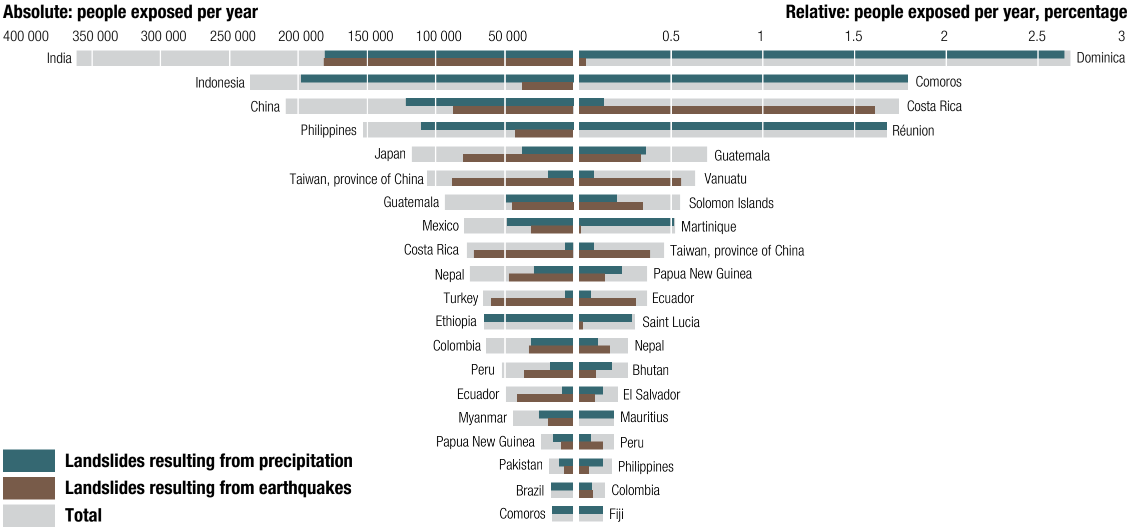


Figure 2.20: GDP exposed to landslides triggered by precipitation or earthquake

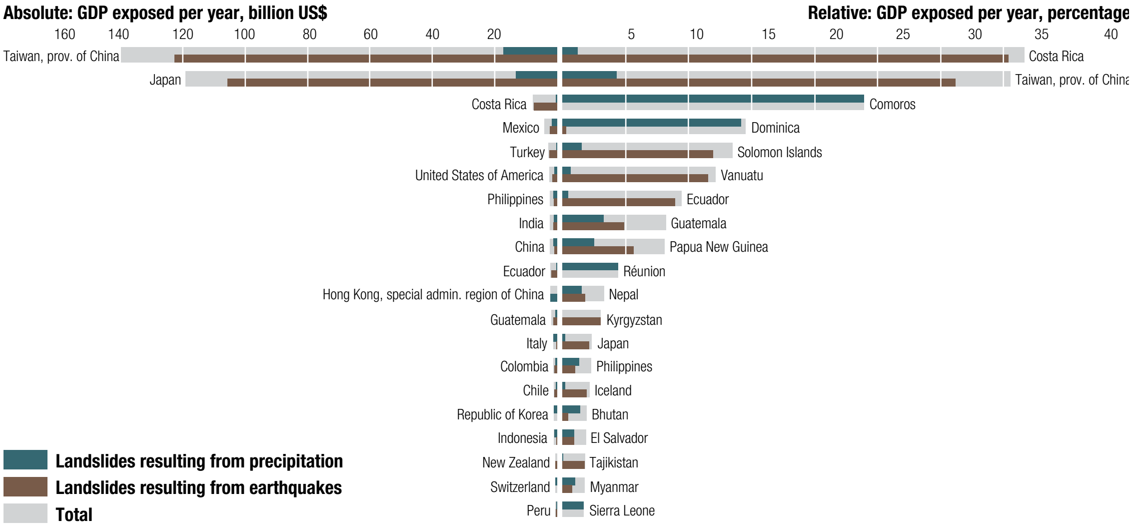


Figure 2.21: Mortality and exposure to landslides by income class

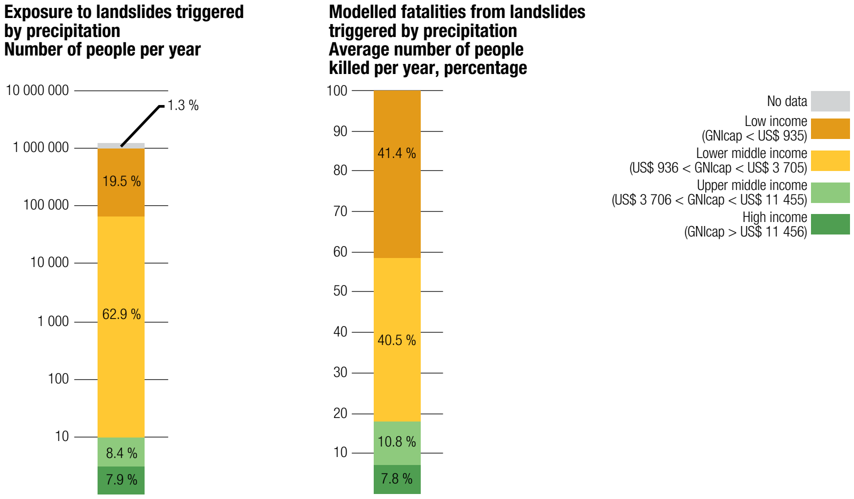
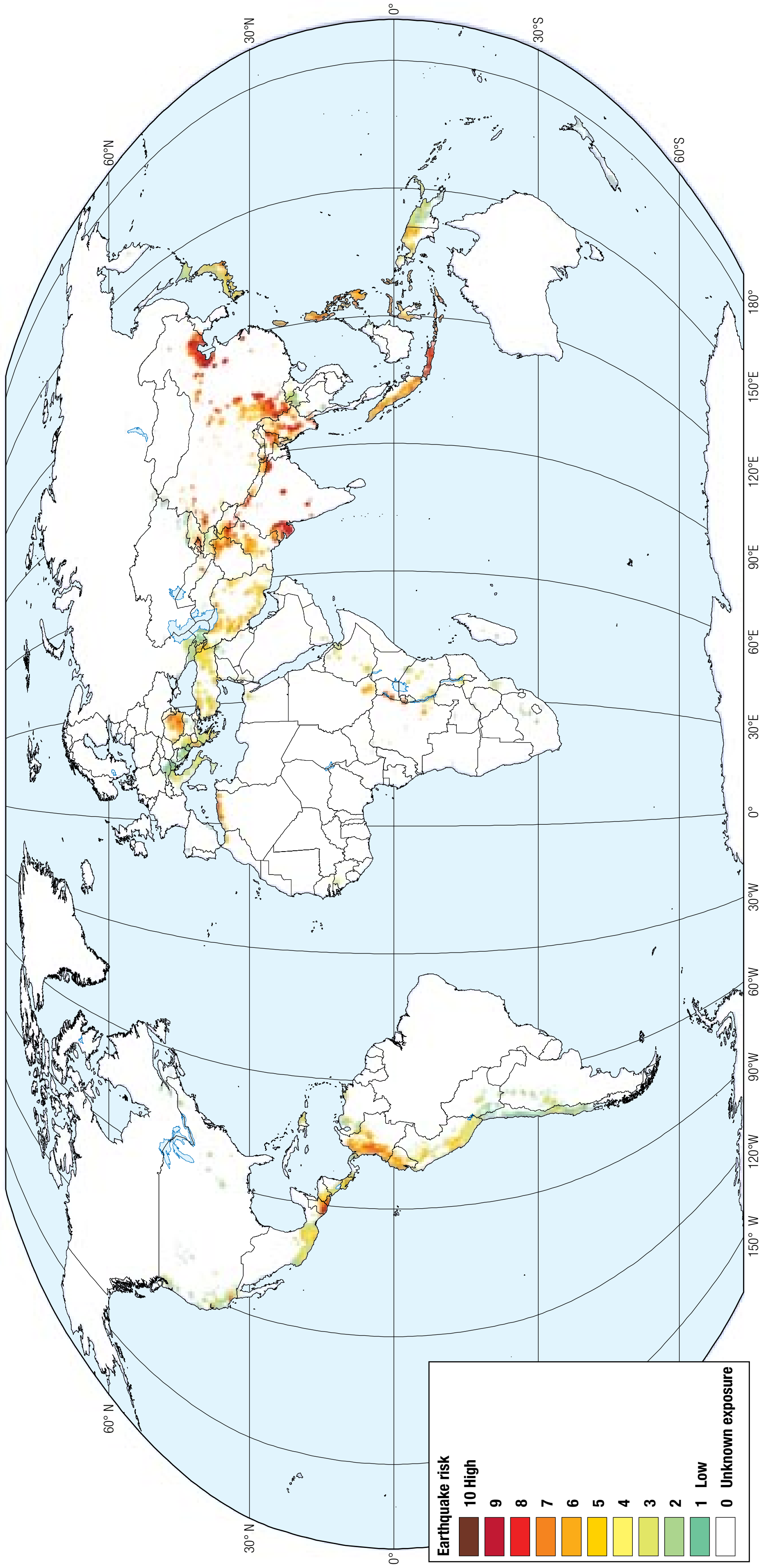


Figure 2.22:
Distribution of mortality risk associated with earthquakes (10 × 10 km)

GIS and cartography: P. Peduzzi, ISDR, UNEP/GRID-Europe, 2009.



2.3 Other hazards

2.3.1 Earthquakes

Earthquake risk has been calculated using four categories of seismic intensity, corresponding to values between V and XII on the Modified Mercalli Intensity scale (MMI) (see Table 2.4). Different exposure models were used to calculate mortality risk and economic loss risk and results are presented with a medium level of confidence. As with other hazards, economic loss risk is calculated only for groups of countries (regions and income classes).

Categories 1 and 2 include 93.0% and 5.8% respectively of the population exposure, but account for only 0.6% of the mortality risk. Most mortality risk is concentrated in earthquakes of higher intensities (Categories 3 and 4).

Figure 2.22 shows the geographic distribution of mortality risk as modelled for each 10 km × 10 km square of the Earth's surface. Figure 2.23 shows the distribution of both absolute and relative mortality risk from all categories of earthquakes aggregated at the country level.

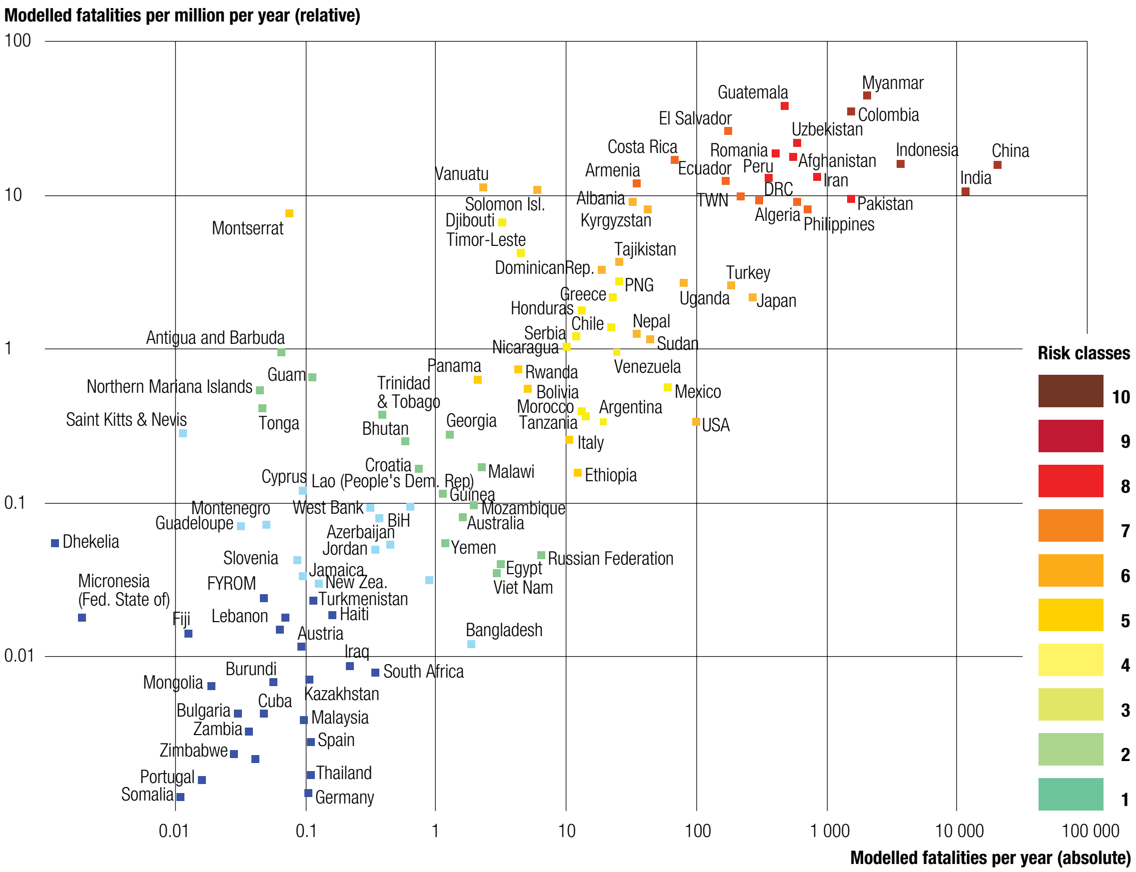
China, India and Indonesia are the countries with the highest absolute mortality risk, while some smaller countries, such as El Salvador and Guatemala have very high relative risk. Some countries, such as the Democratic Republic of the Congo, that have not experienced recent major earthquake disasters have high levels of both absolute and relative mortality risk. Mortality risk is highly concentrated. The model

Table 2.4: Categories of seismic intensity

Categories	1	2	3	4
MMI	V to VI	VII	VIII	IX to XII

Figure 2.23: Absolute and relative mortality risk for earthquakes

Note: BIH, Bosnia and Herzegovina; DRC, Democratic Republic of the Congo; FYROM, Former Yugoslav Republic of Macedonia; PNG, Papua New Guinea; TWN, Taiwan, province of China.



suggests that 86% of mortality risk is manifested in disasters with more than 10,000 fatalities. This is consistent with the observed losses. Of the 246,200 people killed by earthquakes over the last ten years [20], 226,000 (91.8%) were killed in just five mega-disasters [21]. The top ten countries on the Mortality Risk Index for earthquakes and their respective values are China (8.5), India (8.5), Indonesia (8.5), Colombia (8.5), Myanmar (8.5), Guatemala (8), Pakistan (7.5), Afghanistan (7.5), Iran (7.5) and Peru (7.5).

Table 2.5 shows the modelled economic losses from earthquakes. OECD countries account for 58% of the modelled annual total losses. East Asia also has high absolute modelled economic losses, followed by Latin America and the Caribbean. Relative to GDP, modelled losses are most significant in the Middle East and North Africa region, followed by Eastern Europe and Central Asia. The vulnerability of economic infrastructure appears to be much higher in both Asia and the Pacific, and Eastern Europe and Central Asia, than elsewhere. The ratio of modelled damages to exposed GDP is between 8 and 10 times greater in these two regions than in OECD countries.

Risk drivers and vulnerability factors

Earthquake hazard is shown for each region in the regional multi-hazard maps presented in Figures 2.1, 2.2 and 2.3. Figure 2.24 shows the number of people exposed to each category of earthquake hazard. More than one hundred million people worldwide (103.2 million) are exposed to an average of 144 earthquake events per year, with intensities higher than V on the MMI scale. As with other hazard types, absolute exposure is concentrated in large countries, particularly in Asia, but also in the United States of America and parts of Latin America. Relative exposure is higher in smaller countries.

Figure 2.25 shows that exposure is higher in lower middle-income countries than in all other income classes. However, altogether, 85.3% of mortality risk is concentrated in lower middle-income countries. Upper middle and high-income countries concentrate only 1.7% and 0.9% of the risk respectively. This means that the countries with the highest human vulnerability are lower middle-income countries. Both low- and high-income countries have relatively lower levels of vulnerability. This suggests that earthquake vulnerability is highest in countries

Table 2.5: Summary of predicted economic losses from earthquake events by region

*insufficient observations

Region	Average annual number of reported earthquakes 1975–2007	Average annual modelled economic losses (million constant 2000 US$)	Average annual GDP exposure (million constant 2000 US$)	Percent of total economic losses	Modelled average annual economic losses as a % of GDP in affected countries	Ratio of economic losses to GDP exposure (global mean = 100)
East Asia and Pacific	3.8	3,266	1,888	14.4	0.12	702
Europe and Central Asia	1.9	1,301	974	5.7	0.15	542
Latin America and Caribbean	2.7	2,010	3,812	8.9	0.12	214
Middle East and North Africa*	1.8	1,277	1,774	5.6	0.31	292
South Asia	1.3	401	570	1.8	0.04	286
Sub Saharan Africa	–	–	–	–	–	–
OECD	2.2	14,446	90,448	63.6	0.07	65
Other high income economies*	–	–	–	–	–	–
Total	**13.7**	**22,701**	**99,466**	**100**		

Figure 2.24: People and GDP exposed to earthquakes

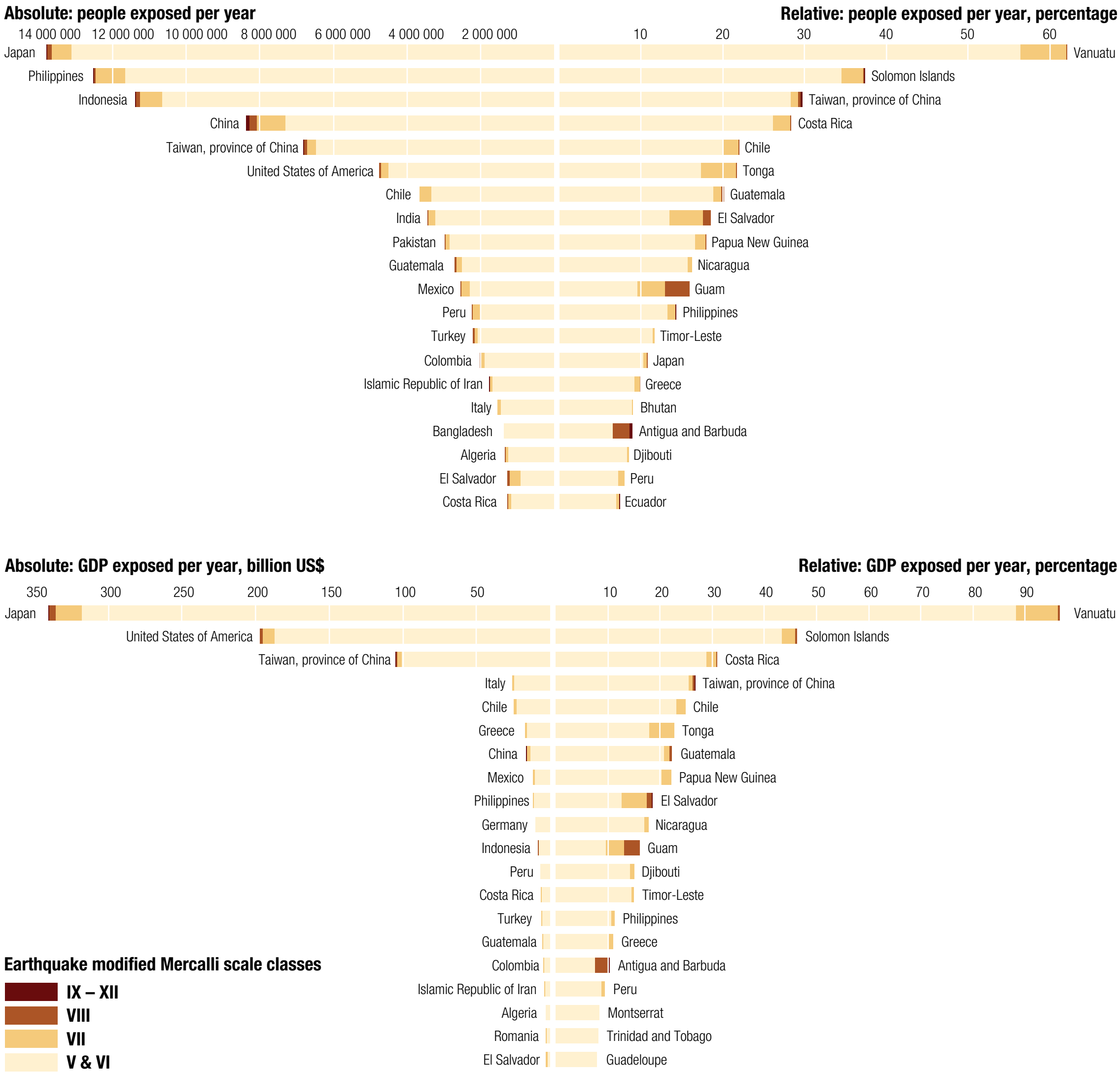
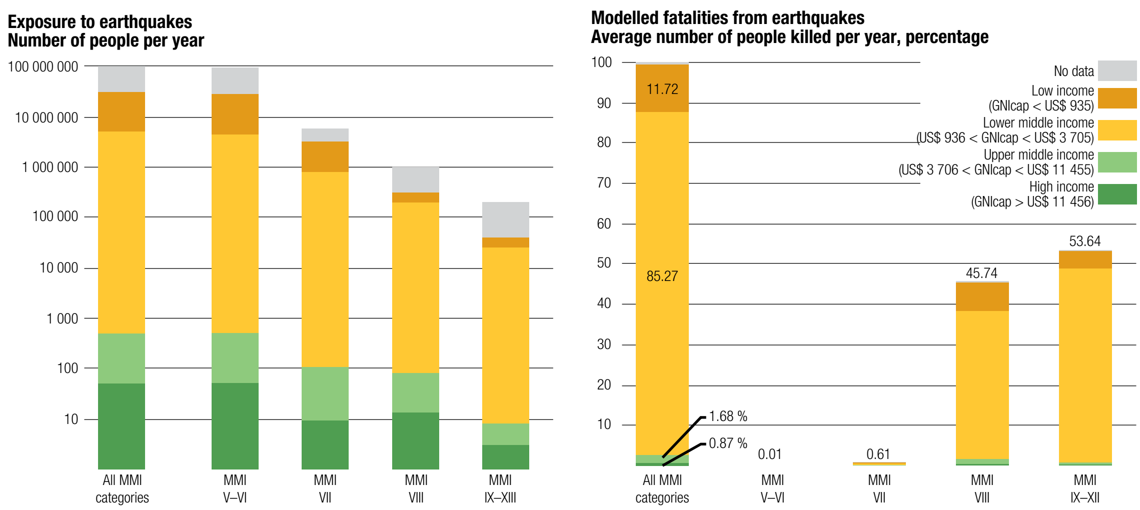


Figure 2.25: Exposure and mortality risk for earthquakes of different intensities by income class



with relatively higher levels of economic and urban growth, but that have not yet put in place planning and regulatory frameworks capable of factoring disaster risk reduction considerations into urban development. Structural collapse of buildings is more frequent in countries with fast rates of urbanization and weak enforcement of building codes, especially where informal construction is prevalent. Some low-income countries have yet to urbanize sufficiently to increase their earthquake risk. High-income countries on the other hand have been able to regulate development through tools such as building codes and land-use zoning and have invested in retro-fitting buildings to withstand strong shaking.

Examination of the risk drivers associated with earthquake damage reinforces these findings. Earthquake mortality for all categories is correlated positively with exposure and, in the case of Category 1 and 3 earthquakes, negatively with GDP per capita. In the case of Category 2 earthquakes, mortality was correlated with rapid urban growth[22], while Category 4 earthquakes mortality was negatively correlated with voice and accountability. Typically, therefore, poorer countries with high exposure, rapid urban growth and weaker governance have the highest mortality.

In the case of economic loss risk, richer countries have higher absolute, and poorer countries greater relative, damages from earthquakes. A country with a GDP of US$ 20,000 per capita would experience 2.3 times the absolute economic losses of a country with a GDP of US$ 2,500 per capita[23]. But relative to GDP, economic losses in the rich country would be only 43% of those in the poorer country. Institutional quality as measured by voice and accountability, and government effectiveness were also identified as relevant to economic loss risk. The model suggests that a country with average per capita income and the highest score in the voice and accountability indicator would experience only a quarter of the economic losses from a Category 4 earthquake than a country with the lowest institutional quality. This provides further evidence that earthquake loss risk is strongly associated with the quality of urban governance, and in particular with the lack of regulation of urban development and the ineffectiveness of building codes.

2.3.2 Drought

Drought differs from other hazard types in several ways. First, unlike earthquakes, floods or tsunamis that occur along generally well-defined fault lines, river valleys or coastlines, drought can occur anywhere (with the exception of desert regions where it does not have meaning). Secondly, drought develops slowly, resulting from a prolonged period (from months to years) of precipitation that is below the average, or expected, value at a particular location. Drought ultimately represents a condition of insufficient water supply relative to demand, both being highly location specific. For example, a few months of deficient rainfall may adversely affect rain-fed agriculture but not a reservoir system with substantial storage capacity, and defining what constitutes ‘deficient’ precipitation depends on the local climate. Scientists therefore distinguish between three general categories of drought: meteorological, agricultural and hydrologic. Meteorological drought refers to a prolonged period of deficient precipitation, while agricultural drought occurs when soil moisture is depleted to the point where crops, pastures or rangelands are impacted. Hydrologic drought refers to a prolonged period with below-average water levels in rivers and streams, lakes and reservoirs, or groundwater.

Drought also differs from other hazard types in the way losses are incurred. Few droughts lead directly to mortality. Those that do cause mortality have generally occurred during a political crisis or civil conflict where aid could not reach the affected population. In these cases the mortality should more properly be attributed to the conflict than to the drought. Impacts might also be highest even after the meteorological drought event has ended, for instance when people have exhausted their food supplies long before the next harvest.

Overall, the unique characteristics of drought make it difficult to analyse vulnerability and risk in the same framework as the other hazard types. Available loss data sets do not provide information on the factors contributing indirectly to drought mortality, while mortality itself is not a good indicator of impact. Similarly, there is also no clear way to translate meteorological drought into agricultural drought since it depends on the farming system and even on individual crop choice. Specific risk and vulnerability to droughts and how they affect income, consumption, health, human development and productivity are therefore best analysed in detailed local and context specific studies (see Chapter 3)[24].

Given the varying impacts of drought, several drought indicators are in use around the globe. These include the Standardized Precipitation Index (SPI) and the coefficient of variation (CV)[25]. Drought intensity and frequency are captured by the SPI. The CV gives additional information since it is a summary measure of how large the variability of precipitation is from year-to-year, relative to the amount of mean annual rainfall. The CV tends to be high in semi-arid regions, where there tends to be both high variability of rainfall and a small mean annual rainfall. In Figures 2.1, 2.2 and 2.3 drought hazard was calculated by multiplying the SPI-defined drought event frequency by the CV therefore combining drought intensity, frequency and information on where interannual precipitation variability is high or low (Fig. 2.26).

Approximately 400 geo-referenced drought disasters recorded in EMDAT were also compared with various SPI drought indicators. The EMDAT disasters were best matched with severe droughts identified using a SPI indicator for six-month total precipitation. This is consistent with the observation that the majority of EMDAT drought disasters are in tropical areas that experience a distinct rainy season with a typical duration of six months or less. Again, the drought indicator showing the best correspondence with EMDAT disasters (or other impacts) may vary locally.

Drought Exposure

Figures 2.27 and 2.28 show the number of people and areas of crops exposed to drought hazard as measured by the six month SPI. In terms of relative exposure, sub-Saharan African countries are highly exposed in both categories. For the reasons explained above, exposure does not necessarily indicate a risk of mortality, crop or economic loss.

Figure 2.26: Number of drought disasters as recorded by EMDAT (1974–2004)

Data source: EMDAT: The OFDA/CRED International Disaster Database: www.emdat.net; *GIS analysis:* IRI, Columbia University; *Cartography:* UNEP/GRID-Europe, 2009.

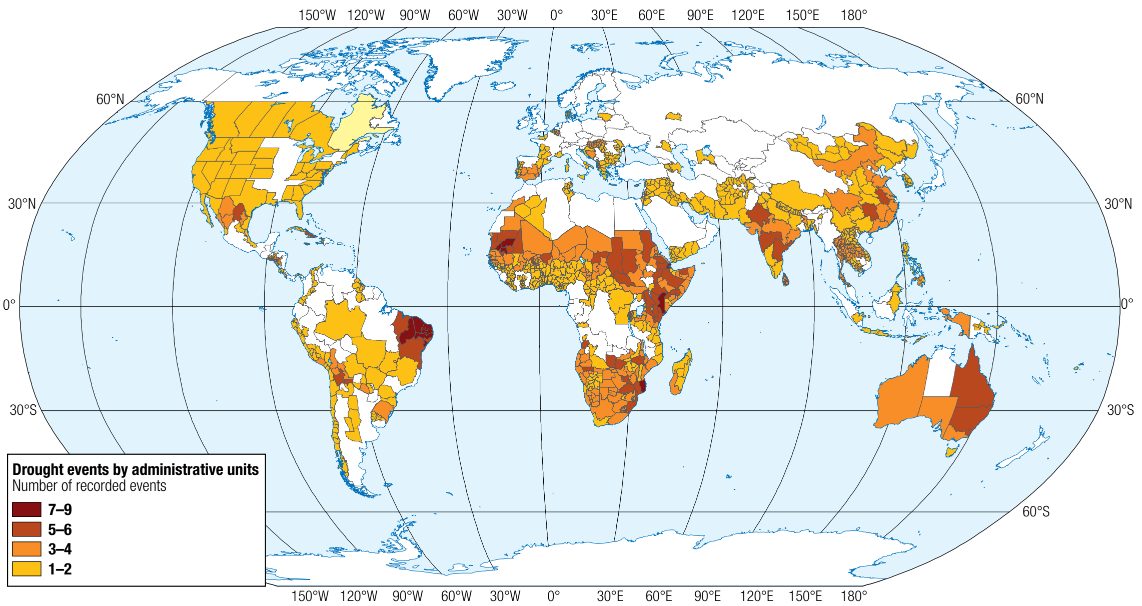


Figure 2.27: People exposed to drought

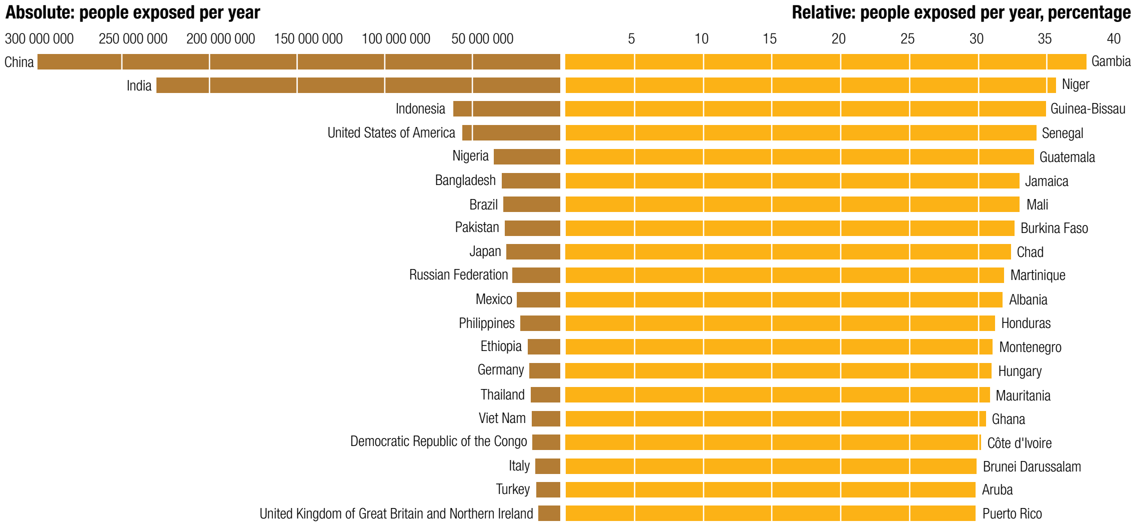
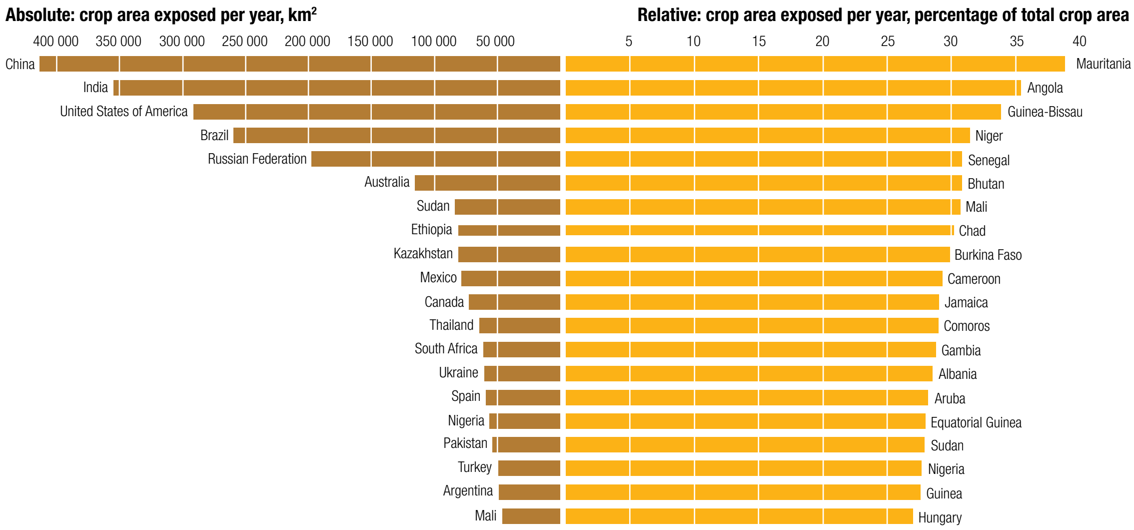


Figure 2.28: Crop area exposed to drought



2.3.3 Tsunamis

Tsunamis are relatively infrequent with only 5–10 events reported globally per year, but as demonstrated in the Indian Ocean in 2004 they can be devastating. Tsunamis are waves set in motion by large and sudden forced displacements of sea water caused by submarine earthquakes or landslides as well as other causes such as submarine volcanoes or asteroid impacts. When the tsunami is generated, its speed in the open sea can reach several hundred kilometres per hour, reaching distant coastlines in relatively short times. Tsunamis slow down as they approach the shoreline but their height increases. Because of their relatively large wavelength, tsunamis may travel far inland, and because of their relatively short wave period, they cause flooding faster than tidal waves and storm surges. Their enormous capacity to erode the landscape and destroy buildings makes them highly destructive both in terms of mortality and economic loss. The Indian Ocean tsunami is estimated to have caused

210,000 deaths and more than US$ 10 billion in damages. Figure 2.29 shows the distribution of tsunami hazard globally.

Large and infrequent, but highly destructive tsunami events generally pose greater mortality risk than the cumulative effect of smaller and more frequent events. The tsunami exposure analysis therefore focuses on extreme events generated by large earthquakes with return periods of approximately 500 years (formally, a probability of 10% of an event occurring in 50 years). Large Asian countries such as Indonesia and Japan account for a large proportion of people living in tsunami prone areas, while SIDS account for the highest proportion of their population (Figure 2.30). Countries on the Pacific coast of South America, notably Chile and Peru have a very high number of people living in tsunami prone areas in both absolute and relative terms. It is worth noting that given the low probability of tsunami occurrence, Figure 2.30 provides the number of people living in tsunami-

Figure 2.29: Sketch of global tsunami hazard

GIS analysis: Norwegian Geotechnical Institute; *Cartography:* UNEP/ GRID-Europe, 2009.

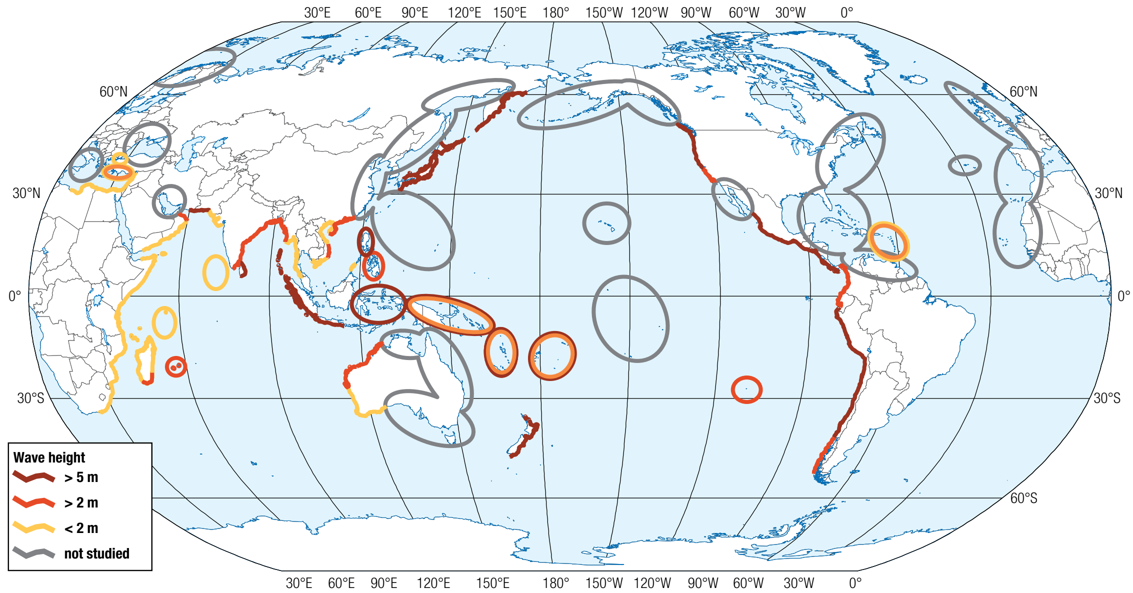
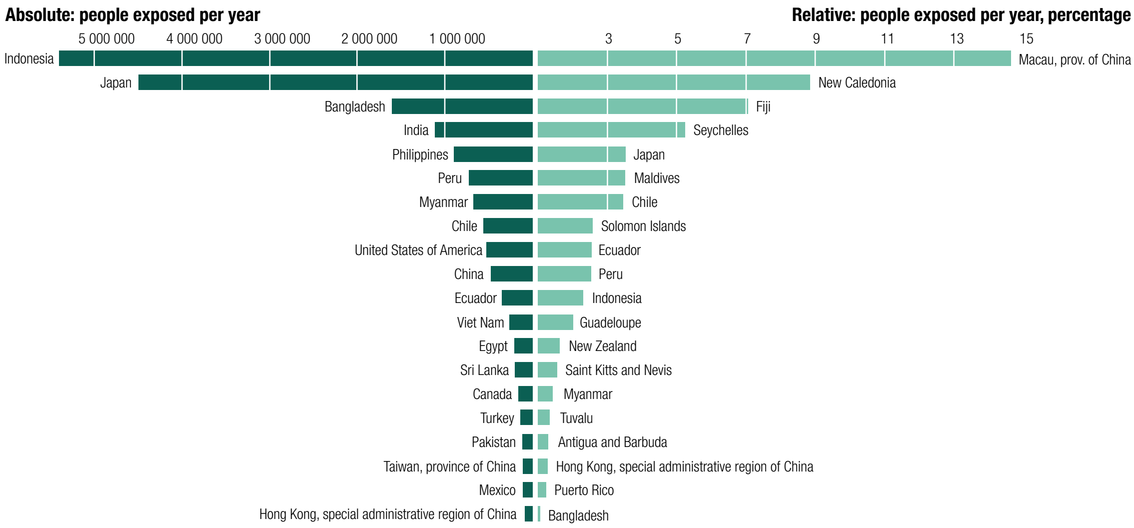


Figure 2.30: Number of people living in areas potentially affected by tsunamis



prone areas and not the average yearly exposure as provided for other hazards.

As shown in Figure 2.31, Japan has the highest absolute GDP exposed to tsunamis, but relative exposure is higher in SIDS and some South American countries, such as Ecuador and Peru.

The time between the triggering event and the tsunami's landfall is a key variable as it influences the effectiveness of tsunami

Figure 2.31: GDP exposed to tsunamis

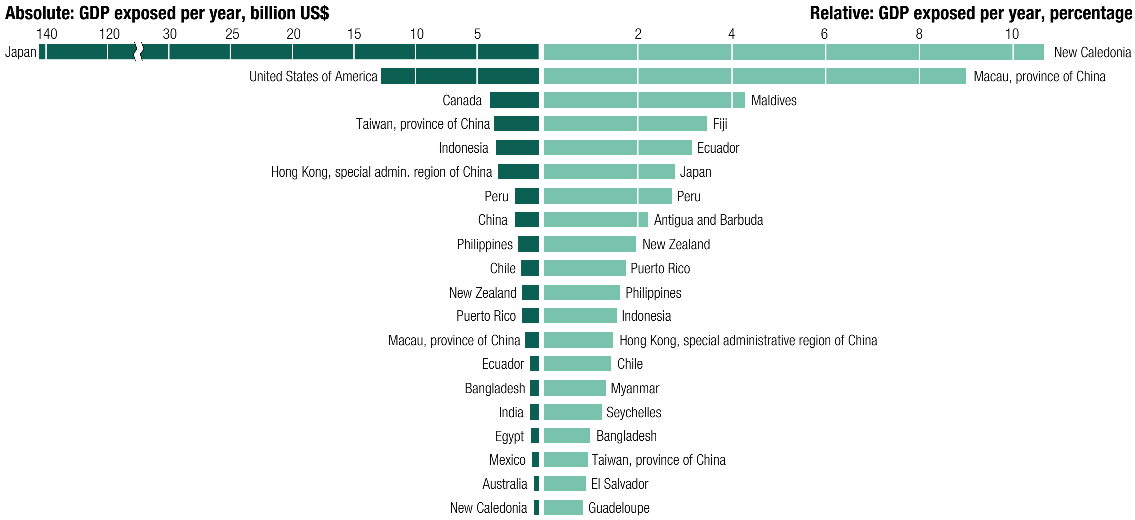


Figure 2.32: Tsunami modelling of Manila Bay (the Philippines)

early warning systems and the possibility of evacuation. Chile, India, Indonesia, Myanmar, Peru, the Solomon Islands, Portugal, Tonga, Pakistan, Papua New Guinea and the Philippines all have particularly high levels of hazard, given that tsunamis could hit the shoreline in less than 15 minutes with wave heights in excess of 6 metres.

It is important to emphasize once again that hazard is modelled with a 10% probability of occurrence every 50 years, or in other words, a 500-year return period. Similarly, the actual tsunami hazard in any particular area in these countries depends on local topography, bathymetry and other factors. For example, while the Philippines could be subject to wave heights of up to 16 metres hitting the shoreline in only 9 minutes, Figure 2.32 shows that the most severe impact zones are outside of the city of Manila.

2.3.4 Forest and other biomass fires

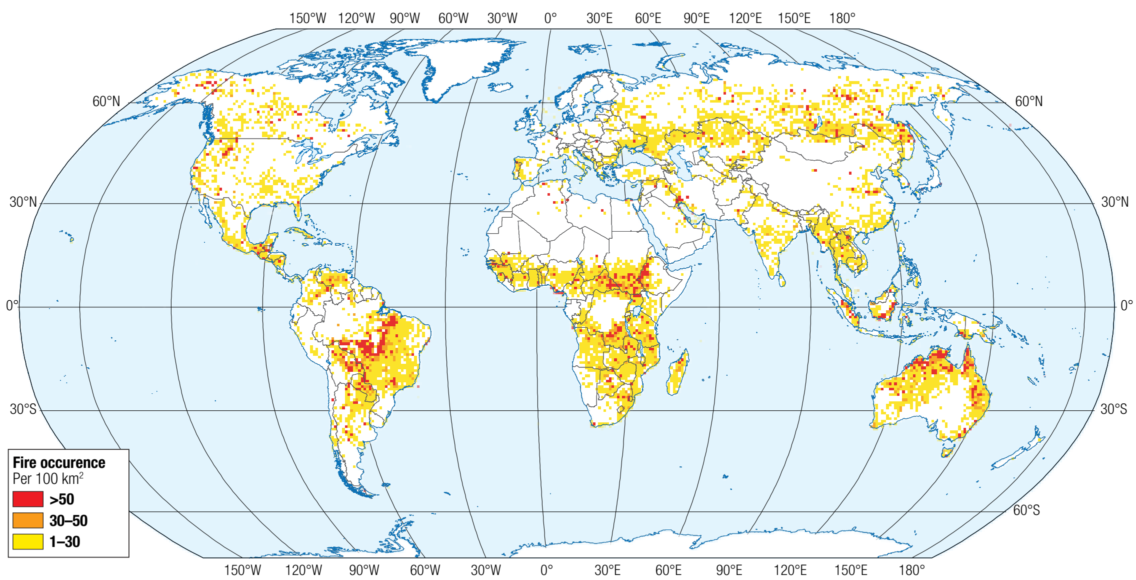
According to a recent inventory[26] wild land fires and other biomass fires annually burn a total land area of between 3.5 and 4.5 million km², equivalent to the surface area of India and Pakistan together, or more than half of Australia. This makes it makes it one of the most spatially prevalent hazards after drought.

Emissions from biomass burning inject pollutants into the atmosphere, as well as GHGs. The IPCC attributes 17.3% of total anthropogenic emissions to biomass burning[27], making it the second largest source of GHGs from human activities after the burning of fossil fuel. However, this figure may in reality be even higher, as it is based on pre-2000 data. Biomass fire is the only hazard that has both an impact on, and is exacerbated by, climate change. Most fires have human causes.

Figure 2.33 shows the average density of fires per 100 km², between 1997 and 2008. Not all high temperature events are biomass fires, as gas flares and other high temperature events are also detected. However, most fires are due to biomass burning.

Figure 2.33: Distribution of average density of fires per 100 km² (1997–2008)

GIS analysis and cartography: P. Peduzzi, ISDR, UNEP/GRID-Europe, 2009.



2.4 Multi-hazard and risk identification

2.4.1 Multi-hazard risk

Figure 2.34 shows multi-hazard risk for tropical cyclones, floods, earthquakes and landslides. Given that drought is not represented, mortality risk is underestimated for countries in some regions, particularly in Africa.

Figure 2.35 shows the spatial distribution of mortality risk accumulated for tropical cyclones, floods, earthquakes and landslides.

Figure 2.34: Absolute and relative multi-hazard mortality risk for tropical cyclones, floods, earthquakes and landslides

Note: DRC, Democratic Republic of the Congo; TWN, Taiwan, province of China; UK, United Kingdom of Great Britain and Ireland; USA, United States of America.

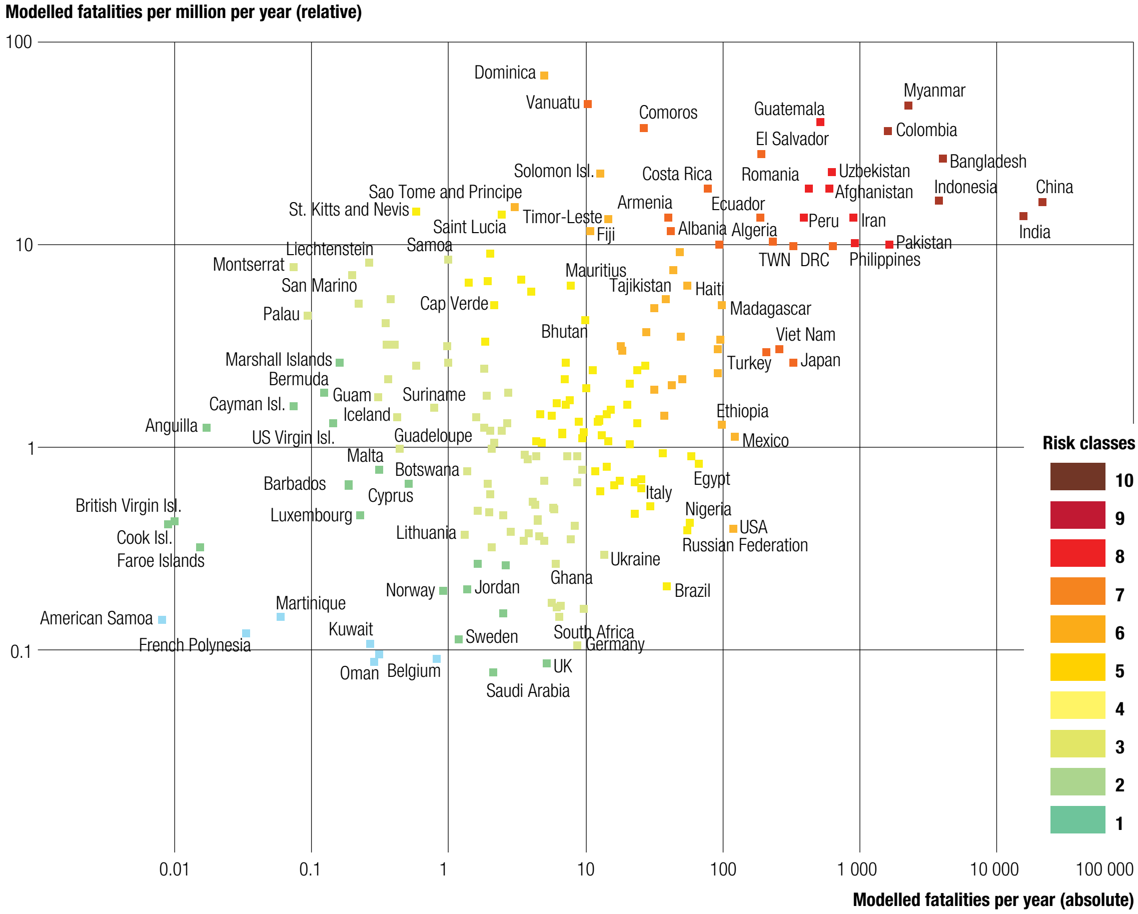
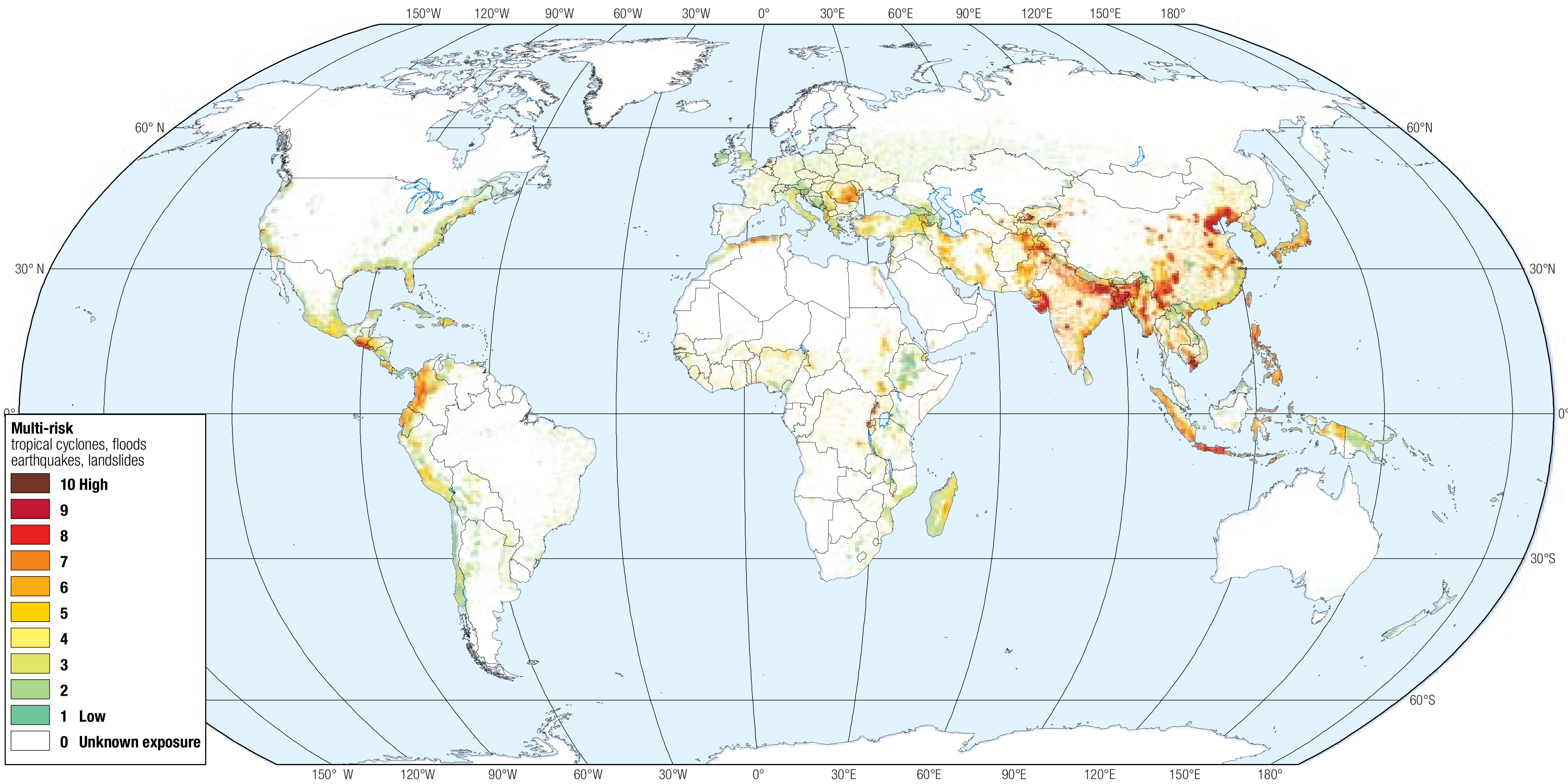


Figure 2.35:
Global distribution of multiple hazards mortality risk

GIS analysis and cartography: P. Peduzzi, ISDR, UNEP/GRID-Europe, 2009.



2.5 Trends in global disaster risk

Both mortality and economic loss risk are increasing in absolute terms for all the principal hazards, except for landslides, where the tendency appears to be stable. However, relative risk when measured as a proportion of population or GDP is stable and, in the case of mortality, may be declining.

Many readers will be familiar with graphs such as Figure 2.36, which show an exponential increase in economic loss from disasters since the 1970s. Figure 2.37 shows that when these losses are adjusted for inflation and expressed as a percentage of global GDP, the trend is far less pronounced and statistically insignificant.

2.5.1 Risk, exposure and vulnerability

In order to see how risk patterns are changing over time, modelled mortality and economic loss in 1990 and 2007 were compared, assuming constant levels of hazard.

Figure 2.36: Total reported economic losses from natural disasters[28]

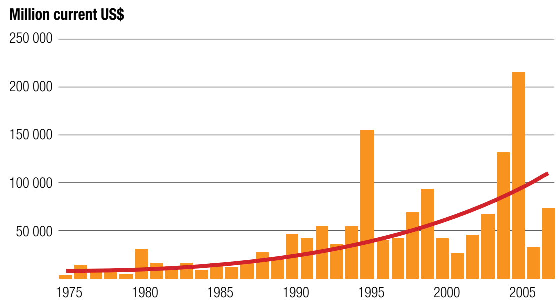
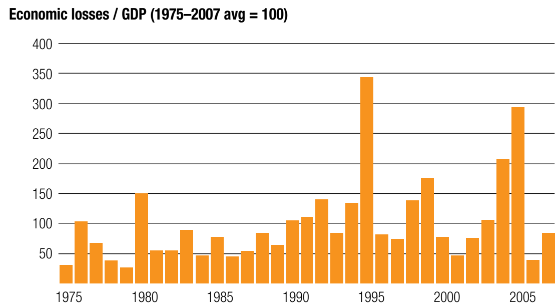


Figure 2.37: Inflation adjusted economic losses as a share of global GDP



In the case of floods, modelled mortality increased by 13% from 1990 to 2007. This increase was driven by a 28% increase in modelled exposure. Vulnerability actually declined by 11%.

Modelled economic loss over the same period increased by 33%, while GDP exposure increased by 98%. Vulnerability actually declined by 33%. This concurs with the fact that globally GDP increased by 64% over the same period, but countries with very high flood exposure, such as China and India, increased their GDP by more, in this case 420% and 185% respectively.

In the case of landslides, mortality risk was stable from 1990 to 2007 (the model indicates a decrease of 1%). Exposure increased by 23%, while vulnerability decreased by 20%, reflecting GDP growth in the countries exposed.

These simulations of risk indicate that increases in weather-related disaster risk are principally being driven by increases in exposure. Vulnerability actually appears to be going down although these simulations do not indicate which specific factors are increasing or decreasing over time.

The overall implication is that while economic development can reduce vulnerability, at the same time it drives increased exposure of people and economic assets in areas prone to weather-related hazards, particularly urban and coastal areas. Economic loss risk appears to be increasing faster than mortality risk, reflecting a faster increase in GDP exposure than population exposure.

Since 1975, for example, the global population has increased by 63%[29]. In terms of economic assets, between 1975 and 2007, global GDP grew by 166%, from US$ 14.8 trillion to US$ 39.4 trillion (in constant 2000 US$), far faster than world population which grew from 4.1 to 6.6 billion. GDP per capita therefore grew from US$ 3,600 to US$ 5,900[30]. But these gains have not been uniform. The economies of richer countries and some successful lower-income countries grew faster than those of many poor countries, especially in Africa and South Asia.

Although solid data are hard to come by, there is evidence that economic activities, assets and productive infrastructure are also further concentrated within countries. Growth has been fastest in coastal regions and near large navigable rivers, many of which are prone to natural hazard events[31]. Urban growth has added significant economic assets to large cities in developing countries, some of which are located in geologically unstable areas. Earthquake prone Tehran and Istanbul, for instance, experienced faster urban and economic growth than the Islamic Republic of Iran and Turkey as a whole. As populations concentrate and economic activity in those centres grows even faster, exposure also increases significantly.

It is also likely that risk is increasing fastest in low and lower-middle income countries with rapidly growing economies. These countries have rapidly increasing exposure at the same time as only slowly improving vulnerability indicators. In contrast, most high-income countries experience more sedate increases in exposure, with very low vulnerability.

2.5.2 Is hazard increasing?

The above simulations of loss trends assume constant hazard levels. Yet hazard is changing, due to climate change, urbanization and environmental degradation.

In the case of tropical cyclones, Table 2.6 shows that there has been an increase in the frequency of Category 4 events during warm years. These results are in line with findings published recently[32] in which it was calculated that a 1°C increase in sea surface temperatures would result in a 31% increase in the global frequency of Category 4 and 5 storms per year. This is also consistent with the IPCC's 4th Assessment report (p. 795)[33] which states that *"Tropical cyclones (including hurricanes and typhoons), are likely to become more intense with sea surface temperature increases."*

Table 2.6 shows that the average number of tropical cyclones between cold, average and hot years is fairly stable (between 56 and 58 tropical cyclones per year). However, Category 3 and 4 cyclones show a marked increase in average and hot years compared with cold years. Global sea surface temperature data are available only since 1985. The "No data" years (1976–1984) show more Category 1 and fewer Category 3, 4 and 5 cyclones.

Any increase in the severity of cyclones will magnify the unevenness of disaster risk distribution. For example, the economic risk model shows that 1.9% of the GDP of Madagascar is at risk annually from Category 3 cyclones, but only 0.09% of the GDP of Japan. If these cyclones were to increase to Category 4 storms, 3.2% of the GDP of Madagascar would be at risk, but only 0.16% of the GDP of Japan.

Table 2.6: Tropical cyclone intensity and occurrence (1977–2006) grouped by sea surface temperature for 1985–2006

Group by average sea surface temperature (SST)	Number of cyclones for the period*	Number of years	Average number of events/ year	Number events Cat. 1	Number events Cat. 2	Number events Cat. 3	Number events Cat. 4	Number events Cat. 5
No data on SST	494	9	54.9	22.7	12.7	12.9	6.2	0.6
Cold SST	407	7	58.1	25.4	13.9	10.4	7.1	1.3
Average SST	448	8	56.0	18.0	13.9	14.0	9.3	1.9
Hot SST	460	8	57.5	20.4	11.6	16.1	8.1	1.3

*Analysis covers the period 1977–2006; sea surface temperature (SST) data were available from 1985–2006; cyclones for the period 1977–1984 were grouped as one category (no data on SST).

2.6 Economic resilience, vulnerability and development constraints in developing countries

Previous research has confirmed that the level of economic losses experienced by a country is not a good indicator per se of the country's capacity to absorb the impact of a major hazard event and recover, even when expressed in relation to the size of a country's GDP or exposed GDP. In the development of the Disaster Deficit Index[34], for example, it was proposed that countries with access to insurance and reinsurance payments (for example through participation in a catastrophe pool), with disaster reserve funds, with access to external credit and with internal reserves would in general be more resilient to catastrophic disaster loss than countries without.

The stock of physical (economic) capital has always been considered as a determinant factor in economic growth, a perspective that has been enriched by incorporating other forms of capital (human, social-relational and natural capital) as well as institutions and knowledge, as *endogenous capacities* contributing to explaining growth[35].

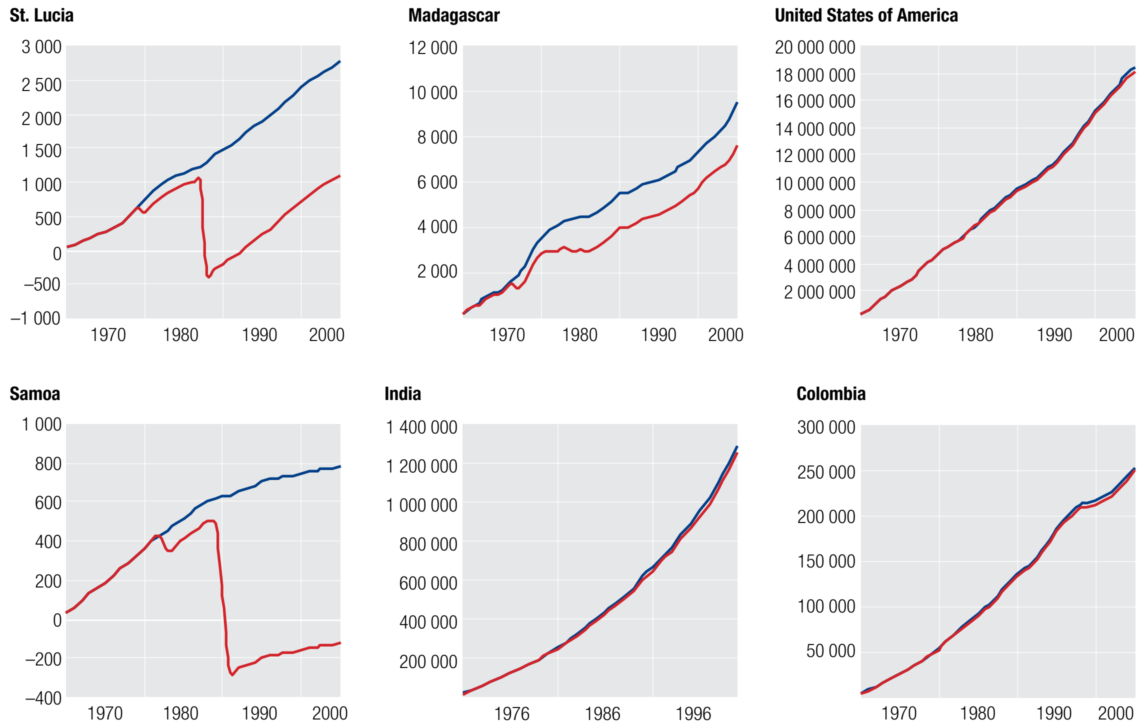
Estimates prepared for this report show that disasters have a major impact on the accumulation of capital stock in a small number of vulnerable countries. The top three countries in this situation, in which the ratio of economic losses to capital stock was highest are all SIDS, namely Samoa, Saint Lucia and Grenada. The next two most affected countries, Afghanistan and Tajikistan, are land-locked countries[36].

Figure 2.38 clearly shows the differential impact of economic loss in countries with different characteristics.

In Samoa, for example, economic losses in a series of disasters including a tropical storm and forest fire in 1983, and a series of back-to-back tropical cyclones between 1989 and 1990 appear to have set back the country's economy by about 30 years. It was not until 2000 that the island's capital stock recovered to its 1970's level. A similar pattern is presented in Saint Lucia due to the impacts of Hurricane Allen in 1980 and

Figure 2.38: Impact of economic loss

Cumulative net capital formation (NCF) from 1970 to 2006, in millions of constant 2000 US$, with (red lines) and without (blue lines) the effect of economic losses in disasters.



Hurricane Gilbert in 1986. Madagascar shows a different pattern but a clear impact of disaster loss on cumulative net capital formation. In contrast, the impact of major disasters on high-income countries such as the United States of America is imperceptible, even though that country has experienced disasters with enormous absolute economic loss. Similarly, the effect in large low-income countries such as India or middle-income countries such as Colombia is not so significant.

The implications are that disasters do not have a significant impact on economic growth in countries with large economies, but a devastating impact on those with small economies. Such economies are highly vulnerable to disaster loss. While in large countries disasters may have a devastating impact on the localities and regions where they occur, as Hurricane Katrina demonstrated, this is not necessarily translated into a national impact unless the affected area concentrates a significant proportion of a country's capital.

Approaches to measuring the resilience of a country to economic shocks have included the Disaster Deficit Index, mentioned above, and others[37]. Another approach is to use net savings as a proxy of a country's ability to absorb the impact and recover from disaster losses. Net savings is probably a better proxy of resilience than GDP per capita because it more accurately estimates the available internal resources, which could be invested in the recovery of losses including capital stock.

However, the factors that influence a country's resilience (i.e. its capacity to recover from deviations in its development path caused by disaster impacts) are complex and cannot be reduced easily to any one variable. Nevertheless, five groups of countries can be identified that share common characteristics in terms of their vulnerability and resilience to disaster loss and their development limitations, particularly their capacity to benefit from international trade[38].

Table 2.7 shows the countries in this classification. Groups 4 and 5 are those with high and very high economic vulnerability to natural hazards. The table also shows the number of developing countries (including LLDCs) in those groups that experience extreme limitations in their ability to benefit from international trade. Countries suffering extreme trade limitations are characterized by a very low participation in world export markets (less than 0.1%) and simultaneously show low export diversification, which render them highly exposed to trade shocks.

The higher the vulnerability of a group to natural hazard risks, the higher the number of developing countries in it that suffer extreme trade limitations[39]. In the groups with high and very high vulnerability (i.e. Groups 4 and 5), 81% of all countries suffer extreme trade limitations (reaching 100% in Group 5), while in groups with very low, low and medium vulnerability (Groups 1, 2 and 3), only 4% suffer such limitations.

It is also clear that SIDS and LLDCs represent the majority of countries with high and very high vulnerability and those suffering extreme trade limitations. In fact, SIDS and LLDCs together constitute 60% and 67% of all countries in Groups 4 and 5 respectively, and about two thirds of all countries in the groups affected by extreme trade limitations.

Given that the risk circumstances of many SIDS and LLDCs are likely to worsen because of climate change trends, in the absence of particular attention from the international community, their prospects for a positive insertion in the global economy will further deteriorate, and even their economic and social viability as nations could be seriously compromised.

Given the limitations on economic loss data mentioned in Section 2.2, it is likely that with more complete information, the specific countries identified in each of those groups would change. The exercises mentioned above should, therefore, be considered illustrative only. Nevertheless, a key conclusion is that SIDS, landlocked countries, LLDCs and others with small and vulnerable economies and low levels of resilience to economic loss will require a specific policy focus that takes into account the complexity of the factors involved. This conclusion will be revisited in the recommendations of the report in Chapter 7.

Table 2.7:
Five groups of countries characterized in terms of their economic vulnerability to natural hazards, and developing countries in each group experiencing extreme limitations in international trade

Short vulnerability characterization	Groups of countries according to their economic vulnerability to natural hazards: Countries in the group	Groups of countries according to their economic vulnerability to natural hazards: Developing countries in the group experiencing extreme trade limitations (Very Low Revealed Competitiveness; High Exposure to Trade Shocks)(3)(4)	Vulnerability factors relative to all countries: Relative economic loss (1)	Vulnerability factors relative to all countries: Economic resilience (2)
1 Very Low	(16) Bahrain; Finland; Gabon; Iraq; Ireland; Kuwait; Lybian Arab Jamahiriya; Luxembourg; Macau; Malta; Norway; Qatar; Saudi Arabia; Singapore; Suriname; United Arab Emirates	0	In the best (lowest) 25% of the world	In the best (highest) 25% of the world
2 Low	(33) Albania; Austria; Belgium; Botswana; Bulgaria; Canada; Congo, Rep. of; Cyprus; Czech Republic; Denmark; Egypt; Equatorial Guinea; France; Germany; Hong Kong; Iceland; Kiribati; Lithuania; Malaysia; Netherlands; New Zealand; Oman; Panama; Russian Federation; Slovenia; South Africa; Sweden; Switzerland; Trinidad & Tobago; Tunisia; United Kingdom; Uruguay; Venezuela.	(2) Equatorial Guinea; Kiribati	In the second quartile (Between 25% and 50% of the world)	In the third quartile (Between 50% and 75% of the world)
3 Medium	(23) Algeria; Antigua & Barbuda; Azerbaijan; Bahamas; Chile; China; Costa Rica; Dominican Republic; Fiji; India; Iran, Islamic Republic of; Jamaica; Liberia; Mauritius; Moldova; North Korea; Peru; Portugal; Phillipines; Romania; Somalia; Sudan; Turkey	0	In the third quartile (Between 50% and 75% of the world)	In the second quartile (Between 25% and 50% of the world)
4 High	(33) Bangladesh; Barbados; Bermuda; Bolivia; Bosnia-Herzegovina; Cape Verde; Chad; Cuba; Ecuador; Georgia; Grenada; Guyana; Honduras; Jordan; Madagascar; Malawi; Mauritania; Mongolia; Nauru; Nepal; Pakistan; Papua New Guinea; St Kitts & Nevis; St Lucia; Seychelles; Solomon Islands; Sri Lanka; Swaziland; Tajikistan; Tuvalu; Vanuatu; Vietnam; Zimbabwe	(25) Bangladesh; Barbados; Bermuda; Bolivia; Cape Verde; Cuba; Ecuador; Grenada; Guyana; Honduras; Jordan; Madagascar; Malawi; Mauritania; Mongolia; Nepal; Nicaragua; Papua New Guinea; St Kitts & Nevis; St Lucia; Sri Lanka; Swaziland; Tajikistan; Tuvalu; Vanuatu	...Either in the worst (highest) 25% of economic losses and between 25% and 50% of resilience simultaneously, ...	
			...Or in the worst (lowest) 25% of resilience and between 50% and 75% of economic losses simultaneously	
5 Very High	(18) Afghanistan; Armenia; Belize; Cambodia; Comoros; Dominica; El Salvador; Guatemala; Haiti; Kyrgyzstan; Lao People's Democratic Republic; Former Yugoslav Republic of Macedonia; Mozambique; Myanmar; St Vincent & The Grenadines; Samoa; Senegal; Tonga	(18) Afghanistan; Armenia; Belize, Cambodia; Comoros; Dominica; El Salvador; Guatemala; Haiti; Kyrgyzstan; Lao People's Democratic Republic; Former Yugoslav Republic of Macedonia; Mozambique; Myanmar; St Vincent & The Grenadines; Samoa; Senegal; Tonga	In the worst (highest) 25% of the world	In the worst (lowest) 25% of the world

(1) Economic losses relative to GDP and/or to capital stock are used to proxy fragility; (2) Net savings per capita is used as a proxy for economic resilience; (3) A share of 0.10% or less of world export market in is used for very low revealed competitiveness; (4) Being in the worst 50% of the world in terms of trade diversification is used as an indicator of high exposure to trade shocks

Endnotes

1 The LandScan™ Dataset comprises a worldwide population database compiled on a 30” × 30” latitude/longitude grid. Census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights and other information. LandScan has been developed as part of the Oak Ridge National Laboratory Global Population Project for estimating ambient populations at risk: http://www.ornl.gov/sci/landscan/index.html

2 The ShakeMap Atlas: http://earthquake usgs.gov/eqcenter/pager/prodandref/index php; Allen, et al, 2008

3 Wald, et al, 2008

4 Normally economic loss in disasters is divided into direct economic loss referring to the value of destroyed and damaged assets, and indirect economic loss, referring to knock-on effects in broader economic flows. The term economic loss risk in this chapter refers specifically to the former, although in practice it is often impossible to know whether reported loss estimates include indirect losses.

5 MunichRe NatCatService, GeoRisikoForschung, Great Natural Disasters 1950–2007: http://www.munichre.com/en/ts/geo_risks/natcatservice/default.aspx; EMDAT, 2008; analysis by ISDR (data as of September 2008).

6 IPCC, 2007b

7 Detailed information on data sources and methodology is provided in Appendix 1 and in the technical background papers produced for this chapter. Maps, figures and tables illustrating key highlights of the findings are presented in this chapter. User-generated maps and graphs may be created on http://preview.grid.unep.ch

8 UNDP/BCPR, 2004; Dilley et al., 2005

9 World Bank, 2000

10 Altez, 2007; Altez and Revet, 2005

11 BBC, 29 December, 1999. Venezuala disaster ‘worst this century’: http://news.bbc.co.uk/2/hi/americas/581579.stm

12 Cormac, 2007

13 The level of confidence of the model for Category 1 events was (R^2 = 0.417), Category 2 (R^2 = 0.413), Category 3 (R^2 = 0.450), Category 4 (R^2 = 0.681) and Category 5 (R^2 = 0.998).

14 Estimates are based on EMDAT reported damages and predicted losses for cyclone events during 1975–2007 for which no damage estimates were available.

15 McTaggart-Cowan, et al., 2006

16 Marcelino, et al., 2004

17 NOAA/NHC (United States National Oceanic and Atmospheric Administration/National Hurricane Center): http://www.nhc.noaa.gov/aboutsshs.shtml

18 The difference would be smaller if extra-tropical storms were included in the analysis.

19 As observed by the Dartmouth Flood Observatory between 1980 and 2001.

20 As reported by CRED/EMDAT for earthquakes between 1999 and 2008; EMDAT, 2008; analysis by ISDR (data as of September 2008).

21 Izmit (Turkey, 1999; 17,000 killed); Bhuj (Gujarat, India, 2001; 20,000 killed); Bam (Iran, 2003; 26,800 killed); Jammu/Kashmir (Pakistan/India, 2005; 74,000 killed) and Sichuan (China, 2008; 87,900 killed).

22 GDP per capita, voice and accountability, and urban growth were highly correlated and therefore could not be used in the same regression. For Categories 1 and 3 earthquakes, GDP per capita was the best fit; for Category 2 urban growth, and for Category 4 voice and accountability.

23 Assuming average earthquake magnitude, exposure and institutional quality.

24 Fuente and Dercon, 2008

25 See Appendix 1 for details.

26 Lehsten, et al., 2009

27 IPCC, 2007c

28 EMDAT, accessed 12 December 2008

29 Data sources: UN Population Division, on UNEP geodata portal: http://geodata.grid.unep.ch

30 GDP data: DDP, 2008. Population data: UN Population Division, 2006.

31 McGranahan, et al., 2007

32 Elsner, et al., 2008)

33 IPCC 2007a

34 Cardona, 2005

35 Corrales and Miquilena, 2008.

36 Baritto, 2009.

37 For example, Brugiglio’s Economic Vulnerability Index, and Economic Resilience Index

38 Risk factors used were the per capita net savings, a proxy for resilience, and the ratio of economic losses to capital stock, as a proxy of vulnerability. The capacity to benefit from insertion in the global economy was expressed in terms of the ‘revealed competitiveness’ of countries (the market share of world exports), and the concentration of exports in a few export lines, an indicator of the country’s exposure to trade shocks. The indicators of development outcomes were the human development index, and countries’ per capita GDP.

39 Corrales and Miquilena, 2008