NATURAL DISASTER HOTSPOTS: A GLOBAL RISK ANALYSIS
Synthesis Report

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Maxx Dilley[1], Robert S. Chen[2], Uwe Deichmann[3], Arthur L. Lerner-Lam[4] and Margaret Arnold[5], with Jonathan Agwe[5], Piet Buys[3], Oddvar Kjekstad[6], Bradfield Lyon[1] and Gregory Yetman[2]

Preface

This synthesis summarizes the findings of the Global Natural Disaster Risk Hotspots project. The Hotspots project generated a global disaster risk assessment and a set of more localized or hazard-specific case studies. The synthesis draws primarily from the results of the global assessment. Full details on the data, methods and results of the global analysis can be found in volume one of *Natural Disaster Hotspots: A Global Risk Analysis*[7]. The case studies are contained in volume two (forthcoming).

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[1] International Research Institute for Climate Prediction, Columbia University
[2] Center for International Earth Science Information Network (CIESIN), Columbia University
[3] Development Economics Research Group (DECRG), The World Bank
[4] Center for Hazards and Risk Research (CHRR) and Lamont-Doherty Earth Observatory (LDEO), Columbia University
[5] Hazard Management Unit (HMU), The World Bank
[6] International Centre for Geohazards (ICG), Norwegian Geotechnical Institute (NGI)
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CENTER FOR HAZARDS & RISK RESEARCH
AT COLUMBIA UNIVERSITY
THE WORLD BANK
IRI
CIESIN Columbia University
ICG International Centre for Geohazards
NGI
PROVENTION CONSORTIUM
DFID Department for International Development
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Department for International Development. Additional support for the case studies was provided by the Norwegian Ministry of Foreign Affairs and the U.S. Agency for International Development. The Hotspots project benefited enormously from interactions with the project on "Reducing Disaster Risk (UNDP 2004)," a collaborative effort involving the United Nations Development Program (UNDP), the United Nations Environment Program (UNEP) and others.

Introduction

Earthquakes, floods, drought, and other natural hazards continue to cause tens of thousands of deaths, hundreds of thousands of injuries, and billions of dollars in economic losses each year around the world. EM-DAT, a global disaster database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) in Brussels, records upwards of 600 disasters globally each year. Disaster frequency appears to be increasing (http://www.cred.be). Disasters represent a major source of risk for the poor and wipe out development gains and accumulated wealth in developing countries.

In this report we assess the global risks of two disaster-related outcomes: mortality and economic losses. We estimate risk levels by combining hazard exposure with historical vulnerability for two indicators of elements at risk—gridded population and Gross Domestic Product (GDP) per unit area—for six major natural hazards: earthquakes, volcanoes, landslides, floods, drought, and cyclones. By calculating relative risks for each grid cell rather than for countries as a whole, we are able to estimate risk levels at sub-national scales. A set of accompanying case studies, available separately, explores risks from particular hazards or for localized areas in more detail, using the same theoretical framework as the global analysis.

Disaster losses are caused by interactions between hazard events and the characteristics of exposed elements that make them susceptible to damage. A hazard's destructive potential is a function of the magnitude, duration, location and timing of the event (Burton *et al.,* 1993). To be damaged, however, elements exposed to a given type of hazard must also be vulnerable to that hazard; that is, the elements must have intrinsic characteristics, or vulnerabilities, that allow them to be damaged or destroyed (UNDRO 1979). Valuable but vulnerable include people, infrastructure and economically or environmentally important land uses.

The destructive power of natural hazards, combined with vulnerabilities across a spectrum of exposed elements, can lead to large-scale covariate losses during hazard events in areas where population and economic investment are concentrated. Aggregate losses start with losses to individual elements, reaching a point in disaster situations where economic or social systems partly or completely break down.

Risks of individual element losses or of aggregate covariate losses can be stated as the probability of loss, or as the proportion of elements that will be damaged or lost over time (Coburn *et al.,* 1994). Disaster risk assessment examines the factors that cause losses in order to estimate loss probabilities. Risk factors include the probability of destructive hazard events as well as the contingent vulnerabilities of exposed elements at risk.

Because disaster risk assessment is based on identification of latent causal factors, it can help inform efforts to intervene to reduce risks and therefore losses before such losses occur. Making risks foreseeable provides motivation for risk reduction (Glantz, 2002). Identification of risk factors creates possibilities for shifting emphasis from reliance on relief and reconstruction following disasters towards prevention of losses and preparedness to reduce recovery time following disasters. Risk assessment, reduction and transfer are the major elements of risk management (Kreimer *et al.*, 1999), a desirable alternative to managing disasters through emergency management.

A coherent body of risk management theory and methods (Blaikie *et al.*, 1994, Dilley and Boudreau 2001, UNDP 2004) and an increasingly public discourse about risk management (IFRC 2002, ISDR 2002, UNDP 2004) are emerging. Risk management tools and techniques can be applied at a range of scales – from the level of individual facilities and communities to nationally and internationally.

The global analysis undertaken in this project is limited by issues of scale as well as by the availability and quality of data. For a number of hazards, we had only 15- to 25-year records of events for the entire globe and relatively crude spatial information for geolocating these events. Data on historical disaster losses, and particularly on economic losses, are also limited.

While the data are inadequate for understanding the *absolute* levels of risk posed by any specific hazard or combination of hazards, they are adequate for identifying areas that are at relatively higher single- or multiple-hazard risk. In other words, we do not feel that the data are sufficiently reliable to estimate, for example, the total mortality risk from flooding, earthquakes, and drought over a specified period. Nevertheless, we can identify those areas that are at *higher* risk of flood losses than others and at *higher* risk of earthquake damage than others or at *higher* risk of both. We can also assess in general terms the *exposure* and *potential magnitude* of losses to people and their assets in these areas. Such information can inform a range of disaster prevention and preparedness measures, including prioritization of resources, targeting of more localized and detailed risk assessments, implementation of risk-based disaster management and emergency response strategies, and development of long-term land-use plans and multihazard risk management strategies.

Within the constraints summarized above, we developed three indices of disaster risk:

1. disaster-related mortality risks, assessed for global gridded population,
2. risks of total economic losses, assessed for global gridded GDP per unit area, and
3. risks of economic losses expressed as a proportion of the GDP per unit area for each grid cell.

We hope that in addition to providing interesting and useful results, the Hotspots global analysis and case studies will stimulate additional research, particularly at national and local levels, increasingly linked to disaster risk reduction policy-making and practice.

Data

The global natural disaster risk assessment involves three types of data on elements at risk, hazards and vulnerability. Citations and complete descriptions can be found in the full Hotspots project reports.

Elements at risk

The risk assessments presented below – of mortality and economic losses -- are based on two data sets characterizing elements at risk: population and GDP per unit area.

Mortality-related risks are assessed on a 2.5' x 2.5' latitude-longitude grid of global population, the Gridded Population of the World (GPW) (CIESIN *et al.,* 2000). The GPW transformed population census data, which most countries collected for subnational administrative units, into a regular "grid" of "spherical quadrilaterals." Each cell contains an estimate of total population and population density (on land), based on the overlap between the irregular boundaries of administrative units and the regular boundaries of the grid. In this analysis, we used a preliminary version of GPW version 3, which contains population estimates for 1990, 1995, and 2000 for approximately 375,000 sub-national administrative units (CIESIN *et al.,* 2004) .

Economic risks are assessed at the same resolution but for a gridded surface of Gross Domestic Product (GDP) per unit area. At the national level, GDP measures the annual market value of final goods and services produced by a country. For about 50 countries, more than half of which are developing or transitional economies (including Bangladesh, Brazil, China, India, Indonesia and Mexico), GDP data are available for subnational units. Following Sachs and coauthors (2001), we applied these subnational estimates to population density using the World Bank estimates of GDP based on purchasing power parity for 2000 (World Bank, 2000).[8]

Hazards

Global hazard data were compiled from multiple sources. The project collaborated directly with UNDP, UNEP, the International Research Institute for Climate Prediction (IRI), and the Norwegian Geotechnical Institute (NGI) in the creation of data sets for several hazards for which global data sets did not previously exist, e.g., drought and cyclones (UNDP, 2004) and landslides (NGI, 2003). Drought, flood and volcano hazards are characterized in terms of event frequency, storms by frequency and severity, earthquakes by frequency and probability of exceeding a set threshold of peak ground acceleration, and landslides by an index derived from probability of occurrence.

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[8] The population density is based on GPW version 2, projected to 2000, since the preliminary version 3 was not available at the time.

Cyclones. For cyclones, we used storm track data collected from multiple sources and assembled into Geographic Information System (GIS) coverages by the UNEP/GRID-Geneva Project of Risk Evaluation, Vulnerability, Information and Early Warning (PreView). This dataset includes more than 1,600 storm tracks for the period 1 January 1980 through 31 December 2000 for the Atlantic, Pacific, and Indian Oceans.[9] We modeled the wind speeds around the storm tracks in order to assess the grid cells likely to have been exposed to high wind levels.

Drought. For drought, we used the Weighted Anomaly of Standardized Precipitation (WASP) developed by IRI, computed on a 2.5° x 2.5° grid from monthly average precipitation data for 1980 – 2000. The WASP assesses the degree of precipitation deficit or surplus over a specified number of months, weighted by the magnitude of the seasonal cyclic variation in precipitation. A three month running average was applied to the precipitation data and the median rainfall for the 21-year period calculated for each grid point. A mask was applied to eliminate grid points where the three-month running average precipitation was less than 1 mm per day. This excluded both desert regions and dry seasons from the analysis. For the remaining points, a drought event was identified when the magnitude of a monthly precipitation deficit was less than or equal to 50 percent of its long-term median value for three or more consecutive months.

Floods. The Dartmouth Flood Observatory has compiled a global listing of extreme flood events compiled from diverse sources and georeferenced to the nearest degree for the period 1985-2003. Flood extent data are based on regions affected by floods, not necessarily flooded area. Data are poor or missing in the early-mid 1990s.

Earthquakes. For earthquakes, we used data on earthquake probability of occurrence from the Global Seismic Hazard Program (GSHAP) as well as a database of actual earthquake events greater than 4.5 on the Richter scale for the period 1976-2002 (Advanced National Seismic System, 1997). The GSHAP data were sampled at 1' intervals, with a minimum peak ground acceleration (pga) of 2 meters per second per second (m/s^2), or approximately one-fifth of surface gravitational acceleration.

Volcanoes. For volcanoes, we used a spatial coverage of volcanic activity (79 A.D.-2000 A.D.) developed by UNEP-GRID Geneva based on the Worldwide Volcano Database and available at the National Geophysical Data Center (http://www.ngdc.noaa.gov/seg/hazard/vol_srch.shtml). This database includes nearly 4,000 events categorized as moderate or above (values 2-8) according to the Volcano Explosivity Index (VEI) developed by Simkin and Seibert (1994). Some volcanoes are located to the nearest thousandths of a degree, but most have been georeferenced to the nearest tenth or hundredth of a degree.

Landslides. The NGI, working with UNEP GRID-Geneva and this project, has developed a global landslide and snow avalanche hazard map that has been used for global analysis

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[9] The record for the 1980s for some parts of the Indian and Pacific Oceans are incomplete in some cases. See: http://www.grid.unep.ch/data/grid/gnv199.php.

of these hazards. The map is based on a range of data including slope, soil and soil moisture conditions, precipitation, seismicity, and temperature (NGI 2004). This index takes advantage of more detailed elevation data that recently became available from the Shuttle Radar Topographic Mission (SRTM) at 30" resolution, compiled and corrected by Isciences, L.L.C. (http://www.isciences.com).

The hazard data were prepared at a variety of spatial resolutions and for varying periods (Table 1).

Table 1. Summary of data sources for each hazard.

Hazard	**Parameter**	**Period**	**Resolution**	**Source(s)**
Cyclones	Frequency by wind strength	1980-2000	30"	UNEP/GRID-Geneva PreView
Drought	Weighted Anomaly of Standardized Precipitation (50% below normal precip. for a 3-month period)	1980-2000	2.5°	IRI Climate Data Library
Floods	Counts of extreme flood events	1985-2003*	1°	Dartmouth Flood Observatory, *World Atlas of Large Flood Events*
Earthquake	Expected pga > 2 m/s^2 (10% probability of exceedance in 50 years)	n/a	sampled at 1'	Global Seismic Hazard Program
	Frequency of earthquakes > 4.5 on Richter Scale	1976-2002	sampled at 2.5'	Advanced National Seismic System Earthquake Catalog
Volcanoes	Counts of volcanic activity	79-2000	Sampled at 2.5'	UNEP/GRID-Geneva and NGDC
Landslides	Index of landslide and snow avalanche hazard	n/a	30"	NGI

* missing data for 1989, 1992, 1996, and 1997; quality of spatial data for 1990-91 and 1993-95 limited.

Vulnerability

The stresses to which a given element at risk is subjected during a hazard event depend on the hazard. These stresses include shaking in the case of earthquakes, moisture stress in the case of drought, inundation during floods, and so on. A given element may be severely challenged by one hazard but completely unaffected by another. A building, for example, may collapse when subjected to seismic shaking or incur damage due to floods, but may suffer little or no impacts in a drought. Similarly, the fertility of agricultural land may benefit directly as a result of flooding, whereas exposed infrastructure may be severely damaged.

For a given hazard, vulnerability will vary across a set of similar elements and from one element to the next. Irrigated agricultural areas tend to experience lower losses during droughts than areas that depend on rainfall, for example. Buildings that are constructed to seismic safety standards are less likely to be damaged during an earthquake than those built of unreinforced masonry. Houses with raised platforms are better suited to withstand flood conditions that those without. People and societies with resources and economic alternatives tend to be better protected from harm and are able to recover more quickly than people with fewer options and resources.

The set of elements that may be damaged by a given hazard is often quite large. Urban infrastructure, for example, consists of multiple sectors–transport, power, water and sanitation, housing, and communications–each of which in turn may encompass many separate systems. Each system is made of subsystems and so on, down to the level of individual components.

When a complex entity like an urban area is subjected to a severe hazard event such as a flood or volcanic eruption, widespread failures of vulnerable components can cause total or partial system failure, resulting in a disaster. Given the number of systems, sub-systems, and components, each of which responds differently when subjected to a given hazard, it is possible to characterize vulnerability only generally (or perhaps stochastically) when operating at scales larger than individual installations or facilities. Similarly, when social systems such as communities or households are the unit of analysis, vulnerability analysis requires detailed knowledge of household or community characteristics. In a global analysis such as the current one, therefore, vulnerability assessment is at best only possible through the use of general proxies.

This analysis assesses global disaster-related risks of mortality and economic losses. The elements at risk are people in the first instance and an estimated value of goods and services produced annually per unit area in the second. Ideally, we would have a complete probability density function for the loss expected to result when particular populations or economic assets are exposed to a range of hazards and hazard severities (that is, we would know the probabilities of different levels of losses likely to be experienced by the exposed units in the grid cells directly affected by different hazard events). Owing to data limitations, we used historical loss rates, using a methodology described in detail below. We calculated loss rates for each hazard from historical losses over 20 years (1981-2000) obtained from EM-DAT. For each hazard we calculated 28 loss rates, one for each combination of seven regions and four country wealth groups based on World Bank classifications.

Estimates of losses per disaster and the degree to which disaster events are consistently captured vary from one disaster loss data source to the next (Sapir and Misson, 1992). For the purpose of estimating loss rates, however, it is not necessary to assume that EM-DAT contains a complete inventory of all deaths and economic losses over the 20-year period. Rather, in this analysis, it is only necessary that the deaths and economic damages recorded in EM-DAT capture *relative* differences in mortality and economic losses between hazards, regions, and country wealth groupings. Improvements in mortality and economic loss data by event in data sets such as EM-DAT would make loss rate calculation more precise. For example, the insurance industry has been developing more consistent loss databases for selected regions and in at least one case has developed a multihazard index of average annual loss based on modelled exposure to hazard events (Risk Management Solutions, 2004).

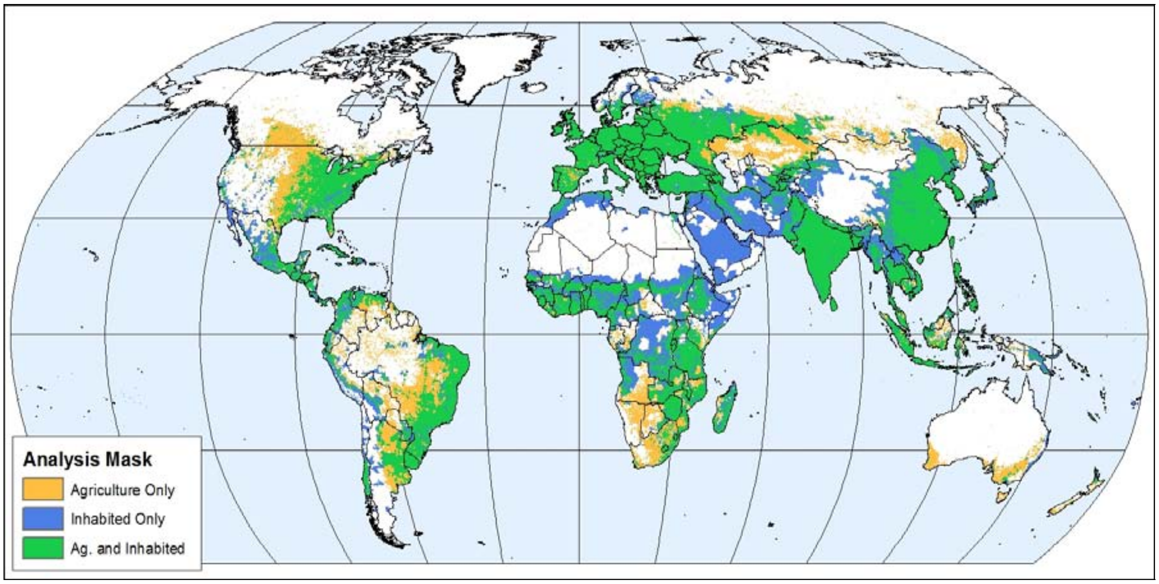
Methods

Since the objective of this analysis is to identify hotspots where natural hazard impacts may be large, it includes the large proportion of the Earth's land surface that is sparsely populated and not intensively used. We have therefore chosen to mask out grid cells with population densities less than 5 persons per square kilometer (cells with less than about 105 residents) and without significant agriculture. Even if all residents of such cells were exposed and highly vulnerable to a hazard, total casualties would still be relatively small in absolute terms, and the potential agricultural impact would be limited.

Masking these cells reduces data processing requirements and ensures that the large number of very low risk cells do not dominate the results. In addition, hazard reporting and frequency data are likely to be poorest in rural, sparsely populated areas, so masking could help to reduce anomalies caused by poor data. A total of approximately 4.1 million grid cells remain after applying the mask (Figure 1). These cells (colored orange, blue, or green in the figure) include slightly more than half of the total estimated land area (about 72 million square kilometers, or about 55 percent of the total), but most of the world's population (6 billion people, or about 99.2 percent of the total population estimate in GPW for the year 2000).

Next, we used historical losses as recorded in EM-DAT across all events from 1981-2000 for each hazard type to obtain mortality and economic loss weights for each hazard for each region for four economic wealth classes within regions (Tables 2 and 3). The weights are an aggregate index of relative losses within each region and country wealth class for each hazard over the 20-year period.

Figure 1. Mask used to eliminate sparsely populated, non-agricultural areas.



Aggregating across more than 6,000 entries in EM-DAT for this period helps compensate for missing data and reporting inaccuracies. In the absence of consistent, accurate loss estimates for individual events, the aggregate indexes reflect broad patterns across multiple events. This is particularly important in case of economic losses, which are unevenly recorded in EM-DAT. Only 30% of the entries in EM-DAT from 1981-2000 contain data on economic losses, and the economic losses recorded were assessed using nonstandardized methodologies.

The procedure used for assessing mortality and economic loss risks for each grid cell was similar. In the case of mortality risks, the weights were based on historical mortality and applied to population exposure values at each grid point (Text Box 1). The derivation of economic loss risk hotspots is the same with two exceptions in the case of economic losses: 1) the unit of analysis is GDP per unit area rather than population density, and 2) loss weights are based on historical economic losses rather than on historical mortality.

Discussion

The resulting regional differences in loss risks are in part due to differences in population density, in the size of the areas affected and in the degree of hazard across regions. But they also reflect differences in vulnerability. For instance, earthquakes in Japan tend to result in lower mortality rates than in many developing countries due to better enforcement of building codes, better emergency response, and the generally high level of preparedness.

In the described series of steps (Text Box 1), we assume that mortality within a given region is not uniformly distributed but rather influenced by the frequency (and ideally severity) of hazard events that have occurred within the region. We therefore allocate more of the region's total mortality to places with a higher apparent degree of hazard.

Rather than applying a constant mortality rate to the region's population, we generate an accumulated mortality by multiplying the mortality rate by the severity measure for each hazard. Since the degree of hazard for each of the six hazards is measured on a different scale (for example, frequency counts for droughts versus probability index values for landslides), the accumulated mortality numbers are not easily comparable across hazards. Before combining the hazards into a multi-hazard index that reflects total estimated impacts from all disaster types, we apply a uniform adjustment to all values within a given region such that the total hazard-specific mortality for all places in the region equals the actual number recorded in EM-DAT. The combined, mortality-weighted multi-hazard index is then simply the sum of the individual hazard mortality estimates for a given place.

Table 2. Mortality-related vulnerability coefficients.

Region and wealth status	**Cyclone**	**Drought**	**Earthquake**	**Flood**	**Landslide**	**Volcano**
Africa						
Low	5.06	118.97		1.51	0.95	79.10
Lower middle	59.35	1.10		3.10	0.00	0.00
Upper middle	0.57	0.00		2.18		
High	5.10	0.00				0.00
East Asia and the Pacific						
Low	10.17	0.42	2.60	2.24	2.08	0.79
Lower middle	5.03	0.15	3.17	2.22	4.74	13.20
Upper middle	39.22	0.00		0.51	23.31	
High	1.33	0.00	5.48	1.10	1.20	0.51
Europe and Central Asia						
Low		0.00	0.75	2.82	5.69	
Lower middle	2.50	0.00	62.16	0.67	1.46	0.00
Upper middle		0.00	0.00	0.33	0.00	
High	1.65	0.00	1.77	0.25	2.67	0.00
Latin America and the Caribbean						
Low	39.72	0.00	4.22	2.36	0.00	0.12
Lower middle	44.16	0.00	3.24	4.44	8.53	231.68
Upper middle	4.27	0.01	13.86	11.21	4.24	1.62
High	3.26	0.00	0.00	0.00	0.00	0.00
Middle East and North Africa						
Low		0.00		5.81		0.00
Lower middle		0.00	271.25	5.11	2.54	
Upper middle		0.00	0.00	0.54	1.91	0.00
High	0.00	0.00	0.00	0.19		
North America						
High	1.01	0.00	0.39	0.19	0.00	0.00
South Asia						
Low	64.52	0.04	8.04	3.90	7.04	
Lower middle	0.20	0.00				
Upper middle						
High		0.00				

These are based on hazard-specific historical mortality rates (persons killed during 1981-2000 per 100,000 persons in 2000) used to weight population exposure to estimate mortality risk (blank cells indicate insignificant recorded historical losses; the number of historical events available to calculate each weight varies, with some weights based on as few as 5-10 events).

Table 3. Economic loss-related vulnerability coefficients.

Region and wealth status	Cyclone	Drought	Earthquake	Flood	Landslide	Volcano
Africa						
Low	38.97	5.55		0.65	0.00	0.00
Lower middle	127.01	0.01		2.33	0.00	0.00
Upper middle	18.49	9.88		0.00		
High	5.24	0.00				0.00
East Asia and the Pacific						
Low	59.47	0.66	0.92	25.97	0.07	7.58
Lower middle	8.62	0.54	10.72	17.45	0.08	12.02
Upper middle	953.20	0.00		0.07	0.00	
High	4.02	8.54	47.97	1.53	0.17	0.00
Europe and Central Asia						
Low		4.52	16.34	5.56	3.80	
Lower middle	0.00	0.76	82.12	24.96	4.23	0.00
Upper middle		4.13	0.00	10.13	0.00	
High	24.04	3.29	19.23	4.23	4.65	0.31
Latin America and the Caribbean						
Low	71.65	7.50	2.23	0.36	0.00	0.17
Lower middle	48.84	2.74	8.82	7.04	3.97	22.94
Upper middle	14.48	1.28	11.72	5.88	1.04	0.37
High	104.27	0.00	0.00	0.00	0.00	0.00
Middle East and North Africa						
Low		0.00		168.87		0.00
Lower middle		9.35	38.98	5.90	0.00	
Upper middle	0.00	0.00	0.00	10.60	0.00	0.00
High		1.03	0.00	0.00		
North America						
High	13.00	0.97	30.82	2.84	0.00	0.00
South Asia						
Low	26.64	0.18	1.33	7.00	0.07	
Lower middle	0.00	0.00		5.26		
Upper middle						
High		0.00				

These are based on hazard-specific historical economic rates (economic losses per $100,000 GDP in 2000 during 1981-2000) used to weight GDP exposure to obtain economic loss risks (blank cells indicate insignificant recorded historical losses; the number of historical events available to calculate each weight varies, with some weights based on as few as 5-10 events).

Text Box 1. Risk assessment procedure for both mortality and economic losses, illustrated by the mortality example.

1. We extract the appropriate measure of total global losses from 1981-2000 from EM-DAT (in the mortality case, the number of fatalities) by hazard h: M_h .
2. Using the GIS data on the extent of each hazard, we compute the total population estimated to live in the area affected by that hazard in the year 2000: P_h .
3. We then compute a simple mortality rate for the hazard: $r_h = M_h / P_h$. If we assume that the 1981-2000 period was representative, this rate is an estimate of the proportion of persons killed during a 20-year period in the area exposed to that hazard. Since the numbers are very small, they are expressed per 100,000 persons in 2000. Future revisions of the index could construct a mortality rate for the 20-year period based on annual rates which are computed using yearly mortality and population figures. As the results are intended only as an index of disaster risk, however, we believe that the computational simplification of using only end-of-period population is justified.
4. For each GIS grid cell i that falls into a hazard zone h, we compute the location-specific expected mortality by multiplying the global hazard-specific mortality rate by the population in that grid cell: $M_{hi} = r_h * P_i$. We do this for all six hazards, then compute a mortality weighted multi-hazard index value for each grid cell: $Y_i = \sum_{h=1}^{6} M_{hi}$. This first estimate represents an unweighted index value that assumes that mortality rates are globally uniform and that hazard severity has no influence on the relative distribution of mortality. In the following steps we relax these assumptions.
5. If we denote the various combinations of region and country-wealth status (see Table 2) by j, then the estimated mortality in a given grid cell is now $M_{hij} = r_{hj} * P_i$.
6. The global hazard data compiled for the analysis measures the degree of hazard in terms of frequency in most, although not all, cases (see Table 1). The various degree of hazard measures are used to redistribute the total regional mortality from EM-DAT across the grid cells in the area of the region exposed to each hazard. For example, if a grid cell were hit four times by a severe earthquake during the 20-year period, the regional mortality rate is multiplied by four to yield an accumulated mortality for that grid cell. More generally, if the degree of hazard measure is denoted by W, and assuming that the weighting scheme is identical across region/wealth-class combinations j, the accumulated mortality in the grid cell is:
$M'_{hij} = r_{hj} * W_{hi} * P_i$.

Since the degree of hazard is not always measured on the same scale across hazards, simply adding up the resulting values would result in an index that could be unduly dominated by a hazard that happens to be measured on a scale with larger values. We therefore deflate the weighted hazard-specific mortality figures uniformly, so that the total mortality in each region adds up to the total recorded in EM-DAT. The resulting weighted mortality from hazard *h* in grid cell *i* and region/wealth-class combination *j* is thus:

$M^{*}_{hij} = M^{'}_{hij} * M_{hj} / \sum_{i=1}^{n} M^{'}_{hij}$, where *n* is the number of grid cells in the area exposed to hazard *h*. Future revisions could be based on alternative definitions of severity such as wind speed and duration for storms or earthquake and volcanic eruption magnitudes.

7. A mortality-weighted multi-hazard disaster risk hotspot index can be calculated as the sum of the adjusted single-hazard mortalities in the grid cell across the six hazard types:

   $$Y^{*}_{i} = \sum_{h=1}^{6} M^{*}_{hij} \quad .$$

8. To avoid literal interpretation of the multi-hazard disaster risk hotspot index as the number of persons expected to be killed in a 20-year period and in recognition of the many limitations of the underlying data, we convert the resulting measure into an index from one to ten using a classification of the global distribution of unmasked grid cell values into deciles.

Reporting actual mortality numbers would portray an unrealistic impression of precision. Our more modest objective here is to provide a relative representation of disaster risk. For cartographic output and interpretation we therefore convert the resulting numbers into index values from one to ten that correspond to deciles of the distribution of place-specific aggregate mortality.

The mortality-weighted multi-hazard index is obviously strongly influenced by the choice of measure for the degree or severity of hazard. Ideally we would have sound rules for applying these and guiding the re-allocation of mortality within regions. If we think of hazard mortality in epidemiological terms, we can think of measures of severity (frequency, duration and magnitude, or combinations thereof) as the right-hand side term in a dose-response function that links the magnitude of an event to the resulting mortality. The form of this function could be linear or exponential (e.g., stronger storms cause proportionally higher damage), or it could be defined by some kind of threshold value (for example, serious damage only occurs beyond a certain wind speed). Given a large enough set of records of hazard events and outcomes—combined with additional characteristics of the events and the exposed areas as controls—a dose-response function could be estimated empirically. This would provide a sounder empirical grounding of the proposed multihazard indicator and would also reduce the problem of including areas of relatively low risk in the definition of exposed areas. Clearly this represents a promising direction for future work.

To extend the mortality-weighted approach to economic loss risk assessment, we use the geographically referenced database of subnational GDP per unit area. Although the global GDP surface is less detailed than the population data set, it represents the best available disaggregated information on economic output. Carrying out the same steps as described above for mortality yields measures of economic losses per unit of GDP. Re-allocation of economic losses within regions and country wealth classes is again guided by hazard-specific loss weights based on historical economic losses from EM-DAT. The resulting economic damage-weighted multihazard disaster risk hotspots indicator reflects that although mortality impacts are lower in richer countries, economic losses for a given event are higher. For instance, a hurricane in southern Florida causes considerably more economic damage than a similar hurricane in a poorer country, since the value of real estate, infrastructure and other economically productive assets is much higher in the United States. Of course, such damage is usually a higher proportion of regional and national income in developing countries than in industrial countries and also higher relative to available resources for relief and construction.

Risk classification

Classification of hotspots on a global basis addresses the central concern of the project, the identification and characterization of high-risk natural disaster hotspots. Because of the limited time period and quality of the input data, we believe that it is appropriate to use the data to identify those areas at *relatively* high risk from a particular natural hazard, and to then compare the spatial distributions of the resulting maps. The data may be inadequate for assessing *absolute* levels of risk or for detailed comparisons of levels of risk across hazards. For a number of the available hazard datasets, such as those based on media reports, we also expect that relatively small or modest events may be substantially undercounted, especially in developing countries where reporting is likely to be less complete.

We therefore divided the total number of grid cells into *deciles*, ten groups of approximately equal number of cells, based on the value of each individual hazard indicator. Cells with the value of zero for an indicator were excluded. When hazard indicators have large numbers of cells with the same values (cyclones, drought, floods and earthquakes), deciles may be grouped together. For example, the result of dividing the flood data into deciles results in output values of 1, 4, and 7 through 10. Since many grid cells have only one or two flood events, the first through third deciles are combined and given the output value 1, and the fourth through sixth deciles are combined and given the output value 4. In all cases, the combined deciles are at the low end of the scale (sixth decile or less).

In general, at least the top three deciles of cells were needed to identify areas of known hazard around the world. As an initial arbitrary cutoff, we therefore chose the top three deciles as our first-order definition of "relative significance" in terms of hazard frequency or probability, exposure, and overall risk. Some cells are classified as relatively high in significance according to more than one hazard, i.e., they fall within the top three deciles of more than one hazard indicator. We therefore build an index that simply sums the decile values for each hazard, with 8 representing the third highest decile, 9 representing the second highest decile, and 10 the highest decile. Thus, a cell in the third decile for just one hazard would have an index value of 8, and a cell in the third highest decile for just two hazards would have an index value of 16. A cell in the top three deciles for three hazards would have an index value between 24 and 30.

Using the same cutoff of the top three deciles for each natural hazard identifies those cells that are at higher relative probability compared with other cells for each hazard, but does not necessarily result in comparable levels of absolute probability across hazards. That is, a cell in the top three deciles for both flood and drought hazards does not necessarily face the same probability of hazard occurrence in terms of drought and flood frequency and intensity. Moreover, hazards such as floods, earthquakes, and volcanoes have very different patterns of occurrence, in terms of their spatial distributions, temporal recurrence, and event characteristics, making absolute intercomparisons difficult. Given the very limited data records available at the global scale, we think that it is currently impossible to determine comparable absolute levels of probability. Moreover, the potential exposure of land, population, and other features of each cell varies greatly both across cells and over time, so that the overall level of risk faced in a multi-hazard hotspot will be determined by a range of highly uncertain factors.

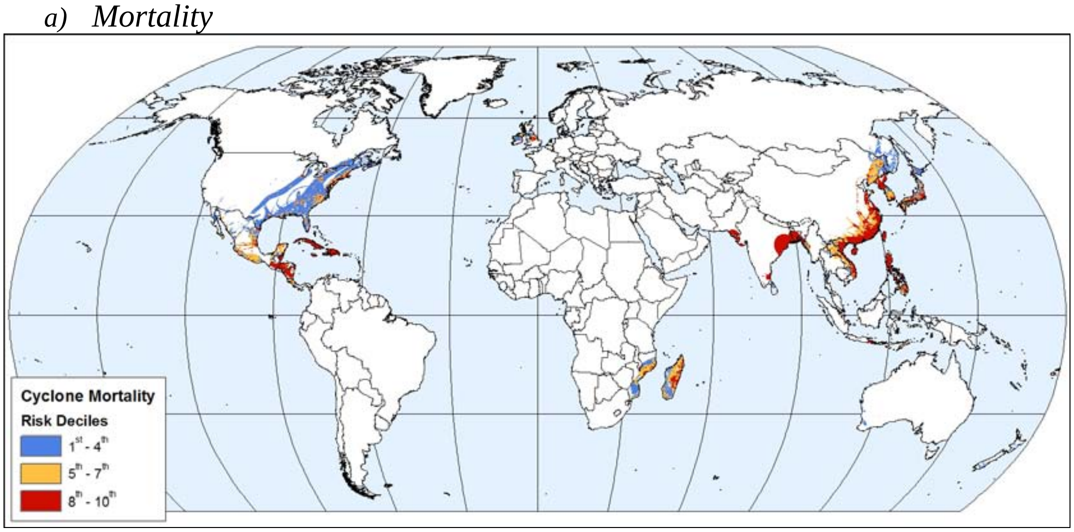
Results

Global results below are for risks of mortality- and economic loss-related outcomes associated with each of the six natural hazards (Figures 2-7). Risks of mortality and economic losses for all hazards combined are given in Figure 8.

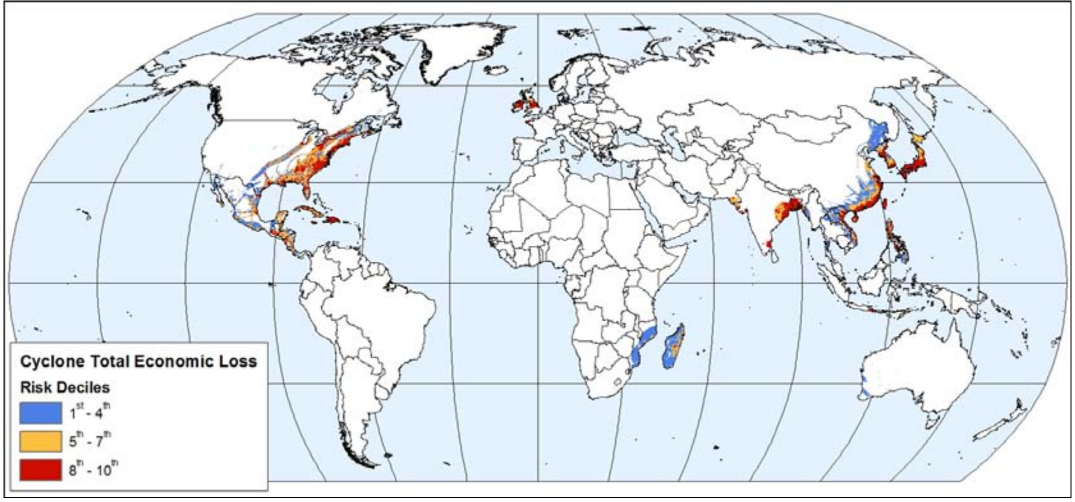
We created the multi-hazard index shown in Figure 8 by summing decile category values between 8 and 10 across all six natural hazards. This results in a multihazard index that reflects the number of hazards considered relatively significant in a particular grid cell. Cells that are in the highest decile for multiple hazards will also rank slightly higher than those composed of slightly lower single-hazard decile values.

Figure 2. Global distribution of cyclone risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

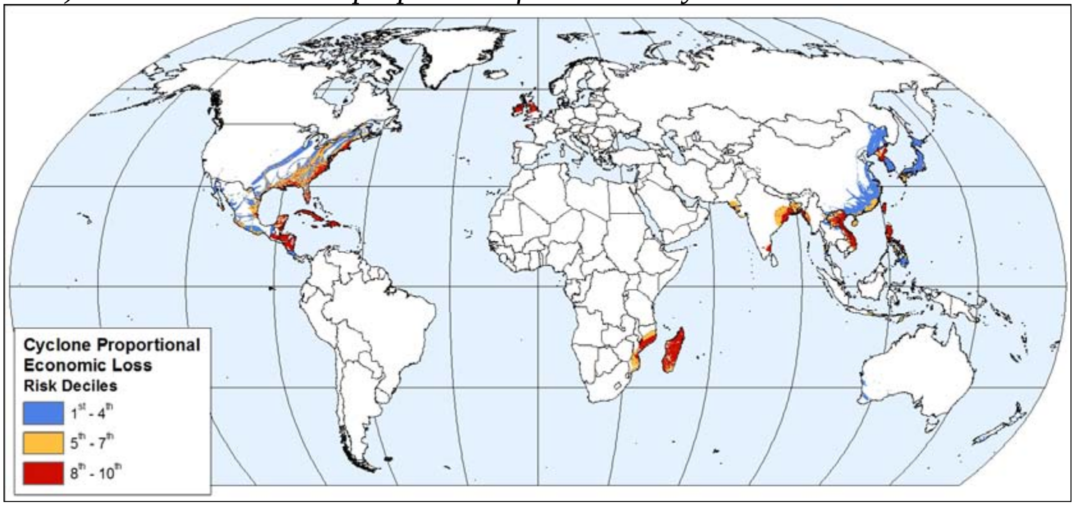
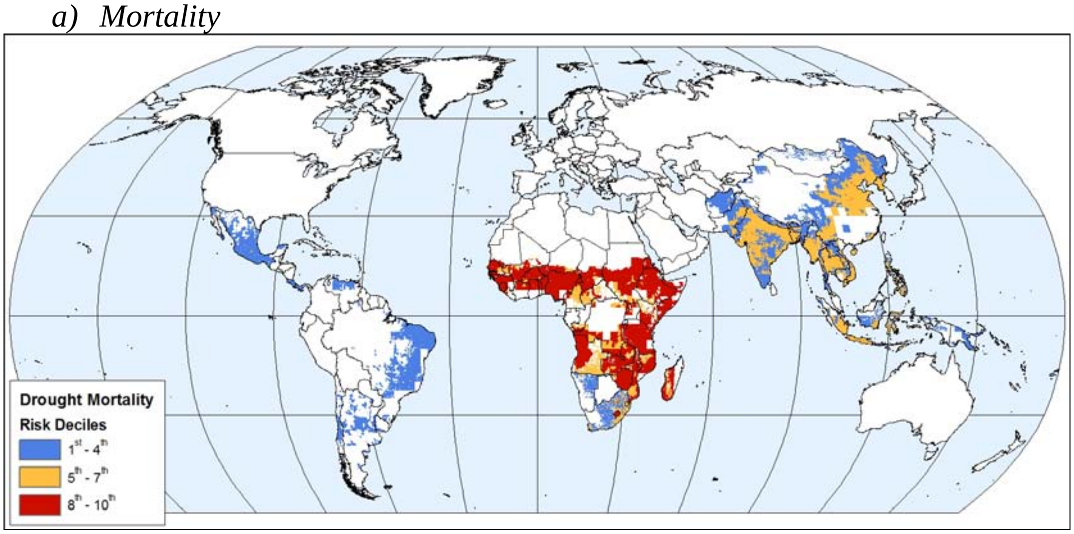
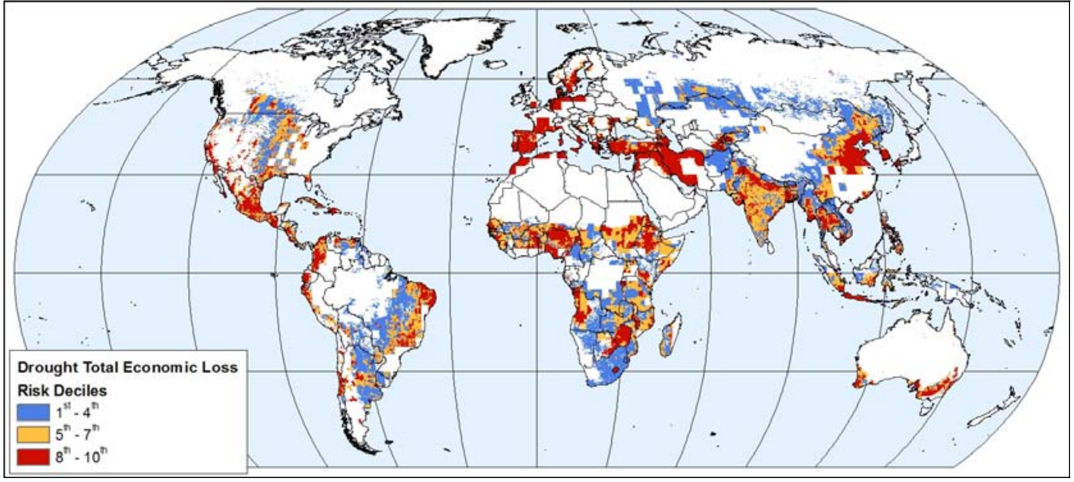


Figure 3. Global distribution of drought risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

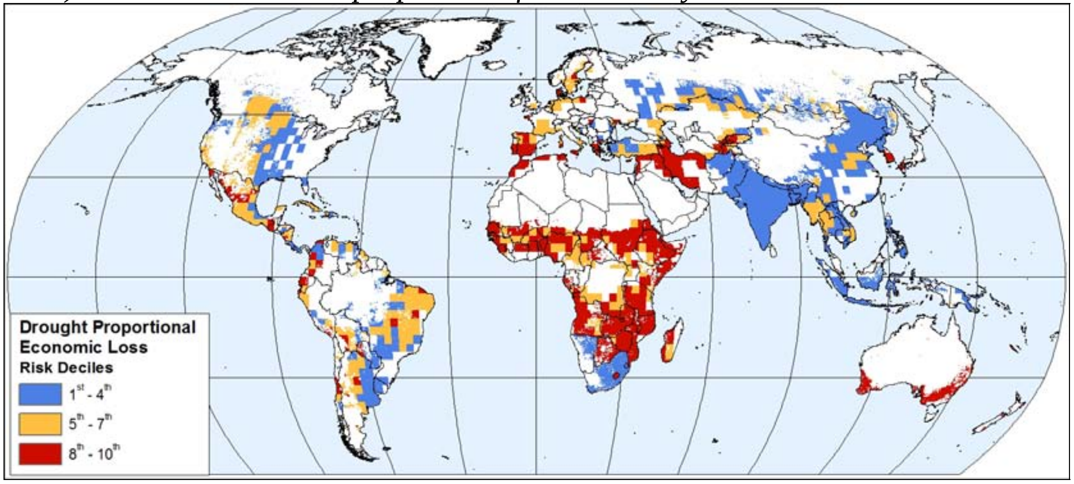
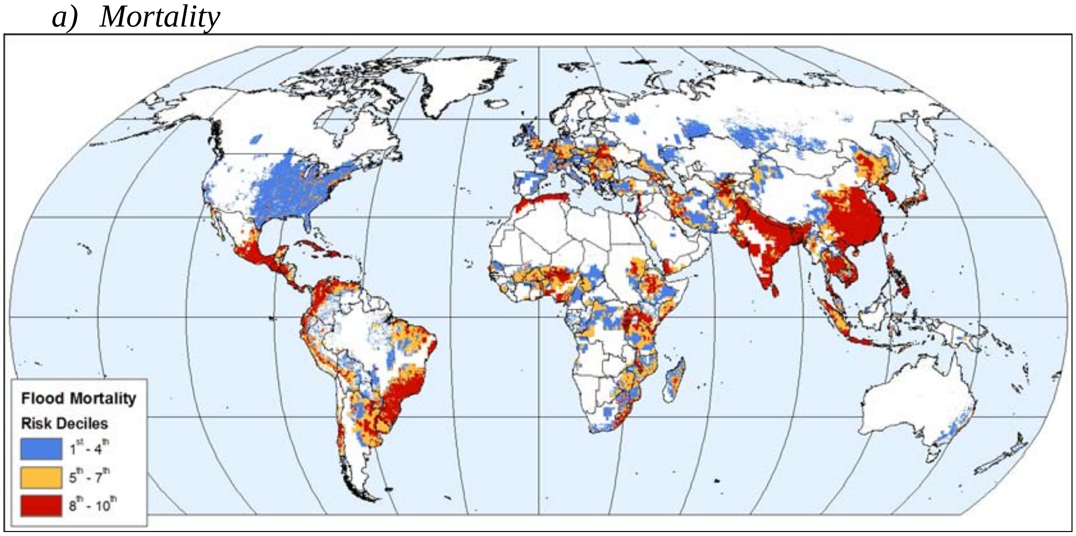
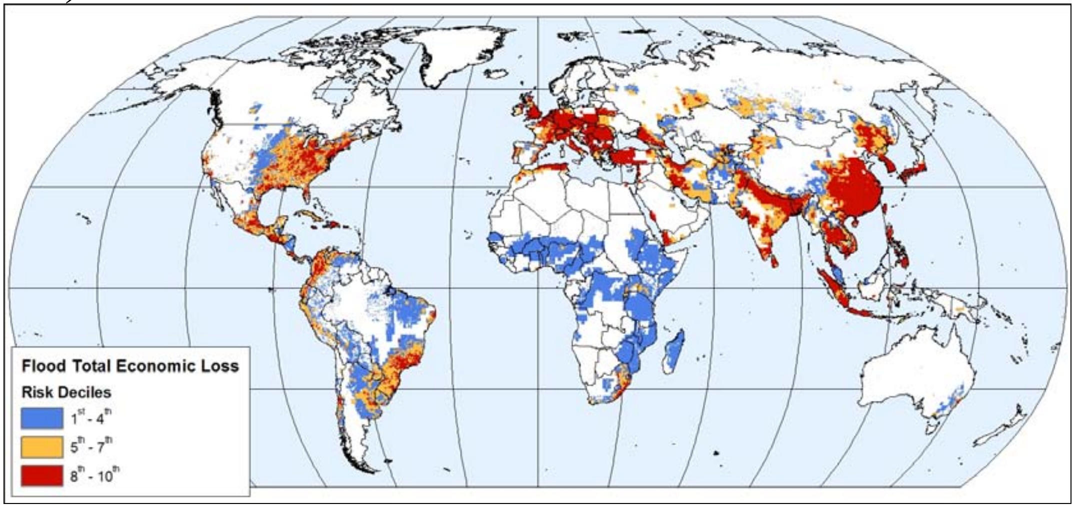


Figure 4. Global distribution of flood risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

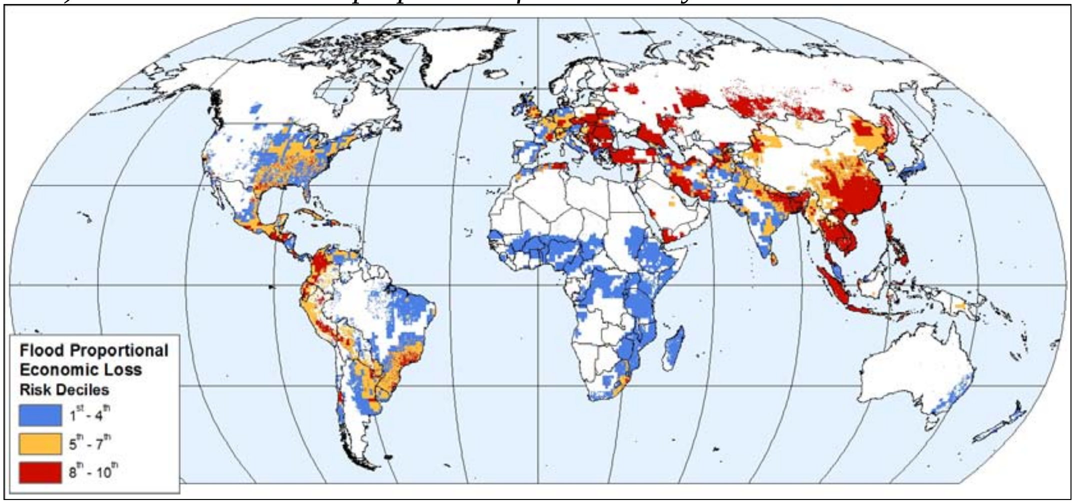
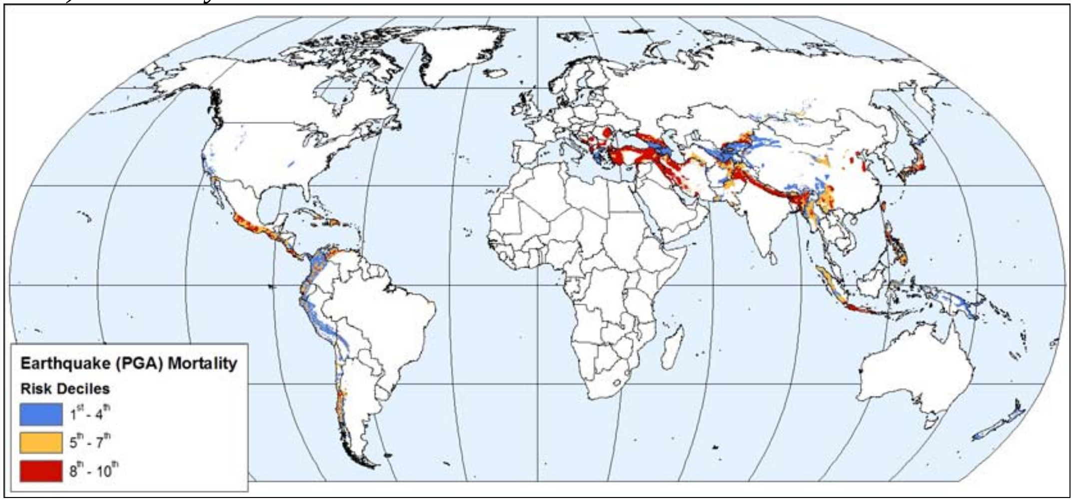
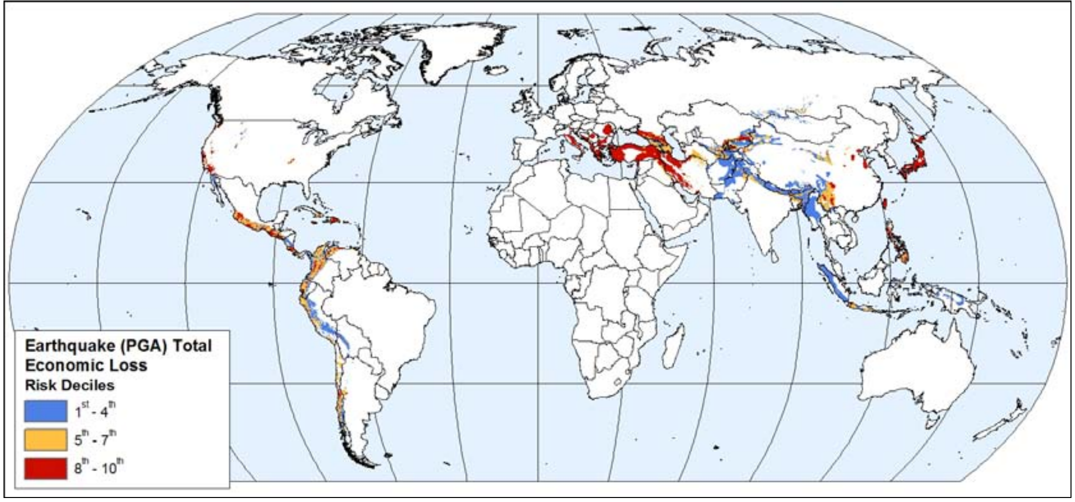


Figure 5. Global distribution of earthquake risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

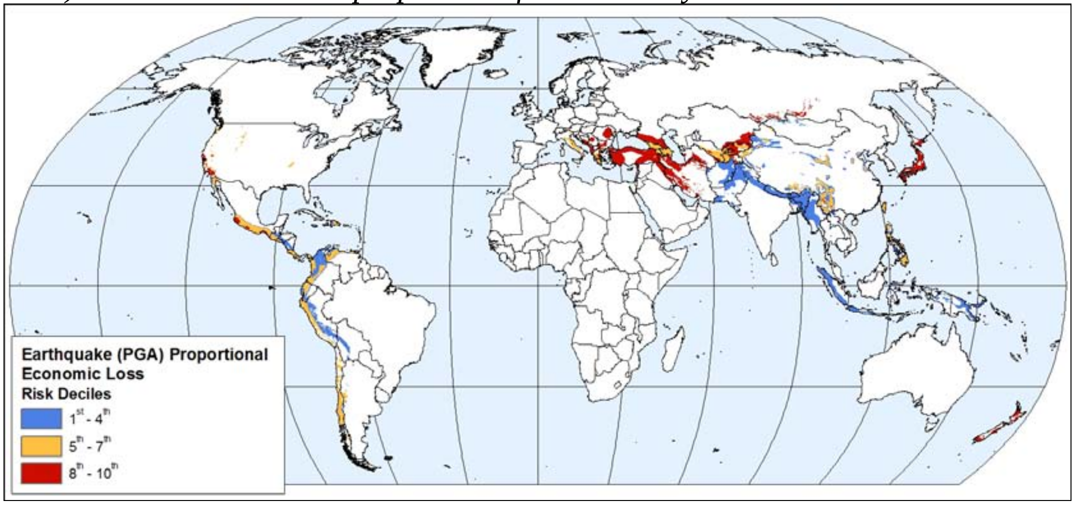
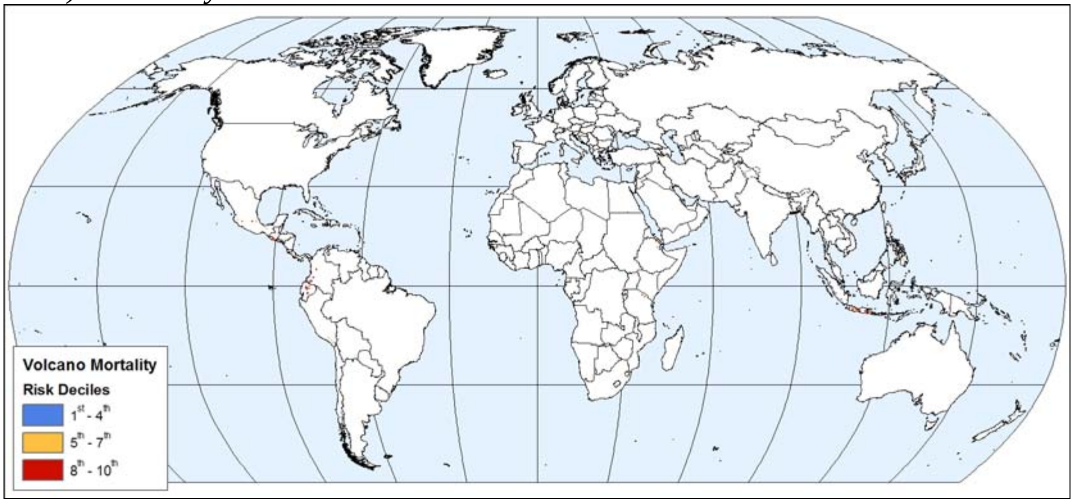
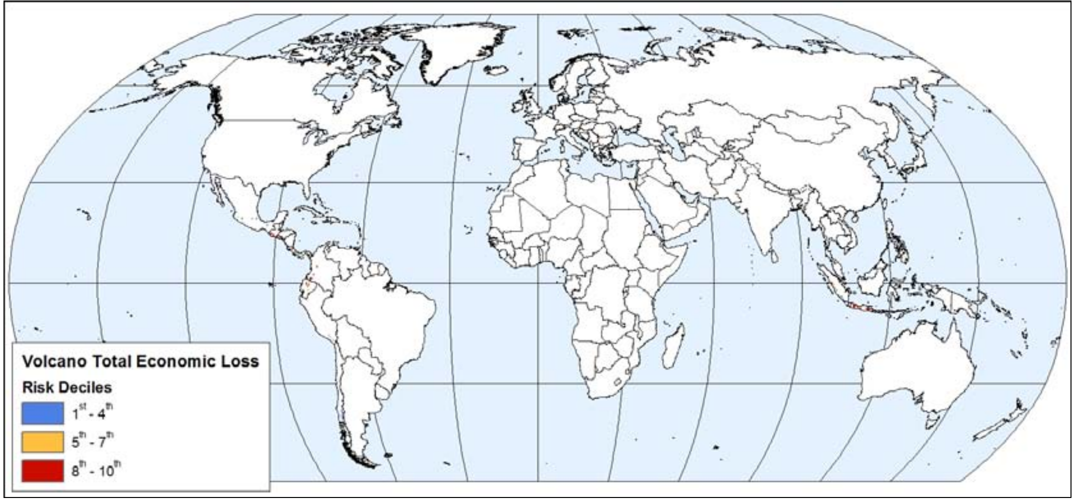


Figure 6. Global distribution of volcano risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

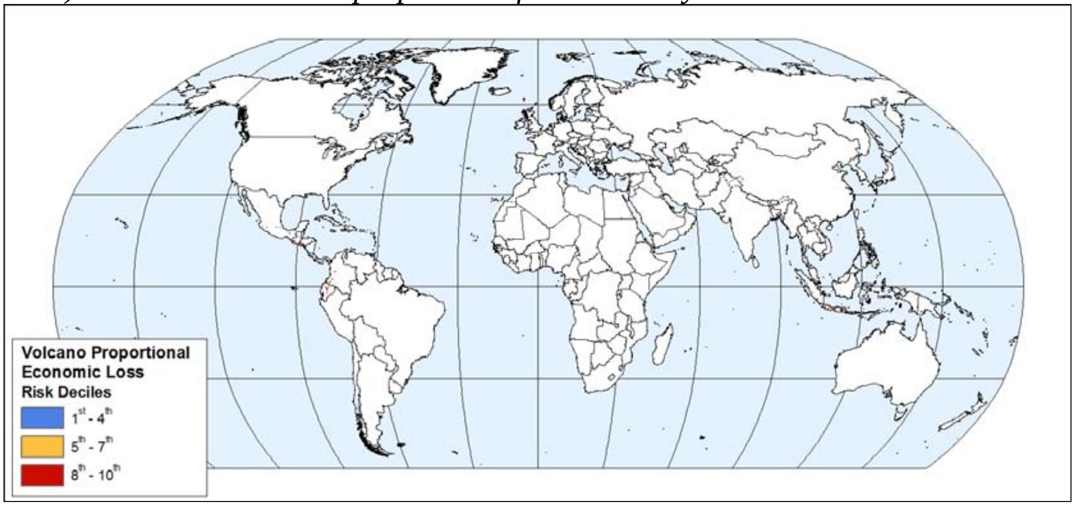
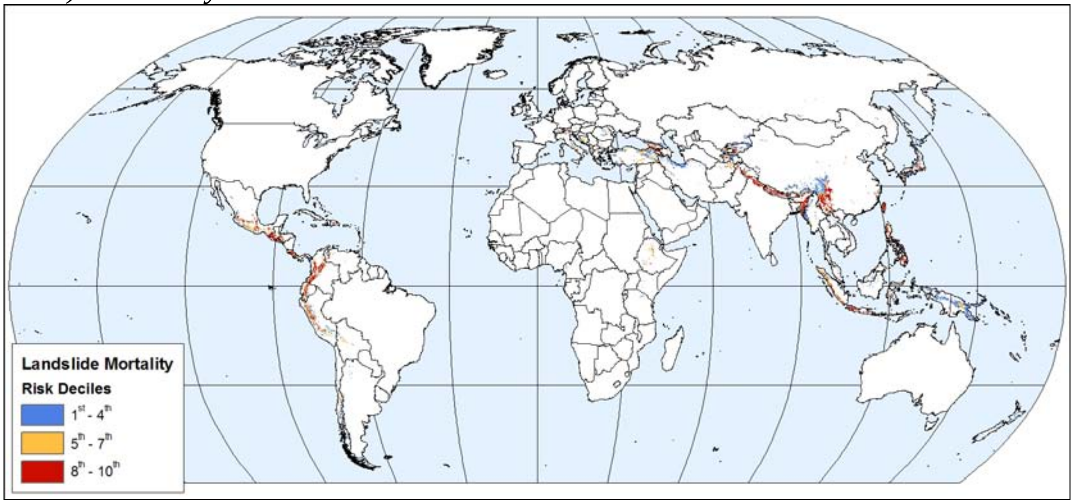
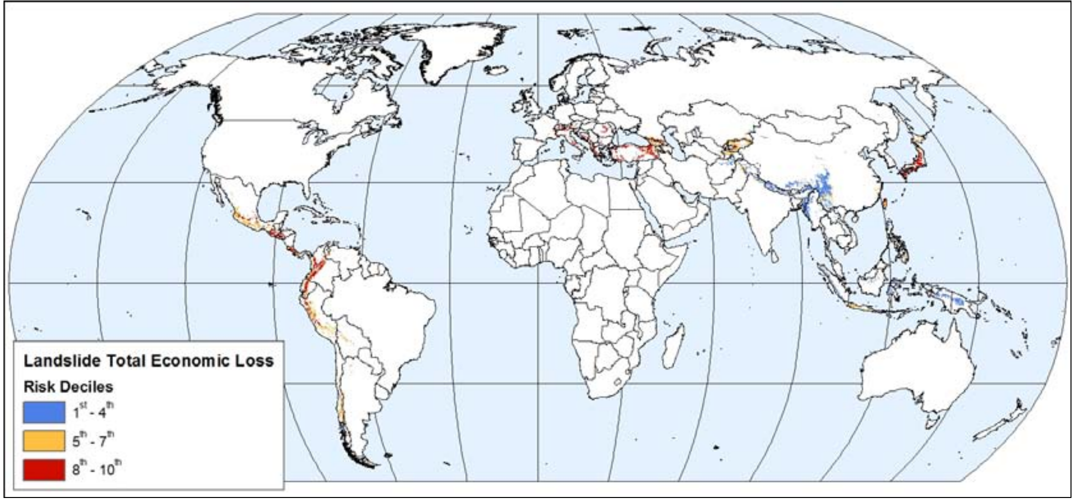


Figure 7. Global distribution of landslide risk.

a) Mortality



b) Total economic loss



c) Economic loss as a proportion of GDP density

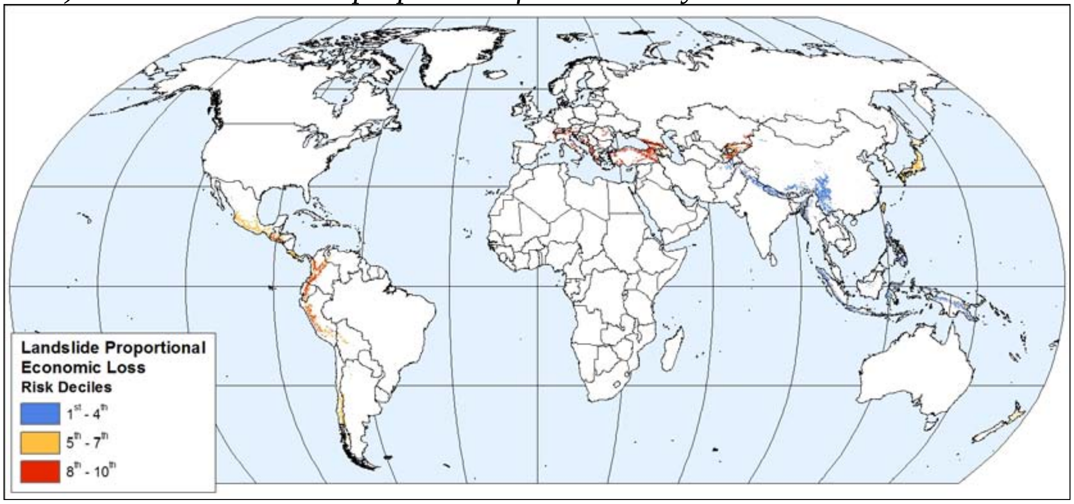
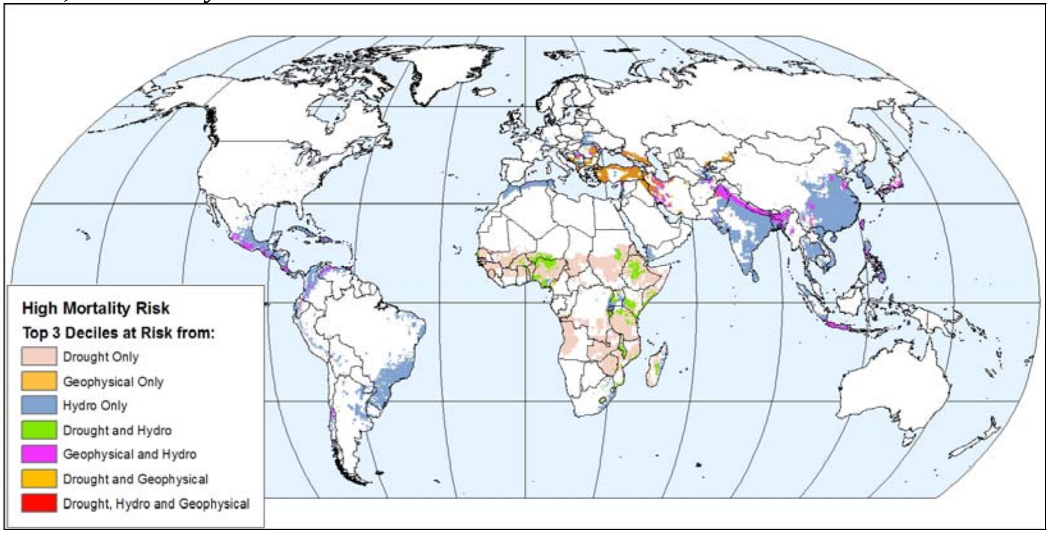
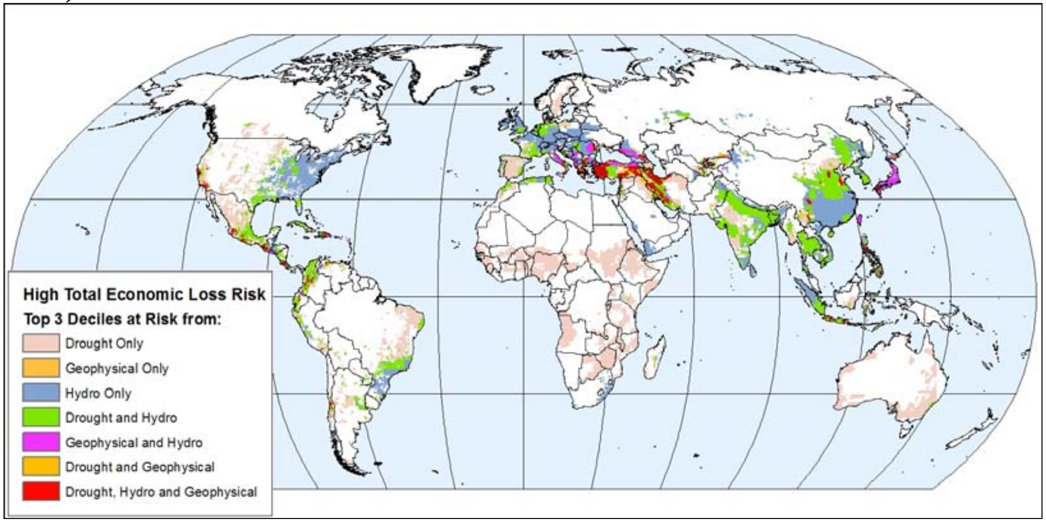


Figure 8. Global distribution of highest-risk disaster hotspots by hazard type.

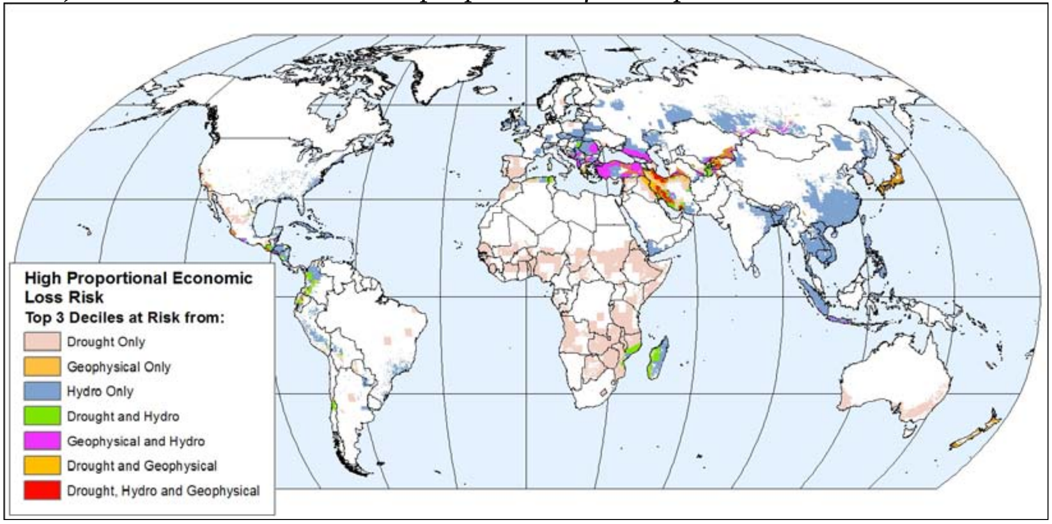
a) Mortality risks



b) Total economic loss risks



c) Economic loss risks as a proportion of GDP per unit area



Interpretation

The significance of high mortality and economic loss risks for socioeconomic development indicated in this analysis extends well beyond the initial direct losses to the population and economy during disasters. Covariate losses accompanying mortality, for example, include partial or total loss of household assets, lost income, and lost productivity. Widespread disaster-related mortality can affect households and communities for years, decades, and even generations.

In addition to mortality and its long-term consequences, both direct and indirect economic losses must also be considered (ECLAC and the World Bank, 2003). Direct losses are losses of assets, whereas indirect losses are losses that accrue while productive assets remain damaged or destroyed. During disasters, both direct losses and indirect losses accumulate across the social, productive and infrastructure sectors. The pattern of losses depends on the type of hazard involved and the affected sector's vulnerabilities to the hazard. In large disasters, cumulative losses across sectors can have macroeconomic impacts.

Disasters impose costs in addition to human and economic losses. Additional costs include expenditures for disaster relief and recovery and for rehabilitation and reconstruction of damaged and destroyed assets. In major disasters meeting these additional costs can require external financing or international humanitarian assistance.

This combination of human and economic losses plus the additional costs of relief, rehabilitation, and reconstruction make disasters an economic issue as well as a humanitarian one. Disaster risks, therefore, deserves serious consideration as an issue for sustainable development.

The costs of disaster risks

Until vulnerability, and consequently risks, are reduced, countries with high proportions of population or GDP in hotspot areas are especially likely to incur repeated disaster-related losses and costs. Data on relief costs associated with natural disasters is available from the Financial Tracking System (FTS) of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) for 1992 through 2003. The FTS database contains information on all humanitarian aid contributions as reported to OCHA by international donors (http://www.reliefweb.int/fts/). Total relief costs from 1992 through 2003 are $2.5 billion. Of this, $2 billion went to just 20 countries: China, India, Bangladesh, Egypt, Mozambique, Turkey, Afghanistan, El Salvador, Kenya, Iran, Pakistan, Indonesia, Peru, Democratic Republic of Congo, Poland, Vietnam, Colombia, Venezuela, Tajikistan and Cambodia (Figure 9).

The World Bank provided data for this study on emergency loans and reallocation of existing loans to meet disaster reconstruction needs from 1980 through 2003 for this study (http://www.worldbank.org/hazards). The total emergency lending and loan reallocation from 1980 through 2003 was $14.4 billion. Of this, $12 billion went to the top 20 countries: India, Turkey, Bangladesh, Mexico, Argentina, Brazil, Poland, Colombia, Iran, Honduras, China, Chile, Zimbabwe, Dominican Republic, El Salvador, Algeria, Ecuador, Mozambique, Philippines and Vietnam (Figure 10).

Figure 9. Mortality risk hotspots and the top 20 recipients of humanitarian relief (1992-2003).

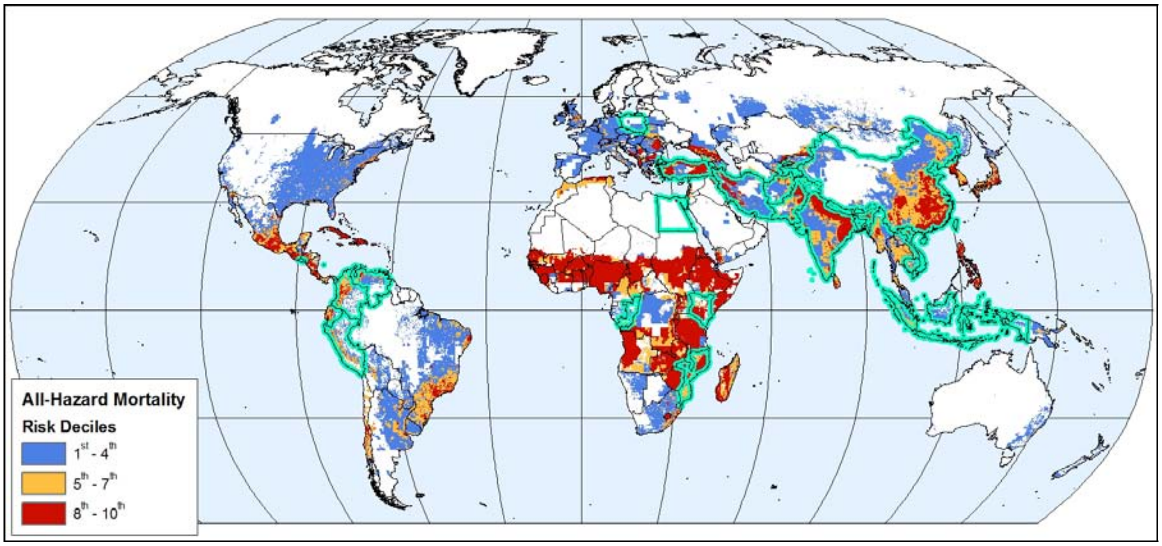
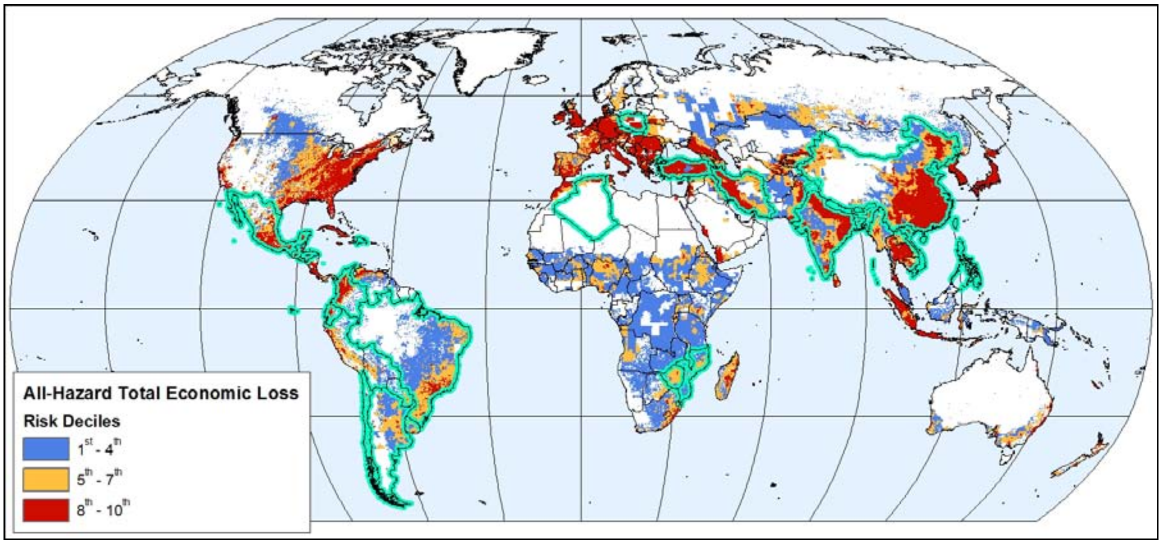


Figure 10. Total economic loss risk hotspots and the top 20 recipients of World Bank emergency lending and loan reallocation (1980-2003).



Many countries highlighted in Figures 9 and 10 have high proportions of population, GDP per unit area or land surface within areas classified as multi-hazard, high mortality and total economic loss risk hotspots, respectively. Presumably, as disasters continue to occur, these and other high-risk countries will continue to need high levels of humanitarian relief and recovery lending unless their vulnerability is reduced.

Disaster relief costs drain development resources from productive investments to support consumption over short periods. Emergency loans have questionable value as vehicles for long-term investment and contribute to country indebtedness without necessarily improving economic growth or reducing poverty.

The most significant implications of having large numbers of people, national GDP, or land surface at risk can be seen in profiles of economic losses from six illustrative disasters in which losses were assessed using a standardized and comprehensive methodology (ECLAC and the World Bank, 2003). The assessment method used allows losses to be disaggregated by sector and into direct losses of assets as well as indirect losses to production due to the loss of productive assets. A look at losses by sector and hazard type for these six disasters clarifies the financial implications of future losses for hotspot areas, and suggest what actual losses may have been in thousands of past disasters for which comprehensive assessments were not conducted.[10]

Total direct and indirect losses for six major disasters were obtained from the Economic Commission for Latin America and the Caribbean (ECLAC) and the World Bank. These disasters were earthquakes in Turkey in 1999 and in India and El Salvador in 2001, Hurricane Keith in Belize in 2000, the Mozambique floods of 2000 and a drought in Central America in 2001 (Table 4). The total direct and indirect loss for these six disasters alone was $9.5 billion. Relief costs (OCHA) and reconstruction loans (World Bank) totaled $487.4 million and $1.4 billion respectively–5 percent and 14 percent, respectively, of the total estimated loss.

Neither the OCHA relief costs nor the World Bank reconstruction loan figures necessarily fully account for the total relief and reconstruction expenditures in these six disasters. Nevertheless the above figures, where data on all three variables are available, suggest that economic losses across all sectors in disasters may considerably exceed the costs of relief and reconstruction. That suggests that the greatest financial implications of the hotspot areas are with respect to potential future economic losses.

Table 4. Direct and indirect losses for six major disasters.

Hazard	Year	Country	Social Sectors (10^6 US$)	Infrastructure Sectors (10^6 US$)	Productive Sectors (10^6 US$)	Environment and Other (10^6 US$)	TOTAL (10^6 US$)
Earthquake	1999	Turkey (Marmara)	2,187	739	1,850	0	4,776
Earthquake	2001	India (Gujarat)	1,302	334	440	55	2,131
Earthquake	2001	El Salvador	472	398	275	68	1,212
Hurricane	2000	Belize	38	44	165	407	655
Flood	2000	Mozambique	69	133	281	5	488
Drought	2001	(Central America)	124	3	83	0	210
		TOTAL	*4,191*	*1,651*	*3,095*	*535*	*9,472*

Sources: ECLAC and the World Bank.

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[10] Due to the fact that data from comprehensive assessments of direct and indirect economic losses have not been systematically compiled and reported to date, economic loss estimates in EM-DAT, where they exist, are based on *ad hoc* reporting.

Implications for decision-making

The Hotspots analysis has implications for development investment planning. disaster preparedness and loss prevention. The highest-risk areas are those in which disasters are expected to occur most frequently and losses are expected to be highest. This provides a rational basis for prioritizing risk reduction efforts and highlights areas where risk management is most needed.

For preparedness, identification of high risk areas provides a basis for contingency planning. The global analysis is appropriate for identifying which types of hazards affect which parts of countries and groups of countries. This allows international relief organizations to anticipate what types of problems might occur, and where, and plan accordingly.

For preventing losses, risk identification paves the way for risk reduction and risk transfer. Currently risks are so high in some areas that they are uninsurable. Reducing them would create possibilities for creating opportunities for at-risk populations or countries to sell a portion of their risk instead of bearing it all themselves.

The resolution of the global data is most appropriate for only very general types of international-scale decision-making, however, and the global map indicates the need for more localized work with better data. In particular more localized work allows greater specificity with respect to identification of vulnerability factors, which is important since vulnerabilities also constitute the greatest opportunities for risk reduction. The fact that the methods used for assessing risks globally can be used for work at the national and local level is demonstrated in the forthcoming Hotspots report volume two containing a series of case studies.

Summary and Conclusions

The above analysis demonstrates that hazard and vulnerability risk factors can be used to obtain disaster risks measured in terms of various types of outcomes. The identification of risk factors, and the correspondence between assessed risks and historical disaster patterns, makes these risks foreseeable, creating an onus for action to reduce risks and losses through pre-emptive action rather than perpetuating a repetitive cycle of disaster, relief and recovery. In high risk areas, where disasters are most frequent and losses highest, failure to reduce risks allows disaster losses to continually drain off hopes of economic development.

The data available globally limits the sophistication of the methods that can be employed to do further work on risk assessment at the global level. Improvement and refinement of the underlying database, taking advantage of both new global-scale datasets currently under development and much more comprehensive regional datasets available in specific regions of interest, would advance future research. CIESIN has developed a global urban extent database in support of the Millennium Ecosystem Assessment that will greatly improve understanding of urban exposure to hazards. CIESIN is also working with the

World Bank and the United Nations Millennium Project to develop better measures of poverty distribution at the subnational level. Much longer records of hazard events for specific regions such as the Caribbean and the Pacific and Indian Oceans could also be harnessed to improve estimates of hazard frequency and intensity in high-risk areas.

More could be done to compile and cross-check existing data on economic and human losses from multiple sources to improve the global disaster loss database. Improvements in data collection would strengthen databases over the long term and contribute to more accurate risk assessment.

The likely reoccurrence of disasters in areas identified as disaster risk hotspots, as well as the high economic losses associated with such events, suggest that aggressive measures are warranted to reduce risks of future losses in such areas. The current global analysis is of a first-order nature. To design risk management strategies at the national and local level, more in-depth risk assessments using more highly resolved and comprehensive hazard, vulnerability and exposure data would be needed. The hotspot areas identified in the current analysis suggest areas where further research along these lines may be advisable. We therefore recommend an effort to generate additional case studies beyond those in volume two of the full Hotspots report (forthcoming), working directly with partner organizations and in-country experts and guided by the theoretical and methodological framework described above.

Finally, a key long-term issue from both a scientific and policy perspective is the potential effect of underlying changes in hazard frequency—e.g., due to human-induced climatic change—coupled with long-term trends in human development and settlement patterns. To what degree could changes in tropical storm frequency, intensity, and tracks interact with continued coastal development (both urban and rural) to increase risks of death and destruction in these regions? Are agricultural areas, already under pressure from urbanization and other land use changes, likely to become more or less susceptible to drought, severe weather, or floods? Although some aspects of these questions have been addressed in the general context of climate change impacts research, interactions between climate change, the full range of hazards, and evolving human hazard vulnerability have not been fully explored. This issue is of high interest to researchers at the Earth Institute at Columbia University, especially those at the Center for Hazards and Risk Research, IRI, and CIESIN.

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