United Nations

Department of Economic and Social Affairs

Population Division

Technical Paper

No. 2015/2

Risks of Exposure and Vulnerability to Natural Disasters at the City Level: A Global Overview

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Risks of Exposure and Vulnerability to Natural Disasters at the City Level: A Global Overview

Danan Gu, Patrick Gerland, François Pelletier, and Barney Cohen

United Nations · New York, 2015

Note

The views expressed in the paper do not imply the expression of any opinion on the part of the United Nations Secretariat.

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The term “country” as used in this paper also refers, as appropriate, to territories or areas.

This publication has been issued without formal editing.

PREFACE

The Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat provides the international community with timely and accessible population data and analysis of population trends and development outcomes for all countries and areas of the world. The Population Division provides guidance on population and development issues to the United Nations General Assembly, the Economic and Social Council and the Commission on Population and Development and undertakes regular studies on population estimates and projections, fertility, mortality, migration, reproductive health, population policies and population and development interrelationships.

The purpose of the *Technical Paper* series is to publish substantive and methodological research on population issues carried out by experts within and outside the United Nations system. The series promotes scientific understanding of population issues among Governments, national and international organizations, research institutions and individuals engaged in social and economic planning, research and training.

This paper examines risks of exposure and vulnerability to natural disasters at city level from a global perspective by using the data from the *2014 Revision* of the *World Urbanization Prospects* and the spatial hotspot data on risks of exposure and vulnerability to natural disasters from the joint research of Columbia University and the World Bank. The 2014 *Revision* of the *World Urbanization Prospects* includes the official United Nations estimates and projections of 1,692 urban agglomerations with 300,000 inhabitants or more on July 1, 2014. The spatial hotspot data include information collected for six types of disaster (cyclones, floods, droughts, earthquakes, landslides, and volcano eruptions). Risk of exposure to the six types of disaster and the vulnerability to disaster-related mortality and economic losses for these 1,692 cities are reviewed. Variations in risk of exposure and vulnerability across city sizes, development groups, major areas, and income groups are also presented. Our findings could be informative for better preparedness, development of adaptive strategies and improvement of resilience, and for addressing and achieving the United Nations sustainable development goals.

The paper was coauthored by Danan Gu, Patrick Gerland, François Pelletier, and Barney Cohen[1] of the Population Division. Earlier versions of the paper were presented at the annual meetings of the Population Association of America in 2013 and 2015, and at the International Seminar on Demographic Differential Vulnerability to Natural Disasters in the Context of Climate Change Adaptation, Kao Lak, Phang, Thailand in 2014. We are grateful to Ms. Sara Hertog, Ms. Cheryl Sawyer and Mr. Thomas Spoorenberg for their useful comments and suggestions.

The *Technical Paper* series as well as other population information is available on the Population Division's website at www.unpopulation.org. For further information concerning this publication, please contact the Office of the Director, Population Division, Department of Economic and Social Affairs, United Nations, New York, NY 10017, USA, by fax: 1-212-963-2147 or by email at population@un.org.

[1] Deceased on 19 September 2015.

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1. INTRODUCTION

Cities are centres for productive activities in industry and services (Brunn, Hays-Mitchell, and Ziegler, 2008). In many countries or areas, it is estimated that 70-80 per cent of the gross domestic product (GDP) is generated in urban areas (Weiss, 2001; Dobbs, Manyika, and Roxburgh, 2011). Indeed, urban centres are where the capacity of our economic development, the future of our society and our planet's ecosystem will be played out (Brunn, Hays-Mitchell, and Ziegler, 2008; Sassen, 2009). In 2014, about 54 per cent of the world's population lived in urban areas (United Nations, 2014), an increase from 43 per cent in 1990. By 2050, two-thirds of the world's population is projected to reside in urban settlements. The increasing concentration of population in urban areas, together with the high density of assets and the socio-economic and spatial vulnerabilities that characterize many cities, could make urban centres more susceptible to the risk of being severely affected by natural hazards than rural settings (Gencer, 2013).

An estimated two trillion US dollars were lost and one million people were killed worldwide due to natural disasters over the period 2000-2009 (United Nations Office for Disaster Risk Reduction (UNISDR), 2013: 38-39). Evidence has shown that rapid urbanization and population growth are root causes in the configuration of natural disaster risk (UNISDR, 2012; 2013). According to the *2011 Global Assessment Report on Disaster Risk Reduction,* over 80 per cent of disasters reported by national sources occurred in urban areas (UNISDR, 2011). The greater the number of people settled in at-risk areas, the higher the probability of casualties and economic losses as a result of climatic or geodynamic events. Therefore, it is crucial to investigate, for the world's major cities, the potential risks of exposure, economic losses and mortality due to natural disasters, environmental degradation and climate change (Dilley et al., 2005).

Urbanization has become a leading issue in the context of sustainable development. The need to reduce the risks posed by natural disasters in urban areas is increasingly urgent in the context of global climate change (Gencer, 2013; UNISDR, 2012). City planners and local governments have been recognized as key actors for reducing the risks posed by natural hazards and building resilient urban societies (UNISDR, 2010). Research on hazards and risks from different disciplines have also improved understanding of natural disasters, vulnerability and risk management (Gencer, 2013). Yet demographic factors related to the size, number, and geographic distribution of urban agglomerations, as well as to the projected patterns of growth of these urban agglomerations and urban populations, have not always been properly integrated into the analyses of climate change and disaster risk reduction (UNFPA, UNISDR, and UN-HABITAT, 2009; 2011). Such information could help improve understanding of the relationship between urbanization and sustainable development, and enable investigation of the potential risks faced by urban populations in the context of rapid urbanization. Moreover, such research can inform future urban development policies and plans that anticipate and respond to environmental challenges, economic growth, public service expansion, changing patterns of energy consumption, and the process of globalization.

The main objective of this technical paper is to provide a global overview of the potential risks of exposure and vulnerability to natural disasters for the world's major cities. In the global context of rapid growth of urban populations exposed to natural disasters, the paper aims to raise awareness about disaster-related risks of exposure and vulnerability faced by major urban areas so as to develop sound management for risk reduction and improved policy frameworks. The paper integrates city population data from the *2014 Revision* of the *World Urbanization Prospects* (WUP) (United Nations, 2014) with spatial hotspot data on risks of exposure and vulnerability to natural disasters produced by the international research community. Specifically, the paper reviews risks of exposure to six types of natural hazard/disaster summarized across cities classified by population size, major area, development group, and income group. It further analyzes vulnerability measures by risk of disaster-related mortality and economic loss. The next section describes the data sources and methodology used in this paper, followed by the presentation of major findings and conclusions.

2. DATA SOURCES AND METHODS

Three major datasets were used to fulfil the objective of this technical paper. The first was the time series on city populations from the *2014 Revision* of the WUP, which contained population estimates and projections from 1950 to 2030 for 1,692 cities of the world with 300,000 inhabitants or more on 1 July 2014. These 1,692 cities collectively were home to 2.2 billion inhabitants in 2014 [2], accounting for 56 per cent of the global urban population of 3.9 billion. The term "city" in this paper was used in a non-precise way, and may refer to a city proper, an urban agglomeration or a metropolitan area.

The second dataset used in this analysis was spatial hotspot data on risks of exposure and vulnerability to natural disasters produced jointly by multiple research institutes at Columbia University[3] and the World Bank[4] (http://www.ldeo.columbia.edu/chrr/research/hotspots/). The natural disaster data in this dataset included historical information on six types of disaster: cyclones (for the period between 1980 and 2000), floods (between 1985 and 2003), droughts[5] (between 1980 and 2000), earthquakes (between 1976 and 2002)[6], landslides[7], and volcano eruptions (between 1979 and 2000).

In the spatial hotspot dataset the events associated with the different types of natural disaster were published on spatial grids with different levels of resolution. Cyclones and landslides were published on a 30 by 30 arc *second* grid (about 1 km at the equator). Volcanic eruptions and earthquakes were published on a 2.5 by 2.5 arc *minute* grid (about 4.6 km at the equator). Floods were published on a 1 by 1 arc *degree* grid (about 110 km at the equator). Droughts were published on a 2.5 by 2.5 arc *degree* grid (about 280 km at the equator) (Dilley et al., 2005: 29). Grid cells with population density less than 5 persons per square kilometre and without significant agricultural activities were excluded from the natural disasters database for all six types of disaster. For each type of disaster and each grid cell, the spatial hotspot dataset records the frequencies of events, as well as the severity or scale of the impact of each event, with respect to both mortality and economic losses. All grid cells with data on the frequencies and the scales by type of disaster were apportioned into deciles, according to the frequency of the disaster. An area was classified as being at high risk of exposure to a particular type of natural hazard/disaster if it was located in grid cells ranking in the top three deciles of the global risk distribution in terms of frequency of occurrences of that specified natural disaster. An area was classified as being at medium level of risk if it was located in grid cells ranking from the 5th to the 7th deciles and at low level of risk if it was located in grid cells ranking from the 1st to the 4th deciles (Dilley et al., 2005: 33). Information on the occurrence or scale of disasters often is incompletely reported, thus the spatial hotspot database is unlikely to be comprehensive. 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, which makes absolute comparisons difficult (Dilley et al., 2005: 34). Using a measure of the relative frequency of natural disasters is thus preferred over comparisons of the absolute frequency of events in the database. However, note that the risk of exposure to each type of disaster was not strictly comparable across disasters. For example, a cell in the top three deciles for flood hazards does not necessarily face the same probability of hazard occurrence as a cell in the top three deciles for drought hazards in terms of

[2] Unless otherwise stated, the world's total city population in this paper refers to 2.2 billion inhabitants; likewise, the total number of cities in the world in this paper was set to 1,692. Furthermore, unless otherwise stated, the date of the size of population of urban areas refers to the mid-year of 2014.
[3] Including the Center for Hazards and Risk Research (CHRR), the Center for International Earth Science Information Network (CIESIN), the International Research Institute for Climate Prediction (IRI) and the Lamont-Doherty Earth Observatory (LDEO).
[4] Including the Disaster Management Unit (HMU) and the Development Economics Research Group (DECRG).
[5] Drought events are defined by periods during which monthly precipitation was lower than 50 per cent of the median value calculated for the period 1980-2000 during at least three consecutive months.
[6] Frequency of earthquakes greater than 4.5 on Richter Scale.
[7] Index of landslide and snow avalanche hazard. There were no date ranges for this type of disaster in the original report.

their frequency and intensity (Dilley et al., 2005). A detailed description of how the natural disaster data were generated and their limitations can be found at the aforementioned website and in the report entitled *Natural Disaster Hotspot: A Global Risk Analysis* (Dilley et al., 2005).

The risks of mortality and economic loss associated with a given type of disaster can vary substantially across populations, depending on the context. For example, drought hazards of the same apparent magnitude and affecting the same numbers of population may be associated with relatively higher mortality and smaller absolute economic losses in low-income countries, but with relatively lower mortality and larger absolute economic losses in high-income countries. Historical data have shown that droughts often had a relatively modest impact on overall mortality relative to the effect produced by other hazards (World Meteorological Organization, 2014). Thus risk indices should account for a population's degree of vulnerability to mortality and economic losses, in addition to the risk of exposure to natural hazards. Risk indices based solely on relative measures of hazard and exposure without vulnerability information could fail to identify accurately the severity of the risks posed by different types of natural hazard (Dilley et al., 2005: 55). Hazard-specific mortality risk was obtained for this analysis by multiplying hazard-specific mortality weights to the population at risk of exposure within each grid cell. There were two indicators for vulnerability risk in terms of economic losses in the work by Dilley and colleagues (2005). One was the total economic losses assessed for global gridded GDP per unit area, and the other was the magnitude of economic losses expressed as a proportion of the GDP per unit area for each grid cell (Dilley et al., 2005:2). Unless otherwise stated, the risks of economic losses refer to total economic losses. The hazard-specific risk of total economic losses was derived by applying hazard-specific economic loss weights to GDP per unit area for each grid cell. The mortality weight and economic loss weight were obtained from data on historical losses over the period of 1981-2000 (Dilley et al., 2005).

Because of very limited data, the estimates can only identify the areas that were at higher risk of economic losses or mortality than other areas for a given natural hazard. In other words, like the risk of exposure to natural hazards, risks of economic losses and mortality were expressed in relative terms. The classification of the relative risk of vulnerability to disaster-related mortality or economic loss was performed similarly to the classification of the relative risk of exposure to natural hazards described above. Specifically, for each single type of natural disaster, all grid cells worldwide with data on mortality risk were apportioned into deciles, such that there were 10 classes consisting of approximately equal numbers of grid cells with a greater value of a grid cell representing a greater risk of mortality associated with the disaster. Likewise, grid cells were apportioned into deciles according to the level of economic loss associated with each type of natural disaster. An area was classified as being at high risk for mortality or economic loss due to a particular type of natural disaster if it was located in grid cells ranking in the top three deciles of the global risk distribution in terms of the mortality rate or level of economic loss associated with that specific type of natural disaster. An area was classified as being at medium risk if it was located in grid cells ranking from the 5th to the 7th deciles and at low risk if it was located in grid cells ranking from the 1st to the 4th deciles (Dilley et al., 2005).[8]

The *2014 Revision* of *World Urbanization Prospects* includes the geographic coordinates of the centroid point for each city, but does not identify the total land area included in each city's boundaries. For this analysis, a buffer zone was generated around each city centroid to reflect approximately its possible urban extent. The buffer zone was a circle with radius proportional to the population size estimated for mid-2014, using the statistical relationship between city population size and urban extents from MODIS 500 meter resolution remote sensing global urban maps for 3,646 urban areas with 100,000 inhabitants or more in 2000 (see Appendix A).

[8] Refer to Chapter 6 of the report by Dilley et al. (2005) for methodology details.

In classifying the degree of risk exposure and vulnerability of a city to a specific type of natural disaster, we took all of the grid cells that fell fully or partially within the city buffer zone and then took the maximum cell value to represent the level of exposure/vulnerability risk. Appendix B compares the results when using the above method to those produced using an alternative method and the results indicate a very high consistency.

The third dataset used in this analysis, the Millennium Ecosystem Assessment, provided information related to the geographic classification of cities according to whether they were coastal cities or inland cities. The coastal areas were defined as areas between 50 meters below mean sea level and 50 meters above the high tide level or extending landward to a distance of 100 kilometres from shore, including coral reefs, intertidal zones, estuaries, coastal aquaculture, and sea grass communities (Millennium Ecosystem Assessment, 2003: 54). If a city's buffered zone was located in a coastal area, the city was considered a coastal city. Otherwise, it was considered an inland city.

The presentation of the main results of this study takes the form of a series of descriptive analyses from frequencies and tabulations and spatial distributions. Key findings are illustrated in the main text through a limited set of maps for the spatial distributions of cities' overall risks of exposure and vulnerability to all six types of natural disaster, whereas spatial distributions of disaster-specific risks of exposure and vulnerability are reported in Appendix C.

3. Major findings

3.1. In 2014, nearly 56 per cent of cities, representing 62 per cent of city dwellers worldwide, were at high risk of exposure to at least one type of natural disaster.

Table 1 shows that out of a total of 1,692 cities with 300,000 inhabitants or more on 1 July 2014, nearly 56 per cent, or 944 cities, were at high risk of exposure to at least one of the six natural hazards (cyclones, floods, droughts, earthquakes, landslides, and volcano eruptions). Slightly less than 15 per cent of all cities, or 249 cities, were highly exposed to at least two of the six types of natural disaster and about 2 per cent, or 27 cities, were exposed to three or more (or multiple) types of natural disaster. In terms of population, about 62 per cent of the 2.2 billion people who resided in the 1,692 cities analysed, or 1.4 billion people, were at high risk of exposure to at least one of these six types of natural disaster. Twenty-three per cent of the total urban population, or 506 million people, lived in areas that were highly exposed to at least two hazards and nearly 5 per cent, or 100 million people, lived in areas that were highly exposed to multiple types of disaster. Figure 1 presents the spatial distribution of the 1,692 cities by population size and type of risk of exposure to natural disasters.

TABLE 1. DISTRIBUTION OF RISKS OF EXPOSURE AND VULNERABILITY TO THE SIX TYPES OF NATURAL DISASTER FOR MAJOR CITIES AND THEIR POPULATIONS

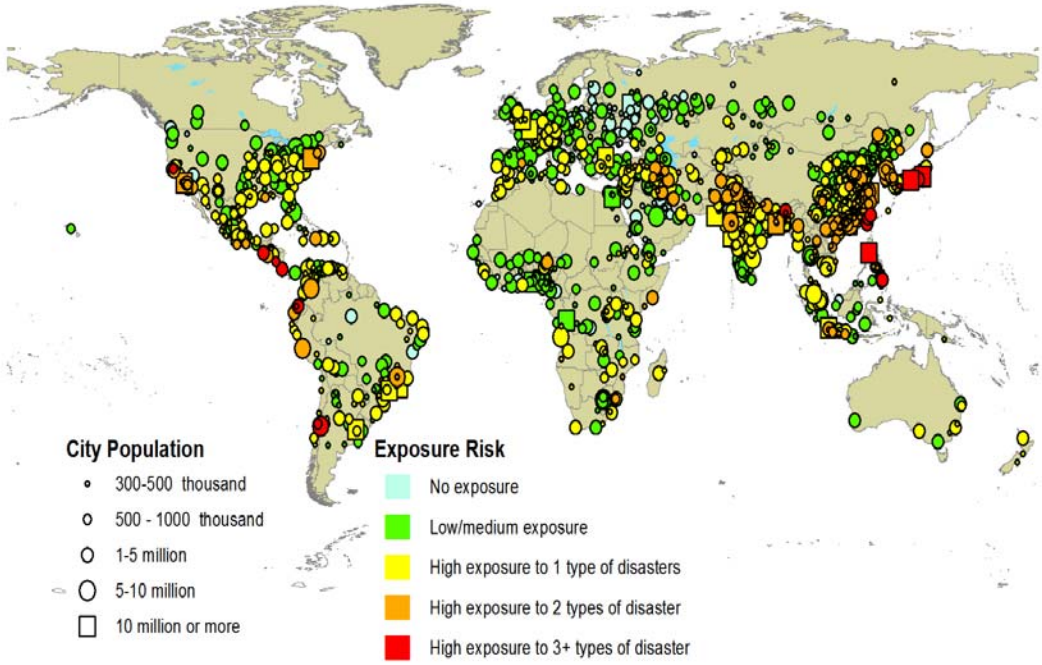
	Exposure risk		*Mortality vulnerability*		*Economic vulnerability*	
Risk of the six types of natural disaster	*City populations*	*Number of cities*	*City populations*	*Number of cities*	*City populations*	*Number of cities*
City populations (millions) and number of cities						
Total [*]	2,202	1,692	2,202	1,692	2,202	1,692
No risk	86	93	161	173	99	108
Low risk only	308	290	25	22	9	18
Moderate risk or low risk	444	365	79	102	41	66
High risk of 1 type of disaster	858	695	802	726	568	513
High risk of 2 types of disaster	405	222	842	551	869	651
High risk of 3+ types of disaster	101	27	293	118	616	336
High risk of 1+ type of disaster [a]	1,363	944	1,936	1,395	2,053	1,500
Percentage distribution						
Total	100.0	100.0	100.0	100.0	100.0	100.0
% No risk	3.9	5.5	7.3	10.2	4.5	6.4
% Low risk only	14.0	17.1	1.1	1.3	0.4	1.1
% Moderate risk or low risk	20.2	21.6	3.6	6.0	1.9	3.9
% High risk of 1 type of disaster	39.0	41.1	36.4	42.9	25.8	30.3
% High risk of 2 types of disaster	18.4	13.1	38.2	32.6	39.5	38.5
% High risk of 3+ types of disaster	4.6	1.6	13.3	7.0	28.0	19.9
% High risk of 1+ type of disaster	61.9	55.8	88.0	82.4	93.2	88.7

NOTE: (1) City populations refer to those with 300,000 inhabitants or more on 1 July 2014. (2) Six types of natural disaster include cyclones, droughts, earthquakes, floods, landslides, and volcano eruptions.(3) * the summation of each category does not necessary equal to total or subtotal due to rounding.

Among 27 cities highly exposed to multiple types of disaster, 13 cities had a population of 1 million or more in 2014. Among these were three megacities, Tokyo (Japan), Osaka (Kinki M.M.A., hereafter referred to as Osaka in Japan) and Manila (Philippines), with more than 10 million inhabitants. Tokyo, with 37.8 million people in 2014, was at high risk of exposure to cyclones, earthquakes, floods and landslides. Osaka, with 20 million people, was at high risk of exposure to cyclones, earthquakes and landslides and was at medium risk of floods. Manila, with 13 million people in 2014, was at high risk of exposure to five types of natural hazard and at low risk of exposure to droughts. Seven other cities with one million inhabitants or more in Asia were at high risk of three or more types of disaster. The remaining three cities were in Central America and the Caribbean (see table D1 in Appendix D for details).

About 655 cities (nearly 39 per cent of the 1,692 cities used in this analysis) representing 752 million people (or 34 per cent of 2.2 billion total city population) in 2014 were at medium or low risk of exposure to one or more of the six types of natural disaster examined in this paper. Only 93 cities (representing less than 6 per cent of the 1,692), which contained in total 86 million people (or approximately 4 per cent of the 2.2 billion total urban population), were entirely immune to any risk of these six types of natural hazard. Moscow (Russia) was the only megacity that was not exposed to the risk of any of the six types of natural disaster analysed. Seventeen cities containing between one and ten million people and 75 cities containing less than one million people were also free from any risk of exposure to all six types of natural disaster. Cairo and Kinshasa were the only megacities that were at low risk of exposure to all six types of natural disaster.

Figure 1. Distribution of cities by population size and risk of exposure to natural disasters



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3.2. Globally, in 2014, about 82 per cent of cities, representing approximately 88 per cent of the total city population, were exposed to high mortality vulnerability from at least one type of natural disaster, and nearly 90 per cent of cities, representing more than 93 per cent of the total city population, were highly vulnerable to economic losses from at least one type of natural disaster.

Table 1 reveals that in 2014 1,395 cities, or 82 per cent of the 1,692 cities under study, were located in areas where the risk of disaster-related mortality from at least one of the six types of natural disaster was in the top three deciles. In other words, about 1.92 billion people in these 1,395 cities, equalling to 88 per cent of the total population of the 1,692 cities, were highly vulnerable to some sort of disaster-related mortality. Five hundred and fifty-one cities (or 33 per cent of all cities) were at high risk of mortality from two types of disaster and 118 cities (7 per cent) were at high risk of mortality from three or more types of disaster. In terms of population, in 2014, about 38 per cent and 13 per cent, respectively, of the total city population residing in these two groups of cities were at high risk from at least one type of natural disaster. Eight of the 118 most vulnerable cities to mortality risk were megacities: Tokyo (Japan), Mexico City (Mexico), Osaka (Japan), Karachi (Pakistan), Kolkata (India), Manila (Philippines), Tianjin (China) and Jakarta (Indonesia), totalling 143 million people, while four were large cities with a population between 5 million to 10 million: Madras (India,9.6 million), Bogotá (Colombia, 9.6 million), Nagoya (Japan, 9.4 million), Tehran (Iran, 8.4 million) (see table D2 in Appendix D). Only 80 cities that were exposed to at least one of the six types of disaster had no higher risk of associated mortality, of which Hong Kong (China, H.K. SAR), Baghdad (Iraq) and Madrid (Spain) were the three largest cities with populations of between 5 million and 10 million in 2014. Figure 2 presents the spatial distribution of vulnerability to disaster-related mortality for all 1,692 cities.

Figure 2. Spatial distribution of cities by population size and vulnerability to disaster-related mortality

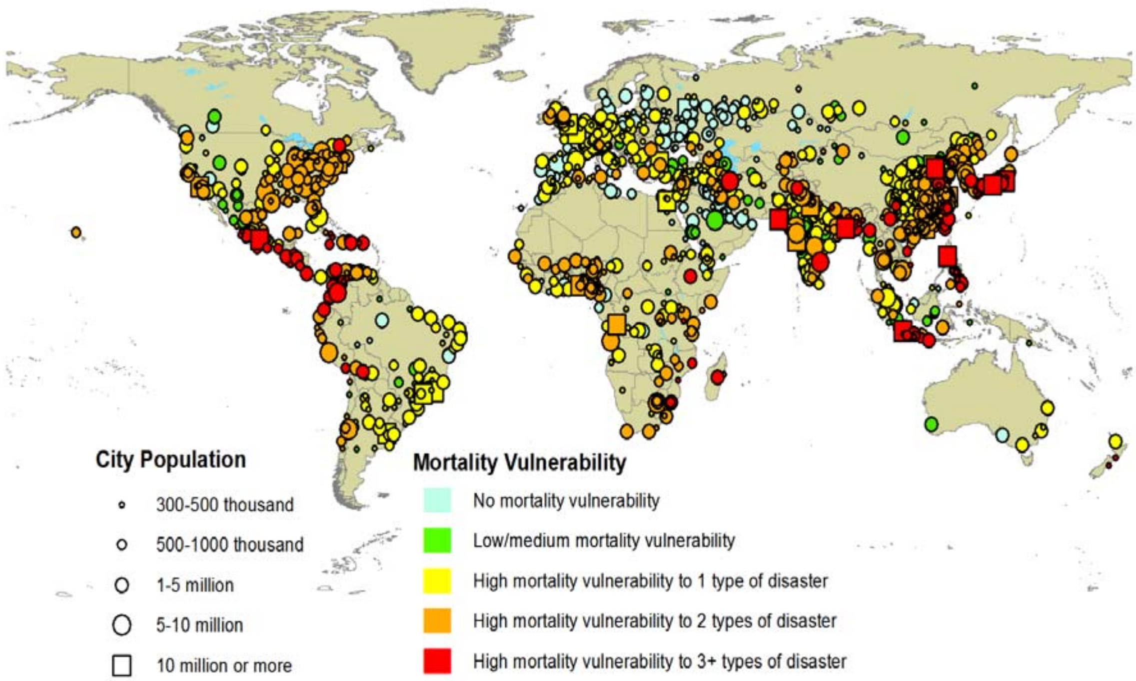

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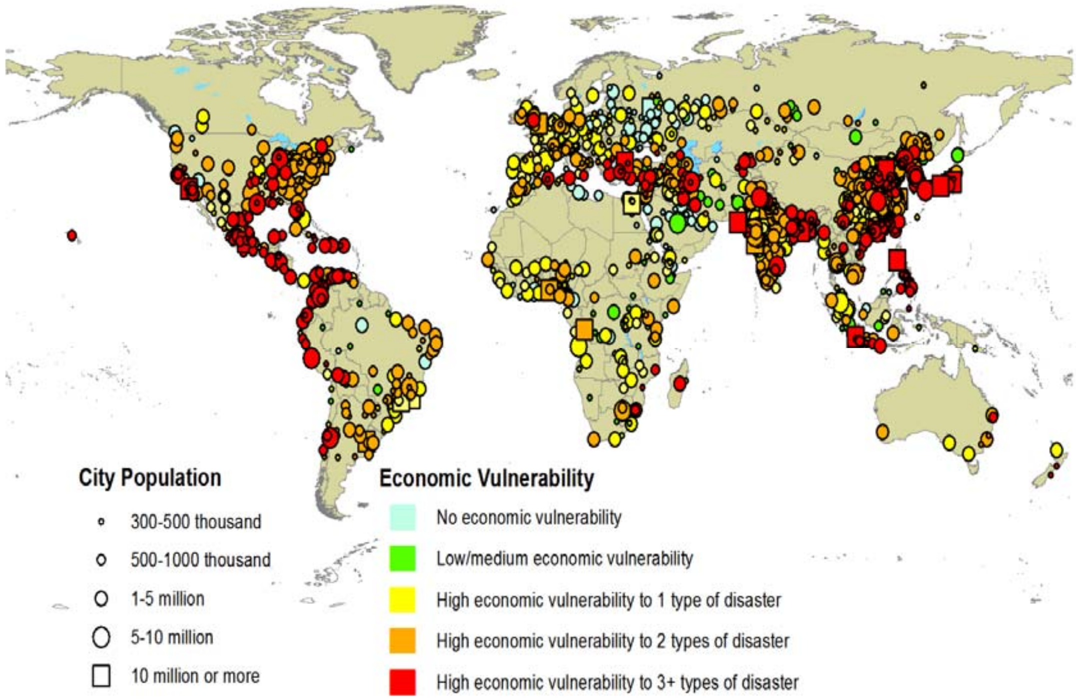
Table 1 further shows that 1,500 cities in 2014 (89 per cent), or 2.1 billion people (more than 93 per cent), were located in areas that were highly vulnerable to economic losses associated with at least one of the six types of natural disaster. Of these, 651 cities were highly vulnerable to two types of disaster, 270 cities were highly vulnerable to three types of disaster, 53 cities were highly vulnerable to four types of disaster, 12 cities were highly vulnerable to five types of natural disaster and one city—Manila—was highly vulnerable to economic losses from all six types of natural disaster analysed. Manila was also the only city that was highly vulnerable to disaster-related mortality from all six types of disaster. Among the 12 cities with high vulnerability to economic losses from five of the six types of disaster, seven cities had a population of over one million inhabitants in 2014. Out of the 66 cities with high levels of economic vulnerability to at least four different types of disaster, four were megacities: Tokyo, Mexico City, Osaka and Manila (see table D3 in Appendix D).

Further exploration revealed that only 15 cities that were at risk of exposure to disasters were not vulnerable to economic losses. Twelve of these cities are located in Western Asia. Most cities in this category were at low or medium risk of exposure to various types of disaster. For example, Tel Aviv-Yafo (Israel), with 3.6 million people in 2014, the largest city in this category, was at low risk of floods and earthquakes. Figure 3 presents the spatial distribution of vulnerability to disaster-related economic losses for all cities under study.

Figure 3. Spatial distribution of cities by population size and vulnerability to disaster-related economic losses



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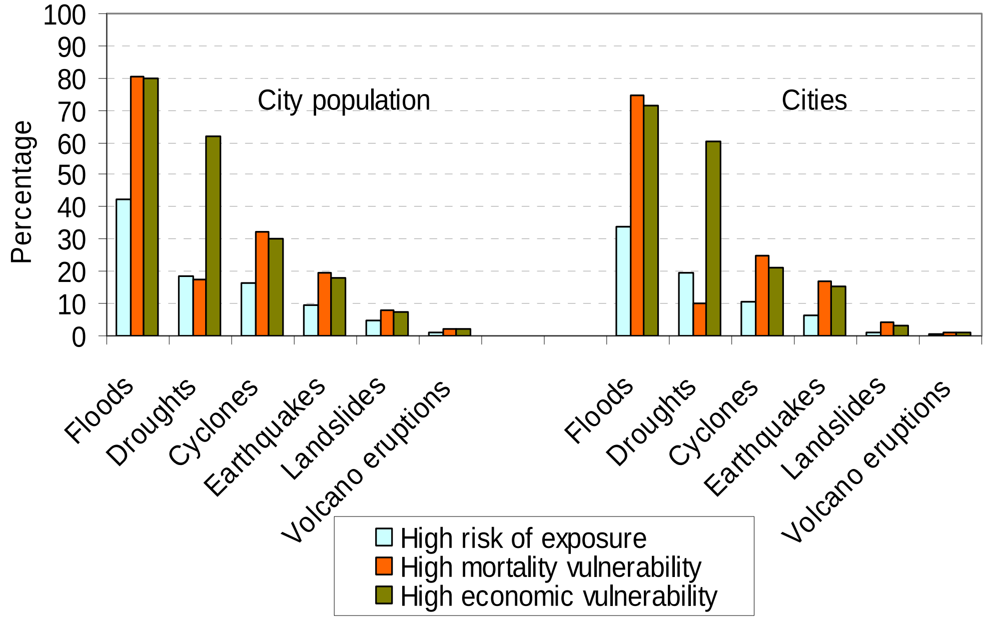
3.3. Floods, droughts and cyclones were the most devastating types of natural disaster threatening city dwellers in terms of risks of exposure, mortality and economic loss.

Between 1980 and 2009, more than 2.8 billion people were affected by floods, making flooding the most common form of natural disaster (Doocy, Daniels, Murray, et al., 2013). Interestingly, more than 80 per cent of flood occurrences during this period were recorded after 1990. Floods affect urban populations more than any other type of natural disaster. Figure 4 shows that flood risk is the most common natural hazard in terms of risk of exposure across the 1,692 cities in this analysis. In 2014, of the 1,692 cities, 577 of them, or slightly more than one-third, were located in areas with high risk of flooding. In absolute population terms, in 2014, 932 million urban dwellers were residing in areas that were at high risk of flooding.

Of greater challenge and concern is the larger proportion of cities and their populations that are highly vulnerable to flood-related mortality and economic losses. Of the 1,692 cities analysed, 1,258 cities (74 per cent) were located in areas that were highly vulnerable to flood-related mortality, while 1,207 cities, (71 per cent) were located in areas where vulnerability to flood-related economic losses was high. The total population living in areas that were highly vulnerable to flood-related economic losses in 2014 was about 1.76 billion, accounting for 80 per cent of the total city population studied. A similar number of people lived in cities at high risk of flood-related mortality, indicating that many cities were at high risk of vulnerability to both flood-related mortality and economic losses even if they were at low or medium exposure to the risk of floods. Only eight cities (several of which were in Israel, such as Jerusalem, Tel Aviv-Yafo and Haifa) that were exposed to floods had almost no risk of flood-related economic losses, and only four cities (Hong Kong (China, H.K. SAR), Venezia (Italy), Vungtau (Viet Nam), and Ar-Rusayfah (Jordan)) that were exposed to floods had almost no risk of flood-related mortality. By contrast, 474 cities at low risk of exposure to floods were highly vulnerable to flood-related mortality, whereas 437 cities at low risk of exposure to floods were highly vulnerable to flood-related economic losses; and about half of these cities were in Asia.

Figure 4. Percentage distributions of city populations and cities with high exposure and high vulnerabilities to each of the six types of natural disaster



Droughts were the second most hazardous type of disaster over the last 30 years or so, affecting 330 cities, accounting for 20 per cent of all cities analyzed. Some 411 million people lived in these 330 cities in 2014, equalling 19 per cent of the total city population (see figure 4). Four megacities (Delhi (India), Karachi (Pakistan), Kolkata (India), Los Angeles-Long Beach (USA)) were highly exposed to the risk of drought. Droughts were also the second most devastating type of disaster in terms of economic losses for the world's 1,692 cities. Sixty per cent of all cities analysed (1,017 cities) or 62 per cent of the total population of cities globally (about 1.36 billion people) were highly vulnerable to drought-related economic losses. This proportion was much higher than the proportion at high risk of exposure, indicating that even if many cities were at low or medium risk of exposure to droughts, they were highly vulnerable to drought-related economic losses. Specifically, 416 cities were at low risk of exposure to droughts, yet highly vulnerable to drought-related economic losses. Eight megacities (Mexico City (Mexico), Dhaka (Bangladesh), Buenos Aires (Brazil), Istanbul (Turkey), Manila (Philippines), Kinshasa (D.R. of the Congo), Shenzhen (China), and London (UK)) fell into this category. Manila and Kinshasa were also the two megacities that were highly vulnerable to drought-related mortality.

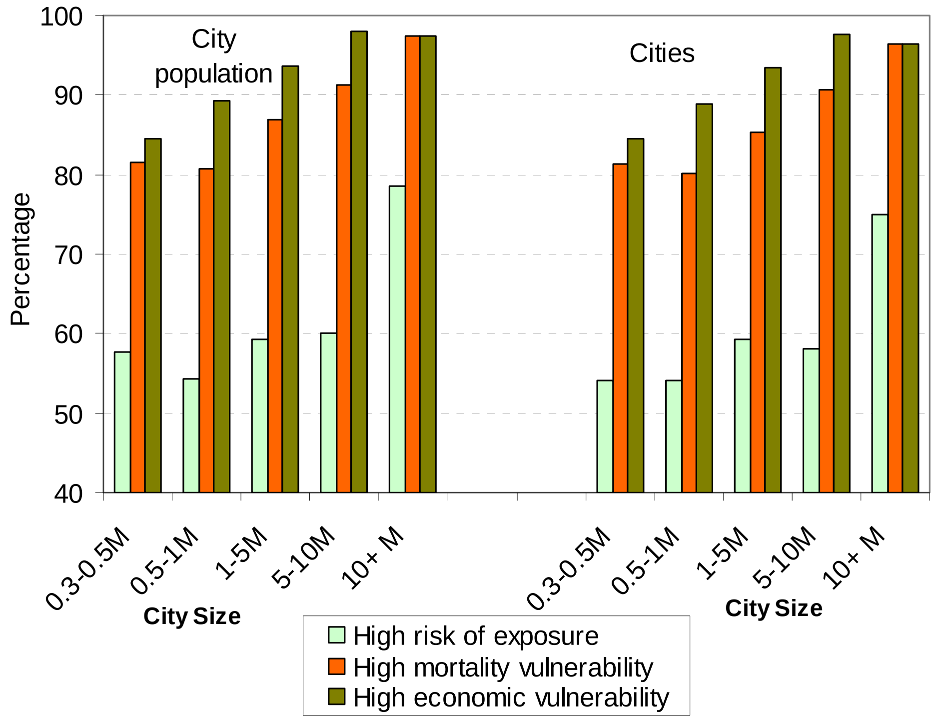
In terms of vulnerability to disaster-related mortality, over the last 30 or so years, cyclones were the second most devastating type of disaster for today's cities. There were 423 cities, or 25 per cent, highly vulnerable to cyclone-related mortality. About 711 million people lived in these 423 cities in 2014, accounting for nearly one-third of the total city population globally. One hundred and seventy-eight cities were highly exposed to cyclones and were also highly vulnerable to cyclone-related mortality. One hundred and fourteen cities were at medium risk of experiencing a cyclone but were highly vulnerable to cyclone-related mortality should one occur. Likewise, 131 cities were at low risk of exposure to a cyclone but were highly vulnerable to cyclone-related mortality should a cyclone strike. Only four cities (Hong Kong (China, H.K. SAR), Chaohu (China), Tuticorin (India), and Cuautla Morelos (Mexico)) were exposed to the risk of cyclones but not considered at risk from cyclone-related mortality.

A detailed distribution of risks of exposure and vulnerabilities to each of the six types of disaster by decile is presented in Appendix E.

3.4. Megacities were more likely to be highly exposed to disasters and were more vulnerable than cities of other sizes.

Previous research has shown both that megacities are exposed to major risks from natural disasters and that megacities are exposed to a wide range of natural disasters, including geological, meteorological and climatic events, as well as wildfires (Gencer, 2013; UN-HABITAT, 2011). Megacities were more likely to be at high risk of exposure to at least one of the six types of natural disaster analysed in this paper. Of 28 megacities with 453 million people in 2014, only one city (Moscow) was at no risk of exposure to any of the six types of natural disaster analysed. Twenty-one megacities, or approximately three-quarters of the 28 megacities in existence in 2014, were at high risk of at least one type of natural disaster. The corresponding figures were 58 per cent for cities with 5-10 million people, 59 per cent for cities with 1-5 million people, and 54 per cent for cities with 1 million people or less. The total population of these 21 megacities was around 355 million, accounting for 78 per cent of the 453 million people living in megacities in 2014 (see the right panel of figure 5). In terms of populations at high exposure, a similar pattern was found for the distribution of cities (see the left panel of figure 5).

Figure 5. Percentage distributions of city populations and cities with high exposure and high vulnerabilities to at least one of the six types of disaster by city population size



Similar patterns of high exposure to the risk of floods and cyclones for megacities were also observed. For example, around 60 per cent of megacities were exposed to high risk of floods, whereas the percentages were only around 32-46 per cent for cities of other sizes. On the other hand, megacities were less likely to be exposed to droughts compared to cities under 5 million people: 14 per cent of megacities were exposed to high risk of droughts, whereas 17-22 per cent of cities in other categories were exposed to high risk of droughts.

Figure 5 indicates that megacities were more vulnerable to disaster-related economic losses and mortality than other classes of city. Nearly 96 per cent of megacities (i.e., 27 of 28 megacities) and city populations (i.e., 441 million) were highly vulnerable to disaster-related mortality, which was significantly higher than the corresponding figure for cities with less than 5 million people. Compared to other cities, megacities further suffered a high vulnerability to flood-, cyclone-, drought-, and earthquake-related mortality, although a lower proportion of megacities were exposed to droughts and earthquakes. About 89 per cent, 43 per cent, and 36 per cent of megacities were highly vulnerable to flood-, cyclone-, and drought-related mortality, respectively. The corresponding figures for cities with less than 5 million people were 72-76 per cent for flood-related mortality, 22-26 per cent for cyclone-related mortality, and 8-21 per cent for drought-related mortality.

In terms of economic vulnerability, all megacities except Moscow were highly vulnerable, compared to less than 90 per cent for cities with less than one million residents and 94 per cent for cities with 1-5 million inhabitants. The differential pattern in economic vulnerability by city size was also observed for flood- and cyclone-related economic losses. For instance, 93 per cent of megacities were highly vulnerable to flood-related economic losses compared to 67-76 per cent for cities with less than 5 million people. Similarly, about 43 per cent of megacities were highly vulnerable to cyclone-related economic losses compared to only 17-24 per cent for cities with 5 million or less. The proportion highly vulnerable to drought-related economic losses was somewhat similar for megacities (60 per cent) as for cities with less than 5 million people (54 to 65 per cent). The high vulnerability to disaster-related economic losses for cities with 5-10 million inhabitants was similar to that of megacities in most cases.

The five most populous megacities in 2014 (in order of size: Tokyo (Japan), Delhi (India), Shanghai (China), Mexico City (Mexico), and São Paulo (Brazil)) all experienced high risk of exposure to at least one major type of natural hazard. These five cities were also highly vulnerable to both disaster-related mortality and disaster-related economic losses. Tokyo was located in a region where there was a high risk of floods, cyclones, earthquakes, and landslides, and was highly vulnerable to mortality risk and economic losses from these types of disaster. Delhi was at high risk of floods and droughts and the associated risk of mortality and economic losses. Shanghai was at high risk of both floods and cyclones and their associated risks of higher mortality and economic losses. Mexico City had a high risk of floods, a low risk of droughts, and a medium risk of landslides and volcano eruptions with high economic vulnerability associated with each of these four types of natural hazard and high mortality vulnerability associated with floods, landslides and volcano eruptions, and medium mortality vulnerability associated with the risk of droughts. São Paulo was exposed to high risk of floods and high vulnerability to both flood-related mortality and economic losses.

Overall, megacities were not only at higher risk of exposure to natural disasters but were also more vulnerable to economic losses and natural-disaster related mortality compared to other smaller cities.

3.5. Cities in the less developed regions, which, on average, were experiencing faster growth than cities elsewhere, were more likely to be exposed to both the risk of natural disasters and the potentially adverse consequences of such natural disasters.

The higher exposure and the greater vulnerability to natural disasters in the less developed regions than in the more developed regions have been well-documented (Alcánatar-Ayala, 2002). The proportion of cities located in highly disaster-exposed areas in the less developed regions was higher than that in the more developed regions. The left panel of Table 2 shows that about 62 per cent of cities (773 out of 1,256 cities) in the less developed regions in 2014 were located in areas considered to be at high risk of exposure to at least one type natural hazard, compared to only 39 per cent of cities (169 of 436 cities) in the more developed regions. In terms of city population, about 1.1 billion urban inhabitants, or 65 per cent, in the less developed regions lived in areas of high risk compared against roughly 300 million urban inhabitants in the more developed regions. The difference in the risk of exposure to droughts between these two development groups was more pronounced. About 22 per cent of cities in the less developed regions were at high risk of exposure to droughts compared to 8 per cent of cities in the developed regions.

The less developed regions were also more vulnerable to disasters in terms of mortality risk. About 90 per cent of cities in the least developed countries and about 85 per cent of cities in other developing countries (the overall figure for less developed regions was 86 per cent) were highly vulnerable to disaster-related mortality compared to 74 per cent of cities in the more developed regions. In other words, the least developed countries tended to have the highest mortality in comparison with other developing countries and more developed regions. Disaster-related economic vulnerability by development group was somewhat different: the least developed countries tended to have the lowest economic vulnerability compared to other countries. Economic vulnerability becomes higher with a higher level of development.

TABLE 2. PERCENTAGE OF MAJOR CITIES AND THEIR POPULATION WITH HIGH EXPOSURE AND HIGH VULNERABILITY TO AT LEAST ONE OF THE SIX TYPES OF NATURAL DISASTER BY DEVELOPMENT GROUP, INCOME GROUP, MAJOR AREA, AND COASTAL-INLAND CITY TYPE

	High exposure risk (%)		*High mortality vulnerability (%)*		*High economic vulnerability (%)*	
	City populations	*Number of cities*	*City populations*	*Number of cities*	*City populations*	*Number of cities*
Development groups						
Less developed regions	65.0	61.3	89.9	85.5	94.3	89.6
Least developed countries	54.6	53.4	95.2	90.3	91.1	77.7
Less developed regions, excluding least developed countries	65.9	62.0	89.4	85.1	94.6	90.6
More developed regions	52.6	39.9	88.2	73.6	90.0	86.0
Income groups						
Low-income	60.2	57.4	95.7	92.6	90.8	77.7
Lower-middle-income	59.8	53.4	87.5	80.5	92.2	85.6
Upper-middle-income	67.0	64.0	92.4	87.9	97.0	93.9
High-income	56.5	44.6	80.3	73.6	89.0	85.3
Major areas						
Africa	27.1	31.0	89.6	85.0	85.3	73.8
Asia	71.5	67.3	89.9	85.2	95.6	91.7
Europe	31.8	28.0	65.0	61.4	80.2	79.1
Latin America & the Caribbean	79.0	67.0	93.1	88.8	96.7	94.7
Northern America	55.7	51.0	93.5	90.1	97.0	96.0
Oceania	48.6	53.8	81.0	76.9	100.0	100.0
Coastal or inland cities						
Inland cities	54.3	54.3	85.0	81.8	91.6	87.8
Coastal cities	71.3	58.8	91.7	83.8	95.3	90.5

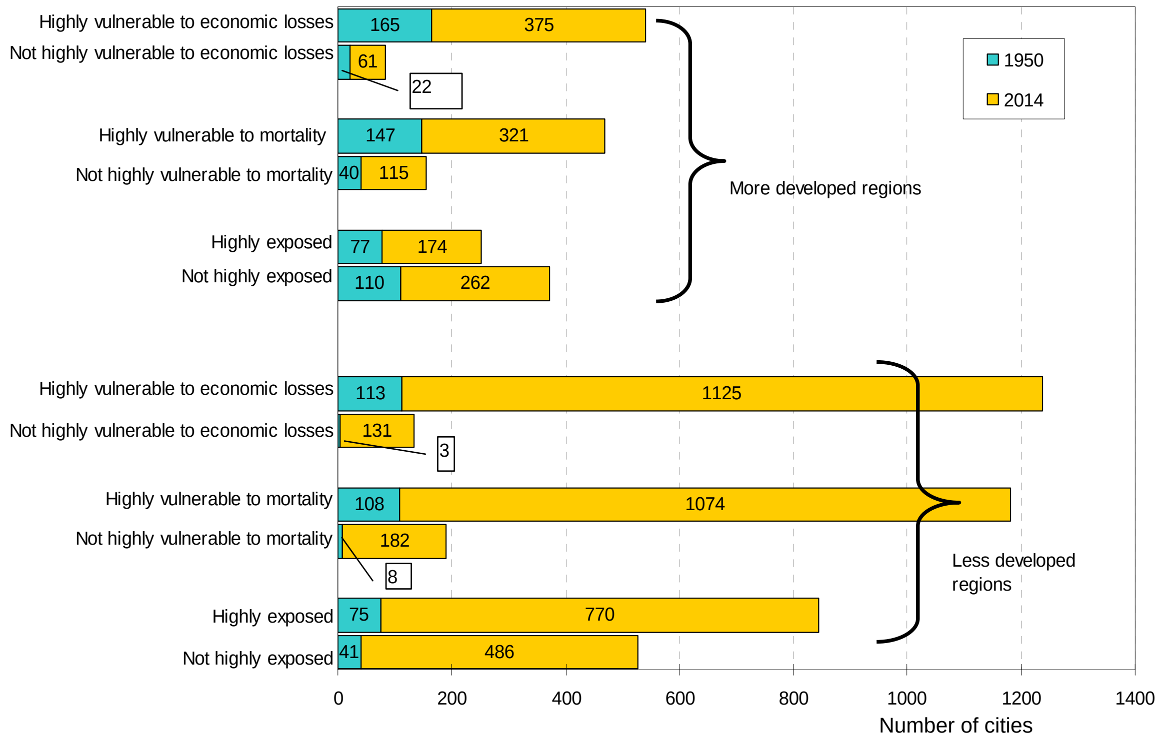
NOTE: (1) City populations refer to those with 300,000 inhabitants or more on 1 July 2014. (2) Six types of natural disaster include cyclones, droughts, earthquakes, floods, landslides, and volcano eruptions.

Three-fourths of cities in the least developed countries were highly vulnerable to disaster-related economic losses in comparison with more than 90 per cent of cities in other less developed regions and 86 per cent of cities in the more developed regions. This was possibly because of the lower economic value of assets in the cities located in the least developed countries compared to the cities in other countries. However, when a different indicator, economic losses as a proportion of national GDP per grid cell, is used to measure economic vulnerability, the results were different: more than 60 per cent of cities in the least developed countries were highly vulnerable to disaster-related economic losses compared to 42 per cent of cities in the more developed regions (results not shown). The economy of a city in the least developed countries is likely to be particularly crucial to its nation's economy; and its disaster-related economic losses could be particularly significant. On the other hand, many cities in the more developed regions were located in areas with high economic vulnerability, but their economic losses were relatively low.

The disparity in risk of exposure and vulnerability to disasters by income group was also substantial. Nearly 45 per cent of cities in high-income countries were at high risk of exposure to at least one type of natural disaster; the corresponding figures are 57 per cent in low-income countries, 53 per cent in middle-income countries and 64 per cent in upper-middle-income countries. However, more than 90 per cent of cities in low-income countries were highly vulnerable to disaster-related mortality, compared to 74 per cent for high-income countries. About 57 per cent of cities in low-income countries were highly vulnerable to drought-related mortality, compared to only 23 per cent, 3 per cent and zero per cent of cities in other three income groups. With respect to economic vulnerability, about 78 per cent of cities in low-income countries were highly vulnerable as compared to 86 per cent of cities in lower-middle-income countries, 94 per cent of cities in upper-middle-income countries, and 65 per cent of cities in high-income countries, respectively. Again, the lower proportion of economic vulnerability in low-income countries was probably because of low economic values of their assets.

Figure 6 indicates that the number of cities with 300,000 inhabitants or more in the less developed regions increased by about ten-fold from 1950 to 2014, irrespective of types of risk, compared to only a two- or three-fold increase in the more developed regions. The number of cities in each risk category of exposure and vulnerability in figure 6 in the less developed regions in 1950 was smaller than that in the more developed regions; however, the opposite was true in 2014: the number of cities located in areas with high exposure and high vulnerability to natural disasters were 3.0 to 4.5-fold more in the less developed regions than in the more developed regions. Given the assumptions of constant risks of exposure and vulnerability over time for a given area, the different patterns of population growth by risk of exposure to vulnerability and development group would be attributable to the different patterns of population growth and urbanization between the less developed and more developed regions over the last 64 years.

Figure 6. Number of cities with 300,000 inhabitants or more in 1950 and 2014 by development group and type of risk of exposure and vulnerability to natural disasters



3.6. Variations in exposure and vulnerabilities to natural disasters across major areas were large.

There were substantial variations for cities across major areas with respect to risks of exposure and vulnerability to various forms of natural disasters. Overall, Europe's and Africa's cities were the least exposed to the six types of natural hazard analysed. Table 2 reveals that, in Europe and Africa, only 28 per cent and 31 per cent, respectively, of cities with 300,000 inhabitants or more on 1 July 2014 were located in areas that were at high risk of exposure to at least one of the six types of natural disaster. By contrast, two-thirds of cities in Latin America and the Caribbean and Asia, and about half of cities in both Northern America and Oceania were located in high risk areas. The proportion of each region's total city population that was at high risk of exposure to natural disasters across major areas was similar to the proportion of cities itself, except for in Latin America and the Caribbean where nearly 80 per cent of the city population were at high risk of exposure to at least one type of natural disaster.

Disaster-specific variation in the risk of exposure across major areas was also large. For example, more than 41 per cent of cities in Asia and Latin America and the Caribbean were highly exposed to floods, compared to 12 per cent of African cities, 23 per cent of European cities and 27 per cent of Northern American cities. Around one-fifth or one-fourth of cities in Asia, Latin America and the Caribbean, and Africa were at high risk of exposure to droughts, whereas only 5-8 per cent of cities in Europe and Oceania faced similar risks. No cities in Africa or Europe were at high risk of earthquakes, yet about 15 per cent of cities in Oceania and 10 per cent of cities in Latin America and the Caribbean faced such a risk.

African cities, on average, were less likely to be highly exposed to natural disasters, but were more likely to be highly vulnerable to disaster-related mortality. Table 2 shows that 85 per cent of cities in Africa were highly vulnerable to disaster-related mortality, a level that was quite similar to cities in both Asia (85 per cent) and Latin America and the Caribbean (89 per cent) despite the fact that cities in both Asia and Latin America and the Caribbean had much higher risks of exposure to all forms of disaster. The corresponding figures for the other regions were about 90 per cent for cities in Northern America, 77 per cent for cities in Oceania, and 61 per cent for cities in Europe. The lower exposure to disasters yet higher vulnerability to disaster-related mortality in Africa was likely due to a lack of infrastructure built to withstand extreme weather conditions (Adelekan, 2010).

From a disaster-specific perspective (see figure 7), only 11 per cent of the city population in Africa were at high risk of exposure to floods, yet 77 per cent of the city population were highly vulnerable to flood-related mortality. The corresponding figures for other regions were 27 per cent and 64 per cent for Europe, 33 per cent and 88 per cent for Northern America, 62 per cent and 92 per cent for Latin America and the Caribbean, 48 per cent and 80 per cent for Asia, and 38 per cent and 81 per cent for Oceania. Results further showed that no city populations in Europe, Northern America, Latin America and Caribbean and Oceania were highly vulnerable to drought-related mortality compared to two-thirds of the city population in Africa and 18 per cent of the city population in Asia. The proportion of the population in cities with high risk of cyclone-related mortality was higher in Northern America (61 per cent) and Asia (41 per cent) than in other major areas (3-22 per cent), whereas the proportion of the city population with high earthquake-related mortality vulnerability was higher in Latin America and the Caribbean (32 per cent) and Asia (23 per cent) than in other major areas (2-15 per cent).

In terms of vulnerability to economic losses, all cities in Oceania were highly vulnerable to at least one of the six possible types of disaster compared to 74 per cent in Africa, 92 per cent in Asia, 79 per cent in Europe, 95 per cent in Latin America and the Caribbean, and 96 per cent in Northern America. In terms of economic vulnerability as a proportion of GDP per grid cell, the percentages of cities with high vulnerability was once again the highest in Oceania with 77 per cent, followed by Asia (61 per cent), Africa (51 per cent), Latin America and the Caribbean (46 per cent), Northern America (44 per cent). and Europe (37 per cent),

The largest differences in the risk of vulnerability to disaster-related economic losses across the six major areas were found in the cases of floods and cyclones. For example, about 57 per cent of the city population of Africa in 2014 were highly vulnerable to flood-related economic losses, compared to 90 per cent of the city population of Northern America. For cyclone-related economic losses, the differences across geographic areas were even more striking: about 61 per cent of the city population of Northern America were highly vulnerable to cyclone-related economic losses compared to only less than 3 per cent of population for cities in Africa and 6 per cent for cities in Europe. Differences in economic vulnerability to earthquakes and landslides across geographic areas were also relatively large. About 32 per cent of the total city population of Latin America and the Caribbean were highly vulnerable to earthquake-related economic losses, whereas only 2 per cent of the city population of Africa had such a level of vulnerability. Similarly, nearly one-fifth of the city population of Latin America and the Caribbean were at high risk of economic losses due to landslides whereas there were almost no cities in Northern America and Africa that were exposed to similar risks. In contrast, the difference in vulnerability to drought-related economic losses across major geographic areas was not large.

3.7. Coastal cities were more likely to be highly exposed and more vulnerable to cyclones, whereas inland cities were more likely to be highly exposed and more vulnerable to droughts.

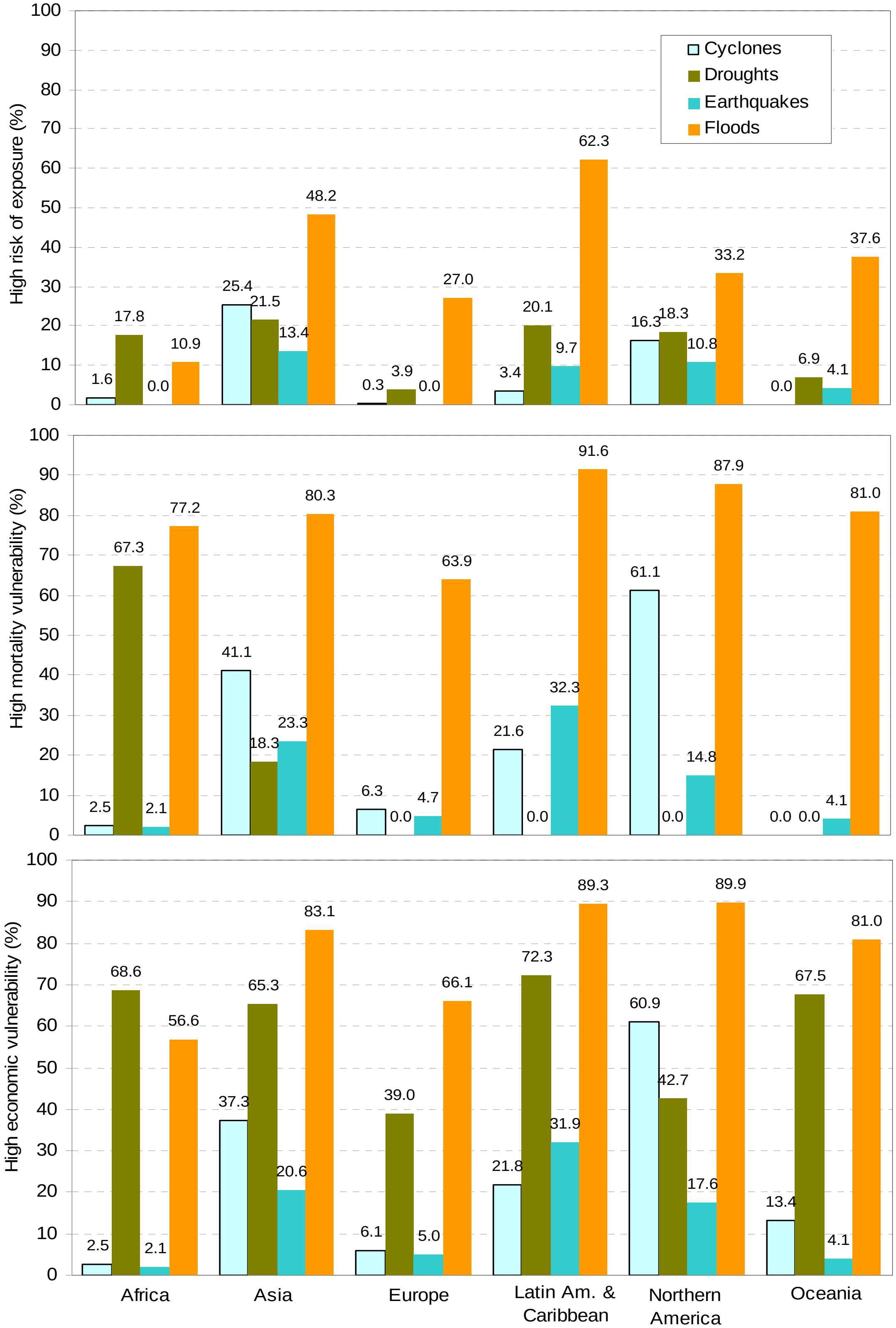
According to estimates provided by the United Nations Inter-governmental Panel on Climate Change (UNIPCC), while the overall frequency of tropical cyclones is expected to either decrease or remain unchanged globally in the 21st century, it is almost certain that there will be increases in the average maximum wind speed of tropical cyclones and increases in total rainfall associated with tropical cyclones (UNIPCC, 2012).

In 2014, 1,143 cities located in inland areas had a total population of 1.2 billion while 549 cities located in the coastal regions had a total population of 971 million. The overall proportion of coastal cities that were at high risk of exposure to at least one type of disaster was similar to that of inland cities (58 versus 54 per cent), despite a higher proportion of population at high exposure found in coastal areas than in inland areas (71 versus 54 per cent). The overall differential patterns of risk of economic and mortality vulnerability between these two groups were similar to those of risk of exposure (see table 2). This finding is important because in the existing literature risks of exposure and vulnerability to natural disasters of inland urban centres have been largely ignored mainly because of limited data. Overall, inland cities experienced the same level of risk of exposure and vulnerability to the six types of natural disaster as coastal cities.

Coastal cities were much more likely to be located in areas that were at high risk of exposure to cyclones compared to inland cities (23 versus 5 per cent), and the former was less likely to be located in areas that were at high risk of exposure to drought (16 versus 21 per cent). The risk of exposure to the other four types of disaster was more or less similar. Except for the difference in cyclone-related economic and mortality vulnerability, coastal cities and inland cities had similar disaster-specific vulnerabilities. About 42 per cent and 38 per cent of coastal cities were highly vulnerable to cyclone-related mortality and economic losses compared to 17 per cent and 13 per cent of inland cities, respectively.

Further investigation revealed that coastal cities with 5-10 million inhabitants and megacities were more likely than smaller coastal cities to be located in highly exposed zones and were more vulnerable to natural disasters in terms of economic losses and mortality, whereas no such differences by city size were found for inland cities. For example, among coastal cities, about 81-90 per cent of very large cities with 5 million inhabitants or more were highly exposed to the risk of at least one type of disaster, depending on the geographic area, compared to 52-60 per cent of smaller cities. Similarly, 95-100 per cent of very large cities with 5 million inhabitants or more were highly vulnerable to disaster-related mortality compared to 80-87 per cent of smaller cities and all cities with 5 million people or more were highly vulnerable to economic-related losses compared to 87-93 per cent of smaller cities. No such significant differences by city size were found among inland cities.

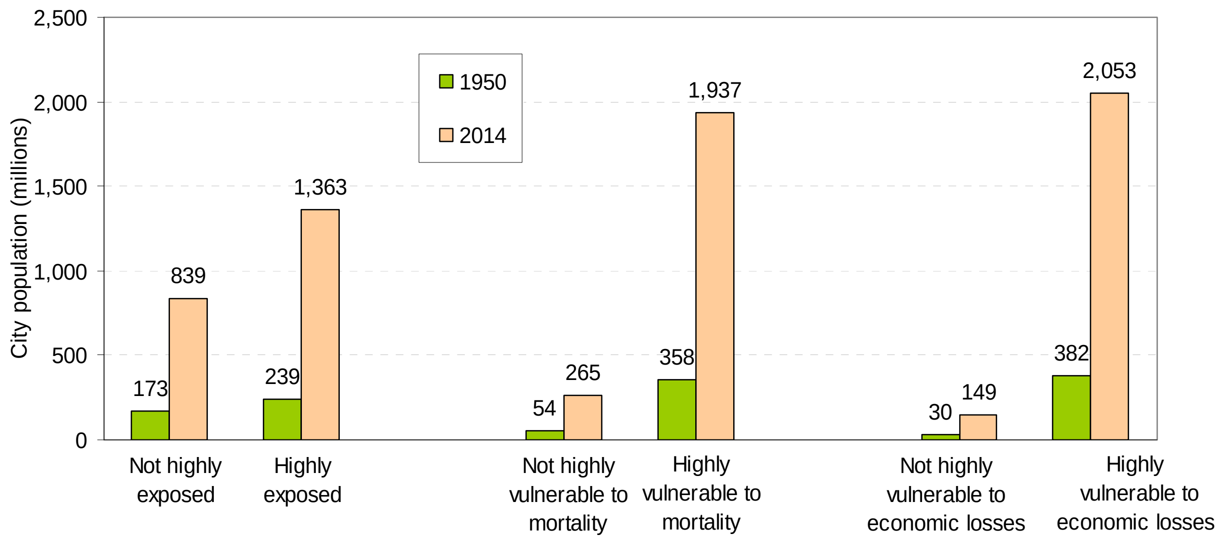
Figure 7. Disaster-specific percentage distribution of city population with high exposure and high vulnerability to the top four types of natural disaster by major area



3.8. The population of cities in areas highly exposed and vulnerable to natural disasters grew rapidly between 1950 and 2014

Figure 8 shows that, at the global level, the total population in the 944 cities that were highly exposed to at least one type of natural disaster increased by 5.7-fold, from 239 million in 1950 to 1.63 billion in 2014, compared to less than 4.9-fold for the 748 not highly exposed cities, from 173 million to 839 million over the same period. A similar pattern of vulnerability of mortality was found for these two types of city. For example, population increased by 5.4-fold, from 358 million in 1950 to 1.94 billion in 2014, for the 1,395 highly vulnerable cities in term of disaster-related mortality, compared to 4.9-fold, from 54 million to 265 million over the same time period, for the 297 not highly vulnerable cities. The difference in population growth from 1950 to 2014 by type of economic vulnerability was also notable: for the 1,500 highly vulnerable cities, the size of population increased by around 5.4-fold compared to 5.0-fold for the 192 cities that were not highly vulnerable.

Figure 8. Growth of city population by type of risks of exposure and vulnerability to natural disasters



Concluding remarks

The incidence of hydrological and meteorological disasters has grown steadily in recent decades, both globally and regionally (Doocy, Daniels, Murray, et al., 2013; Schultz and Elliott, 2013; UNISDR, 2013), causing enormous losses in terms of human lives and economic value and worsening the quality of life of many populations (Pelling and Wisner, 2009; UNFPA, UNISDR and UN-HABITAT, 2011). Along with the increased frequency of some types of natural disaster, there has been an increase in the proportion of the overall population residing in urban areas and the emergence of megacities, especially in the less developed regions. Natural disasters have been a major threat to dense urban spaces in both developed and developing countries (Nelson, 2013; Smith, 2013; Shao Gong, and Xu, 2014; UNISDR, 2012; 2013; Zhang et al., 2009).

Using the *World Urbanization Prospects* population time-series for cities with 300,000 inhabitants or more in 2014, together with spatial hotspot data on risks of exposures and vulnerability to natural disasters, this paper showed that 944 cities, or 1.4 billion people in 2014, faced a relatively high risk of exposure to at least one of the six types of natural disaster, representing 56 per cent of all 1,692 cities and 62 per cent of 2.2 billion people in these cities. Furthermore, about 82 per cent of cities and 88 per cent of the city population were highly vulnerable to disaster-related mortality, and nearly 90 per cent of cities and more than 93 per cent of the city population were highly vulnerable to disaster-related economic losses in 2014. These findings suggest that most cities in today's world are vulnerable to some form of natural disaster. This result is perhaps not surprising given that cities are more densely populated than rural areas and contain larger economic assets. On average, cities in the less developed regions were at higher risk of exposure to natural disasters and were more vulnerable to disaster-related economic losses and mortality than those in the more developed regions, and larger cities were at higher risk of exposure to disasters and more vulnerable to disaster-related economic losses and mortality than smaller cities. We also identified great variation across major areas and income groups. Our results further reveal that urban agglomerations and their populations are becoming more exposed and increasingly vulnerable to natural hazards over time because of rapid population growth and urbanization. Because climate change is expected to alter the intensity and the frequency of hazards, these risks and vulnerabilities will likely be heightened in the next few decades (Gencer, 2013; Satterthwaite et al., 2009).

There is evidence showing that the level of disaster proneness, disaster vulnerability, and management capacities varies widely by city and that the vulnerability to natural disasters varies greatly by macro socioeconomic development level, as well as individual demographics and socioeconomic characteristics (Chen et al., 2012; Uitto, 1998; UNISDR, 2011). Overall, cities in developing countries tend to have higher risk of exposure, are more vulnerable to natural disasters, and are growing more rapidly than cities in the developed countries. Consequently, the losses from natural disasters could be devastating for cities in the less developed regions, particularly if recovery from disasters in such settings is very slow (Blackburn and Johnson, 2012; UNISDR, 2009). It has been reported that around 70 per cent of urban populations in the least developed countries and sub-Saharan Africa are living in slum-like conditions (Campbell-Lendrum and Corvalan, 2007; UN-HABITAT, 2003). For example, in Bangkok, approximately 21 per cent of the general population was affected by flooding compared to 73 per cent of low-income households (UNISDR, 2013). Governments of cities in developing countries often can offer only limited services to residents due to inadequate resources or technical capacity (Hasan and Kahn, 1999; St. Louis and Hess, 2008; Uitto, 1998; UNISDR, 2009). Because the proportion of disaster-related deaths and injuries in urban areas in low- and middle-income countries is likely to grow (Dodman, Hardoy, and Satterthwaite, 2009), partly due to the rapid urbanization in these countries (United Nations, 2014), increasing the capacity of local and national officials of the less developed countries to cope with disasters should be a key priority (UNIPCC, 2001).

Cities in the more developed regions could reduce the risk of natural disasters and vulnerability through investments in protective infrastructure, environmental management and upgrading of informal settlements. Death tolls could be minimized through effective preparedness, evacuation measures and greater utilization of seismic resistant construction. The economic losses in these relatively wealthy cities, however, could still be much higher than those in the less developed regions (Cross, 2001; UNISDR, 2013), as also noted in this paper. For example, during the first decade of the 21st century, the annual average public expenditures for recovery from disasters (including floods, cyclones, winter storms, fires, and so forth) in the United States of America exceeded US$12 billion, more than all federal housing support for the poor, elderly, and disabled combined (Schultz and Elliott, 2013). The role of local governments and the empowerment of the urban poor in both more developed and less developed regions are becoming increasingly important for developing adaptive strategies and to improve resilience (UNISDR, 2009).

This paper focused on assessing the risk of six types of natural disaster for the 1,692 cities of the world with 300,000 inhabitants or more on 1 July 2014, but smaller cities are also at risk of natural disasters (UNISDR, 2009). A study in eight countries in Latin America showed that more than 60 per cent of total disaster events in the past three decades occurred in cities with less than 100,000 inhabitants (UNISDR, 2011). Small communities have far smaller populations at risk, but often have far higher proportions of their populations that could be victims during a disaster (Cross, 2001). Consequently, smaller cities, especially cities in small island countries, could suffer from both disaster-related mortality and economic loss (Charvériat, 2000; Hallegatte et al., 2013; UN-HABITAT, 2009; 2011; UNISDR, 2013). As small- and medium-sized cities are an important contributor to the overall increase of the urban population (United Nations, 2014), the increased risk of disasters in small and medium-sized cities is becoming more challenging.

It is estimated that the economic losses due to flooding alone reached US$6 billion in 2005 among the world's 136 largest coastal cities, and that it could reach US$60-63 billion in 2050 if disaster risk is assumed to remain constant (Hallegatte et al., 2013). The levels of risk and vulnerability found in this analysis underscore the importance of adequate pre-disaster preparedness. As of now, efforts have been tilted heavily towards ex-post interventions with about 95 per cent of funds being spent on relief and reconstruction (Hochrainer and Mechler, 2011; Mechler, 2004). It is essential for effective and long-term disaster-risk reduction to identify and measure risks and vulnerabilities before a disaster occurs rather than after disasters have happened (Birkmann, 2007; ESCAP and UNISDR, 2012).

Several limitations of the present paper should be taken into account in interpreting the results. First and foremost, the data on the natural disasters used in this study to classify categories of risk level did not include any data after 2003. Some of the disaster data, including those on cyclones, floods and droughts, span only twenty years and were insufficient to accurately measure long term risks. Furthermore, the category of risk level of a given city is assumed to be fixed over the period of analysis. There is evidence of increasing trends in the incidence of hydrological and meteorological disasters, and in their associated economic losses in the past few decades (Doocy, Daniels, Murray, et al., 2013; Schultz and Elliott, 2013). An increase in incidence since the period covered by our dataset would imply that recent risks of exposure to vulnerability to disasters for cities are higher than our estimates suggest and may increase in the future. As the risk of disaster-related mortality and economic losses largely depends on the ability of the existing building infrastructure to resist damage from natural disasters, it is possible that a large portion of vulnerability could result from poor infrastructure conditions, defective or faulty building codes and construction, poor governance, failure to evacuate populations at risk based on early warnings, and so on. Furthermore, because estimated vulnerability to disaster-related mortality or economic losses reflects past experience and fatalities mainly in the 1980-2000 period, the risk of mortality and economic vulnerabilities could be smaller for today's cities given the same risk of exposure. Already in some urban settlements in high risk zones, attempts have been made to improve building codes in order to better withstand various natural disasters, and local authorities have implemented some effective mitigation strategies (UNIPCC, 2012; UNISDR, 2012; 2013). A further limitation of the input data is that geographical grid data of some natural hazards (e.g., droughts and floods) were rather crude (e.g., up to 2.5 by 2.5 arc *degree* grid for droughts), which may not accurately reflect the real frequency of exposure to these disasters (Dilley et al., 2005).

Second, other types of disaster such as rising sea levels, wildfires, tsunamis, windstorms, extreme temperatures, heat waves, epidemics, and so forth are common to many cities (UNIPCC, 2012) but were not included in this analysis. The risk of exposure to natural disasters of these 1,692 cities could be greater if additional types of disaster were taken into consideration. It is possible that overall differential patterns of risks of exposure and vulnerability to natural disasters across city size groups, development groups, major areas and income groups could be altered if other types of natural disaster were considered. For instance, there is evidence showing that in the last three decades, Asia has had the highest number of geophysical, hydrological and meteorological disasters, Africa has experienced the highest number of biological disasters and droughts, and Europe has had the highest number of climatological disasters (Gencer, 2013).

Third, in this research, we mainly considered cities that were located in the top three deciles of grid cell values in any of the six types of natural disaster (i.e., 30 per cent most frequently stricken inhabited area by a disaster). Cities located in the remaining seven deciles, which were less frequently exposed or less vulnerable to any of these six types of natural disaster, were not highlighted. This of course does not mean that their potential exposure and vulnerability should be overlooked.

Fourth, there is a consensus within the scientific community that disaster-related deaths, injuries, impoverishment and damage or destruction of housing and infrastructure often go unrecorded (Dodman, Hardoy, and Satterthwaite, 2009; Doocy, Daniels, Murray, et al., 2013; UNISDR, 2011). For example, ample evidence indicates that in many flooding events deaths are unknown and unrecorded (Doocy, Daniels, Murray, et al., 2013). Such omissions from the data could bias downward estimates of vulnerability to mortality or economic losses.

Fifth, in this paper, we measured risks of vulnerability by disaster-related mortality risk and economic losses. However, alongside these measurable vulnerabilities, there could be less measurable losses such as destroyed or disrupted basic social service systems or school systems, weakened or less accountable municipal/city governance, exacerbated poverty or violence, and degraded community cohesion and well-being, which would produce far-reaching and long-term negative impacts on cities' development and individuals' quality of life (Adelekan, 2010). These vulnerabilities were not captured in this analysis yet represent important concerns for disaster recovery.

Finally, the WUP database focuses on the most populated cities, and publishes time series for cities with 300,000 inhabitants or more on 1 July 2014. However, another 1.7 billion people in 2014 lived in smaller cities and urban settlements and about 20-25 per cent of the urban growth by 2030 will come from these smaller cities (United Nations, 2014). Thus, our findings do not provide a full picture of urban exposure risk and economic and mortality vulnerability to natural disasters.

Since this analysis was conducted, new data on natural hazards for years after 2003 have become available (e.g., UNEP/GRID-Geneva, 2013; UNISDR, 2015).[9] Further research integrating these new data and models while addressing some or all of the above noted limitations in the analyses is clearly warranted.

[9] The new data mainly used new modelling techniques, including geo-physical probabilistic risk assessment models for earthquakes, cyclone wind and storm surges, tsunamis, and floods (UNEP/GRID-Geneva, 2013; UNISDR, 2015), CAPRA model (www.ecapra.org), International Best Track Archive for Climate Stewardship (IBTrACS) database (Knapp, Kruk, Levinson, and Gibney, 2009), and LICRICE reconstructed cyclone wind fields by Hsiang (2010).

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Appendix A. City coordinates, analytical buffers and risk zones for exposure, economic-loss and mortality

The primary data sources used to produce the *World Urbanization Prospects* are statistical tabulations that provide total population counts for major urban areas defined by names rather than by geo-spatial features. The exact geo-physical urban extent associated with the total population of most cities included in the *World Urbanization Prospects* analysis is, overall, not made publicly available by national authorities.

Using the name of each locality or urban area, geographic coordinates (i.e., latitude and longitude in decimal degree using the World Geodetic System (WGS84) ellipsoid) for the centroid location of each urban area were obtained from several authoritative public sources (e.g., national authorities' web sites and online public gazetteers such as Geonames[10] and FuzzyG UN/EC Common Gazetteer[11]). Centroid coordinates were further validated using GIS operation like point-in-polygon tests with several reference geographical datasets such as a world map with international boundaries and country polygons (UNmap[12] Level 0 at 1:1 million scale) and the urban extents from the Global Rural-Urban Mapping Project (GRUMP)[13] for each city in the *2014 Revision* of the *World Urbanization Prospects*. Finally, Google Earth with remote sensing imagery was used to resolve discrepancies and to obtain centroid coordinates consistent with land features (i.e., excluding rivers and lakes) and coastlines.

The urban extent for each city included in this analysis was approximated using a proportionate circular polygon buffer based on the population size estimated for mid-2014 as part of the *2014 revision* of the WUP and the statistical relationship between city population size and urban extents estimated using MODIS 500 meter resolution remote sensing global urban map for 3,646 urban areas with 100,000 inhabitants or more in 2000 from the Atlas of Urban Expansion (see Angel et al., 2012).

The radius (R) in kilometres of the circle covering an urban area corresponds to $= \sqrt{\frac{Area\ in\ km^2}{\pi}}$, and the *Atlas of Urban Expansion* provides the urban footprint estimate in 2000 based on remote sensing imagery together with population estimates associated to these 3,646 urban areas. In addition, the *Atlas* provides the average distance *(D)* in km from all points in the urban footprint to the city centre. For the analytical purpose of this study, the maximum distance between *R* and *D* values was used, denoted *max(R, D)*. In almost all instances *R* was greater than *D*, except for urban areas not conforming to circular shapes (e.g., cities stretched along coastline or between mountains).

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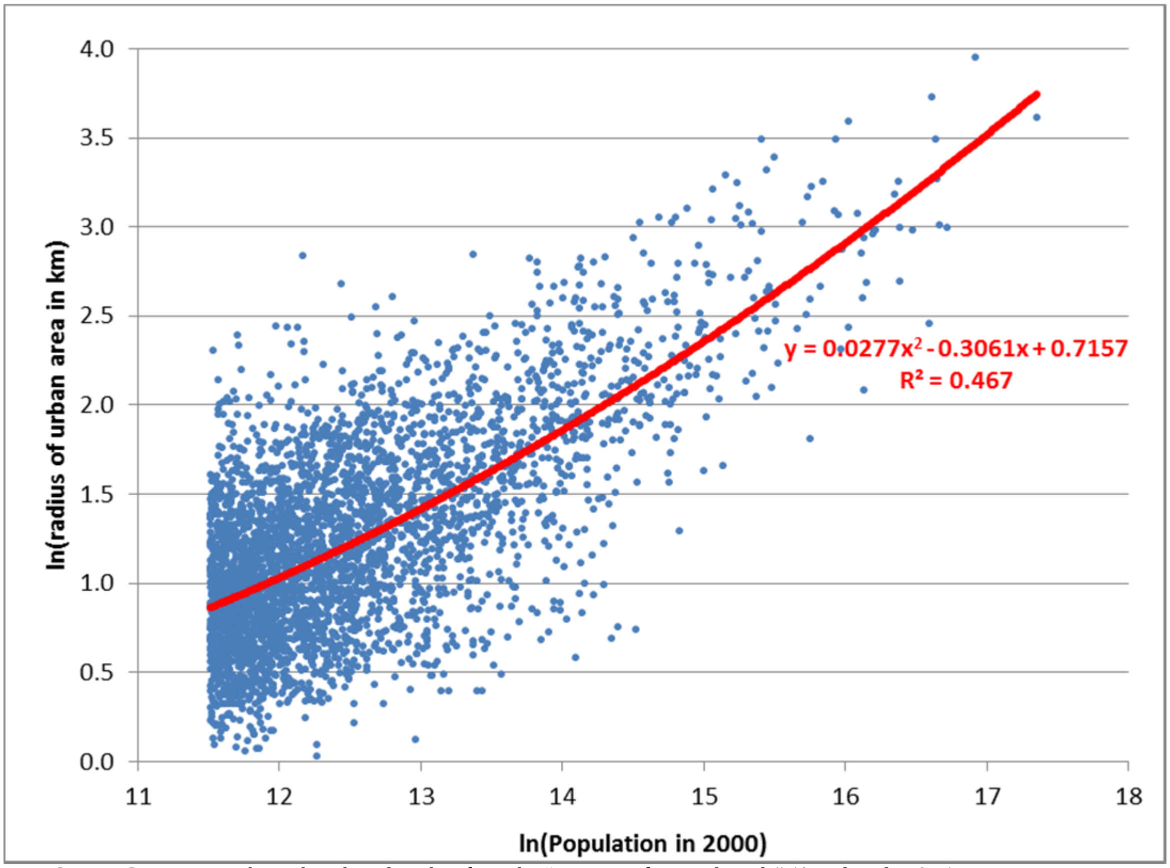
[10] Geonames Gazetteer. http://www.geonames.org. Retrieved 4 March 2014.
[11] FuzzyG is a service of the Joint Research Centre of the European Commission and the Cartographic Section of the United Nations. http://dma.jrc.it/services/gazetteer/ Retrieved 4 March 2014.
[12] UN Cartographic Section (UNCS).UNmap. http://ggim.un.org/projects.html. Retrieved 19 July 2013.
[13] Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Center International de Agriculture Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4GH9FVG. accessed 14 April 2014.

Figure A. Relationship between city populations and the radius of urban extents in 2000



Source: Computations by authors based on data from the "universe-of-cities-data.xls" (Angel et al., 2012).

Figure A shows the relationship between the population in 2000 (in log scale in X-axis) and the radius of the associated urban area in 2000 in km (in log scale in y-axis) in the form of a scatter plot with a second degree polynomial function fitted to these data.

For the purpose of this report, the radius in kilometres for the proportionate circular buffer (Z) for each city in the *2014 Revision* of the *World Urbanization Prospects* was obtained using the statistical relationship in figure A:

$$\ln(\max(R,D)) = 0.0277 \times \ln(City\ Pop)^2 - 0.3061 \times \ln(City\ Pop) + 0.7157$$

with $Z = \exp^{(\ln(\max(R,D)))}$ and "City Pop" expressed in unit (i.e., number of persons) using the city population estimate for the year of 2014 from the *2014 Revision* of the *World Urbanization Prospects.*

Appendix B. Sensitivity analysis of estimating risk zones for exposure, economic-loss and mortality between the buffered circular polygons and the GRUMP urban extents

A sensitivity analysis was performed by comparing our estimates with the estimates using the urban extents from the Global Rural-Urban Mapping Project (GRUMP) [14]for each corresponding city in the *2014 Revision* of the WUP. The very high level of consistency between the two sources clearly suggests that our approach is quite reliable (see tables B-1 to B-3). [15]

TABLE B-1. PERCENTAGES OF CONSISTENCY FOR ESTIMATES OF EXPOSURE TO THE SIX TYPES OF NATURAL DISASTER (IN DECILES) FOR CITIES OF THE WORLD BETWEEN THE BUFFERED CIRCULAR POLYGONS AND THE GRUMP URBAN EXTENTS (%)

	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
All cities (1,692)	93.1	91.7	93.3	89.7	88.9	98.1
City by size						
Megacities (28)	100.0	91.7	96.4	92.9	82.1	89.3
5-10 million (44)	81.4	85.7	97.7	81.4	88.4	95.3
1 -5 million (416)	91.4	81.4	91.6	89.4	88.0	97.8
<1 million (1,204)	93.9	92.5	93.9	90.0	89.4	98.5
City by major area						
Africa (187)	99.5	93.6	100.0	96.3	96.8	100.0
Asia (881)	95.0	93.0	92.2	93.2	90.7	97.7
Europe (254)	96.9	85.4	93.7	88.2	86.2	98.8
Latin America & the Caribbean (206)	91.7	93.7	92.2	88.8	78.6	95.6
Northern America (151)	70.2	88.7	92.1	64.2	87.4	100.0
Oceania (13)	84.6	100.0	100.0	92.3	84.6	100.0
City by development group						
Least developed countries (103)	99.0	94.0	99.0	97.0	97.0	100.0
Less developed regions, excluding least developed countries (1,153)	95.0	94.0	93.0	93.0	90.0	99.0
More developed regions (436)	87.0	86.0	92.0	78.0	84.0	96.0
Cities by income group						
Low-income (94)	98.9	94.7	98.9	97.9	92.6	100.0
Lower-middle-income (395)	98.5	94.9	97.5	93.9	91.4	97.5
Upper-middle-income (734)	93.1	93.1	92.1	93.2	89.9	99.2
High-income (469)	87.4	86.1	90.6	78.9	84.4	98.1

NOTE: (1) The consistency check is for 1,692 cities with 300,000 inhabitants or more in 2014. Percentage of consistency is the number of matched cities between two methods divided by 1,692. (2) Numbers in the parentheses refer to number of cities.

[14]Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4GH9FVG. Accessed 14 April 2014. Note that in the GRUMP dataset several urban extents contain more than one city, which implies that the estimates based on our buffered circular polygon cannot be identical to those based on the GRUMP.

[15]Note that in the GRUMP dataset several urban extents contain more than one city, which implies that the estimates based on our buffered circular polygon cannot be identical to those based on the GRUMP.

TABLE B-2. PERCENTAGES OF CONSISTENCY FOR ESTIMATES OF MORTALITY VULNERABILITY TO THE SIX TYPES OF NATURAL DISASTER (IN DECILES) OF CITIES OF THE WORLD BETWEEN THE BUFFERED CIRCULAR POLYGONS AND THE GRUMP URBAN EXTENTS (%)

	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
All cities (1,692)	96.9	95.7	96.0	94.7	91.4	98.3
City by size						
Megacities (28)	100.0	85.7	96.4	96.4	89.3	89.3
5-10 million (44)	100.0	93.0	97.7	95.3	93.0	95.3
1 -5 million (416)	96.4	96.2	95.9	95.2	91.6	98.1
<1 million (1,204)	96.8	95.8	96.0	94.4	91.3	98.7
City by major area						
Africa (187)	99.5	96.8	100.0	97.3	97.3	99.5
Asia (881)	97.5	94.8	96.0	96.0	91.9	97.8
Europe (254)	97.6	100.0	94.5	91.7	86.6	100.0
Latin America & the Caribbean (206)	93.7	93.7	96.6	95.6	83.0	95.6
Northern America (151)	93.4	94.7	92.7	86.8	100.0	100.0
Oceania (13)	92.3	100.0	100.0	100.0	92.3	100.0
City by development group						
Least developed countries (103)	99.0	95.1	100.0	99.0	98.1	100.0
Less developed regions, excluding least developed countries (1,153)	97.0	94.8	96.7	96.1	91.4	98.6
More developed regions (436)	96.1	98.2	93.3	89.9	89.7	97.0
Cities by income group						
Low-income (94)	98.9	94.7	100.0	98.9	95.7	100.0
Lower-middle-income (395)	99.7	97.5	98.7	96.7	93.2	97.7
Upper-middle-income (734)	96.0	95.1	95.4	95.8	91.3	99.0
High-income (469)	95.3	95.3	94.0	90.4	89.1	97.2

NOTE: (1) The consistency check is for 1,692 cities with 300,000 inhabitants or more in 2014. Percentage of consistency is the number of matched cities between two methods divided by 1,692. (2) Numbers in the parentheses refer to number of cities.

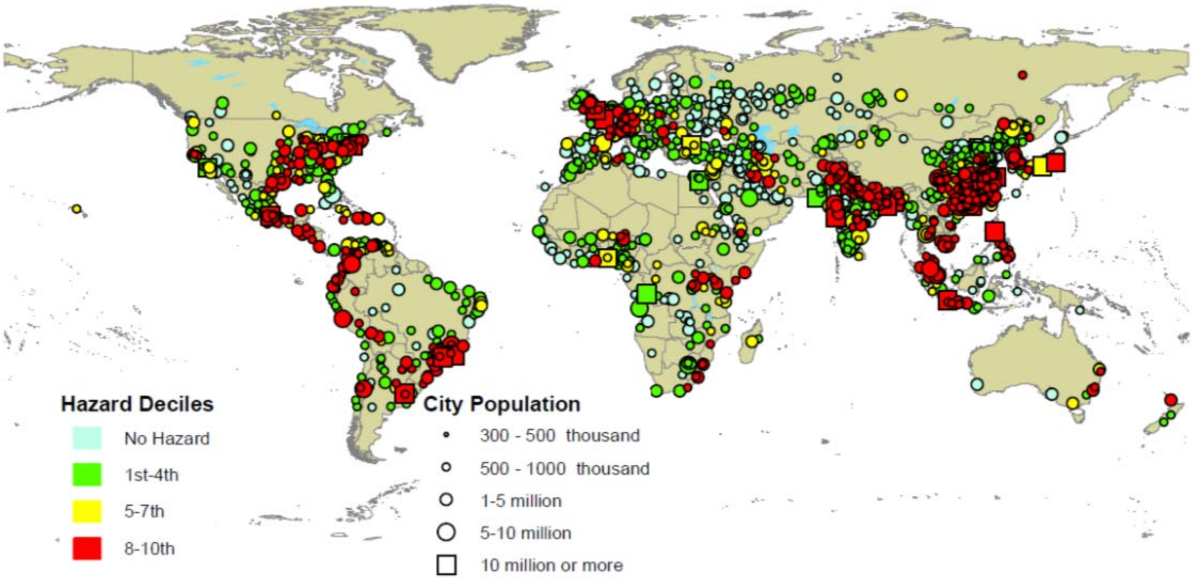
TABLE B-3. PERCENTAGES OF CONSISTENCY FOR ESTIMATES OF ECONOMIC VULNERABILITY TO THE SIX TYPES OF NATURAL DISASTER (IN DECILES) OF CITIES OF THE WORLD BETWEEN THE BUFFERED CIRCULAR POLYGONS AND THE GRUMP URBAN EXTENTS (%)

	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
All cities (1,692)	96.7	93.5	91.0	95.0	92.1	98.9
City by size						
Megacities (28)	100.0	85.7	96.4	100.0	89.3	96.4
5-10 million (44)	100.0	86.0	97.7	95.3	93.0	100.0
1 -5 million (416)	97.1	94.0	90.9	94.2	92.2	98.8
<1 million (1,204)	96.4	93.8	90.6	95.1	92.1	98.9
City by major area						
Africa (187)	99.5	94.7	100.0	95.2	100.0	100.0
Asia (881)	97.2	95.1	85.7	96.3	93.0	99.3
Europe (254)	98.0	85.4	93.7	93.3	87.0	98.8
Latin America & the Caribbean (206)	94.2	96.6	91.3	93.2	81.6	95.1
Northern America (151)	92.7	91.4	94.0	92.1	100.0	100.0
Oceania (13)	92.3	100.0	100.0	100.0	92.3	100.0
City by development group						
Least developed countries (103)	99.0	94.2	89.3	98.1	98.1	100.0
Less developed regions, excluding least developed countries (1,153)	96.8	95.9	90.1	95.6	92.3	98.6
More developed regions (436)	96.1	86.9	93.6	92.7	90.1	99.3
Cities by income group						
Low-income (94)	98.9	93.6	87.2	98.9	95.7	100.0
Lower-middle-income (395)	100.0	96.2	90.9	94.9	92.7	98.0
Upper-middle-income (734)	95.4	96.3	90.2	95.9	92.9	98.9
High-income (469)	95.7	86.8	93.0	92.8	89.6	99.4

NOTE: (1) The consistency check is for 1,692 cities with 300,000 inhabitants or more in 2014. Percentage of consistency is the number of matched cities between two methods divided by 1,692. (2) Numbers in the parentheses refer to number of cities.

Appendix C. Selected maps for spatial distributions of exposure and economic and mortality vulnerability to the six types of natural disaster for cities of the world

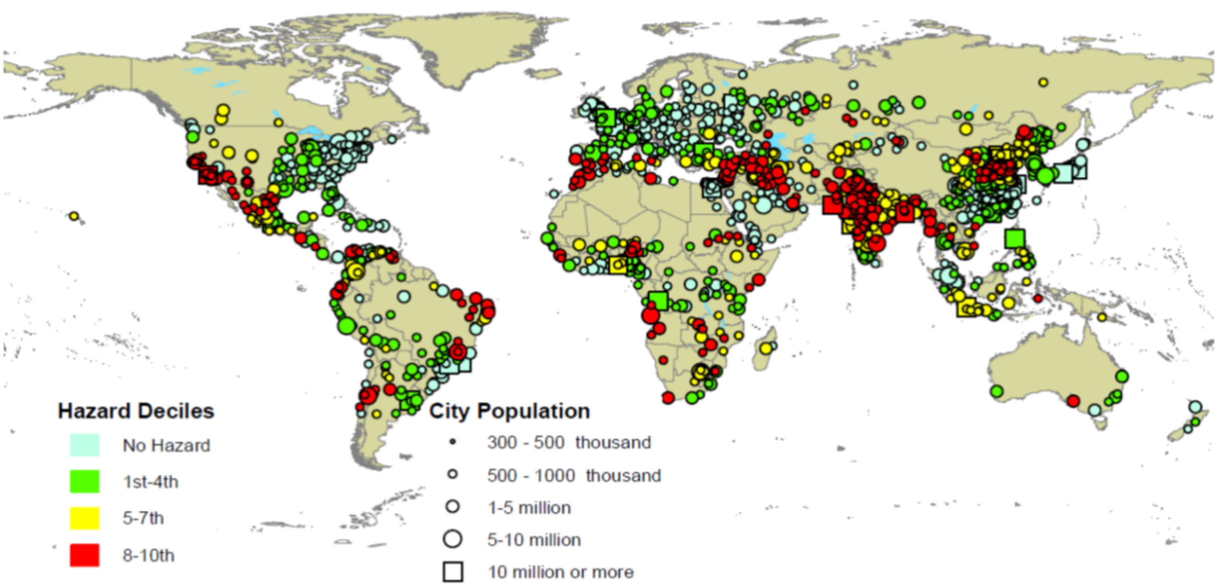
Figure C1a. Spatial distribution of risk of exposure to floods for cities of the world



Disclaimer: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

NOTE: City population refers to mid-2014.

Figure C1b. Spatial distribution of risk of exposure to droughts for cities of the world



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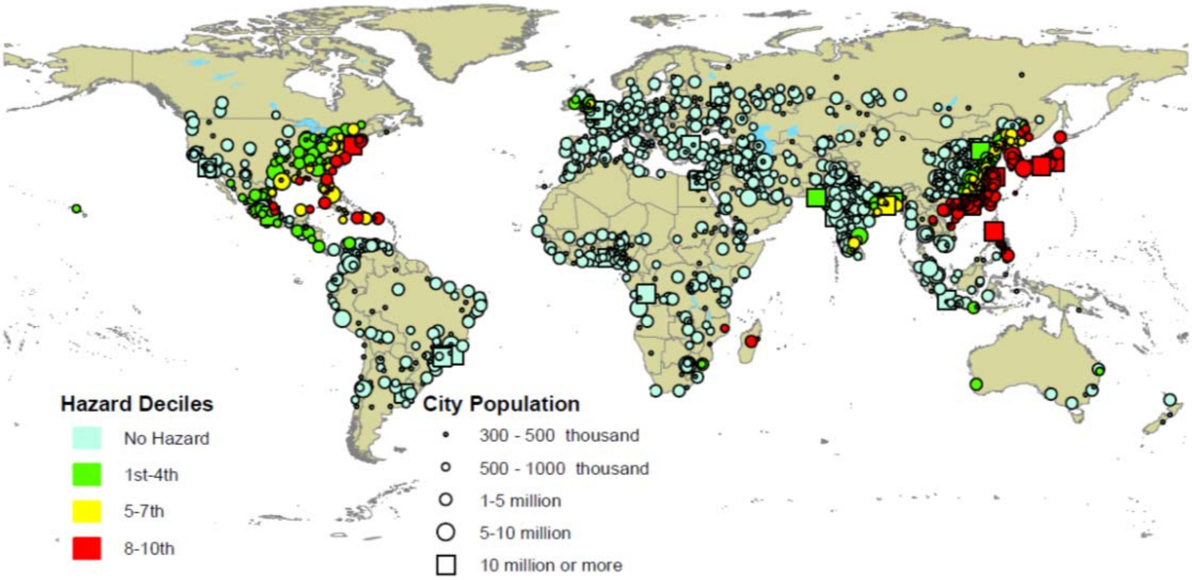
NOTE: City population refers to mid-2014.

Figure C1c. Spatial distribution of risk of exposure to cyclones for cities of the world



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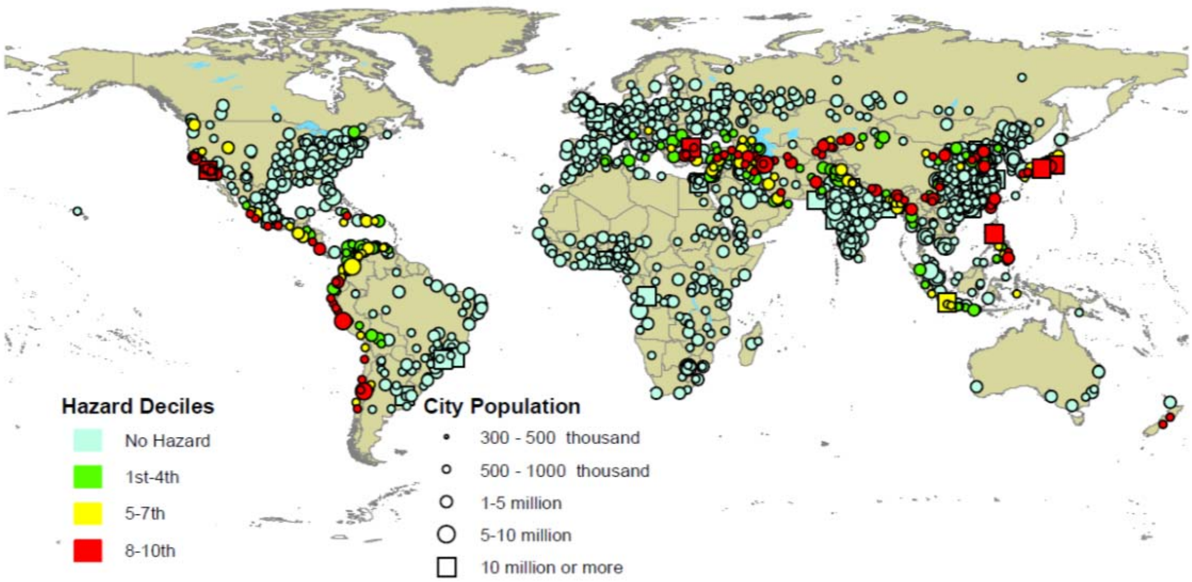
NOTE: City population refers to mid-2014.

Figure C1d. Spatial distribution of risk of exposure to earthquakes for cities of the world



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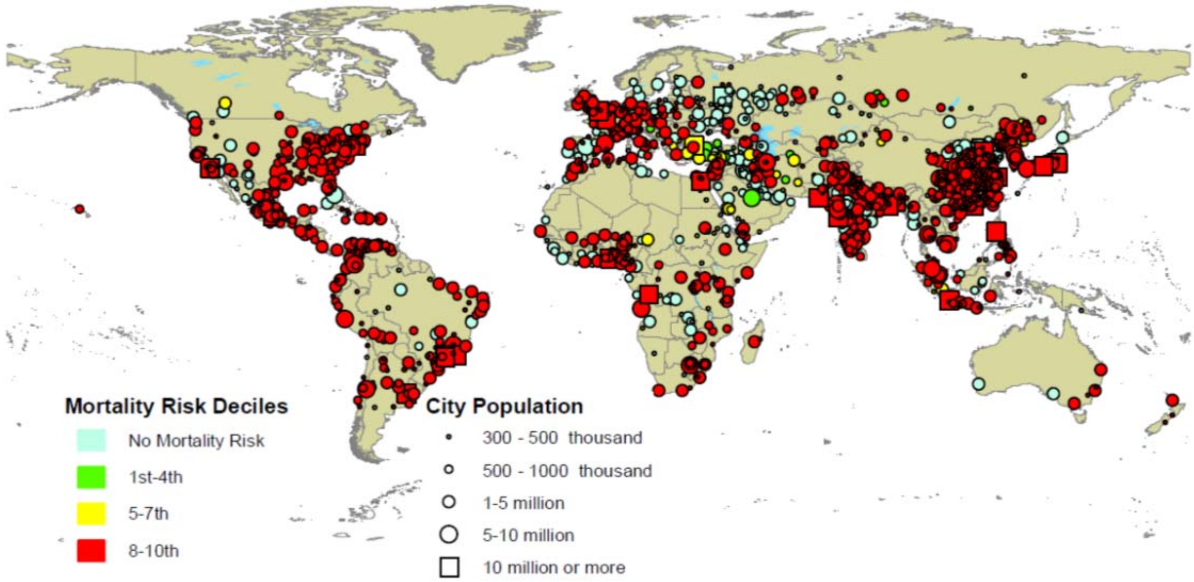
NOTE: City population refers to mid-2014.

Figure C2a. Spatial distribution of risk of mortality vulnerability to floods for cities of the world



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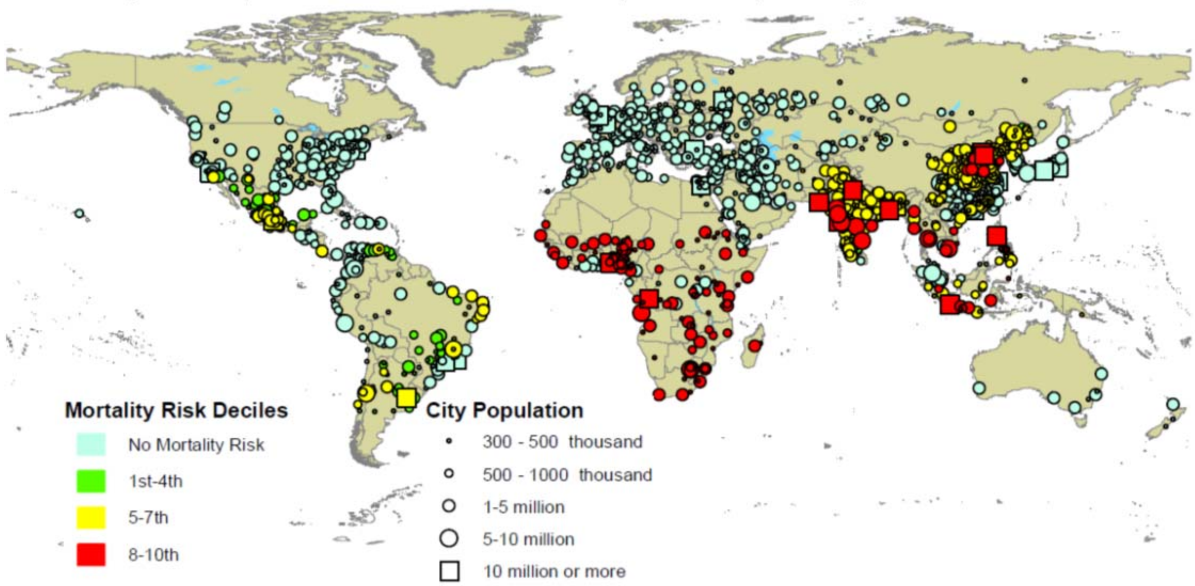
NOTE: City population refers to mid-2014.

Figure C2b. Spatial distribution of risk of mortality vulnerability to droughts for cities of the world



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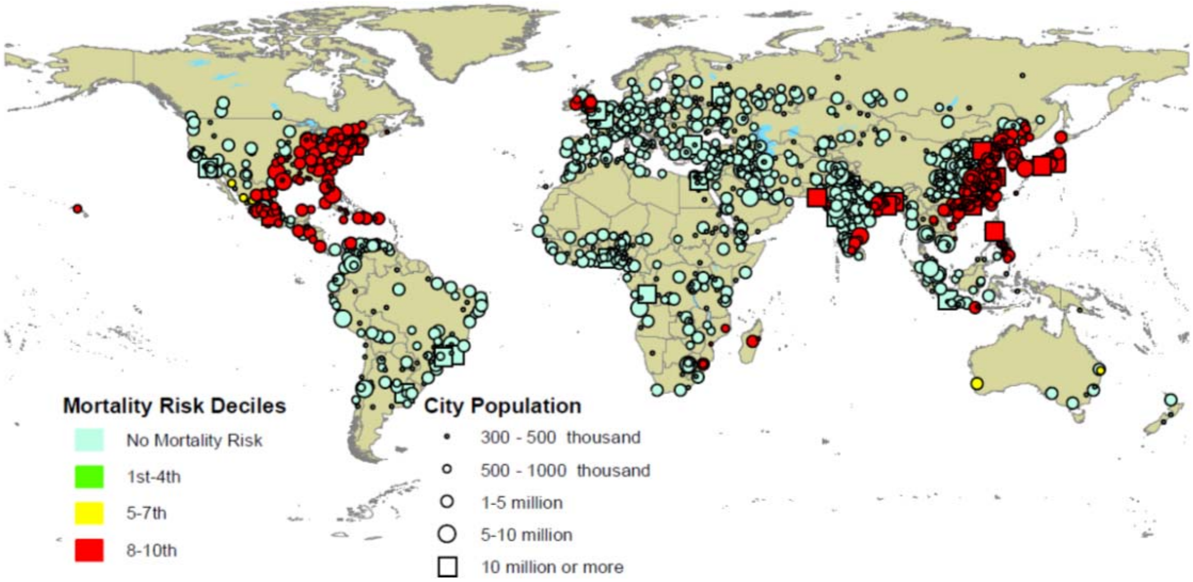
NOTE: City population refers to mid-2014.

Figure C2c. Spatial distribution of risk of mortality vulnerability to cyclones for cities of the world



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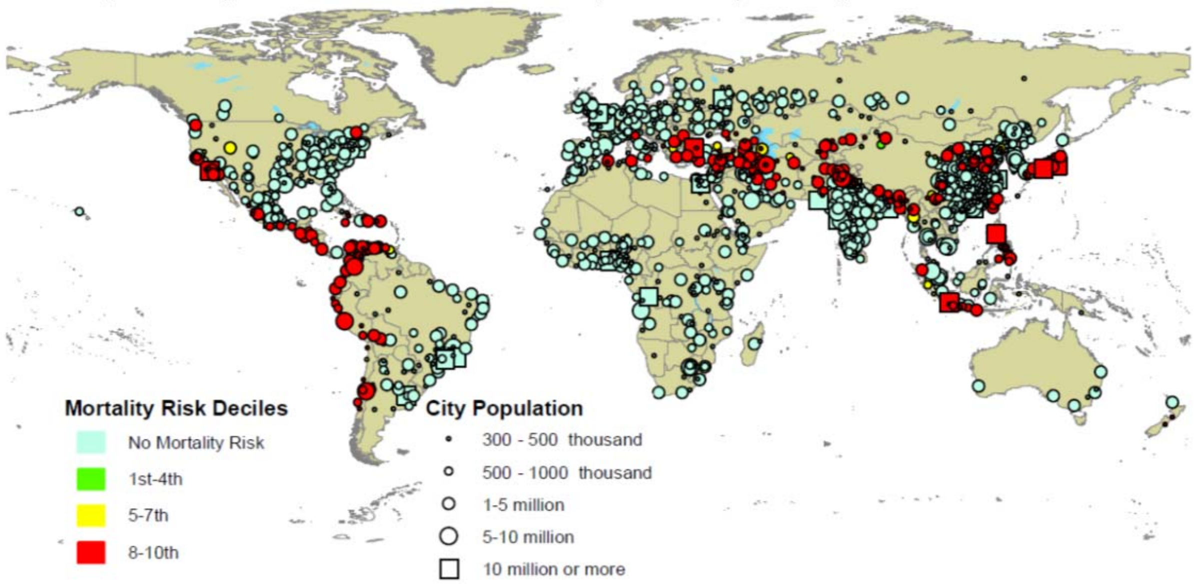
NOTE: City population refers to mid-2014.

Figure C2d. Spatial distribution of risk of mortality vulnerability to earthquakes for cities of the world



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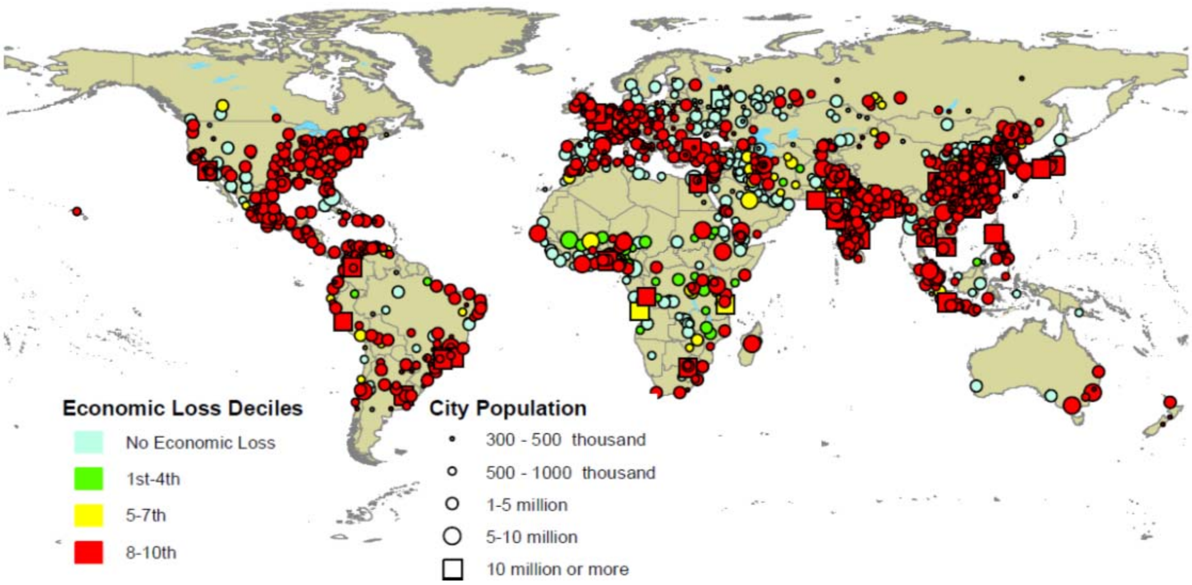
NOTE: City population refers to mid-2014.

Figure C3a. Spatial distribution of risk of economic vulnerability to floods for cities of the world



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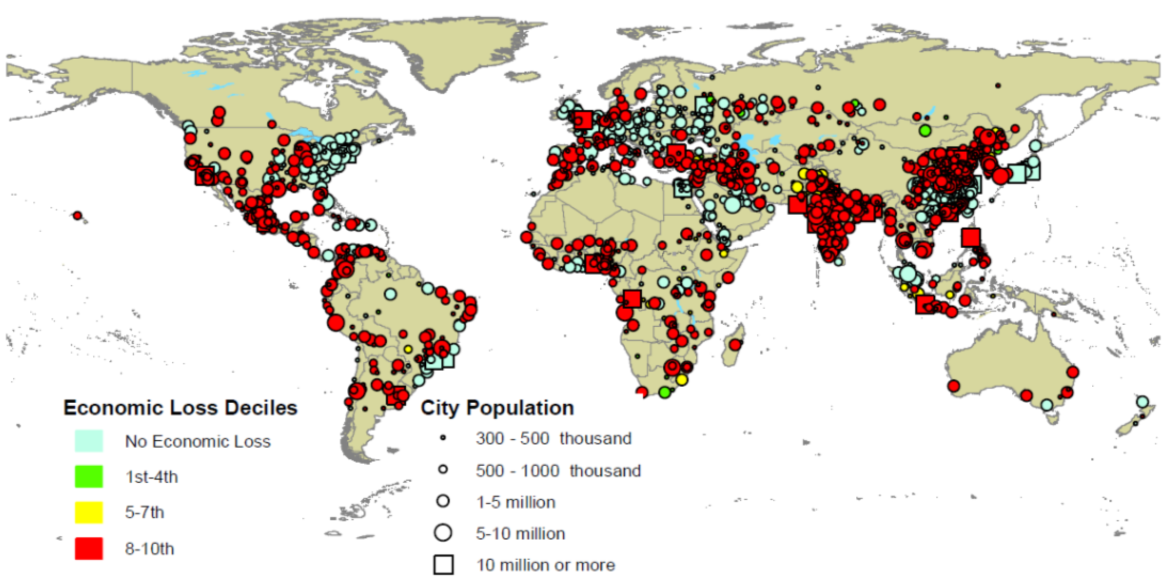
NOTE: City population refers to mid-2014.

Figure C3b. Spatial distribution of risk of economic vulnerability to droughts for cities of the world



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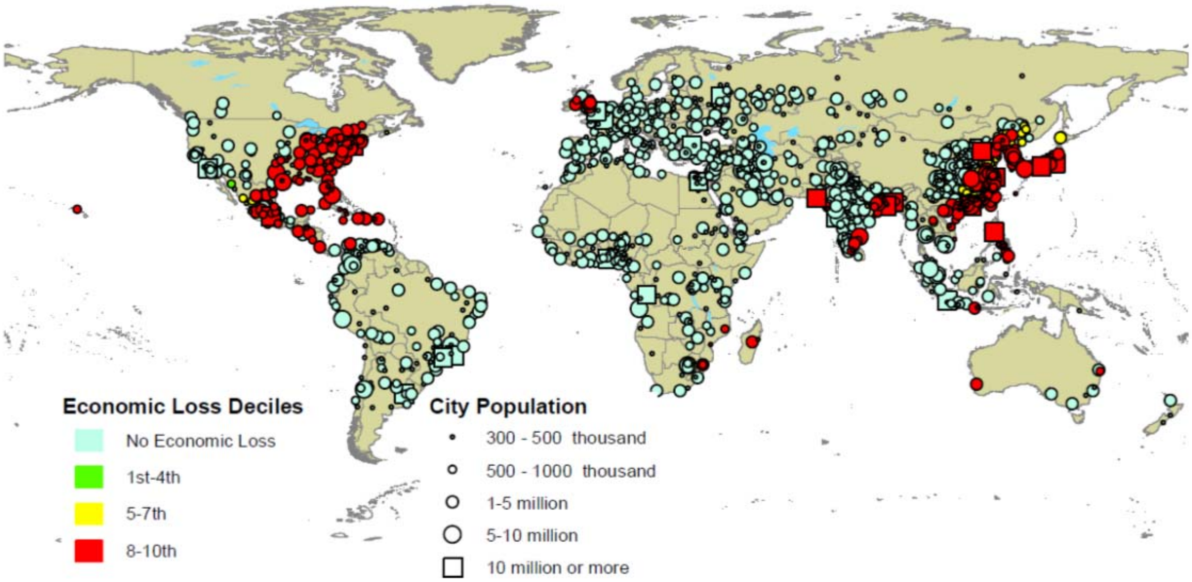
NOTE: City population refers to mid-2014.

Figure C3c. Spatial distribution of risk of economic vulnerability to cyclones for cities of the world



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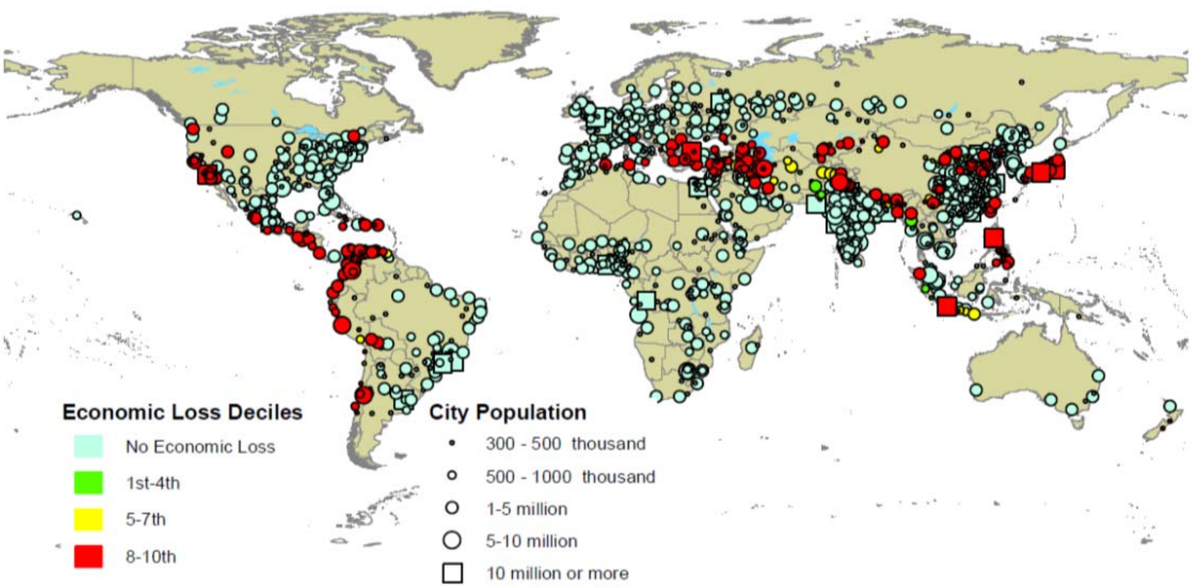
NOTE: City population refers to mid-2014.

Figure C3d. Spatial distribution of risk of economic vulnerability to earthquakes for cities of the world



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NOTE: City population refers to mid-2014.

Appendix D. Lists of selected cities with high exposure and vulnerabilities to the six types of natural disaster

TABLE D1. LIST OF CITIES WITH ONE MILLION INHABITANTS OR MORE ON 1 JULY 2014 THAT WERE EXPOSED TO AT LEAST THREE OF THE SIX TYPES OF NATURAL DISASTER

			Risk of exposure (in decile)					
City Names	*Countries*	*Population (millions) **	*Cyclones*	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Tokyo	Japan	37.8	8-10	0	8-10	8-10	8-10	0
Osaka	Japan	20.1	8-10	0	8-10	5-7	8-10	0
Manila	Philippines	12.8	8-10	1-4	8-10	8-10	8-10	8-10
Santiago	Chile	6.5	0	8-10	8-10	8-10	5-7	0
Shizuoka-Hamamatsu M.M.A.	Japan	3.2	8-10	0	8-10	1-4	8-10	0
Guatemala City	Guatemala	2.8	1-4	8-10	5-7	8-10	8-10	0
Taipei	Taiwan, China	2.7	8-10	0	8-10	8-10	8-10	0
Quito	Ecuador	1.7	0	8-10	8-10	8-10	8-10	8-10
Davao City	Philippines	1.6	8-10	1-4	8-10	8-10	5-7	0
Kaohsiung	Taiwan, China	1.5	8-10	0	8-10	5-7	8-10	0
Taichung	Taiwan, China	1.2	8-10	0	8-10	8-10	8-10	0
San José	Costa Rica	1.2	1-4	8-10	8-10	8-10	8-10	8-10
Gauhati	India	1.0	0	8-10	8-10	8-10	0	0

NOTE: *, referring to 1 July 2014. The risk of exposure is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of exposure to a natural disaster. See Data and Method for details.

TABLE D2. LIST OF CITIES WITH 5 MILLION INHABITANTS OR MORE ON 1 JULY 2014 THAT WERE VULNERABLE TO AT LEAST THREE OF THE SIX TYPES OF NATURAL HAZARD IN TERMS OF DISASTER-RELATED MORTALITY

			Vulnerability to disaster-related mortality (in decile)					
City Names	*Countries*	*Population (millions) **	*Cyclones*	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Tokyo	Japan	37.8	8-10	0	8-10	8-10	8-10	0
Mexico City	Mexico	20.8	8-10	5-7	0	8-10	8-10	8-10
Osaka	Japan	20.1	8-10	0	8-10	8-10	8-10	0
Karachi	Pakistan	16.1	8-10	8-10	0	8-10	0	0
Kolkata	India	14.8	8-10	8-10	0	8-10	0	0
Manila	Philippines	12.8	8-10	8-10	8-10	8-10	8-10	8-10
Tianjin	China	10.9	8-10	8-10	0	8-10	0	0
Jakarta	Indonesia	10.2	0	8-10	8-10	8-10	0	0
Madras	India	9.6	8-10	8-10	0	8-10	0	0
Bogotá	Colombia	9.6	0	0	8-10	8-10	8-10	0
Nagoya	Japan	9.4	8-10	0	8-10	8-10	0	0
Tehran	Iran	8.4	0	0	8-10	8-10	8-10	0

NOTE: *, referring to 1 July 2014. The risk of vulnerability is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of mortality vulnerability to a natural disaster. See Data and Method for details.

TABLE D3. LIST OF CITIES WITH 5 MILLION INHABITANTS OR MORE ON 1 JULY 2014 THAT WERE HIGHLY VULNERABLE TO AT LEAST THREE OF THE SIX TYPES OF NATURAL HAZARD IN TERMS OF DISASTER-RELATED ECONOMIC LOSSES

			Vulnerability disaster-related economic losses (in decile)					
City Names	*Countries*	*Population (millions) **	*Cyclones*	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Tokyo	Japan	37.8	8-10	0	8-10	8-10	8-10	0
Mexico	Mexico	20.8	8-10	8-10	0	8-10	8-10	8-10
Osaka	Japan	20.1	8-10	8-10	8-10	8-10	8-10	0
Dhaka	Bangladesh	17.0	8-10	8-10	0	8-10	0	0
Karachi	Pakistan	16.1	8-10	8-10	00	8-10	0	0
Kolkata	India	14.8	8-10	8-10	0	8-10	0	0
Istanbul	Turkey	14.0	0	8-10	8-10	8-10	0	0
Manila	Philippines	12.8	8-10	8-10	8-10	8-10	8-10	8-10
Los Angeles-Long Beach-Santa Ana	USA	12.3	0	8-10	8-10	8-10	0	0
Tianjin	China	10.9	8-10	8-10	0	8-10	0	0
Shenzhen	China	10.7	8-10	8-10	0	8-10	0	0
Jakarta	Indonesia	10.2	0	8-10	8-10	8-10	0	0
Seoul	Rep. Korea	9.8	8-10	8-10	0	8-10	0	0
Lima	Peru	9.7	0	8-10	8-10	8-10	0	0
Madras	India	9.6	8-10	8-10	0	8-10	0	0
Bogotá	Colombia	9.6	0	8-10	8-10	8-10	8-10	0
Chukyo M.M.A. (Nagoya)	Japan	9.4	8-10	0	8-10	8-10	0	0
Chicago	USA	8.7	8-10	8-10	0	8-10	0	0
Lahore	Pakistan	8.5	0	8-10	8-10	8-10	0	0
Tehran	Iran	8.3	0	8-10	8-10	8-10	0	0
Wuhan	China	7.8	8-10	8-10	0	8-10	0	0
Hong Kong	China, H.K. SAR	7.3	8-10	8-10	0	8-10	0	0
Santiago	Chile	6.5	0	8-10	8-10	8-10	0	0
Shenyang	China	6.2	8-10	8-10	0	8-10	0	0
Kitakyushu-Fukuoka M.M.A.	Japan	5.5	8-10	8-10	0	8-10	8-10	0
Houston	USA	5.5	8-10	8-10	0	8-10	0	0

NOTE: *, referring to 1 July 2014. The risk of vulnerability is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of mortality vulnerability to a natural disaster. See Data and Method for details.

Appendix E: Distribution of risks of exposure and vulnerability to the six types of natural disasters by decile of grid cells

TABLE E1. DISTRIBUTION OF RISK OF EXPOSURE TO THE SIX TYPES OF NATURAL DISASTER BY DECILE

	Natural disasters					
	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Risks by decile for number of cities						
# of cities	1,692	1,692	1,692	1,692	1,692	1,692
% 0	73.1	32.6	80.0	20.4	93.7	98.7
% 1-4 deciles	8.7	28.8	8.0	32.2	0.0	0.3
% 5-7 deciles	7.3	19.1	5.9	13.3	5.0	0.2
% 8-10 deciles	10.8	19.5	6.1	34.1	1.3	0.8
% Total	100.0	100.0	100.0	100.0	100.0	100.0
Risks by decile for city populations						
# of populations (millions)	2,202	2,202	2,202	2,202	2,202	2,202
% 0	66.5	34.3	78.9	15.2	89.3	97.6
% 1-4 deciles	11.5	27.9	6.5	27.8	0.0	0.2
% 5-7 deciles	5.8	19.1	4.8	14.5	6.0	1.1
% 8-10 deciles	16.2	18.7	9.8	42.3	4.7	1.1
% Total	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Only includes cities with 300,000 inhabitants or more on 1 July 2014. The risk of exposure is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of exposure to a natural disaster. See Data and Method for details.

TABLE E2. DISTRIBUTION OF RISK OF MORTALITY VULNERABILITY TO THE SIX TYPES OF NATURAL DISASTER BY DECILE

	Natural disasters					
	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Risks by decile for number of cities						
# of cities	1,692	1,692	1,692	1,692	1,692	1,692
% 0	73.3	54.9	80.7	20.7	94.9	98.9
% 1-4 deciles	0.0	6.1	0.2	0.9	0.6	0.0
% 5-7 deciles	1.7	29.0	2.3	4.0	0.3	0.2
% 8-10 deciles	25.0	10.0	16.8	74.3	4.2	0.9
% Total	100.0	100.0	100.0	100.0	100.0	100.0
Risks by decile for city populations						
# of populations (millions)	2,202	2,202	2,202	2,202	2,202	2,202
% 0	66.9	55.0	79.6	15.8	91.1	97.7
% 1-4 deciles	0.0	3.7	0.1	0.9	0.5	0.0
% 5-7 deciles	0.8	24.0	1.0	2.8	0.2	0.1
% 8-10 deciles	32.3	17.3	19.3	80.5	8.2	2.2
% Total	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Only includes cities with 300,000 inhabitants or more on 1 July 2014. The risk of mortality vulnerability is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of mortality to a natural disaster. See Data and Method for details.

TABLE E3. DISTRIBUTION OF RISK OF ECONOMIC VULNERABILITY TO THE SIX TYPES OF NATURAL DISASTER BY DECILE

	Natural disasters					
	Cyclones	*Droughts*	*Earthquakes*	*Floods*	*Landslides*	*Volcano eruptions*
Risks by decile for number of cities						
# of cities	1,692	1,692	1,692	1,692	1,692	1,692
% 0	73.3	33.3	80.6	20.9	95.6	99.1
% 1-4 deciles	0.9	1.6	0.8	2.7	0.2	0.1
% 5-7 deciles	4.8	5.0	3.4	5.0	1.0	0.1
% 8-10 deciles	20.9	60.1	15.2	71.3	3.2	0.8
% Total	100.0	100.0	100.0	100.0	100.0	100.0
Risks by decile for city populations						
# of populations (millions)	2,202	2,202	2,202	2,202	2,202	2,202
% 0	66.6	34.7	79.6	15.8	91.7	97.8
% 1-4 deciles	0.3	0.6	0.4	1.2	0.3	0.0
% 5-7 deciles	2.7	2.9	2.0	3.0	0.8	0.1
% 8-10 deciles	30.3	61.7	18.1	80.0	7.2	2.1
% Total	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Only includes cities with 300,000 inhabitants or more on 1 July 2014. The risk of economic vulnerability is measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no risk of economic losses to a natural disaster. See Data and Method for details.