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Exposure and vulnerability to natural disasters for world's cities*

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Abstract

This paper aims to investigate exposure and vulnerability to natural disasters for cities with 300,000 inhabitants or more in 2018. The report uses data from the 2018 revision of World Urbanization Prospects, the spatial hotspot data on exposure and vulnerability to natural disasters, as well as sources for estimating the urban extent of each city and for the classification of coastal and inland cities. The 2018 revision of World Urbanization Prospects includes estimates and projections for 1,860 urban agglomerations with 300,000 inhabitants or more as of mid-2018. The spatial hotspot data, produced by Columbia University and the World Bank, includes information for six types of disaster, that is, cyclones, floods, droughts, earthquakes, landslides and volcanic eruptions. Based on these data, the paper examines exposure of the 1,860 cities to the six types of disaster and the vulnerability to disaster-related mortality and economic losses. Variations in exposure to risk of and vulnerability to natural disasters across city sizes, development groups, Sustainable Development Goals region and income groups are also presented. The present study seeks to inform urban planners and policy makers about the need to strengthen resilience, improve preparedness, and adapt strategies of cities to address the effects of natural disasters with a view to achieving the Sustainable Development Goals.

Keywords: Natural disasters, climate change, urbanization, city, exposure, vulnerability

Sustainable Development Goals: 11, 13

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CONTENTS

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I. INTRODUCTION

The world is urbanizing. In 2018, about 55 per cent of the world's population lived in urban areas, an increase from 43 per cent in 1990. By 2050, more than two-thirds of the world's population is projected to live in urban areas. The number of cities with 300,000 inhabitants reached 1,860 in 2018, rising from 305 cities in 1950 and 976 in 1990 (United Nations, 2018).

Cities are socioeconomic hubs (Brunn, Hays-Mitchell, and Ziegler, 2008). In many countries, it is estimated that 70 to 80 per cent of the gross domestic product (GDP) is produced in urban areas (Weiss, 2001; Dobbs, Manyika, and Roxburgh, 2011). Indeed, cities are the locations where the capacity of our economic development, the future of societies and the world's ecosystem will play out (Brunn, Hays-Mitchell, and Ziegler, 2008; Sassen, 2009). 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, makes urban centres more susceptible to the risk of being severely affected by natural hazards than rural settings (Gencer, 2013).

It has been estimated that the direct losses from all disasters in the period 1998-2017 totalled $2.9 trillion, which is 2.3 times as much as the overall losses of $1.3 trillion in the period 1978-1997. Slightly over two-thirds of the total losses in the period 1978-1997 were caused by climate- and weather-related disasters and this share increased to three-fourths in the period 1998-2017 (United Nations Office for Disaster Risk Reduction (UNDRR), 2019a). As a result of natural disasters, 1.3 million people were killed and 4.4 billion were injured in the past two decades, while millions were left homeless, displaced or required emergency help. Earthquakes and related tsunamis were responsible for more than half of these deaths (Centre for Research on the Epidemiology of Disasters (CRED) and UNISDR, 2015a). In the year of 2018 alone, about 60 million people were affected by extreme weather events around the world, thousands of lives were lost because of earthquakes, tsunamis and volcanic activities, and millions of people were displaced because of floods, drought and storms (UNDRR, 2019a).

The number of reported disasters is growing. It is estimated that the reported number of annual weather-related disasters was 335 between 2005 and 2014, an increase of 14 per cent compared to the period 1995-2004, and almost twice the level recorded during 1985-1995 (CRED and UNISDR, 2015b). Climate-related disasters accounted for about 90 percent of the 7,255 major disasters between 1998 and 2017, most of which were floods and storms (UNDRR, 2019a). The devastating impact of these disasters underscore the importance to reduce the loss of life, the numbers of people affected, the damage to critical infrastructure and the economic losses.

Evidence has shown that rapid urbanization and population growth drive to a large extent the impact of natural disasters (UNISDR, 2012; 2013). 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 prominent issue in the context of achieving the 2030 Agenda for Sustainable Development. Consequently, 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 are key actors in efforts to reduce the risks posed by natural hazards and to build resilient urban societies (UNISDR, 2010). In recent years, research on hazards and risks from different academic disciplines have improved the 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 analyses of climate change and disaster risk reduction (UNFPA, UNISDR, and UN-HABITAT, 2009; 2011). Such information could help improve understanding 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 exposure and vulnerability to natural disasters for the world's cities with 300,000 inhabitants or more on 1 July 2018. In the 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 as well as to provide information to inform sound management for risk reduction and improved policy frameworks under the Sendai Framework and the 2030 Agenda (UNDRR, 2019a; 2019b). The report integrates city population data from the 2018 Revision of the World Urbanization Prospects (WUP) (United Nations, 2018) with spatial hotspot data on risks of exposure and vulnerability to natural disasters produced by the international research community (Dilley et al., 2005). The report reviews levels of exposure to six types of natural hazards or disasters for cities classified by population size, region, development group and income group. It further analyzes levels of vulnerability by risk of disaster-related mortality and economic losses.

II. DATA SOURCES AND METHODS

Several major datasets were used in the analysis contained in this technical paper. The 2018 revision of World Urbanization Prospects (WUP) contains population estimates (from 1950 to 2018) and projections (from 2018 to 2035) for 1,860 cities with 300,000 inhabitants or more on 1 July 2018. These 1,860 cities collectively were home to 2.5 billion inhabitants in 2018, accounting for 56 per cent of the global urban population (4.5 billion). The term "city" in this report refers to the definitions used in WUP, based on national sources, and may refer to a city proper, an urban agglomeration or a metropolitan area. The 1,860 cities are located in 154 countries, of which 79 countries had three or more cities and 59 countries had five or more cities with 300,000 inhabitants on 1 July, 2018.

As the 2018 revision of WUP only included the geographic coordinates of the centroid point for each city and did not identify the total land area within each city's boundaries, the official urban boundaries (or urban extent) were obtained from a separate dataset, internally maintained by the Population Division. This dataset provides urban boundaries for 40 countries, including 31 European countries and 9 other countries (Australia, Brazil, Canada, Columbia, Japan, Mexico, New Zealand, the Philippines and USA). These 40 countries had 449 cities with 300,000 inhabitants or more in 2018, 24 per cent of cities included in the 2018 WUP. For countries without official urban boundaries available, a "buffer zone" was used to approximate the urban extent. This buffer zone was generated around each city centroid using a circle with the radius proportional to population size. The method used is 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 (Angel et al., 2012. See Appendix A).

The Millennium Ecosystem Assessment provided information about the geographic classification of cities according to whether they were located in coastal areas or non-coastal areas. The coastal areas were defined as areas between 50 meters below the 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 zones (Millennium Ecosystem Assessment, 2003: 54). If a city's official polygon or buffer zone was located in a coastal area, the city was considered a coastal city. Otherwise, it was considered an inland city. Based on this definition, out of 1,860 cities with inhabitants over 300,000, 616 cities were classified as coastal cities.

The analysis used spatial hotspot data on exposure and vulnerability to natural disasters, which was jointly produced by multiple research institutes at Columbia University [1] and the World Bank (www.ldeo.columbia.edu/chrr/research/hotspots/). [2] The data on natural disasters in this dataset includes information on six types of disaster: cyclones (between 1980 and 2000), floods (between 1985 and 2003), droughts[3] (between 1980 and 2000), earthquakes (between 1976 and 2002)[4], landslides[5], and volcanic eruptions (between 1979 and 2000). The spatial hotspot data for the period 2000-2012 from UNEP and UNISDR (UNEP and UNISDR, 2013) were used to investigate future possible occurrences of cyclones, floods, draughts and earthquakes for each city.

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*1 km^2 at the equator). Volcanic eruptions and earthquakes were published on a 2.5 by 2.5 arc *minute* grid (about 4.6 *4.6 km^2 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*280c km^2 at the equator) (Dilley et al., 2005: 29). According to Dilley et al. (2005), grid cells with a population density of 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 for 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 frequencies and scales by type of disaster were apportioned into deciles, according to the frequency of the disaster. A city was classified as being highly exposed to a particular type of natural hazard/disaster if any part of its extent was located in grid cells ranking in the top three deciles of the global risk distribution in terms of frequency of occurrences of the respective natural disaster. Among the remaining cities, a city was classified as being at a medium level of exposure if any piece of its extent was located in grid cells ranking from the 5th to the 7th deciles, and a city was defined as being at a low level of exposure if any area of its extent was located in grid cells ranking from the 1st to the 4th deciles (Dilley et al., 2005).

Information on the occurrence or the scale of disasters is often incompletely reported, thus the spatial hotspot dataset is unlikely to be comprehensive. Moreover, hazards such as floods, earthquakes and volcanoes have very different patterns of occurrence in terms of their spatial distribution, 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, it should be noted that the exposure to each type of disaster was not strictly comparable across disasters. For example, a grid cell in the top three deciles for flood hazards does not necessarily face the same probability of hazard occurrence as a grid cell in the top three deciles for drought hazards in terms of their frequency and intensity (Dilley et al., 2005). A detailed description of how the natural disaster data were

[1] 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).
[2] Including the Disaster Management Unit (HMU) and the Development Economics Research Group (DECRG).
[3] Drought events were 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.
[4] Frequency of earthquakes greater than 4.5 on Richter Scale.
[5] Index of landslide and snow avalanche hazard. There were no date ranges for this type of disaster in the original report of Dilley et al. (2005).

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 losses 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 (Dilley et al., 2005). 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 linked to mortality and economic losses, in addition to the levels 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 by multiplying hazard-specific mortality weights to the population at exposure within each grid cell. The hazard-specific risk of total economic losses was derived by applying hazard-specific economic loss weights to GDP per one square kilometre for each grid cell. The mortality weight and the economic loss weight were obtained from data on historical losses over the period from 1981 to 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 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 losses was performed similarly to the classification of the relative exposure to risk of 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 losses due to a particular type of natural disaster if it was located in grid cells ranking in the top three deciles (i.e., 8^{th} to 10^{th}) 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 5^{th} to the 7^{th} deciles and at low risk if it was located in grid cells ranking from the 1^{st} to the 4^{th} deciles (Dilley et al., 2005).[6] We relied on *spatial join* between the layer of city boundary and the layer of spatial hotspot polygon to obtain levels of exposure and vulnerability of mortality and economic losses to different types of disaster for each city.

In analyzing the future possible occurrence of cyclones, floods and earthquakes for each city using the hotspot data for the period 2000-2012 from UNEP and UNISDR (2013), we followed the common practice in the literature of climate change by applying the term *return period* of a specific disaster. The *return period* is the average frequency that a particular event (such as an earthquake or a flood) in a given period is expected to occur that results in a certain amount of casualty and economic losses (UNISDR, 2015). The *return period* can be understood as an estimated time interval between events of a similar size or intensity or can refer to a yearly probability of occurrence of an event with similar size or intensity. For example, an earthquake of a certain size with a 100-year *return period,* or a "100-year earthquake" of a certain size, means that such an earthquake with a given size will occur every one hundred years on average. In the present study, the 100-year *return period* for cyclones, the 50-year *return period* for floods and the 250-year *return period* for earthquakes were applied.

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

Similar to the method used for estimating the current levels of exposure and vulnerability to disasters for each city, we also relied on *spatial join* to obtain city-specific possibility of future occurrence of cyclones, floods and earthquakes at different sizes.

The study benefited from several sources that contain global urban extents, such as MODIS Land Cover 500 meters imagery data (hereafter referred to as MODIS 500M) (Friedl et al., 2010) and GRUMP urban extents (CIESIN, IFPRI, World Bank et al., 2011). These two datasets were mainly used for the purpose of sensitivity analysis that examined the difference in outcomes if alternative criteria for the definition of urban extents are used. Appendix B compares the results using the above method to those using an alternative method; and the results indicate a very high consistency.

III. MAJOR FINDINGS

A. In 2018, nearly 58 per cent of cities worldwide had a high level of exposure to at least one type of natural disaster

Out of a total of 1,860 cities with 300,000 inhabitants or more on 1 July 2018, nearly 58 per cent, or 1,087 cities, were highly exposed to at least one of the six natural hazards (cyclones, floods, droughts, earthquakes, landslides, and volcanic eruptions) (table 1). These 1,087 cities were home to 1.6 billion inhabitants in 2018, representing 64 per cent of the total population of the 1,860 cities. Slightly less than 14 per cent of 1,860 cities (256 cities) were highly exposed to two of the six types of natural disaster and about 2 per cent (45 cities) were highly exposed to three or more types of natural disaster.

Table 1. Exposure and vulnerability to the six types of natural disaster for world's cities

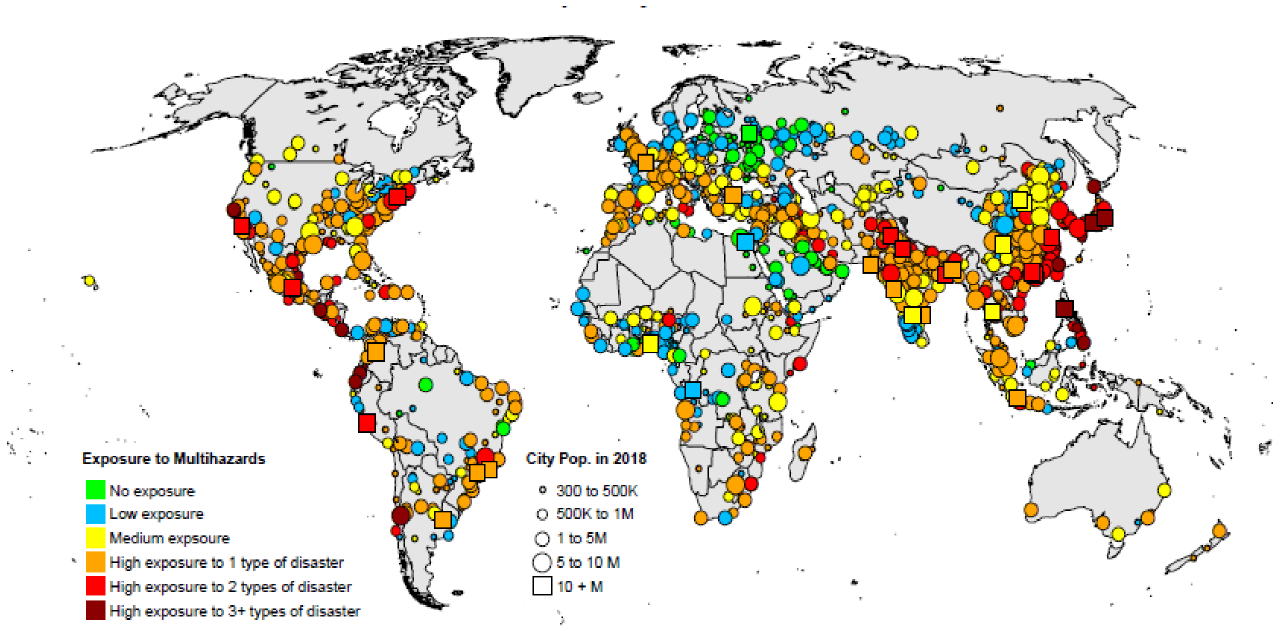
	*Exposure**		*Mortality vulnerability**		*Economic vulnerability**	
Risk to the six types of natural disaster	*No. of cities*	*Percentage***	*No. of cities*	*Percentage***	*No. of cities*	*Percentage***
Total	1,860	100.0	1,860	100.0	1,860	100.0
No risk	92	5.0	172	9.3	105	5.6
Low risk	283	15.2	29	1.6	20	1.1
Medium risk	398	21.4	118	6.3	82	4.4
High risk to 1 type of disaster	786	42.3	806	43.3	539	29.0
High risk to 2 types of disaster	256	13.8	598	32.1	763	41.0
High risk to 3+ types of disaster	45	2.4	137	7.4	351	18.9
High risk to 1+ type of disaster	1,087	58.4	1,541	82.8	1,653	88.9

Note: Cities only included those with 300,000 inhabitants or more on 1 July 2018. The six types of natural disaster include cyclones, droughts, earthquakes, floods, landslides, and volcano eruptions. * The exposure to risk was assessed using the spatial hotspot data. Cities within the 8th to 10th decile of the respective global risk distribution for each type of risk were classified as at high risk, cities within the 5th to 7th decile as at medium risk and within the 1st to 4th decile as at low risk. Hazard-specific mortality risk was obtained for this analysis by multiplying hazard-specific mortality weights to the population at exposure within each grid cell. The hazard-specific risk of total economic losses was derived by applying hazard-specific economic loss weights to GDP per one square kilometre for each grid cell. The mortality weight and the economic loss weight were obtained from data on historical losses over the period from 1981 to 2000 (Dilley et al., 2005). ** the summation of each category is not necessarily equal to total or subtotal due to rounding.

Among 45 cities highly exposed to three or more types of disaster, 19 cities had a population of one million or more in 2018, of which Tokyo (37,5 million, Japan), Osaka, Kinki M.M.A. (hereafter referred to as Osaka, 19.3 million, Japan) and Manila (13.5 million, Philippines) were megacities with more than 10 million inhabitants. Tokyo was exposed to high risk of cyclones, earthquakes, floods and landslides. Osaka was exposed to high risk of cyclones, earthquakes and landslides and was at medium risk of floods. Manila was highly exposed to five types of natural hazard and was exposed to low risk of droughts. Eight other cities with one million inhabitants or more in Asia were highly exposed to three or more types of disaster. The remaining eight cities highly exposed to three or more types of disaster were in Central America and the Caribbean (see table D1 in Appendix D for details).

Out of the 1,860 cities, 681 cities (or 37 per cent) were at a medium or low level of exposure to one or more of the six types of natural disaster. These 681 cities were home to 802 million people in 2018, accounting for 33 per cent of 2.5 billion population of the 1,860 cities. Only 92 cities (representing less than five per cent of the 1,860 cities) were immune to any level of exposure to these six types of natural hazard. These 92 cities were home of 88 million people, accounting for four per cent of the 1,860 cities' total urban population. Moscow (Russia) was the only megacity that was not exposed to any of the six types of natural disaster analysed. Nineteen cities with population between one and ten million and 72 cities with population less than one million were also free from exposure to any risk of all six types of natural disaster. Among 283 cities with low levels of exposure to natural hazards are two megacities: Cairo and Kinshasa (see figure 1).

Figure 1. Location of cities by population size and level of exposure to natural disaster



Source: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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B. Globally, in 2018, about 83 per cent of cities were at high mortality risk from at least one type of natural disaster, and nearly 89 per cent of cities were highly vulnerable to economic losses from at least one type of natural disaster

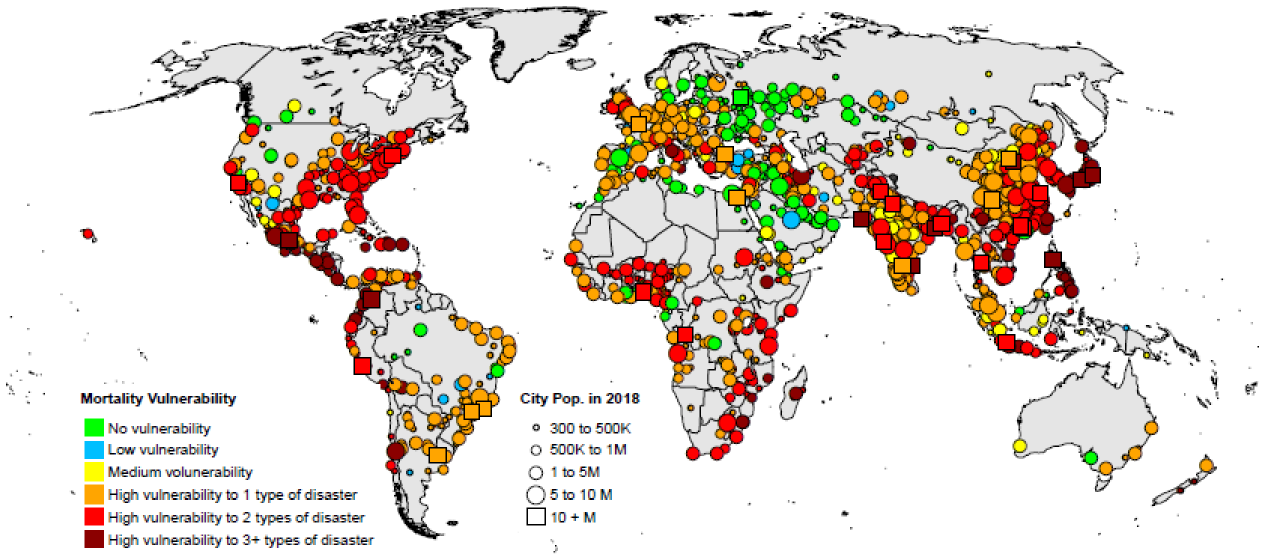
Table 1 reveals that 1,541 cities (83 per cent) were at high risk of disaster-related mortality from at least one of the six types of natural disaster. These 1,541 cities were home of 2.2 billion city inhabitants in 2018, or 88 per cent of the total population of the 1,860 cities. In total, 598 cities (32 per cent) were at high risk of mortality from two types of disaster and 137 cities (7 per cent) were at high risk of mortality from three or more types of disaster. Nine of the 137 most vulnerable cities in terms of mortality risk were megacities: Tokyo (37.5 million, Japan), Mexico City (19.4 million, Mexico), Osaka (19.3 million, Japan), Karachi (15.4 million, Pakistan), Kolkata (14.7 million, India), Manila (13.5 million, Philippines), Tianjin (13.2 million, China), Bogotá (10.6 million, Colombia), and Chennai (10.5 million, India), with a total of 156 million people in 2018; five were large cities with a population between 5 million to 10 million: Nagoya (9.5 million, Japan), Tehran (8.9 million, Islamic Republic of Iran), Santiago (6.7 million, Chile), Kitakyushu-Fukuoka M.M.A. (5.6 million, Japan), and Guadalajara (5.0 million, Mexico) (see table D2 in Appendix D). Eighty cities at a high level of exposure to at least one of the six types of disaster were not located in areas with high level of disaster-associated mortality risk, of which Hong Kong (China, H.K. SAR) and Madrid (Spain) were two largest cities with populations of between 5 million and 10 million in 2018. Figure 2 presents locations of all 1,860 cities with their levels of vulnerability to disaster-related mortality.

Table 1 further shows that 1,653 cities in 2018 (89 per cent) were located in areas that were highly vulnerable to economic losses from at least one of the six types of natural disaster. In 2018 there were 2.3 billion urban residents living in these 1,653 cities. Of the 1,653 cites, 763 cities were highly vulnerable to two types of disaster, 351 cities were highly vulnerable to three types or more disaster. Of these 351 cities, 270 cities were highly vulnerable to three types of disaster, 53 cities were highly vulnerable to four types of disaster, 24 cities were highly vulnerable to five types of natural disaster, and four cities (Alajunela (0.3 million) and Heredia (0.3 million) in Costa Rica, and Manila (13.5 million) and Dasmarinas (0.7 million) in Philippines) were highly vulnerable to economic losses from all six types of natural disaster. Manila was also the only city that was highly vulnerable to disaster-related mortality from all the six types of disaster. Among 24 cities with high level of vulnerability to economic losses to five of the six types of disaster, seven cities had a population of over one million inhabitants in 2018. Out of the 53 cities with high levels of economic vulnerability to four different types of disaster, four were megacities: Tokyo (37.5 million), Osaka (19.3 million), Tianjin (13.2 million), and Bogotá (10.6 million) (see table D3 in Appendix D). Figure 3 presents the locations of all 1,860 cities with different levels of vulnerability to disaster-related economic losses.

C. Floods, droughts and cyclones were the most devastating types of natural disaster threatening city dwellers in terms of levels of exposure vulnerability of mortality and economic losses

Between 1980 and 2009, more than 2.8 billion people were ever affected by floods, making flooding the most common form of natural disaster (Doocy, Daniels, Murray et al., 2013). Flood risk is the most common natural hazard in terms of levels of exposure across the 1,860 cities (figure 4). In 2018, 683 of the 1,860 cities, or slightly more than one-third, were located in areas with high level of exposure to flooding. These 683 cities were homes of 1,093 million urban dwellers in 2018.

Figure 2. Location of cities by population size and level of vulnerability to disaster-related mortality



Sources: World Urbanization Prospects: The 2018 Revision; Dilley et al. (2005)

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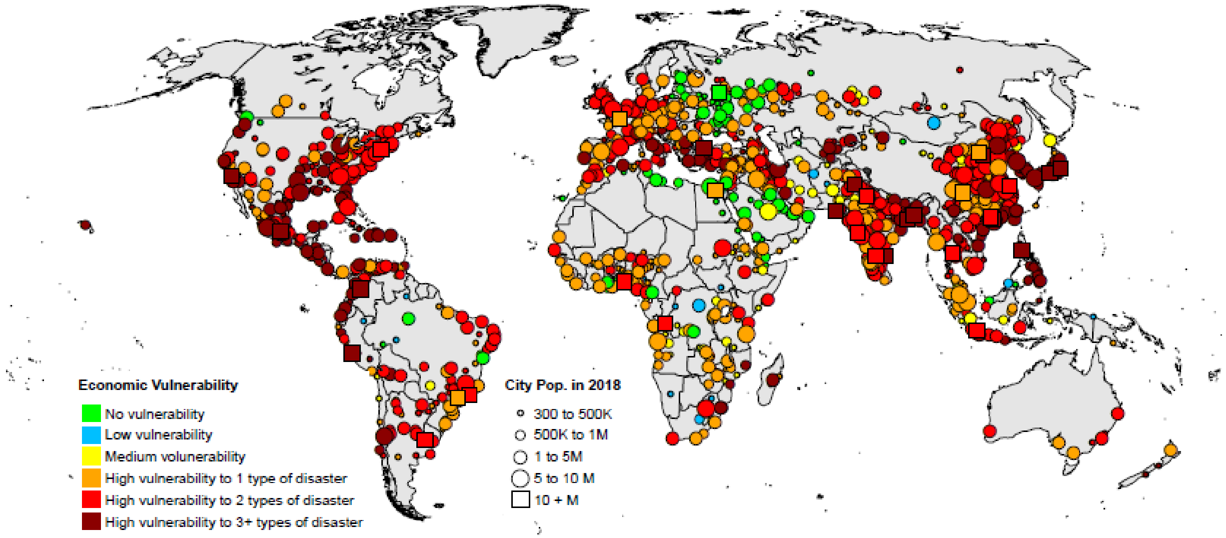
Figure 3. Location of cities by population size and level of vulnerability to disaster-related economic losses



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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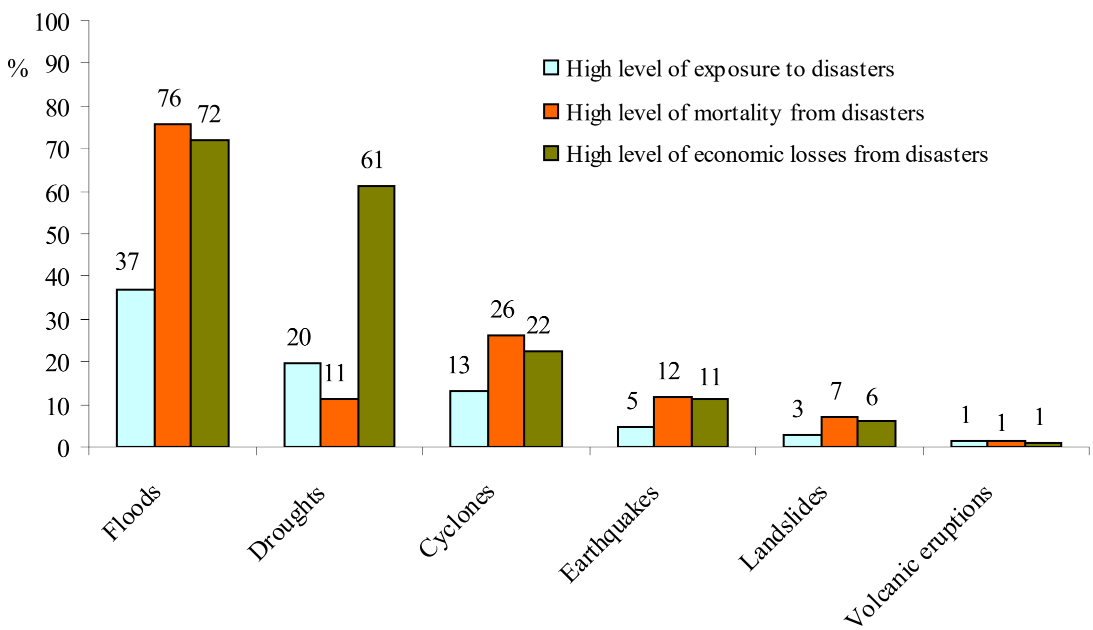
Of greater challenge and concern is the larger proportion of cities and their populations that are highly vulnerable to flood-related mortality and economic losses (figure 4). Of the 1,860 cities analysed, 1,406 cities (76 per cent) were located in areas that were highly vulnerable to flood-related mortality, and the total population living in these cities in 2018 was about 2.0 billion, accounting for nearly 82 per cent of the total city population studied. Similar patterns in level of exposure to economic losses were found: 1,340 cities (72 per cent) were located in areas where the level of vulnerability to flood-related economic losses was high, and there were 2.0 billion people living in these cities in 2018. These findings indicated that a majority of cities were highly vulnerable to both flood-related mortality and economic losses even if they were at a low or medium level of exposure to floods.

Figure 4. Percentage of cities with high levels of exposure and vulnerability to six types of natural disaster



Note: Cities only included those with 300,000 inhabitants or more on 1 July 2018. See table 1 for definition of indicators.

Three cities (General Trias (Philippines), Vungtau (Viet Nam), and Hong Kong (China, H.K. SAR)) that were highly exposed to floods had no or low risk of flood-related mortality; six cities (Bunia (Democratic Republic of the Congo), Iquitos (Peru), Zinder (Niger), Kismaayo (Somalia), Vungtau (Viet Nam) were highly exposed to floods had no or low risk of flood-related economic losses. By contrast, 494 cities at a low level of exposure to floods were highly vulnerable to flood-related mortality, whereas 446 cities at a low level of exposure to floods were highly vulnerable to flood-related economic losses; and about half of these cities are in Asia.

Droughts were the second most hazardous type of disaster, affecting 363 cities, accounting for 20 per cent of all 1,860 cities (see figure 4). Some 480 million people lived in these 363 cities in 2018. Six megacities were highly exposed to droughts: three in India (Delhi (28.5 million), Kolkata (14.7 million), and Chennai (10.5 million)), two in Pakistan (Karachi (15.4 million) and Lahore (11.7 million)), and one in the USA (Los Angeles-Long Beach(12.5 million)). Droughts were also the second most devastating type of disaster in terms of economic losses for the world’s 1,860 cities. Out of 1,860 cities, 1,140 cities (or 61 per cent) were highly vulnerable to drought-related economic losses. The total inhabitants in these 1,140 cities in 2018 were 1.6 billion, accounting for about 64 per cent of the 2.5 billion people living in 1,860 cities.

Out of 1,860 cities, 474 cities were at a low level of exposure to droughts, yet highly vulnerable to drought-related economic losses. Ten megacities (Mexico City (21.6 million, Mexico), Dhaka (19.6 million, Bangladesh), Buenos Aires (15.0 million, Argentina), Istanbul (14.8 million, Turkey), Manila (13.5 million, Philippines), Rio de Janeiro (13.3 million, Brazil), Kinshasa (13.2 million, D.R. of the Congo), Shenzhen (11.9 million, China), Lima (10.4 million, Peru), and Bangkok (10.2 million, Thailand)) fell into this category. Among them, Manila, Kinshasa, and Bangkok were also highly vulnerable to drought-related mortality.

In terms of the level of vulnerability to disaster-related mortality, cyclones were the second most devastating type of disaster facing by world's cities with 300,000 inhabitants in 2018. There were 490 cities (or 26 per cent) highly vulnerable to cyclone-related mortality. About 803 million people lived in these 490 cities in 2018, accounting for nearly one-third of the sum of the population of 1860 cities. Two hundred and thirty-seven cities were highly exposed to cyclones and were also highly vulnerable to cyclone-related mortality. One hundred and twenty-two cities were at medium risk of experiencing a cyclone but were highly vulnerable to cyclone-related mortality risk. Likewise, 131 cities were at low risk of exposure to a cyclone but were highly vulnerable to cyclone-related mortality should a cyclone occur. Only six cities (Hong Kong (7.4 million, China, H.K. SAR), Jeonju (0.7 million, Republic of Korea), Songyuan (0.5 million, China), Gumi (0.38 million, Republic of Korea), General Trias (0.36 million, Philippines), and Pohang (0.36 million, Republic of Korea)) were highly exposed to cyclones but not at high risk from cyclone-related mortality.

A tabulation of levels of exposure and vulnerabilities to each of the six types of disaster by decile is presented in Appendix E.

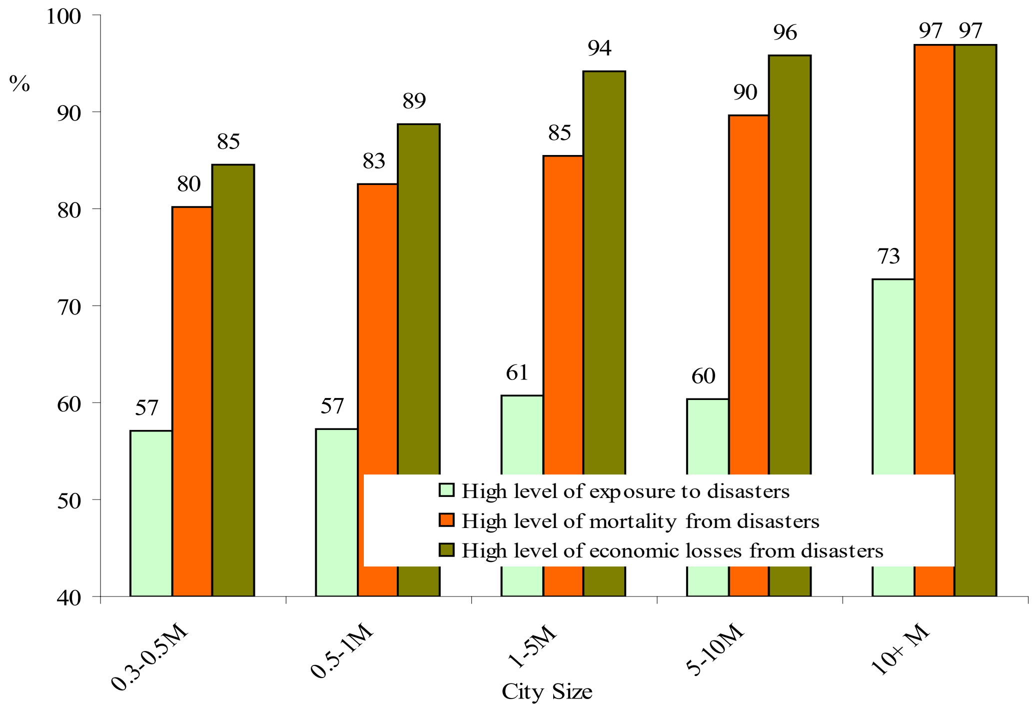
D. Megacities were more likely to be located in areas with high exposure to disasters and were more vulnerable to disasters than cities of other sizes.

Previous research has shown 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). Our results showed that megacities were more likely to be at a high level of exposure to at least one of the six types of natural disaster than other types if cities. For example, of 33 megacities with 529 million people in 2018, only one city (Moscow) was at no exposure to any of the six types of natural disaster, 8 megacities were at a low or medium level of exposure to at least one type of natural disaster, and 24 megacities (or 73 per cent of the 33 megacities in 2018) were at a high level of exposure to at least one type of natural disaster. The corresponding proportion of high level of exposure were 60 per cent for cities with 5 to 10 million people, 61 per cent for cities with 1-5 million people, and 57 per cent for cities with 1 million people or less. The total population of these 24 megacities was around 401 million, accounting for 76 per cent of the 529 million people living in megacities in 2018.

Similar patterns for the high-level exposure to floods and cyclones for megacities were also observed. For example, around 58 per cent of megacities were highly exposed to floods, whereas the percentages ranged between 34 and 46 per cent for cities of other sizes. Conversely, the difference in levels of exposure to droughts by city population size was small: 18 per cent of megacities were located in the high exposure to droughts, compared to 15 to 23 per cent for cities with other size.

Figure 5 indicates that megacities were more vulnerable to disaster-related mortality and economic losses than other city sizes. Nearly 97 per cent of megacities (32 out of 33) were highly vulnerable to disaster-related mortality from at least one of the six types of natural disaster, which was higher than the corresponding figure for cities with less than 10 million people (80 to 90%). Compared to other cities, megacities further had a higher level of vulnerability to flood-, cyclone-, drought-, and earthquake-related mortality, although a lower proportion of megacities were exposed to droughts and earthquakes (not shown). About 90 per cent, 39 per cent, and 36 per cent of megacities were highly vulnerable to flood-, cyclone-, and drought-related mortality, respectively. For cities with less than five million inhabitants, the corresponding figures were 73 to 78 per cent for flood-related mortality, 25 to 26 per cent for cyclone-related mortality, and 10 to 13 per cent for drought-related mortality.

Figure 5. Percentage of cities with high levels of exposure and vulnerability to at least one of six types of disaster by city population size



Note: Cities only included those with 300,000 inhabitants or more on 1 July 2018. See table 1 for definition of indicators.

Figure 5 further reveals that in terms of level of economic vulnerability, all megacities except one (i.e., Moscow) (or 97 per cent) were highly vulnerable. This proportion is similar to that for cities with 1 to 5 million inhabitants (94 per cent) and with 5 to 10 million inhabitants (96 per cent), but it is higher than that for cities with less than one million residents (85 to 89 per cent). The difference in economic vulnerability by city size seems more pronounced for flood- and cyclone-related economic losses, except for a similar proportion between megacities and cities with 5 to 10 million inhabitants (not shown). For instance, 94 per cent of megacities were highly vulnerable to flood-related economic losses compared to 67 to 78 per cent for cities with less than five million people. About 39 per cent of megacities were highly vulnerable to cyclone-related economic losses compared to only 20 to 24 per cent for cities with five million or less.

The five most populous megacities in 2018 (Tokyo (37.5 million, Japan), Delhi (28.5 million, India), Shanghai (25.6 million, China), São Paulo (21.7 million, Brazil), and Mexico City (21.6 million, Mexico)) all experienced a high level 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 is located in an area where there is a high risk of floods, cyclones, earthquakes, and landslides, and is highly vulnerable to mortality risk and economic losses from these types of disaster. Delhi was at a high level of exposure to floods and droughts and at high risk of mortality and economic losses. Shanghai was at a high level of exposure to both floods and cyclones and at high risk of mortality and economic losses. São Paulo was highly exposed to floods and high vulnerability to both flood-related mortality and economic losses. Mexico City was at a high level of exposure to floods and landslides, a low level of exposure to droughts, and a medium level of exposure to volcanic eruptions with high levels of economic and mortality vulnerability associated with each of these four types of natural disaster. Mexico City also had a medium level of mortality vulnerability and a high level of economic vulnerability to cyclones.

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

E. Cities in the less developed regions, which, on average, were experiencing faster population growth than cities elsewhere, were more likely to be highly exposed and highly vulnerable to natural disasters

The higher level of exposure and the greater level of vulnerability to natural disasters of cities 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. About 61 per cent of cities (854 out of 1,392 cities) in the less developed regions in 2018 were located in areas considered being at a high level of exposure to at least one type natural disaster, compared to only 50 per cent of cities (233 of 468 cities) in the more developed regions (table 2). The difference in the level of exposure to droughts between these two development groups was also noticeable: about 23 per cent of cities in the less developed regions were at a high level of exposure to droughts compared to 10 per cent of cities in the developed regions.

The less developed regions were also more vulnerable to disasters in terms of mortality risk. About 92 per cent of cities in the least developed countries and about 85 per cent of cities in other developing countries were highly vulnerable to disaster-related mortality compared to 76 per cent of cities in the more developed regions. In other words, the least developed countries have the highest level of mortality risk in comparison with other developing countries and more developed regions. Disaster-related economic vulnerability by development group was somewhat different: 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 89 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 (Dilley et al., 2005).

From the perspective of income classification, two interesting findings are noteworthy. In comparing with those of other income groups of countries, the low-income countries had the lowest proportion of cities with high exposure to at least one type of natural disaster (47 per cent vs. 58-60 per cent), yet these low-income countries had the highest proportion of cities with high disaster-related mortality risk (93 per cent vs. 81-83 per cent). In the case of droughts, the low-income countries had nearly 21 per cent of cities with high exposure compared to 27 per cent, 19 per cent, and 11 per cent in lower-middle-income countries, upper-middle-income countries, and high-income countries, respectively (not shown); however, the low-income countries had more than 70 per cent of cities with high risk of drought-related mortality, compared to 26 per cent in lower-middle-income countries, 3 per cent in upper-middle-income countries, and zero per cent in high-income countries.

The number of cities with 300,000 inhabitants or more in 2018 in the less developed regions increased by about ten-fold from 1950 to 2018, irrespective of types of risk, compared to only a two- or three-fold increase in the more developed regions (figure 6). The number of cities in each category of exposure and vulnerability in the less developed regions in 1950 was smaller than that in the more developed regions. However, the opposite was true in 2018: the number of cities being at high exposure and high vulnerability to natural disasters was 3.0 to 4.5 times greater than that in the more developed regions. Assuming that exposure and vulnerability of a given area remain constant over time, our findings would imply that the spatial pattern in the change of population subject to exposure and vulnerability is equivalent to the population growth and urbanization of the respective areas.

TABLE 2. PERCENTAGE OF CITIES WITH HIGH LEVELS OF EXPOSURE AND VULNERABILITY TO AT LEAST ONE OF SIX TYPES OF NATURAL DISASTER BY DEVELOPMENT GROUP, INCOME GROUP, SDG REGION, AND COASTAL-INLAND CITY TYPE

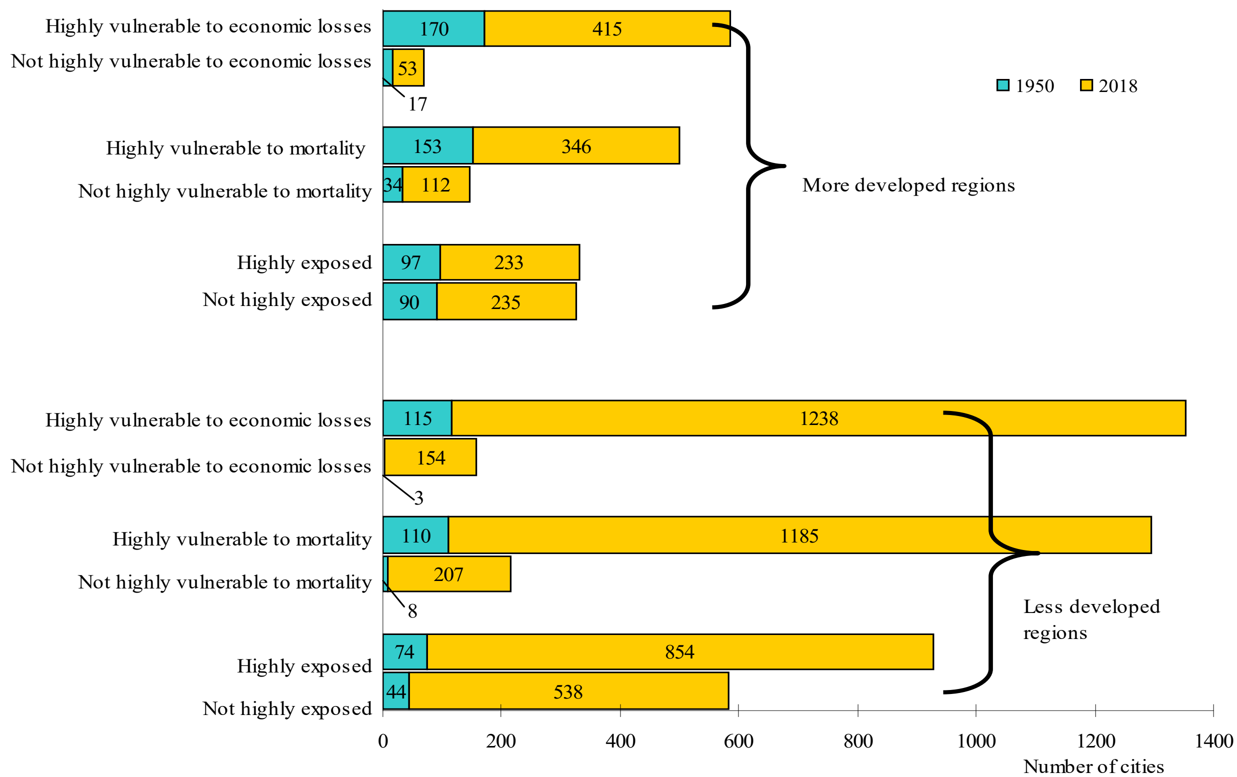
	Per cent of cities located in areas with high level of exposure to natural disasters	*Per cent of cities located in areas with high level of mortality to natural disasters*	*Per cent of cities located in areas with high level of economic losses to natural disasters*
Development groups			
Less developed regions	61.4	85.1	88.9
Least developed countries	53.3	91.8	75.4
Less developed regions, excluding least developed countries	62.1	84.5	90.2
More developed regions	49.8	76.1	88.7
Income groups			
Low-income	46.5	93.0	70.9
Lower-middle-income	57.5	82.7	86.3
Upper-middle-income	59.5	82.7	90.6
High-income	59.7	81.2	91.7
SDG Regions			
Sub-Saharan Africa (SSA)	33.3	93.8	76.8
Northern Africa and Western Asia (NAWA)	38.7	46.0	66.7
Southern and Central Asia (SCA)	66.0	83.2	90.3
Eastern and South-Eastern Asia (ESEA)	71.9	91.9	95.5
Latin America and the Caribbean (LAC)	70.5	91.0	94.8
Australia New Zealand and Oceania* (AZO)	60.0	80.0	100.0
Europe and Northern America (ENA)	45.4	73.9	88.1
Coastal or inland cities			
Inland cities	55.9	81.9	87.9
Coastal cities	63.5	84.7	90.9

Note: Cities included those with 300,000 inhabitants or more on 1 July 2018. Six types of natural disaster include cyclones, droughts, earthquakes, floods, landslides, and volcano eruptions. Oceania* refers to Oceania excluding Australia and New Zealand. Because only has one city in Oceania* in this dataset, we combined Australia and New Zealand with Oceania* (AZO) and refers to Oceania as a whole. See table 1 for definition of indicators.

F. VARIATIONS IN LEVELS OF EXPOSURE AND VULNERABILITIES TO NATURAL DISASTERS ACROSS REGIONS WERE LARGE

Table 2 shows that there were substantial variations for cities across regions with respect to exposure and vulnerability to natural disasters. Less than 50 per cent of cities in Sub-Saharan Africa, Northern Africa and Western Asia, and Europe and Northern America were located in areas with high level of exposure to at least one of the six types of natural disasters, comparing to over 70 per cent of cities in Eastern and south-eastern Asia and Latin America and the Caribbean. However, about 94 per cent of cities in Sub-Saharan Africa were located in areas with high level of mortality risk from at least one of the six types of natural disasters, the highest among all regions. Although about 60 per cent of cities in Oceania were at a high level of exposure to at least one of the six types of disasters, all cities in Oceania were located in areas with high risk of economic losses from disasters.

Figure 6. Number of cities by levels of exposure and vulnerability to natural disasters and development group in 1950 and 2018



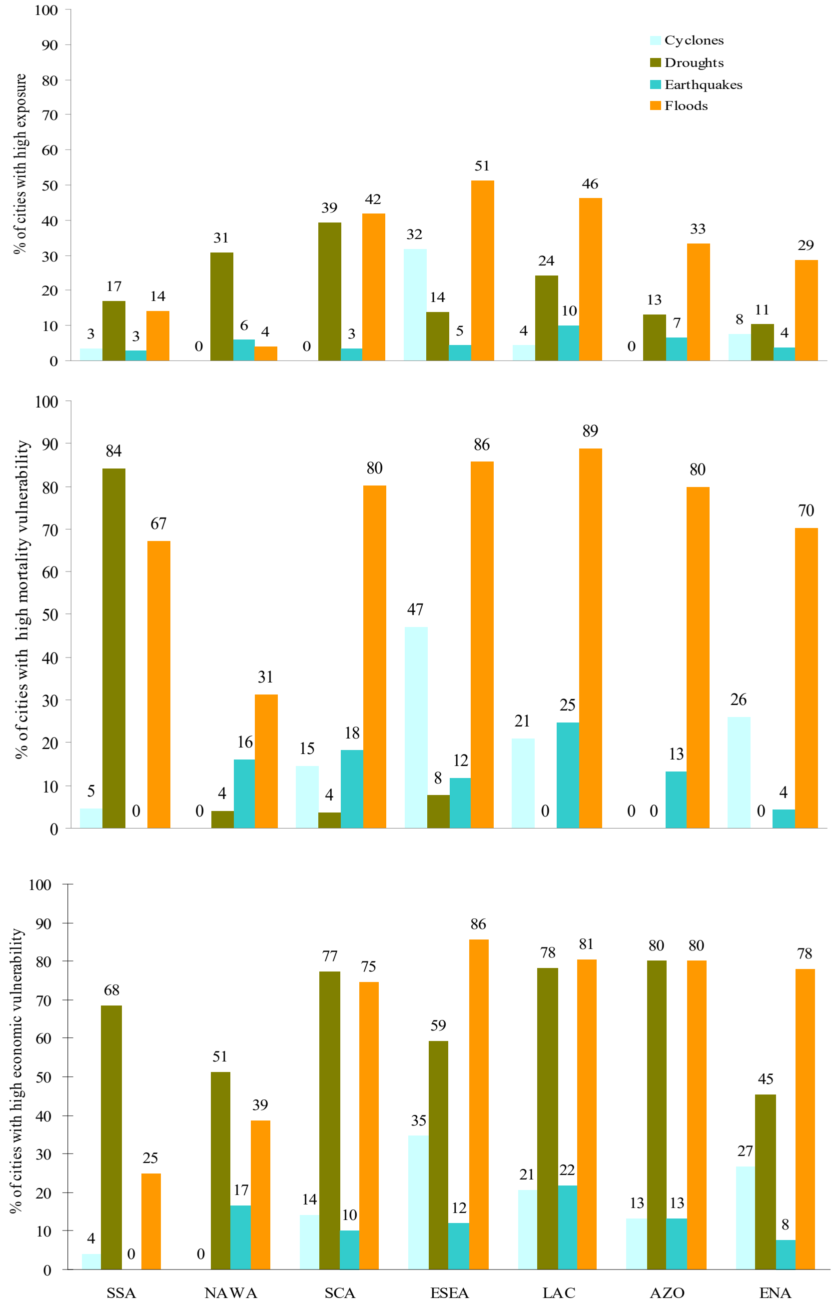
Note: Cities with 300,000 inhabitants or more in 1950 and 2018. See table 1 for definition of indicators.

The disaster-specific variation in the exposure across major regions was also large (figure 7). For example, 31 per cent of cities in Eastern and South-Eastern Asia were located in the areas highly exposed to cyclones, whereas almost no city in sub-Saharan Africa, Northern Africa and Western Asia, Southern and Central Asia, and Australia and New Zealand was located in areas with high level of exposure to cyclones. More than 40 per cent of cities in Southern and Central Asia, Eastern and South-Eastern Asia, and Latin America and the Caribbean were highly exposed to floods, compared to four per cent of cities in Northern Africa and Western Asia, and 14 per cent of cities in sub-Saharan Africa. More than 30 per cent of cities in Northern Africa and Western Asia and Southern and Central Asia were highly exposed to droughts, compared to less than 15 per cent in Europe and Northern America, Australia and New Zealand, and Eastern and South-Eastern Asia. On average, slightly less than five per cent of the world's cities were highly exposed to earthquakes, although the exposure for cities to earthquakes was slightly higher in Latin America and the Caribbean (10 per cent), Australia and New Zealand (7 per cent) and Southern and Central Asia (6 per cent) were slightly more exposed. The lower level of exposure to disasters combine with a higher level of vulnerability to disaster-related mortality in Africa was likely due to a lack of infrastructure built to withstand extreme weather conditions (Adelekan, 2010).

G. 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

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 the average maximum wind speed of tropical cyclones and the total rainfall associated with tropical cyclones will increase (UNIPCC, 2012).

Figure 7. Percentage of cities with high levels of exposure and vulnerability to four types of natural disasters by region



Note: SSA, Sub-Saharan Africa; NAWA, Northern Africa and Western Asia; SCA, Southern and Central Asia; ESEA, Eastern and South-eastern Asia; LAC, Latin America and the Caribbean; AZO, Oceania; ENA, Europe and Northern America. See table 1 for definition of indicators.

Out of 1,860 cities with 300,000 inhabitants in 2018, 1,244 cities were located in inland areas with a total population of 1.4 billion, while 616 cities were located in the coastal regions with a total population of 1.1 billion. The overall proportion of coastal cities that were at a high level of exposure to at least one type of disaster was higher than that of inland cities (63 per cent versus 56 per cent). The different patterns of risk of economic and mortality vulnerability between these two groups of cities were more significant than the pattern for exposure (table 2). This finding is important and adds additional value to the existing literature on exposure and vulnerability to natural disasters of inland urban centres.

The different patterns in levels of exposure and vulnerability between these two types of cities were mainly from cyclones and droughts. In the case of level of exposure to cyclones, 27 per cent of coastal cities were located in areas with a high level of exposure to cyclones, while only 6 per cent of inland cities were located in such areas. By contrast, inland cities had a somewhat larger proportion of high level of exposure to droughts than coastal cities (21 per cent versus 16 per cent). Regarding the mortality risk from cyclones, about 44 per cent of coastal cities were located in high mortality risk areas compared to 18 per cent of inland cities. In terms of economic losses from cyclones, nearly 40 per cent of coastal cities were located in the areas with high risk of losses compared to 14 per cent of inland cities.

Cities with 5 to 10 million inhabitants and megacities in coastal areas were more likely than smaller coastal cities to be highly exposed and 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 73 to 86 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, compared to 57 to 67 per cent for smaller cities. In the case of mortality risk, 92 to 100 per cent of very large cities with 5 million inhabitants or more were highly vulnerable to disaster-related mortality compared to 81 to 84 per cent for cities with population less than 1 million.

H. Large variations exist between countries in exposure, mortality risk, and economic vulnerability to multiple natural disasters

Out of 154 countries where 1,860 cities with 300,000 inhabitants in 2018 were located, there were 57 countries that had not one city with a high level of exposure to any of the six types of disaster. By contrast, there were 41 countries where every city was highly exposed to at least one of the six types of disaster. In the remaining 56 countries, only some cities were highly exposed to one or more types of disaster included in this study. Among the 41 countries with all of their cities being highly exposed, 7 countries had five or more cities, another 7 countries had three or four cities, 5 countries had two cities, and 22 countries had 1 city. In terms of mortality risk from disaster, 24 countries had no cities that were exposed to high mortality risk from disaster, whereas in 87 countries all cities were exposed to such risk. The remaining 43 countries had a portion of their cities that were located in high mortality risk areas from disaster. Regarding economic losses from disaster, only cities in 16 countries were not exposed to high risk of economic losses from disaster, whereas in 94 countries all cities were exposed to such risk.

Overall, among 79 countries with three or more cities having 300,000 inhabitants or more in 2018, there were nine countries or territories where all cities were highly exposed and vulnerable to disasters in term of mortality and economic losses: Bangladesh, Taiwan Province of China, Colombia, Costa Rica, Ecuador, Kenya, Madagascar, New Zealand, and Zimbabwe. In the United Kingdom, Republic of Korea, Viet Nam, Japan and the Philippines, over 90 per cent of cities were highly exposed to one or more natural disasters, to high mortality risk and to high risk of economic losses.

TABLE 3. LIST OF SELECTED COUNTRIES WITH HIGHEST PROPORTION OF THEIR CITIES AT RISK TO NATURAL DISASTERS

*Countries **	*Per cent of cities located in areas with high level of exposure to natural disasters*	*Per cent of cities located in areas with high level of mortality to natural disasters*	*Per cent of cities located in areas with high level of economic losses to natural disasters*
Bangladesh (11)	100.0	100.0	100.0
China, Taiwan Province of China (8)	100.0	100.0	100.0
Colombia (18)	100.0	100.0	100.0
Costa Rica (3)	100.0	100.0	100.0
Ecuador (4)	100.0	100.0	100.0
Kenya (6)	100.0	100.0	100.0
Madagascar (3)	100.0	100.0	100.0
New Zealand (3)	100.0	100.0	100.0
Zimbabwe (3)	100.0	100.0	100.0
United Kingdom (28)	96.4	100.0	100.0
Republic of Korea (25)	92.0	100.0	100.0
Viet Nam (11)	100.0	90.9	100.0
Japan (33)	100.0	100.0	93.9
Philippines (31)	93.5	96.8	96.8

Note: *Countries also refers, as appropriate, to territories. Only countries with three or more cities and all their cities were either highly exposed or highly vulnerable to mortality and economic losses were presented. Figures in the parentheses are the total number of cities with 300,000 inhabitants or more in 2018. See table 1 for definition of indicators.

I. SEVERAL CITIES FACE GREAT CHALLENGES FROM NATURAL DISASTERS IN THE COMING DECADES

Disasters can be devastating. For example, in the US, Hurricane Katrina killed more than 1,800 people and caused $160 billion (in 2017 value) in losses in 2005, while Hurricane Harvey directly killed 68 people, caused $125 billion in damages and affected 13 million persons in 2017 (Blake and Zelinsky, 2018; National Hurricane Center, 2017). Damages caused by such extreme disasters can upset or even destroy local economies, especially in poor countries. For example, the earthquakes of Nicaragua (1972), Guatemala (1976), El Salvador (1986) and Haiti (2010) caused direct economic losses of approximately 98 per cent, 82 per cent, 40 per cent and 120 per cent, respectively of the nominal GDP of each country in the year of the event (UNDRR, 2019b).

Based on our analysis, 37 of 1,860 cities could expect to be affected by a category-5 cyclone, and 111 cities could expect to be hit by a category-4 cyclone with 100-year return period. Nearly 40 cities could expect to be hit by a flood with a magnitude of an inundation depth of 540 centimeters or more with 5-year return period. Eighty-six cities are expected to be affected by an earthquake of 7.0 to 7.9 on the Richter scale with 250-year return period, and four cities all in Japan (Tokyo (37.5 million), Utsunomiya (0.52 million), Iwaki (0.35 million), and Koriyama(0.33 million)) could expect to be hit by an earthquake of 8.0+ on the Richter scale. Overall, out of 1,860 cities, only two cities (Davao City (1.7 million) in the Philippines, Acapulco De Jurez (0.95 million) in Mexico) could expect to be hit by a combination of a category-5 cyclone with 100-year return period, a flood with an inundation depth of 360 to 540 centimeters with 50-year return period, and an earthquake of 7.0 to 7.9 Richter scale with 250-year return period.

IV. CONCLUDING REMARKS

Using the population time-series for cities with 300,000 inhabitants or more from the 2018 revision of World Urbanization Prospects together with the spatial hotspot data on risks of exposures and vulnerability to natural disasters, this paper showed that 1,087 cities in 2018 faced a relatively high risk of exposure to at least one of the six types of natural disaster, representing 58 per cent of all 1,860 cities. The total population in these cities in 2018 was about 1.6 billion, accounting for 64 per cent of the total population living in these cities. Furthermore, about 83 per cent of cities were highly vulnerable to disaster-related mortality and nearly 89 per cent of cities were highly vulnerable to disaster-related economic losses in 2018. These findings suggest that most cities in today's world are vulnerable to some forms of natural disaster. These results are 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 or low-income countries 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 or high-income countries. Evidence has shown that 92 per cent of mortality attributed to internationally reported natural disasters since 1990 has occurred in low- and middle-income countries (UNDRR, 2019b). Larger cities were at a higher level of exposure to disasters and more vulnerable to disaster-related economic losses and mortality than smaller cities. Coastal cities were more likely to be highly exposed and more vulnerable to cyclones. We also identified great variation across SDG regions with regard to exposure and vulnerability to natural disasters. Several cities could face great challenges from extreme natural disasters in the future.

There is evidence that the level of disaster proneness, disaster vulnerability, and coping capacities vary greatly not only by socioeconomic development level, but also by demographic and socioeconomic characteristics (Chen et al., 2012; Uitto, 1998; UNISDR, 2011). For example, 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. It is reported that people in poorer countries are seven times more likely to be killed by a disaster than in richer ones (Centre for Research on the Epidemiology of Disasters (CRED) and United Nations International Office for Disaster Risk Reduction (UNISDR), 2018). Thus, poor people in the developing or low-income countries are the most vulnerable population to be affected by disasters. 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). Given that the proportion of disaster-related deaths and injuries in urban areas in low- and middle-income countries is likely to increase (Dodman, Hardoy and Satterthwaite, 2009), partly due to the rapid urbanization in these countries (United Nations, 2018), increasing the capacity of local and national officials of the less developed countries to cope with disasters should be a priority (UNIPCC, 2001; UNDRR, 2019a; 2019b). As cities in developing or low-income countries are growing more rapidly, consequences of losses from natural disasters are likely to increase too, particularly if recovery from disasters in such settings is very slow (Blackburn and Johnson, 2012; UNISDR, 2009; UNDRR, 2019a). However, the economic losses in cities of wealthier countries could remain much higher than those in the less developed regions (Cross, 2001; UNISDR, 2013). For example, as was noted earlier, Hurricane Katrina in 2005 and Hurricane Harvey in 2017 in the US each brought a damage of over US$100 billion. In other words, there is no escape for attacks by natural disasters for cities with high levels of exposure or vulnerability, regardless of whether they are in developed countries or developing countries.

Floods, droughts and cyclones are the most devastating types of natural disaster that are threatening world's cities. Climatologic and meteorological disasters take the lead in causing large 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). According to a recent UN report (CRED and UNISDR, 2018), the reported total direct economic losses during 1998-2017 were around $2.9 trillion, more than three-fourths were caused by climate-related disasters. 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 to 63 billion in 2050 if disaster risk is assumed to remain constant (Hallegatte et al., 2013). In March 2019 alone, the global losses due to flooding events reached US$8.0 billion (Aon, 2019). The drought that occurred in central eastern Brazil during 2013–2015 had a reported loss of about $5 billion; and the 2010–2011 drought in the Horn of Africa is estimated to have caused up to a quarter of a million deaths and 13 million people relying on humanitarian aid (UNDRR, 2019b). One pressing challenge is that the incidence of hydrological and meteorological disasters has evidenced to grow steadily in recent decades, both globally and regionally (Doocy, Daniels, Murray et al., 2013; Schultz and Elliott, 2013; UNISDR, 2013; UNDRR, 2019a; 2019b).

The findings about levels of exposure and vulnerability of the world's cities in this analysis imply the importance of adequate preparedness. By the mid-2010s, efforts had 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). The Sendai Framework for Disaster Risk Reduction 2015–2030 and the 2030 Agenda for Sustainable Development Goals (SDGs), the Paris Agreement, the Addis Ababa Action Agenda and New Urban Agenda each provide guidelines for the world to address challenges related to climate changes. SDG 11 aims to achieve substantial reductions by 2030 in number of deaths, number of people affected and direct economic losses caused by disasters, in particular water-related disasters with a focus on protecting the poor and the most vulnerable (United Nations General Assembly 2015). To achieve SDG 11, multi-hazard early warning systems, integrated development, sound disaster and climate risk management, effective local governance and the empowerment of the urban poor in both more developed and less developed regions are becoming increasingly important for developing adaptive strategies, improving resilience and building sustainability (UNISDR, 2009; UNDRR, 2019a). It is our hope that the findings of this study could inform city governments in planning for and addressing natural disasters.

This report expands on our previous report (No. 2015/2, Gu et al., 2015) by using several additional and newer datasets. First, this report used the official urban extents for cities in forty countries compared to using buffer zones for all cities in the previous version. Second, this report included 1,860 cities from the 2018 revision of WUP, 168 cities more compared to the previous report that was based on the 2014 revision. Third, this report includes additional analyses of *return period* for all cities using the latest available data from the UNDRR. The information about the *return period* of a certain type of disaster in a given city is useful for risk reduction or preparation in decision-making regarding whether a project in a zone of a certain level of exposure to disaster should be implemented or whether certain infrastructure should be designed to withstand the expected events. The additional analyses provided added values to assessment of the risk of world cities to natural disasters for a better preparation and decision making.

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 levels of a given city is assumed to be constant over the period of analysis; yet 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). In other words, the mortality and economic vulnerabilities for today's cities could be higher than what we presented. An increase in incidence since the period covered by our dataset would imply that recent exposure or vulnerability to disasters for cities are higher than what 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, defective or faulty building codes and construction, poor governance, failure to evacuate populations at risk based on early warnings, and so on. In some urban settlements in high risk zones, attempts have already been made to improve building codes in order to better improve resistance to various natural disasters, and some local authorities have implemented 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 exposure to natural disasters of these 1,860 cities could be greater if additional types of disaster were taken into consideration. It is possible that patterns of risks of exposure and vulnerability to natural disasters across city size groups, development groups, regions and income groups could be altered if other types of natural disasters were considered. For instance, there is evidence showing that in the last three decades, Asia had the highest number of geophysical, hydrological and meteorological disasters, Africa experienced the highest number of biological disasters (disease epidemics and insect/animal plagues) and droughts, and Europe 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 affected 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.

Finally, this report assesses the exposure and vulnerability to the six types of natural disaster for 1,860 cities of the world with 300,000 inhabitants or more on 1 July 2018. However, another 2.0 billion people in 2018 lived in smaller cities and urban settlements and about 20 to 25 per cent of the urban growth by 2030 will come from these smaller cities (United Nations, 2018). Studies have shown that 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 because 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). Thus, more studies that include smaller cities are needed to provide a fuller picture of urban exposure risk and economic and mortality vulnerability to natural disasters.

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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.

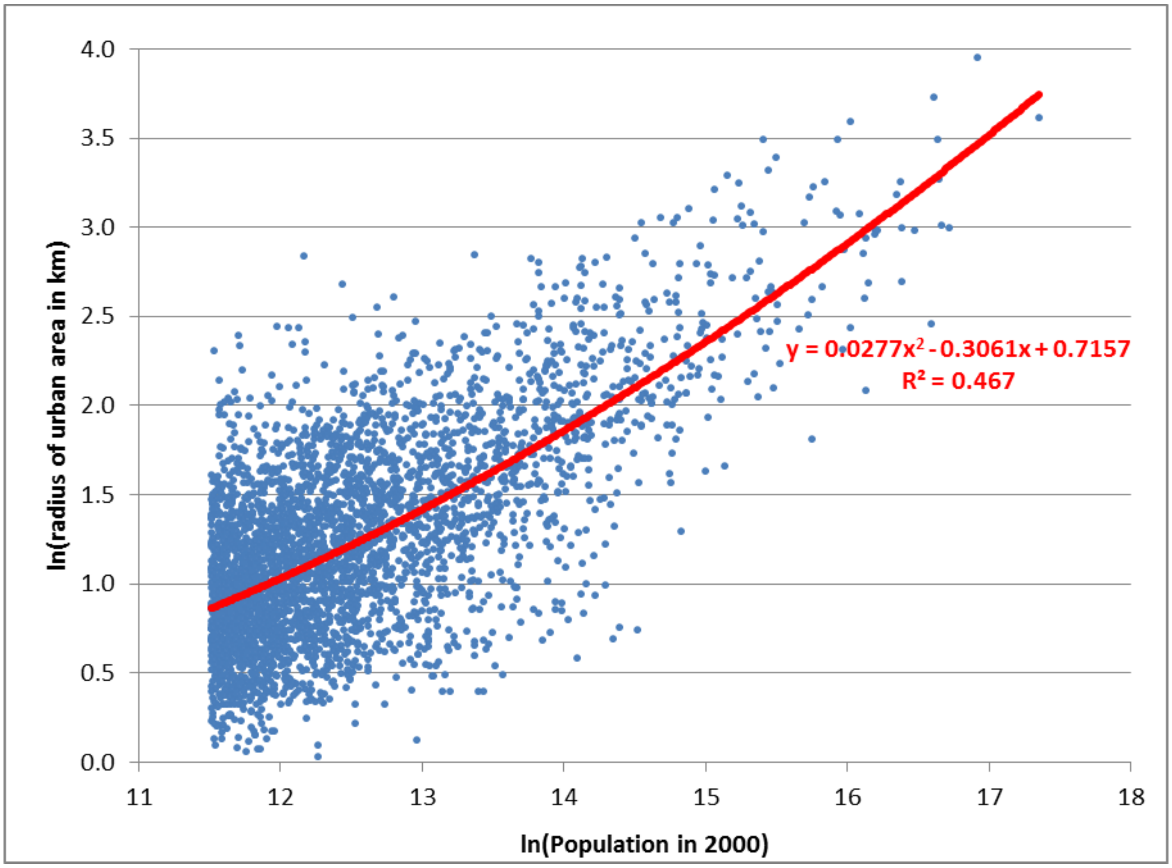
Using the name of each locality or urban area, geographic coordinates (i.e., latitude and longitude in decimal degree using the World Geodetic System (WGS84) ellipsoid) for the centroid location of each urban area were obtained from several authoritative public sources (e.g., national authorities' web sites and online public gazetteers such as Geonames[7] and FuzzyG UN/EC Common Gazetteer[8]). 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[9] Level 0 at 1:1 million scale) and the urban extents from the Global Rural-Urban Mapping Project (GRUMP)[10] for each city in the *2018 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-2018 as part of the *2018 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).

[7] Geonames Gazetteer. Available at www.geonames.org. Retrieved 4 March 2018.
[8] FuzzyG is a service of the Joint Research Centre of the European Commission and the United Nations Geospatial Information Section (formerly the United Nations Cartographic Section). http://dma.jrc.it/services/gazetteer/ Retrieved 4 March 2018.
[9] UN Cartographic Section (UNCS).UNmap. http://ggim.un.org/projects.html. Retrieved 19 July 2013.
[10] 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 2018.

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 *2018 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 2018 from the *2018 Revision* of the *World Urbanization Prospects.*

B. Sensitivity analysis of estimating risk zones for exposure, economic losses and mortality between our approach and urban extents from the GRUMP and the MODIS land cover imagery datasets

A sensitivity analysis was performed by comparing our estimates with the estimates using the urban extents from the Global Rural-Urban Mapping Project (GRUMP) [11] and urban extents from MODIS land cover 500 meters imagery dataset for each corresponding city in the *2018 Revision* of the WUP. The very high level of consistency between the two sources clearly suggests that our approach is quite reliable. [12]

TABLE B-1. PERCENTAGES OF CONSISTENCY FOR ESTIMATES OF EXPOSURE TO SIX TYPES OF NATURAL DISASTER (IN DECILES) FOR CITIES OF THE WORLD BETWEEN OUR APPROACH AND THE GRUMP AND MODIS LAND COVER 500M URBAN EXTENTS

	Cyclones	*Droughts*	*Floods*	*Earthquakes*	*Landslides*	*Volcanic eruptions*
Compared with urban extents derived from GRUMP dataset						
All cities (1,860)	95.3	92.8	92.4	87.4	90.1	97.3
City by size						
Megacities (33)	100.0	87.9	93.9	87.9	78.8	90.9
5-10 million (48)	91.7	89.6	95.8	86.3	93.8	95.8
1 -5 million (467)	94.2	91.0	91.2	86.7	90.8	97.4
<1 million (1,312)	95.7	93.7	92.7	87.8	90.0	97.4
City by geographic region						
Sub-Saharan Africa (177)	99.4	96.6	98.9	96.6	96.6	100.0
Northern Africa and Western Asia (150)	100.0	90.0	89.3	78.0	95.3	100.0
Southern and Central Asia (268)	98.1	95.5	95.5	88.8	89.2	100.0
Eastern and South-Eastern Asia (619)	94.5	92.6	94.0	87.6	89.5	93.4
Latin America and the Caribbean (210)	92.9	91.4	91.0	86.7	81.4	96.2
Australia New Zealand and Oceania* (15)	93.3	93.3	93.3	83.3	93.3	100.0
Europe and Northern America (521)	92.4	91.4	87.2	86.0	91.2	99.5
Compared with urban extents derived from MODIS Land Cover 500m						
All cities (1,860)	97.3	98.0	95.6	96.4	94.8	99.2
City by size						
Megacities (33)	93.9	93.9	90.9	87.9	93.9	100.0
5-10 million (48)	95.8	93.8	93.8	95.8	93.8	100.0
1 -5 million (467)	96.4	96.7	95.7	95.7	95.1	99.1
<1 million (1,312)	97.8	98.9	95.8	96.9	94.8	99.2
City by geographic region						
Sub-Saharan Africa (177)	100.0	100.0	98.9	98.9	98.3	99.4
Northern Africa and Western Asia (150)	100.0	100.0	98.7	96.7	97.3	100.0
Southern and Central Asia (268)	98.9	99.3	98.9	98.9	98.5	100.0
Eastern and South-Eastern Asia (619)	97.6	99.2	97.7	97.3	95.2	99.0
Latin America and the Caribbean (210)	93.8	93.8	91.9	93.8	88.6	96.7
Australia New Zealand and Oceania* (15)	93.3	93.3	100.0	100.0	93.3	100.0
Europe and Northern America (521)	95.7	98.0	89.8	93.6	92.9	99.8

Note: The consistency check is for 1,860 cities with 300,000 inhabitants or more in 2018. Percentage of consistency is the number of matched cities between two methods divided by 1,860. Numbers in the parentheses refer to number of cities. Oceania* refers to Oceania excluding Australia and New Zealand. Because only has one city in Oceania* in this dataset, we combined Australia and New Zealand with Oceania* (AZO) and refers to Oceania as a whole.

[11] 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 2018. 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.

[12] 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 RISK TO SIX TYPES OF NATURAL DISASTER (IN DECILES) FOR CITIES OF THE WORLD BETWEEN OUR APPROACH AND THE GRUMP AND MODIS LAND COVER 500M URBAN EXTENTS

	Cyclones	*Droughts*	*Floods*	*Earthquakes*	*Landslides*	*Volcanic eruptions*
Compared with urban extents derived from GRUMP dataset						
All cities (1,860)	97.9	96.1	96.7	96.8	92.3	97.2
City by size						
Megacities (33)	100.0	90.9	97.0	97.0	87.9	90.9
5-10 million (48)	100.0	938	100.0	100.0	93.8	95.8
1 -5 million (467)	97.4	95.5	96.1	96.8	92.7	97.9
<1 million (1,312)	97.9	96.5	96.8	96.6	92.1	97.1
City by geographic region						
Sub-Saharan Africa (177)	99.4	97.7	98.3	100.0	99.4	99.4
Northern Africa and Western Asia (150)	100.0	100.0	92.0	92.7	92.0	100.0
Southern and Central Asia (268)	99.6	98.1	97.8	99.3	91.4	100.0
Eastern and South-Eastern Asia (619)	97.4	92.7	97.7	96.1	89.2	93.5
Latin America and the Caribbean (210)	94.3	94.3	97.1	96.2	88.6	94.3
Australia New Zealand and Oceania* (15)	93.3	100.0	100.0	100.0	86.7	100.0
Europe and Northern America (521)	98.1	98.3	95.2	96.4	96.4	100.0
Compared with urban extents derived from MODIS Land Cover 500m						
All cities (1,860)	98.7	98.5	97.6	98.4	95.8	99.4
City by size						
Megacities (33)	97.0	97.0	97.0	100.0	93.9	100.0
5-10 million (48)	100.0	100.0	97.9	97.9	97.9	100.0
1 -5 million (467)	98.5	97.4	97.2	98.5	96.1	98.9
<1 million (1,312)	98.7	98.9	97.8	98.4	95.6	99.5
City by geographic region						
Sub-Saharan Africa (177)	100.0	98.3	97.7	100.0	98.3	100.0
Northern Africa and Western Asia (150)	100.0	100.0	99.3	98.7	95.3	100.0
Southern and Central Asia (268)	100.0	99.3	99.3	99.6	97.0	100.0
Eastern and South-Eastern Asia (619)	0.989	98.1	99.2	98.9	96.0	99.0
Latin America and the Caribbean (210)	0.938	95.2	96.2	97.1	90.5	97.0
Australia New Zealand and Oceania* (15)	100.0	100.0	100.0	100.0	93.3	100.0
Europe and Northern America (521)	98.8	99.8	94.3	96.9	96.4	100.0

Note: The consistency check is for 1,860 cities with 300,000 inhabitants or more in 2018. Percentage of consistency is the number of matched cities between two methods divided by 1,860. Numbers in the parentheses refer to number of cities. Oceania* refers to Oceania excluding Australia and New Zealand. Because only has one city in Oceania* in this dataset, we combined Australia and New Zealand with Oceania* (AZO) and refers to Oceania as a whole.

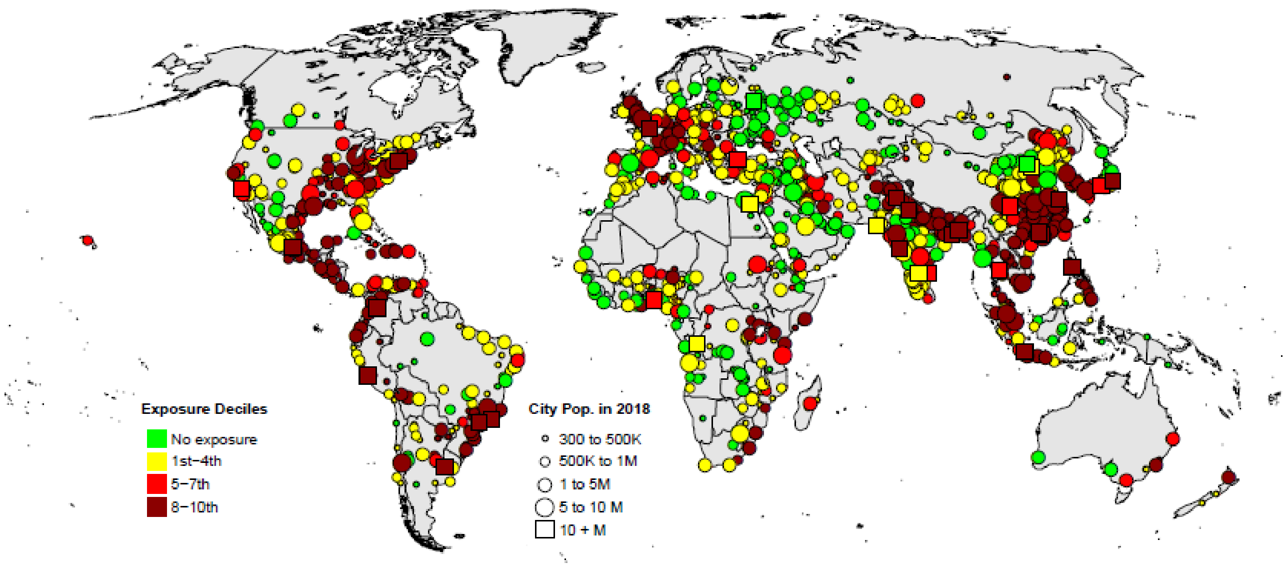
TABLE B-3. PERCENTAGES OF CONSISTENCY FOR ESTIMATES OF RISK OF ECONOMIC LOSSES TO SIX TYPES OF NATURAL DISASTER (IN DECILES) FOR CITIES OF THE WORLD BETWEEN OUR APPROACH AND THE GRUMP AND MODIS LAND COVER 500M URBAN EXTENTS

	Cyclones	*Droughts*	*Floods*	*Earthquakes*	*Landslides*	*Volcanic eruptions*
Compared with urban extents derived from GRUMP dataset						
All cities (1,860)	97.6	94.6	96.5	97.2	93.3	98.2
City by size						
Megacities (33)	100.0	90.9	100.0	100.0	87.9	97.0
5-10 million (48)	100.0	91.7	100.0	100.0	91.7	100.0
1 -5 million (467)	97.9	95.3	95.3	96.8	94.0	98.3
<1 million (1,312)	97.4	94.5	96.7	97.1	93.3	98.2
City by geographic region						
Sub-Saharan Africa (177)	99.4	95.5	96.6	100.0	100.0	100.0
Northern Africa and Western Asia (150)	100.0	91.3	91.3	93.3	96.3	100.0
Southern and Central Asia (268)	100.0	96.3	97.0	98.9	95.9	100.0
Eastern and South-Eastern Asia (619)	96.8	95.6	97.6	96.9	89.8	97.1
Latin America and the Caribbean (210)	93.8	95.7	95.2	95.7	87.1	93.8
Australia New Zealand and Oceania* (15)	93.3	100.0	100.0	100.0	86.7	100.0
Europe and Northern America (521)	97.9	91.9	96.9	97.2	96.4	99.5
Compared with urban extents derived from MODIS Land Cover 500m						
All cities (1,860)	98.5	98.0	98.2	98.9	96.0	99.4
City by size						
Megacities (33)	97.0	97.0	97.0	97.0	93.9	100.0
5-10 million (48)	100.0	93.8	97.9	100.0	97.9	100.0
1 -5 million (467)	98.5	97.2	97.6	98.5	96.6	99.1
<1 million (1,312)	98.5	98.5	98.4	99.1	95.8	99.4
City by geographic region						
Sub-Saharan Africa (177)	100.0	96.0	98.3	100.0	100.0	100.0
Northern Africa and Western Asia (150)	100.0	98.7	99.3	99.3	96.7	100.0
Southern and Central Asia (268)	100.0	99.3	99.6	99.3	98.9	100.0
Eastern and South-Eastern Asia (619)	98.2	99.0	99.4	99.5	96.1	99.4
Latin America and the Caribbean (210)	94.3	96.7	96.7	98.1	88.6	96.7
Australia New Zealand and Oceania* (15)	100.0	100.0	100.0	100.0	93.3	100.0
Europe and Northern America (521)	98.8	96.9	95.7	97.6	96.0	99.8

Note: The consistency check is for 1,860 cities with 300,000 inhabitants or more in 2018. Percentage of consistency is the number of matched cities between two methods divided by 1,860. Numbers in the parentheses refer to number of cities. Oceania* refers to Oceania excluding Australia and New Zealand. Because only has one city in Oceania* in this dataset, we combined Australia and New Zealand with Oceania* (AZO) and refers to Oceania as a whole.

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

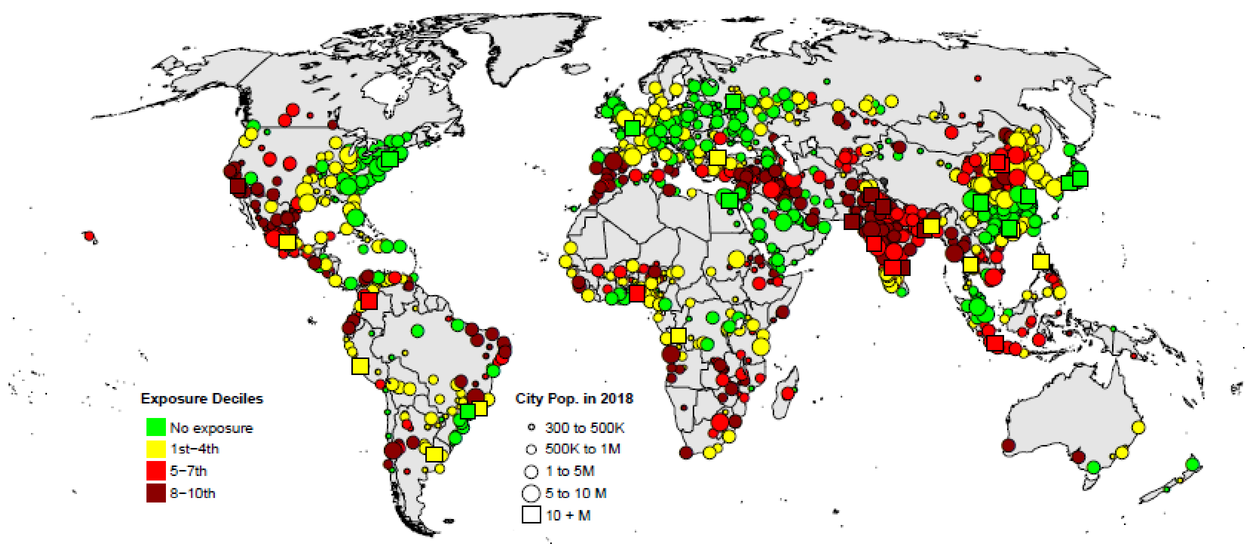
Figure C1a. Spatial distribution of exposure to floods for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

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



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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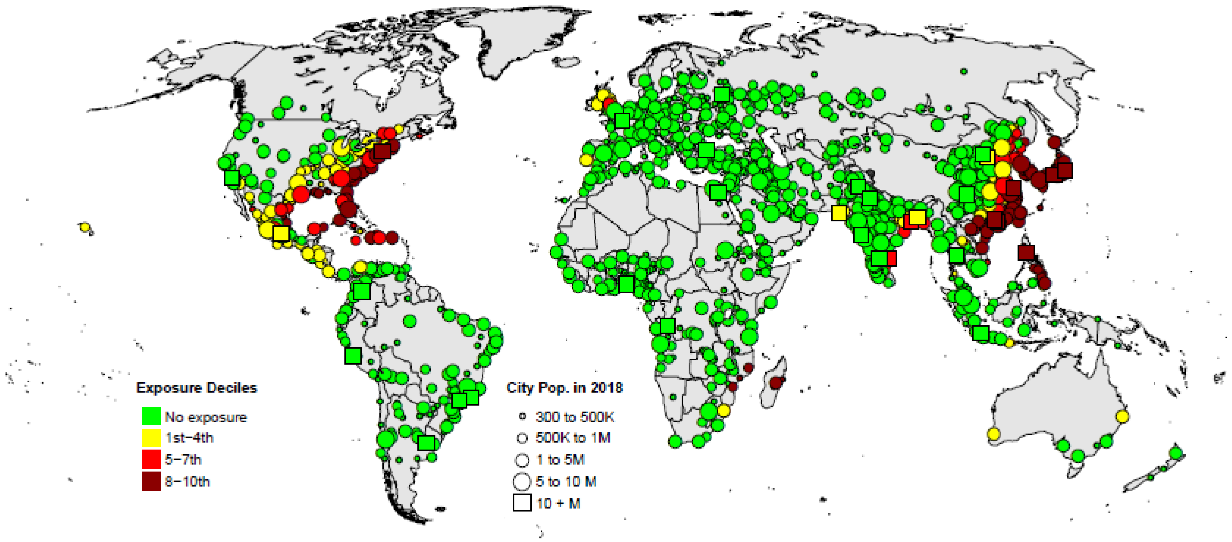
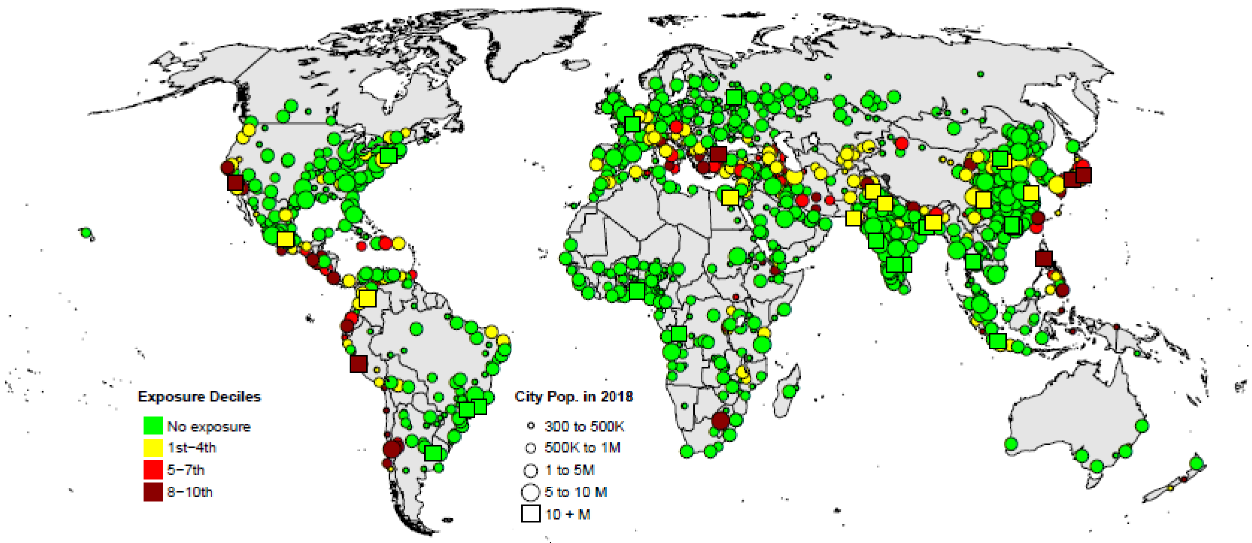
Figure C1c. Spatial distribution of exposure to cyclones for cities of the world



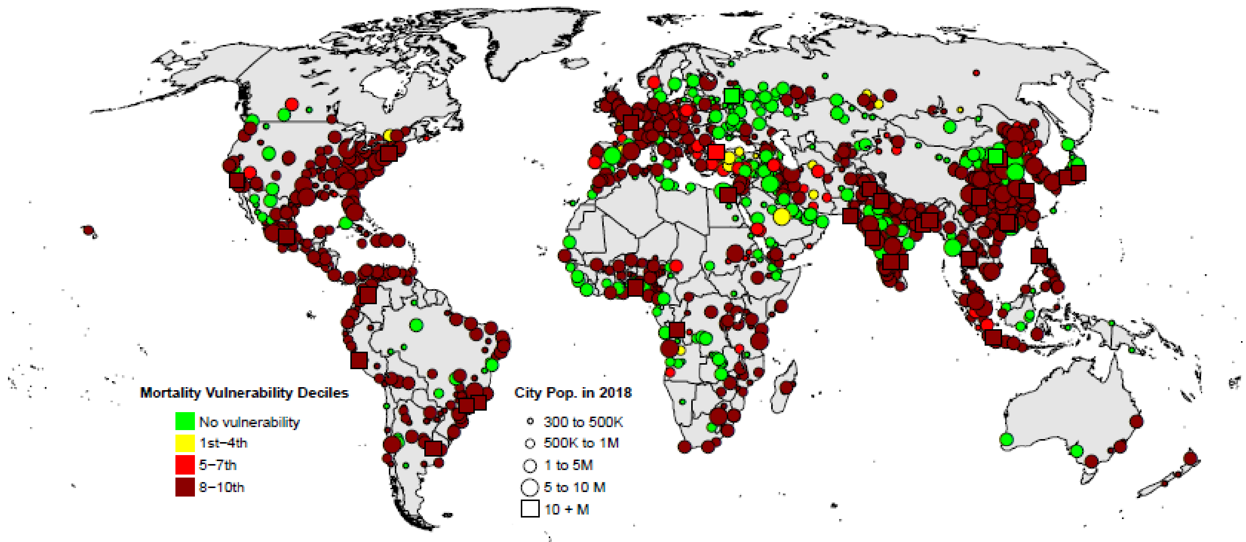
Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)
Disclaimer: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

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



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)
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. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

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



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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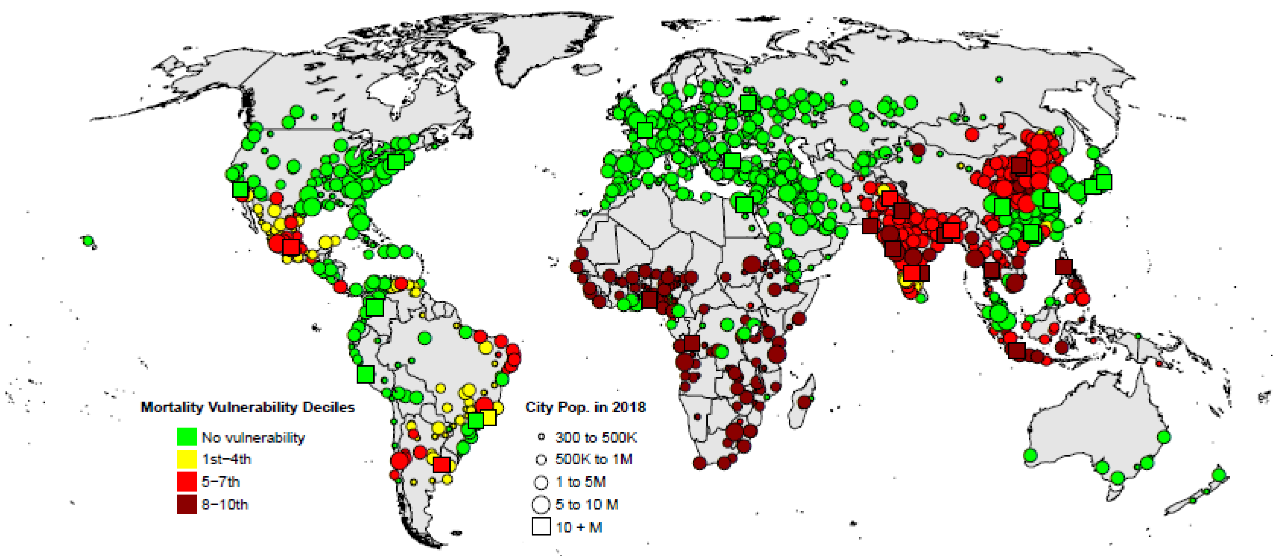
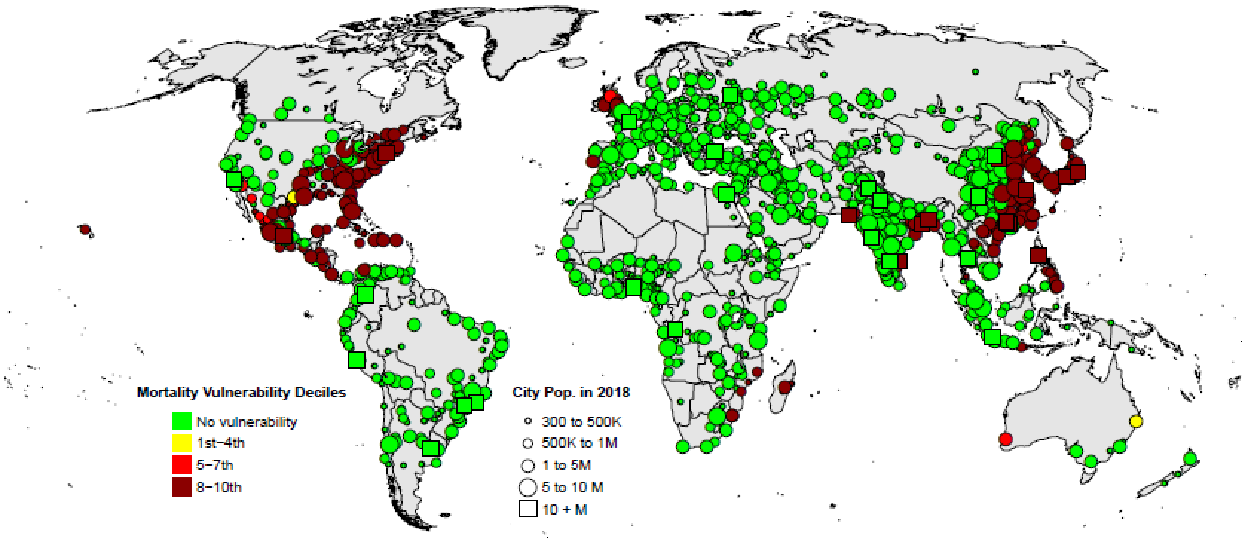
Figure C2b. Spatial distribution of mortality vulnerability to droughts for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

*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. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

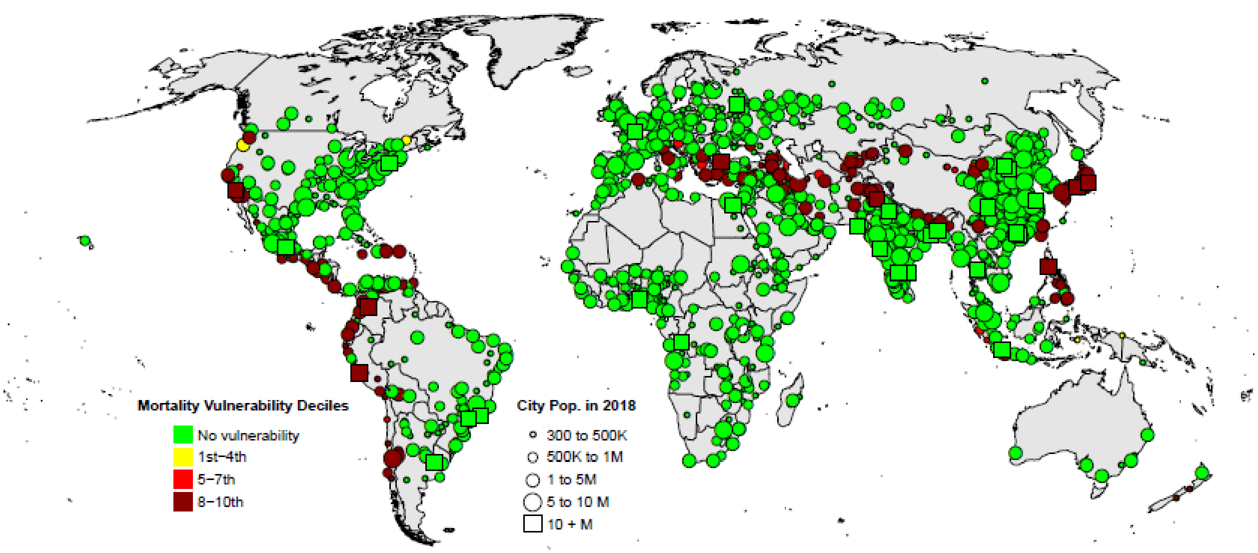
Figure C2c. Spatial distribution of risk of mortality vulnerability to cyclones for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

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



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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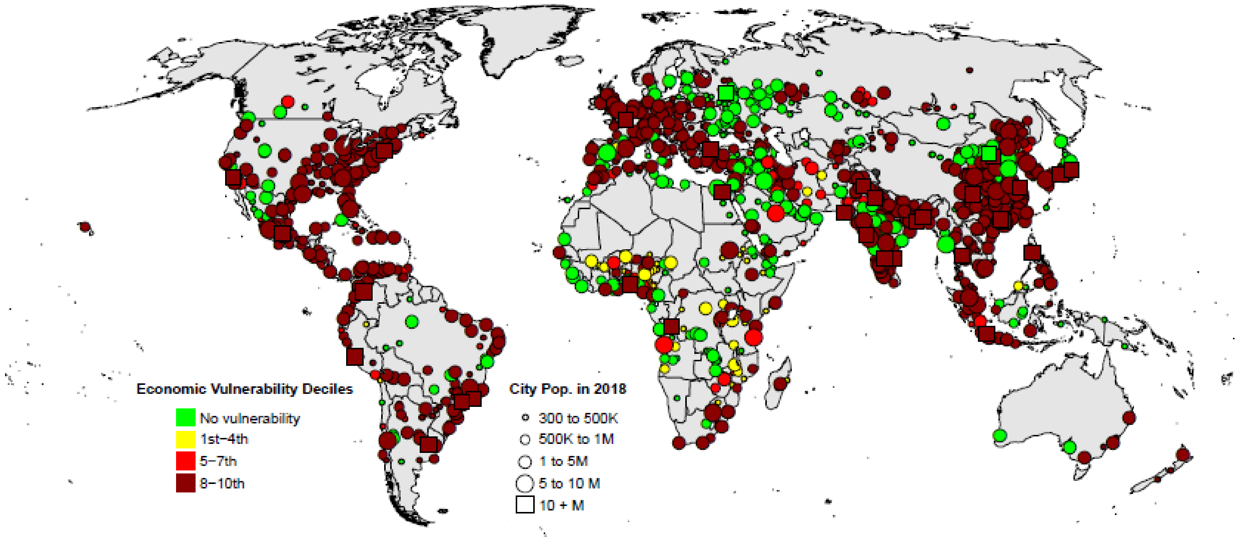
Figure C3a. Spatial distribution of economic vulnerability to floods for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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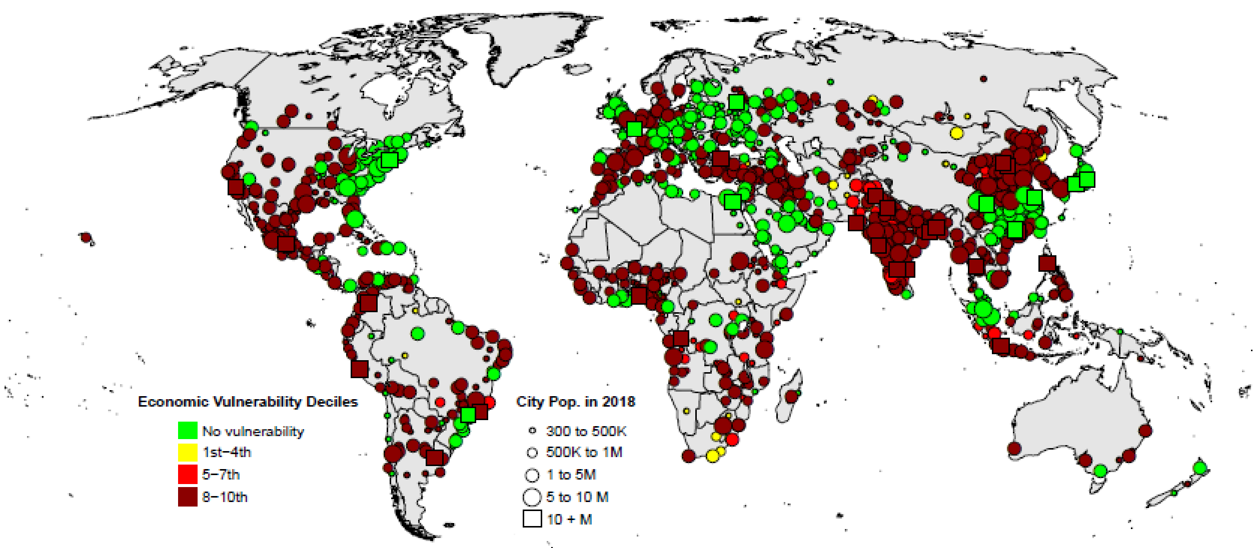
Figure C3b. Spatial distribution of economic vulnerability to droughts for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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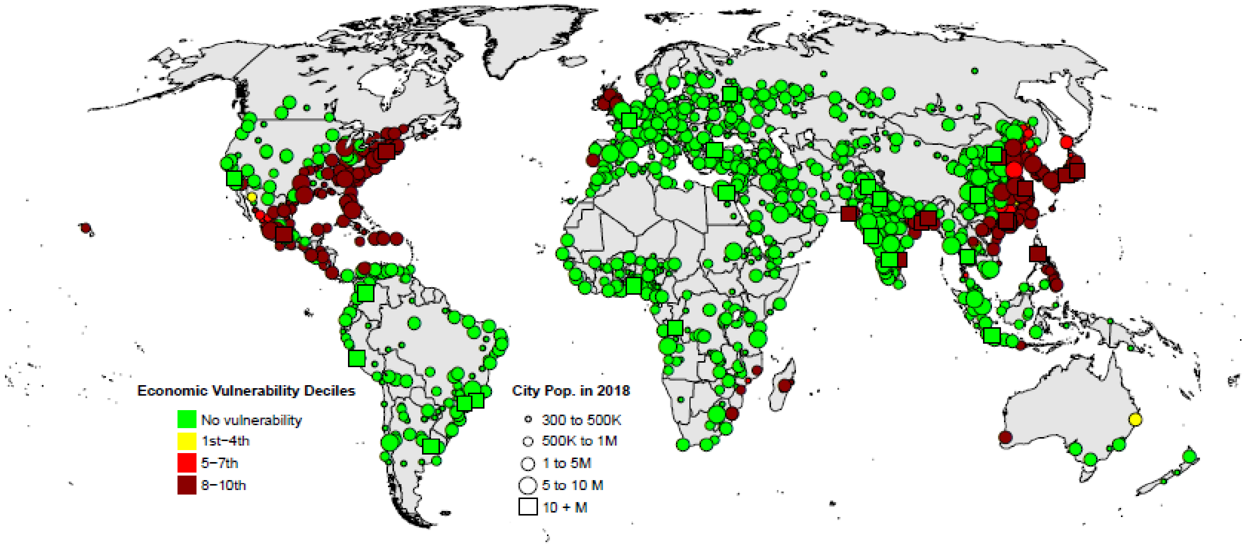
Figure C3c. Spatial distribution of economic vulnerability to cyclones for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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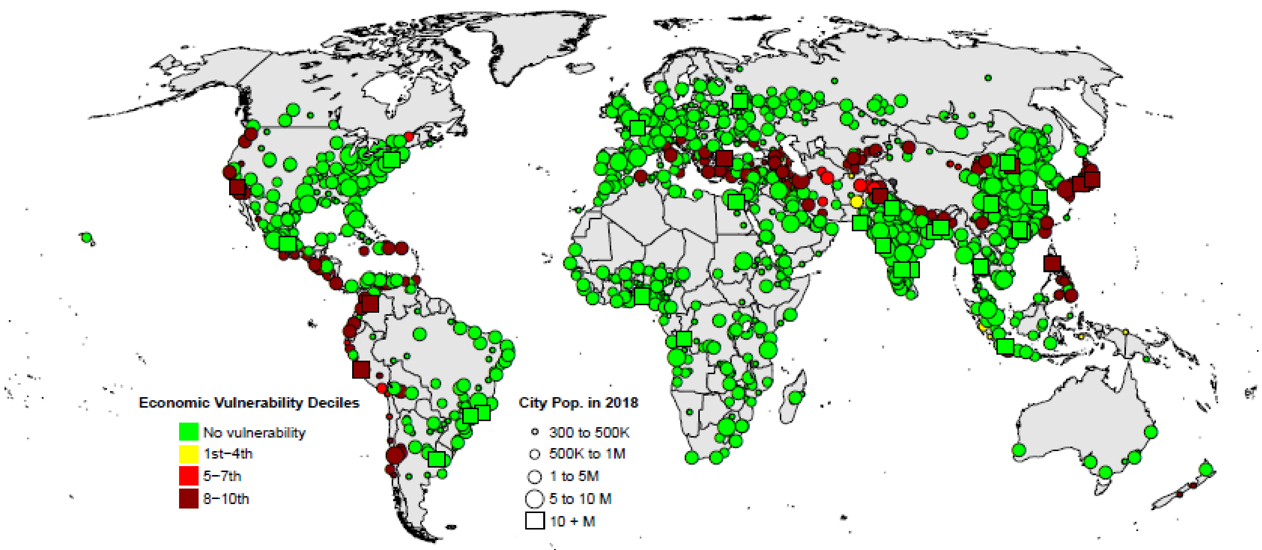
Figure C3d. Spatial distribution of economic vulnerability to earthquakes for cities of the world



Sources: *World Urbanization Prospects: The 2018 Revision*; Dilley et al. (2005)

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

TABLE D1. LIST OF CITIES WITH ONE MILLION INHABITANTS OR MORE ON 1 JULY 2018 THAT WERE HIGHLY EXPOSED TO AT LEAST THREE OF SIX TYPES OF NATURAL DISASTER

			Risk of exposure (in decile) [3]					
City Names	Countries [1]	Population (millions) [2]	Cyclones	Droughts	Floods	Earthquakes	Landslides	Volcanic eruptions
Tokyo	Japan	37.47	8-10	0	8-10	8-10	8-10	0
Osaka	Japan	19.28	8-10	0	5-7	8-10	8-10	0
Manila	Philippines	13.48	8-10	1-4	8-10	8-10	8-10	8-10
Santiago	Chile	6.68	0	8-10	8-10	8-10	8-10	0
Xinbei	China, Taiwan Province of China	4.32	8-10	0	8-10	8-10	8-10	0
San Francisco-Oakland	USA	3.33	0	8-10	8-10	8-10	5-7	0
Shizuoka-Hamamatsu M.M.A.	Japan	2.90	8-10	0	1-4	8-10	8-10	5-7
Guayaquil	Ecuador	2.90	0	8-10	8-10	8-10	0	0
Guatemala City	Guatemala	2.85	1-4	8-10	8-10	8-10	8-10	0
Taipei	China, Taiwan Province of China	2.71	8-10	0	8-10	8-10	8-10	0
Sapporo	Japan	2.66	8-10	0	0	0	8-10	8-10
Taoyuan	China, Taiwan Province of China	2.19	8-10	0	8-10	0	8-10	0
Quito	Ecuador	1.82	0	8-10	8-10	5-7	8-10	8-10
San Jose	USA	1.78	0	8-10	1-4	8-10	8-10	0
Davao City	Philippines	1.74	8-10	1-4	8-10	8-10	8-10	1-4
San José	Costa Rica	1.36	1-4	1-4	8-10	8-10	8-10	8-10
Taizhong	China, Taiwan Province of China	1.28	8-10	0	8-10	8-10	8-10	0
Bogor	Indonesia	1.11	0	5-7	8-10	8-10	5-10	8-10
San Salvador	El Salvador	1.11	0	0	8-10	8-10	8-10	5-7

Note: (1) The term “countries” also refers, as appropriate, to territories. (2) referring to 1 July 2018. The risk of exposure is measured by decile based on the distribution over the global grid cells. (3) 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 2018 THAT WERE VULNERABLE TO AT LEAST THREE OF SIX TYPES OF NATURAL HAZARD IN TERMS OF DISASTER-RELATED MORTALITY

			Vulnerability to disaster-related mortality (in decile)[3]					
City Names	Countries [1]	Population (millions) [3]	Cyclones	Droughts	Floods	Earthquakes	Landslides	Volcano eruptions
Tokyo	Japan	37.47	8-10	0	8-10	8-10	8-10	0
Mexico City	Mexico	21.58	8-10	5-7	8-10	0	8-10	8-10
Osaka	Japan	19.28	8-10	0	8-10	8-10	8-10	0
Karachi	Pakistan	15.40	8-10	8-10	8-10	0	0	0
Kolkata	India	14.68	8-10	8-10	8-10	0	0	0
Manila	Philippines	13.48	8-10	8-10	8-10	8-10	8-10	8-10
Tianjin	China	13.21	8-10	8-10	8-10	0	0	0
Bogotá	Colombia	10.57	0	0	8-10	8-10	8-10	0
Madras	India	10.46	8-10	8-10	8-10	0	0	0
Nagoya	Japan	9.51	8-10	0	8-10	8-10	0	0
Tehran	Iran	8.90	0	0	8-10	8-10	8-10	0
Santiago	Chile	6.68	0	5-7	8-10	8-10	8-10	0
Kitakyushu-Fukuoka M.M.A.	Japan	5.55	8-10	0	8-10	8-10	8-10	0
Guadalajara	Mexico	5.02	8-10	5-7	8-10	0	8-10	0

Note: (1) The term "countries" also refers, as appropriate, to territories. (2) referring to 1 July 2018. The risk of exposure is measured by decile based on the distribution over the global grid cells. (3) A decile value equalling to zero indicates no risk of exposure to a natural disaster. See Data and Method for details.

Table D3. List of cities with 5 million inhabitants or more on 1 July 2018 that were highly vulnerable to at least three of six types of natural hazard in terms of disaster-related economic losses

City Names	Countries [1]	Population (millions) [2]	Vulnerability disaster-related economic losses (in decile) [3]					
			Cyclones	Droughts	Floods	Earthquakes	Landslides	Volcano eruptions
Tokyo	Japan	37.47	8-10	0	8-10	8-10	8-10	0
Mexico	Mexico	21.58	8-10	8-10	8-10	0	8-10	8-10
Dhaka	Bangladesh	19.58	8-10	8-10	8-10	0	0	0
Osaka	Japan	19.28	8-10	0	8-10	8-10	8-10	0
Karachi	Pakistan	15.40	8-10	8-10	8-10	0	0	0
Istanbul	Turkey	14.75	0	8-10	8-10	8-10	8-10	0
Kolkata	India	14.68	8-10	8-10	8-10	0	0	0
Manila	Philippines	13.48	8-10	8-10	8-10	8-10	8-10	8-10
Tianjin	China	13.21	8-10	8-10	8-10	8-10	0	0
Los Angeles-Long Beach-Santa Ana	USA	12.46	0	8-10	8-10	8-10	0	0
Shenzhen	China	11.91	8-10	8-10	8-10	0	0	0
Lahore	Pakistan	11.74	0	8-10	8-10	8-10	0	0
Bogotá	Colombia	10.57	0	8-10	8-10	8-10	8-10	0
Chennai	India	10.46	8-10	8-10	8-10	0	0	0
Lima	Peru	10.39	0	8-10	8-10	8-10	0	0
Seoul	Rep. Korea	9.96	8-10	8-10	8-10	0	0	0
Chukyo M.M.A. (Nagoya)	Japan	9.51	8-10	0	8-10	8-10	0	0
Tehran	Islamic Rep. of Iran	8.90	0	8-10	8-10	8-10	0	0
Chicago	USA	8.86	8-10	8-10	8-10	0	0	0
Wuhan	China	8.18	8-10	8-10	8-10	0	0	0
Hong Kong	China, H.K. SAR	7.43	8-10	8-10	8-10	0	0	0
Shenyang	China	6.92	8-10	8-10	8-10	0	0	0
Santiago	Chile	6.68	0	8-10	8-10	8-10	5-7	0
Houston	USA	6.11	8-10	8-10	8-10	0	0	0
Dallas-Port Worth	USA	6.10	8-10	8-10	8-10	0	0	0
Kitakyushu-Fukuoka M.M.A.	Japan	5.55	8-10	8-10	8-10	8-10	8-10	0
Guadalajara	Mexico	5.02	8-10	8-10	8-10	0	8-10	0

Note: (1) The term “countries” also refers, as appropriate, to territories. (2) , referring to 1 July 2018. The risk of exposure is measured by decile based on the distribution over the global grid cells. (3) A decile value equalling to zero indicates no risk of exposure to a natural disaster. See Data and Method for details

E. Exposure and vulnerability to six types of natural disaster by decile of grid cells

TABLE E. CITIES BY LEVEL OF EXPOSURE AND VULNERABILITY TO SIX TYPES OF NATURAL DISASTER IN DECILE

	Natural disasters					
	Cyclones	Droughts	Floods	Earthquakes	Landslides	Volcanic eruptions
Exposure to natural disasters						
Number of cities	1,860	1,860	1,860	1,860	1,860	1,860
% 0	71.3	30.9	18.9	77.5	89.8	97.7
% 1-4 deciles	8.5	30.3	31.0	14.1	0.0	0.5
% 5-7 deciles	7.1	19.3	13.4	3.6	7.6	0.6
% 8-10 deciles	13.1	19.5	36.7	4.8	2.6	1.2
% Total	100.0	100.0	100.0	100.0	100.0	100.0
Mortality risk from natural disasters						
Number of cities	1,860	1,860	1,860	1,860	1,860	1,860
% 0	71.6	52.8	19.1	86.2	91.9	98.2
% 1-4 deciles	0.2	6.2	1.2	0.3	0.6	0.0
% 5-7 deciles	1.8	29.6	4.1	1.8	0.4	0.6
% 8-10 deciles	26.4	11.4	75.6	11.7	7.1	1.2
% Total	100.0	100.0	100.0	100.0	100.0	100.0
Economic losses from natural disasters						
Number of cities	1,860	1,860	1,860	1,860	1,860	1,860
% 0	71.5	31.3	19.2	79.2	1.3	98.4
% 1-4 deciles	1.6	1.7	3.3	0.8	0.3	0.2
% 5-7 deciles	4.5	5.7	5.4	3.4	1.7	0.3
% 8-10 deciles	22.4	61.3	72.1	16.6	6.7	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 2018. The exposure and vulnerability are measured by decile based on the distribution over the global grid cells. A decile value equalling to zero indicates no exposure or no or negligible risk in mortality and economic losses to a natural disaster. See Data and Method for details.