Swiss Re

Mind the risk

A global ranking of cities under threat from natural disasters

Preface

For the first time in human history more people live in cities than in rural areas. The United Nations expects 6.3 billion people or 68% of the world's population to be living in urban areas by 2050, with the highest increase occurring in high growth markets. Many of these cities are located on the coast and are threatened by floods, storms, earthquakes and other natural hazards.

The vibrancy of these cities is a key driver for economic development. However, the growing concentration of people, assets and infrastructure also means that the loss potential in urban areas is high and rising. At the same time the gap between economic and insured losses is large because insurance penetration is relatively low and city infrastructure often not insured at all. Another reason is that the risk exposure faced by the world's metropolitan areas remains underexplored, largely due to the lack of detailed hazard information and poor data quality.

This publication seeks to address this knowledge deficit by providing a comprehensive analysis of natural disaster risk in locations around the world. Based on Swiss Re's risk modelling expertise and the latest hazard information from our CatNet® tool, it focuses on the most severe natural disasters confronting 616 of the world's largest urban areas and assesses the potential impact they have on local residents and the wider economy.

We know from past events that physical prevention measures alone do not suffice to build a resilient city, since damage from the most severe catastrophes cannot be fully averted. An important part of resilience is how well urban societies are able to cope with the financial consequences of a disaster, which includes access to the requisite funding for relief, recovery and reconstruction. Swiss Re can offer risk transfer solutions that help bridge the gap between economic and insured losses and reduce the financial burden on local communities.

We hope the findings of this study will give fresh impetus to the global debate about strengthening the resilience of cities and encourage governments, citizens and the insurance industry to take collective action to mitigate the risks faced by urban communities around the world.

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Group Chief Underwriting Officer

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New Orleans under water after severe flooding caused by Hurricane Katrina in August 2005. Total damage amounted to USD 108 billion, the costliest natural disaster in US history.

Part I – Introduction

Cities at risk: an introduction

Hurricane Sandy hit New York City after making landfall in New Jersey in the evening hours of Monday, 29 October 2012. Sandy showed us how susceptible modern societies and metropolitan areas are to the impact of natural catastrophes. Across the eastern seaboard of the United States, the hurricane killed 72 people in eight States and caused USD 68 billion in damage. In New York State, 48 people lost their lives and over 300 000 homes were destroyed. Besides these casualties, the storm inundated dozens of tunnels and subway stations. Even residents of neighbourhoods not directly affected were unable to get to work. Consequently, shortly after the storm, New York Governor Andrew Cuomo convened the NYS 2100 Commission to provide recommendations for a more resilient New York.

The impact of a natural disaster in a densely populated area can be catastrophic. This is why disaster planning is nowhere more urgent than in the world's big urban centres.

In its wake, Sandy left 8.5 million people without electricity across the Tri-State area.[1] Scores of residents, companies and local authorities had to wait for weeks to get their power back. The New York Stock Exchange closed trading for two full days, airlines cancelled more than 12 000 flights and about 70% of all East Coast oil refineries were shut down. Gas stations across the region stayed closed for days.

The event not only generated enormous reconstruction costs for the city. It also had a significant impact on the US economy since the metropolitan area of New York produces about 8% of the nation's total economic output. While Hurricane Sandy laid bare the disaster risk faced by a world city like New York, it is worth noting that Sandy was little more than an average storm when measured in terms of wind force. Bearing in mind that New York is not among the cities most exposed to natural disasters, we are reminded of the fact that things could get a lot worse when the next major hurricane hits.

Cities are tightly woven into the global risk landscape because they are highly interconnected and integrated in a global, digitised economy. Perhaps more than anything, Sandy showed us how vulnerable our cities are, and how fast a breakdown of critical infrastructure can happen, particularly in areas with a high concentration of people and properties. This is why the need for disaster management is nowhere more urgent than in the world's sprawling urban centres.

While natural catastrophes caused average economic losses of USD 60–100 billion annually, a single large-scale disaster in the heart of a big metropolitan centre can surpass this figure significantly.[2] Recent events showed how real the risk is in some of the world's most populated regions. With an estimated USD 210 to 300 billion in total economic losses, the 2011 Tohoku earthquake along the northeastern seaboard of Japan was the costliest catastrophe ever. Flooding around Bangkok, Thailand, in the same year broke a new record for being the most expensive freshwater flood in history, causing USD 47 billion in economic losses.

Rapid growth that outpaces planning, flaws in zoning laws and construction failures can all exacerbate the risk of natural hazards to urban communities. When an event does occur in such circumstances, it drives up the costs for disaster recovery and increases the burden on public budgets. All of this combined raises the pressure on city authorities to provide services which not only make urban communities function more smoothly but also make them more resilient when a disaster strikes. Understanding the risks faced by cities is a necessary first step to better prepare them for future catastrophes.

1 Source: http://news.msn.com/us/new-york-new-jersey-put-dollar71b-price-tag-on-sandy

2 sigma No 2/2013: Natural catastrophes and man-made disasters in 2012

Risk analysis of 616 metropolitan areas

The world's big and sprawling cities are centres of economic activity and growth. But many of them are also highly exposed to natural hazards. As more people move to the cities and businesses invest in their local economy, more lives and assets concentrate in disaster-prone areas. By 2050, the number of people residing in cities will have reached 6.3 billion, according to the United Nations. Strengthening the resilience of these communities is therefore becoming a matter of urgency.

Cities are centres of economic activity and growth. As more people move to the cities and businesses invest locally, more lives and assets concentrate in disaster-prone areas.

To assess the risk exposure faced by urban populations around the world, we investigated the loss potential of 616 major metropolitan areas using Swiss Re's proprietary hazard data on five perils: earthquake, storm, storm surge, tsunami and river flood. We chose the largest urban agglomerations based on the most recent population data and identified city limits, including city outskirts and commuter towns, using satellite data. These 616 urban areas are home to about 1.7 billion people, roughly 25% of the world's total population, and cover USD 34 000 billion or about 50% of the global GDP.[3] Of these metropolitan regions 334 are located in Asia/Oceania, 90 in Europe, 83 in North America, 60 in Africa and 49 in South America.

Based on hazard data from Swiss Re's CatNet® we devised a risk scenario per peril for each metropolitan area. We focused on rare catastrophes: a hurricane with winds substantially stronger than Sandy or a tsunami similar to the one triggered by the Tohoku earthquake in Japan. Statistically, a city would be hit by such an event once every few hundred years or less. At this level of intensity, protection measures typically fail because the force of the disaster exceeds the impact anticipated by local building codes and protection measures.

The human and economic toll of an event like this can be enormous. To show the effects a natural disaster can have on a metropolitan area and the economy, we considered two indicators: the size of the urban population that could be hit by one or more natural perils (index of people potentially affected) and the impact this can have on the local and national economy (index of the value of working days lost).

3 United Nations Department of Economic and Social Affairs/Population Division, World Urbanization Prospects: The 2011 Revision

For the population index, we calculated the effects on city residents using detailed data on population distribution and hazard vulnerability estimates for all relevant perils. Our definition of "people potentially affected" comprises fatalities, injuries and evacuations. It also includes people whose homes were damaged and who were unable to access their workplace.

For the economic index, we assessed the costs of large natural catastrophes in terms of lost economic production or the value of working days lost. This estimate approximates the time during which affected residents would be unable to go to work in the event of a disaster and the costs resulting from lost output.[4] The definition does not include secondary effects, such as power outages or interruption of traffic lines. Our assessment of the Pearl River Delta in China provides a practical explanation of how we used this methodology (see pages 8–9).

A set of risk parameters guided our analysis: the geographic area affected by a storm, flood, earthquake or tsunami and the intensity used to assess the impact of each peril (table 1).

Table 1: Assumptions used to calculate exposed metropolitan area by city and peril

Scenario	Assumed affected area per city	Intensity parameter for impact assessment
Storm (Winter storm, tropical cyclone)	Full area	Peak gust wind speed
Storm surge	Reduced area (low lying coastal areas)	Coastal flood risk zones, in combination with simplified factors for bathymetry, coastal morphology, estuarine conditions, peak gust wind speed and angle of landfall
River flood	Reduced area	Variable intensity per flood risk zone
Earthquake	Full area	Peak ground acceleration and potential for seismic wave amplification
Tsunami	Reduced area (low lying coastal areas)	Coastal flood risk zones, in combination with simplified factors for bathymetry, coastal morphology, estuarine conditions and regional sea quake risk

4 Working days lost here reveal a fraction of the GDP/capita which is not being produced in the short term due to the event. We account for the economic importance of the metropolitan areas and build working assumptions based on various publicly available sources; country GDP-data is based on Oxford Economics. For areas without information on a respective city GDP/capita, we use multipliers on the country GDP/capita. These multipliers are tailored to the Word Bank country classifications.

The Pearl River Delta is a densely populated metropolitan area comprising Hong Kong and Guangzhou. Situated in one of the world's most disaster-prone regions, floods and typhoons put more people at risk than in any other metropolitan area in the world.

Our approach in focus: Example Pearl River Delta, China

The Pearl River Delta is a densely populated metropolitan area that is home to more than 42 million inhabitants. Covering a territory of some 20 600 square kilometres, it comprises the urban districts of Hong Kong, Shenzhen, Dongguan, Macau and Guangzhou. The region is one of China's main economic centres, with an estimated GDP of USD 690 billion. Its average GDP per capita is much higher than the national average.

Perils affecting Pearl River Delta
The maps on page 9 (fig. 1.1 to 1.4) show the metropolitan area of the Pearl River Delta, local population density and four perils: typhoon-related storm hazard, river and coastal flood zones, and earthquake intensity.

Population potentially affected
In a first step, we overlaid population data with our hazard and vulnerability information presented in CatNet® and identified the number of people at risk from each peril. We used the result to globally rank all 616 cities. Due to its high exposure and the great number of residents, the Pearl River Delta ranks number one among all metropolitan areas when looking at the absolute number of people potentially affected by storm, storm surge and river flood (see table 2). The area does not feature in the earthquake rankings because the earthquake risk is almost inexistent. Due to an active subduction zone along the Philippines trench several hundred kilometres away, there is some probability of a tsunami hitting the area, but it is relatively low. Since the area is very large, the picture changes when looking at the percentage of people potentially affected rather than absolute numbers.

Index of working days lost
In a second step, we calculated the potential economic value of working days lost – or the total GDP value for all days during which a certain percentage of the population cannot go to work. Again, we compared it to the other 615 metropolitan areas. In this respect, the Pearl River area is ranked highest for storm surge, third for wind behind Tokyo-Yokohama and Osaka-Kobe, and fifth for river flood after Tokyo-Yokohama, Nagoya, Osaka-Kobe and Paris. The value of working days lost could reach up to a low two-digit billion USD figure for a strong typhoon – and is therefore in the range of 1–2 percent of the region's annual GDP. Due to our general approach, however, we decided not to provide specific GDP values and instead developed a ranking of all 616 cities.

Table 2:
Results and global rankings for the Pearl River Delta with a population of approximately 42 million

Peril scenario	Population potentially affected in mn (absolute numbers)	Rank population potentially affected (absolute numbers)	Population potentially affected in % of metro area population	Rank value of working days lost (global index)
Storm	17.2	1	41	3
Storm surge	5.3	1	12	1
River flood	12.0	1	28	5
Earthquake	–	–	–	–
Tsunami	–	–	–	–

Pearl River Delta: population at risk from multiple perils

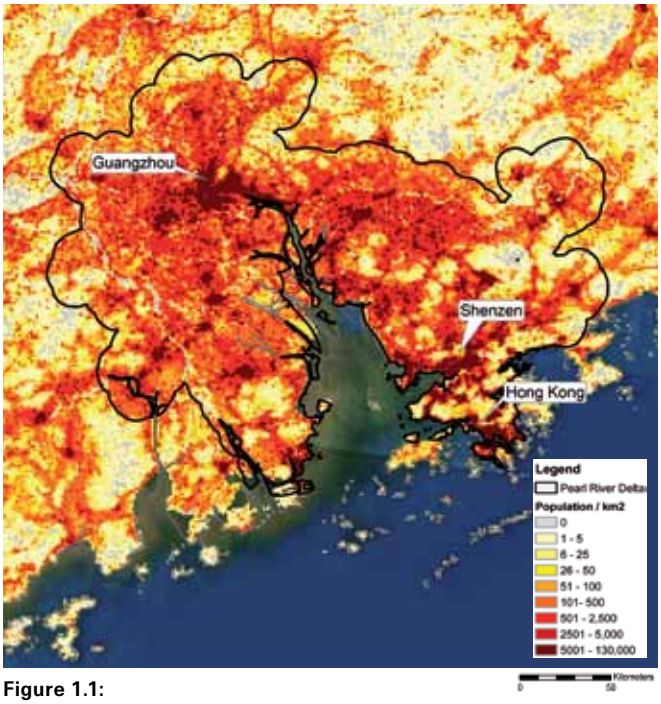

Figure 1.1:
Population density, Pearl River Delta, Asia
Source: Eastview LandScan2011™

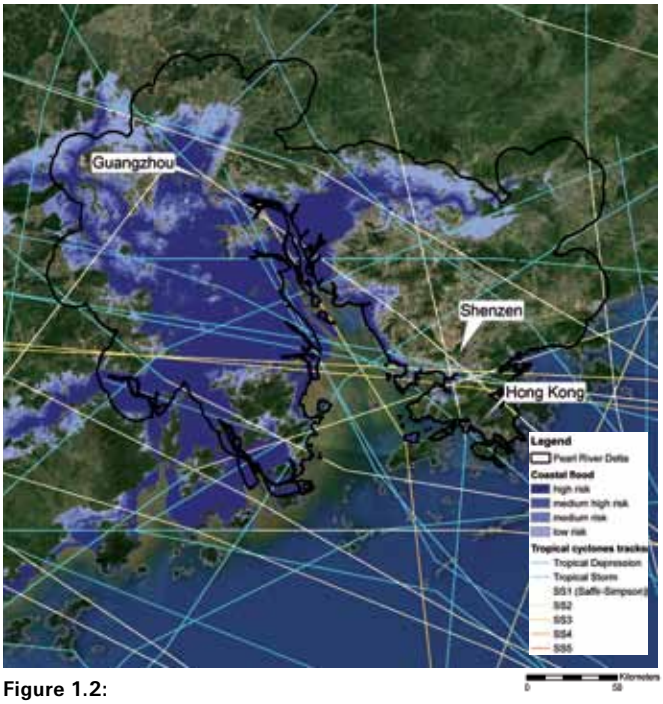

Figure 1.2:
Tropical cyclone tracks and coastal flood zones, Pearl River Delta, Asia
Source: Unisys/track set, Swiss Re

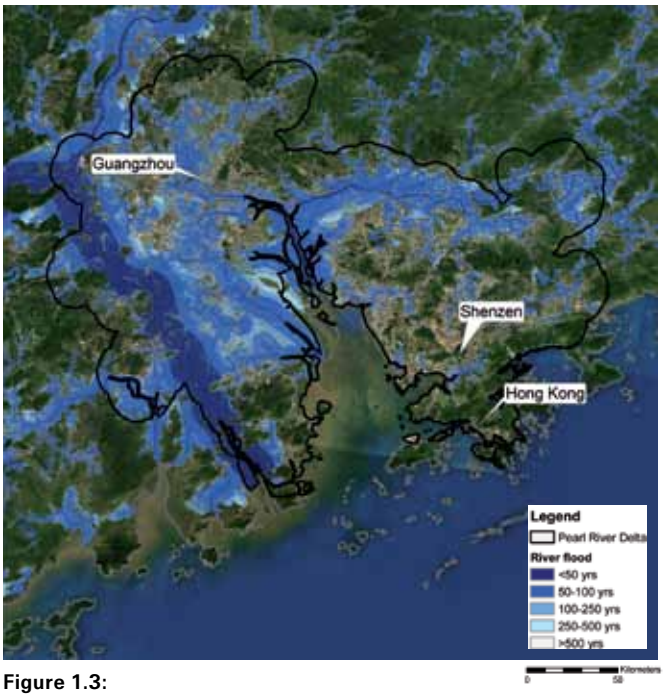

Figure 1.3:
River flood risk zones, Pearl River Delta, Asia
Source: Swiss Re Global Flood Zones™

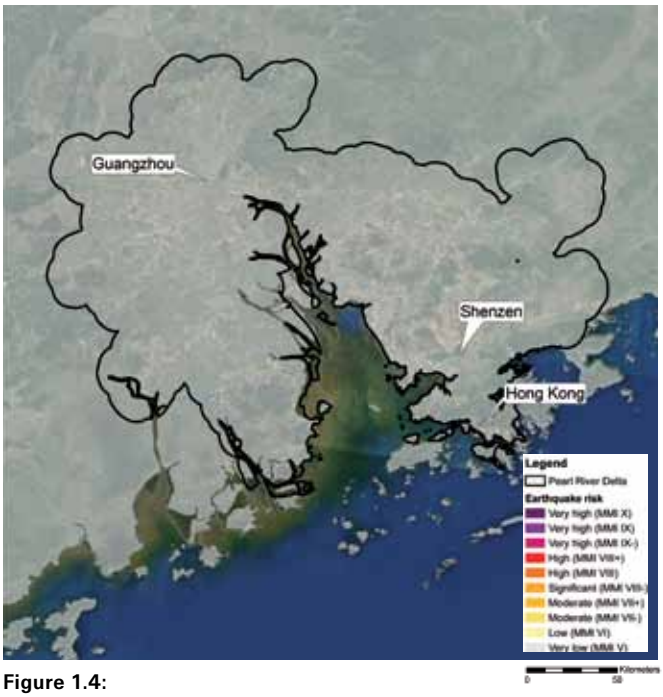

Figure 1.4:
Earthquake risk, Pearl River Area, Asia
Source: GSHAP

All figures based on:
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Roads in the North Bangkok Business District are submerged in floodwaters in November 2011 after heavy rainfall during the annual monsoon season. The Thailand flood of 2011 cost the insurance industry USD 15 billion, the largest insured fresh water flood loss ever.

Part II – Global findings

People potentially affected – a global ranking

Some of the world's fastest-growing metropolitan areas are situated along China's coastlines, such as the Pearl River Delta and Shanghai. Besides being exposed to frequent tropical cyclones and storm surges, many cities in the region are also located in zones of high seismic activity, including Tokyo, Taipei and Manila.

When looking at their exposure to natural disasters, most of the world's riskiest cities are therefore situated in East Asia, notably China, Taiwan, the Philippines and Japan. But there are different ways of looking at risk exposure. No doubt, human life comes first. In that respect, Tokyo-Yokohama, the Pearl River Delta and Osaka-Kobe are the riskiest metropolitan areas in the world (table 3).

Table 3:
Most people potentially affected, aggregated for all five perils (in million)

Tokyo-Yokohama (JPN)	57.1
Manila (PHL)	34.6
Pearl-River Delta (CHN)	34.5
Osaka-Kobe (JPN)	32.1
Jakarta (IND)	27.7
Nagoya (JPN)	22.9
Kolkata (IND)	17.9
Shanghai (CHN)	16.7
Los Angeles (USA)	16.4
Tehran (IRN)	15.6

Table 4:
Cumulative number of people potentially affected in all metropolitan areas – by peril

Peril	People potentially affected globally, in million
River flood	379
Earthquake	283
Wind storm	157
Storm surge	33
Tsunami	12

Like East Asia's sprawling conurbations, most other major cities developed along the sea and natural waterways such as lakes and rivers. So it is hardly surprising that flood risk threatens more people than any other natural catastrophe. Across the 616 metropolitan areas included in this study, river flooding poses a threat to over 379 million residents. That is more than the 283 million inhabitants potentially affected by earthquakes and the 157 million people at risk from strong winds.

In contrast, coastal storm surge potentially affects only about 33 million urban dwellers, and tsunamis pose a risk to just over 12 million people. This is because only about 220 million – or 13% – of the metropolitan areas' residents actually live in coastal plains. The maps on the following pages illustrate how different regions are potentially affected by each of these perils, with detailed results listed in the appendix.

The vast majority of cities are prone to river flooding

Situated on river flood plains or along river deltas, almost all large metropolitan areas are in danger of flooding to some degree. India and China, in particular, face a significant threat from river flooding. With 12 million residents potentially affected, the Pearl River Delta is the most flood-exposed urban area in the world. Shanghai (11.7 million) and Kolkata (10.5 million) follow in second and third place. We do not find a single European metropolitan area among the twenty most potentially affected urban populations. This, however, changes when looking at the economic loss potential from river flooding in the next chapter.

Earthquakes are prevalent in many locations

Most people potentially affected by earthquakes live along the so-called Ring of Fire, an area of high seismic and volcanic activity along the Pacific Ocean. Besides their proximity to the sea, many of these settlements sit in flat basins often characterised by soft soil conditions, which make shaking intensities even stronger. Earthquakes in these areas can also result in soil liquefaction, a phenomenon whereby the saturated soil substantially loses its strength and reacts like a liquid.

With close to 30 million people potentially affected, the metropolitan area of Tokyo-Yokohama in Japan is by far the most earthquake-exposed community in our rankings. Other populations threatened by earthquakes are Jakarta (17.7 million) and Manila (16.8 million), followed by Los Angeles (14.7 million) and Osaka-Kobe (14.6 million).

The danger faced by cities near the San Andreas Fault, such as San Francisco and Los Angeles, is widely known. But the tremendous loss potential in regions of Central Asia and along the Northern Anatolian fault in the Middle East is often overlooked and not immediately apparent. For example, the populations of the Iranian capital of Tehran (13.6 million) or Tashkent (2.9 million), the capital of Uzbekistan, are highly exposed to earthquake risk and feature prominently in our earthquake rankings. Unlike cities in New Zealand, metropolitan areas in Australia are relatively safe, as are cities in the eastern parts of South America and most regions of Africa.

Storms endanger mostly urban areas on the coast

The danger of wind storms is most acute in the metropolitan areas of eastern Asia. Tropical cyclones in this part of the world, also known as typhoons, are most active in the basin of the West Pacific. In addition, more people live in larger and more condensed metropolitan areas located along the coast than they do anywhere else in the world.

Eight out of the ten most heavily exposed urban communities are therefore all in East Asia, with the Pearl River Delta (17.2 million people potentially affected), Tokyo-Yokohama (14.1 million) and Manila (12.6 million) topping the rankings. The Indian cities of Mumbai (4.3 million) and Chennai (4.0 million) are ranked 8th and 9th. The highest non-Asian metropolitan area is London (2.2 million, winter storms) ranked 18th. Miami (1.4 million, tropical cyclons) is ranked 23rd.

In contrast to winter storms, tropical cyclones lose their destruction potential relatively quickly once they make landfall, and their geographic expanse is limited. In western and central Europe, metropolitan areas are threatened by winter storms which maintain their strength even when they move far inland. However, their wind speeds are lower than those of tropical cyclones. When looking at winter storms in Europe, London (2.2 million), Paris (1.1 million), the Rhine-Ruhr area in Germany (1.0 million) and Amsterdam-Rotterdam (0.9 million) assume the top four spots.

Since most major cities developed along the sea or waterways, flood risk threatens more people than any other natural catastrophe. Across the 616 cities assessed, river flooding poses a threat to over 379 million residents. Over 283 million inhabitants could potentially be affected by earthquakes, and 157 million people are at risk from strong winds. In many cases, urban populations must be prepared to cope with more than one hazard.

CatNet®

Most results of this study, including hazard data used, are available in CatNet®, Swiss Re's online natural hazard information and mapping system. This tool allows you to zoom in on individual regions and produce tailor-made maps like the ones below. Users can import their own coordinates and information into the tool to generate customised data sets.

CatNet® is free of charge to Swiss Re clients and is available on request to third parties.

For further information or to register:
www.swissre.com/catnet
or contact our CatNet office at
CatNet@swissre.com

Figure 2.1: CatNet® map showing the number of people potentially affected by river floods in blue and storm surges in light blue.

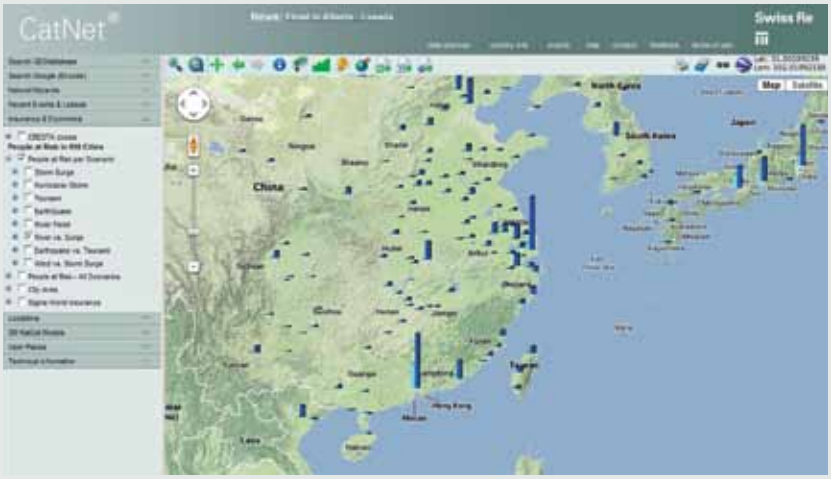
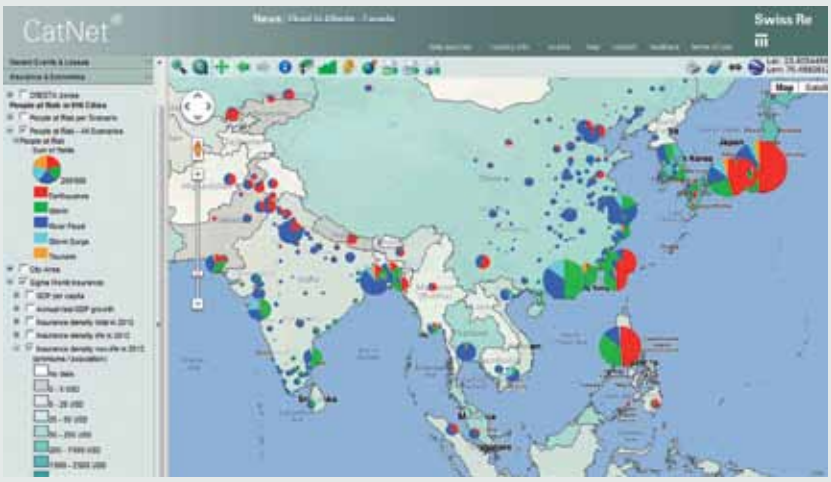
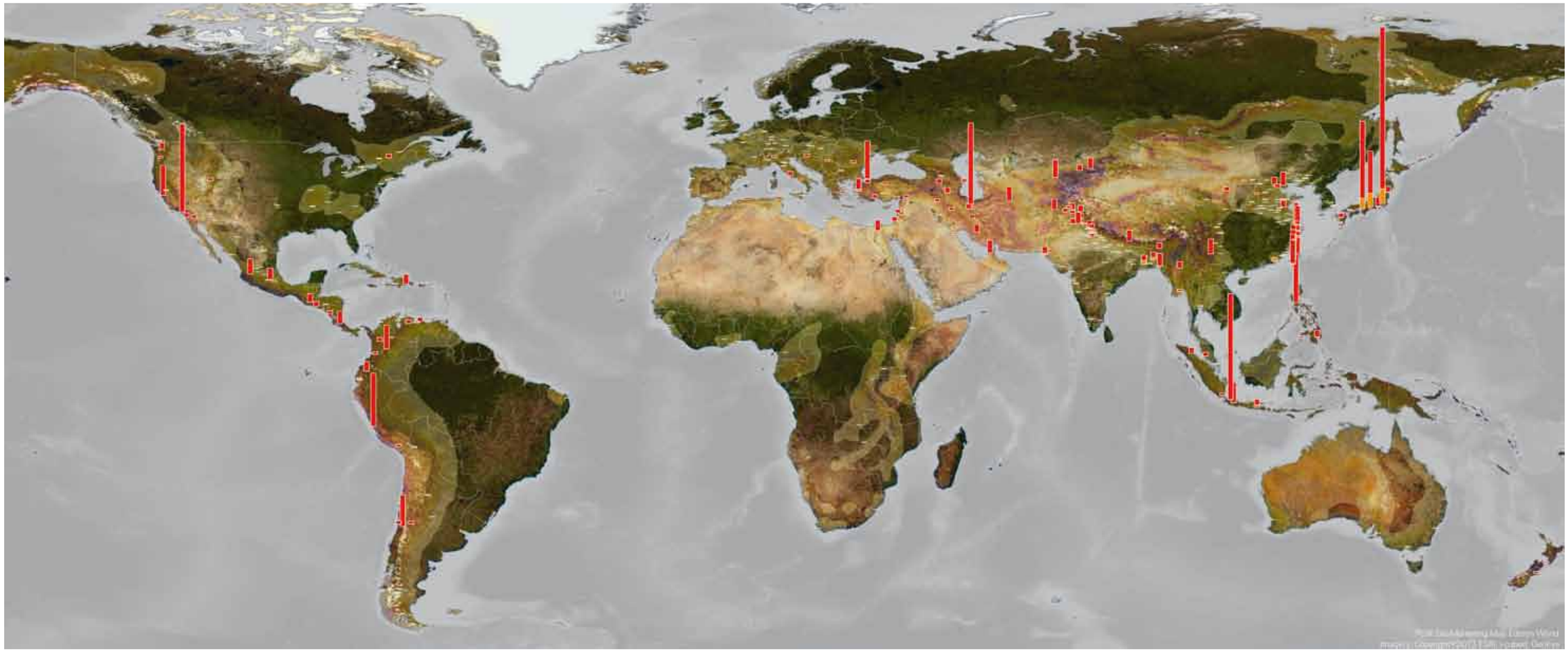


Figure 2.2: CatNet® map showing the aggregated number of people potentially affected and the share per peril. The bubbles are exemplarily displayed on top of SIGMA world insurance information for the density of non-life premiums.



People potentially affected by earthquakes and tsunamis



People at risk per metropolitan area and peril scenario

Earthquakes:
10 million people potentially affected

Tsunamis:
2.5 million people potentially affected

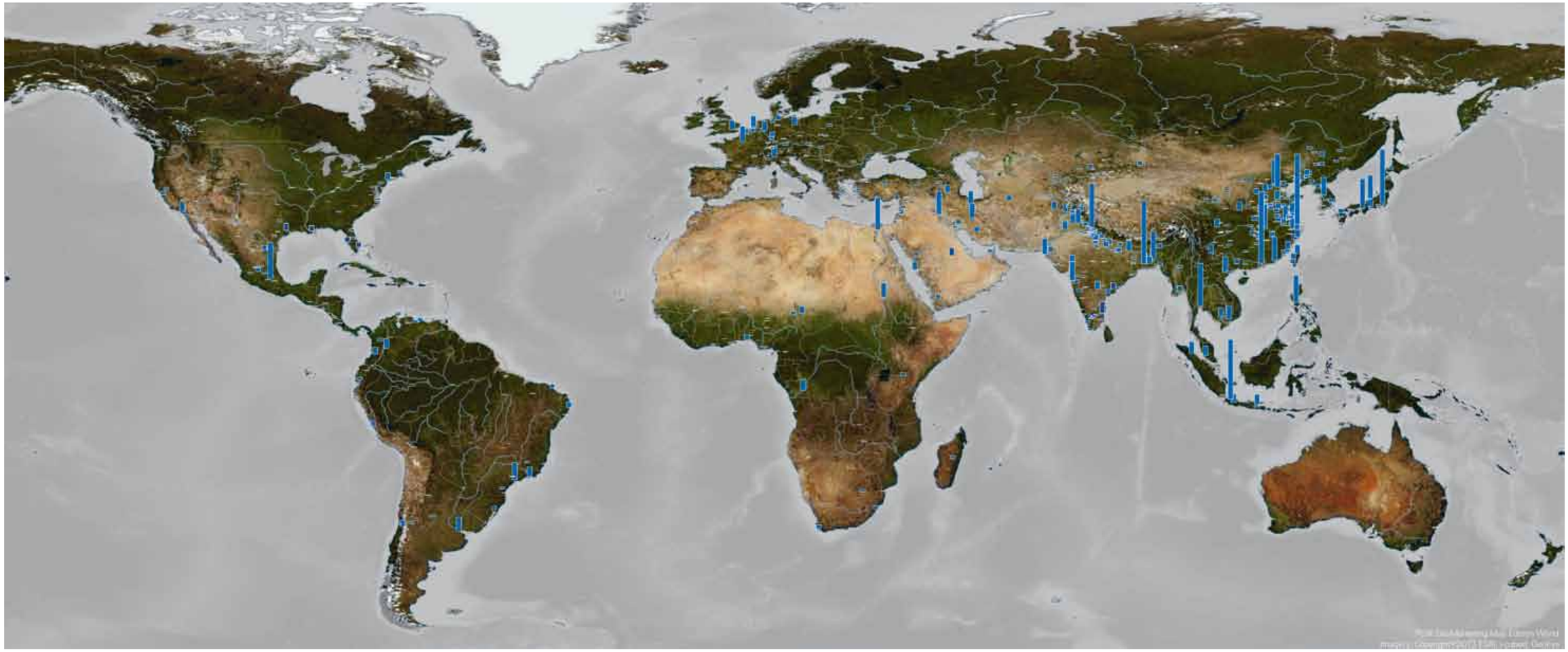
Modified Mercalli Intensity corresponds to return period of 475 years

- Very high (MMI X)
- Very high (MMI IX)
- Very high (MMI IX-)
- High (MMI VIII+)
- High (MMI VIII)
- Significant (MMI VIII-)
- Moderate (MMI VII+)
- Moderate (MMI VII-)
- Low (MMI VI)
- Very low (MMI V)

Source: GSHAP, www.swissre.com/catnet

Most urban populations potentially affected by earthquakes live along the Ring of Fire, an area of high seismic activity in the Pacific Ocean. While the danger faced by American and Japanese cities is well known, the loss potential from earthquakes in Central Asia and the Northern Anatolian Fault in the Middle East is significant and often overlooked.

People potentially affected by river floods



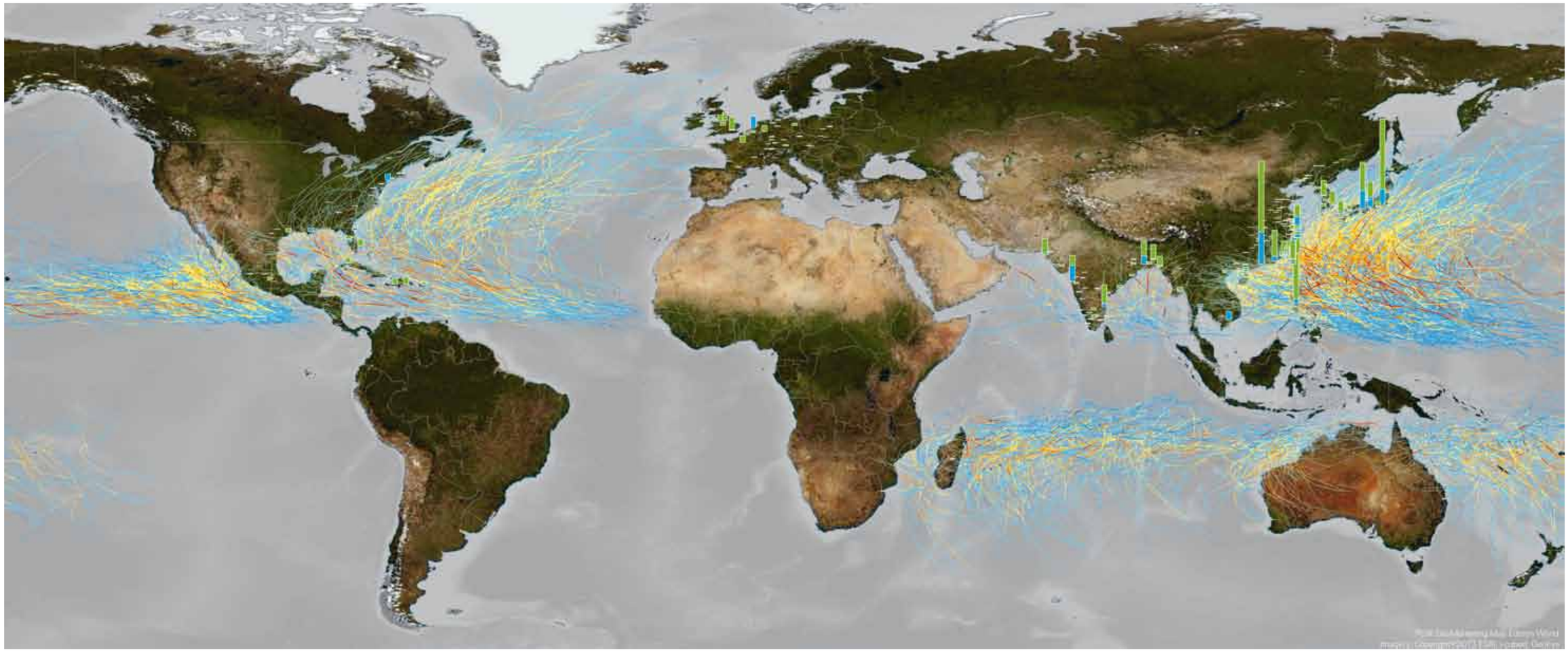
People at risk per metropolitan area and peril scenario

River floods:
10 million people potentially affected

Most of the world's major cities developed along the sea and natural waterways such as lakes and rivers. Many are situated on river flood plains or near river deltas. Almost all large metropolitan areas are therefore exposed to some risk of flooding. The threat from river flooding is particularly high for cities in India and China.

Source: www.swissre.com/catnet

People potentially affected by storms and storm surges



People at risk per metropolitan area and peril scenario

Storms:
10 million people potentially affected

Storm surges:
2.5 million people potentially affected

Tropical cyclone tracks (1970–2011)

- Tropical Depression
- Tropical Storm
- SS1 (Saffir-Simpson)
- SS2
- SS3
- SS4
- SS5

The danger posed by storms is most acute in eastern Asia. Tropical cyclones in this region, known as typhoons, are most active in the basin of the West Pacific. In Europe, cities are threatened by winter storms. While they have lower wind speeds than tropical cyclones, winter storms can keep their force even when far inland.

Source: http://weather.unisys.com/hurricane and data processing by Swiss Re, www.swissre.com/catnet

Storm surge risk is linked to heavy winds
People living in coastal areas exposed to heavy winds are also endangered by storm surge. Eastern Asia is most at risk because typhoons, which have the highest wind speeds, regularly hit the region. Pearl River Delta (some 5.3 million people), Osaka-Kobe (3.0 million people) and Mumbai (2.6 million people) are ranked highest for storm surge risk, since these metropolitan areas developed on large coastal plains.

Natural catastrophes not only endanger human lives, but they can also significantly disrupt the local economy of a city and, in some cases, the economy of an entire country.

The Amsterdam-Rotterdam conurbation in the Netherlands is entirely located within a zone of highest risk and holds a top spot in the storm surge rankings, with 1.8 million people potentially affected. Most sections of these cities are even situated below sea level. However, it is important to point out that these areas are protected extremely well by massive storm surge defences, so the chance of catastrophic damage is substantially lower than in other lesser protected areas. New York City is the most exposed urban area in the United States, with more than 1 million people directly at risk from storm surge. Following Hurricane Sandy, city authorities are taking measures to strengthen local defences.

Tsunami risk dominates in the Pacific
The cities most exposed to tsunami risk are in Japan, since they are located along the active faults of the Western Pacific. Tokyo-Yokohama and Nagoya, each with around 2.4 million people who are potentially affected, top our tsunami rankings. Osaka-Kobe (1.8 million), Shantou (0.7 million) and Kolkata (0.6 million) complete the list of the five most tsunami-exposed metropolitan areas.

Subduction zones, whereby oceanic plates dive underneath the continental crust, are expected to create much larger tsunamis than so-called strike-slip faults such as the San Andreas Fault. For this reason, the Californian coastline is only classified as a medium risk zone. A tsunami can, however, travel over very large distances and affect coastal areas far away from the triggering seaquake. Metropolitan areas within the medium and low risk zones can therefore also experience devastating tsunamis.

Working days lost – a global ranking

Natural catastrophes do not only affect people. They can also significantly disrupt the economy of an affected metropolitan area and, in some cases, the economy of an entire country. We estimated the economic effects of earthquakes, storms and floods using average assumptions of working days lost for each hazard and developed an index for cross-city comparisons.[5]

We can look at the results from a global and a local perspective. In our global rankings, standardised absolute values of working days lost apply. By this measure, the metropolitan areas of high-income countries top the list. This is because absolute losses are generally higher in places like Tokyo-Yokohama or Los Angeles than in Jakarta or Istanbul, even though similar numbers of people are potentially affected by a natural disaster.

However, when we take a local view and put the productivity losses of a city in relation to the GDP of an entire country, the picture changes. In this case, a smaller country with only one or a handful of urban centres can end up in the first ranks because these cities play an essential role to their home country's national economy. Examples include the Latin American capitals of San Jose, Costa Rica and Lima, Peru. These local rankings give an indication of how a disaster can impact the resilience of a whole nation.

5 In our rankings, an index value of "1" denotes the city with the highest potential impact from one particular peril. To index the impact of all five perils combined (earthquake, wind speed, river flood, storm surge and tsunami), the individual peril indices are added up.

How to read the charts
Each chart shows the economic impact ranking (working days lost) for each city from both a global and a national perspective, along with the size of the urban population potentially affected by one or more perils. The sketch below illustrates the four values presented in each chart (figure 3):

1) The size of each bubble represents the number of inhabitants living in a given metropolitan area.
2) The coloured wedge in the pie chart is the share of inhabitants potentially affected by a given peril.
3) The x-axis marks the value of working days lost per city using a logarithmic scale (global index).
4) The y-axis marks the value of working days lost per city in relation to the country's national economy using a logarithmic scale (global index, relative to the national economy of home country).

As the four quadrants illustrate, we can draw different conclusions from the position of each city on the chart. Since we cannot fit all 616 cities in one chart we have limited the choice to the top ten ranks using a logarithmic scale. They combine the top 10 ranks for the analyses 'people potentially affected,' 'global index of working days lost', 'global index of working days lost relative to the national economy'.

For illustrative purposes, figure 4 shows the distribution of cities on a linear scale for earthquake risk. It highlights the wide divergences in numerical values between cities, such as the gap between the first and second ranks.

Figure 3:
Visualisation of global rankings. Cities in the upper right-hand corner of each chart face the highest potential impact in absolute terms and in relation to their country's national economy.

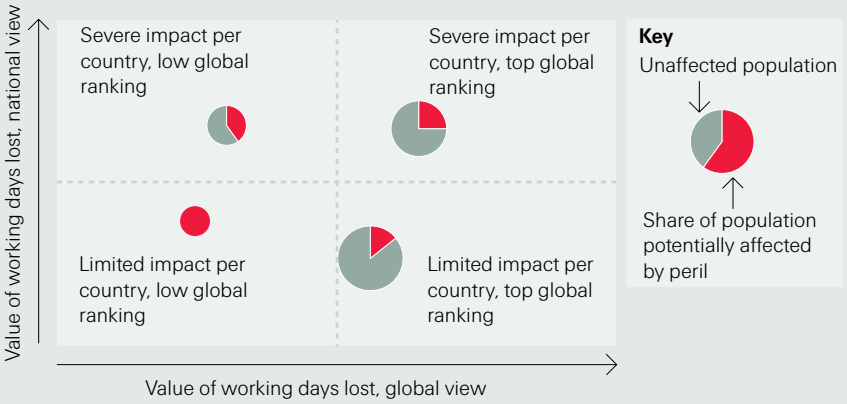
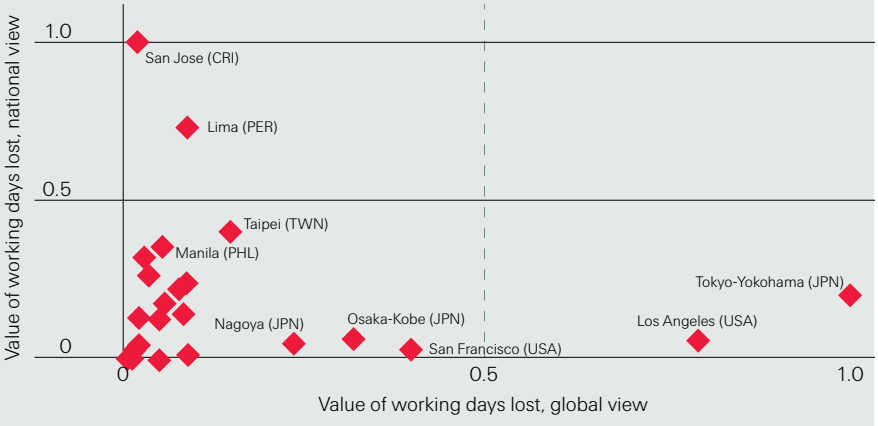


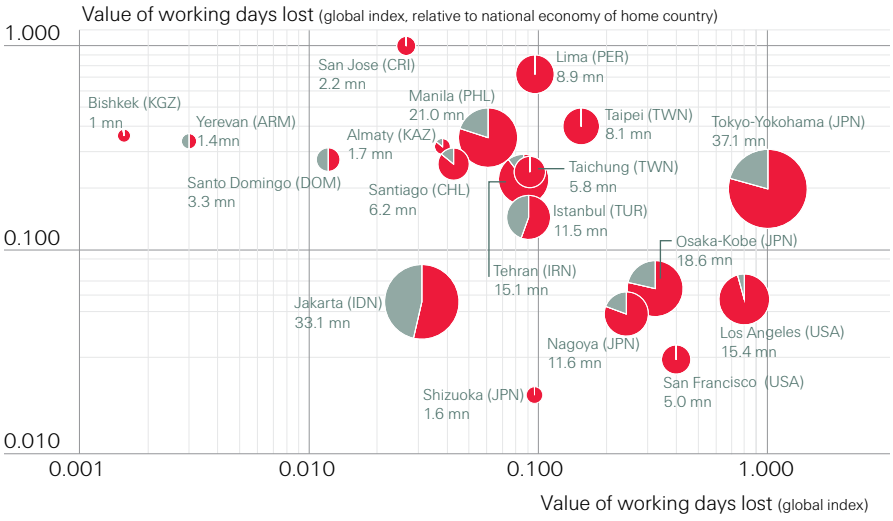
Figure 4:
Illustrative chart using a linear scale for earthquake risk instead of a logarithmic scale (see figure 7 for comparison). This shows the actual distribution of cities and the unequal gaps in risk exposure between them.



Earthquakes

A major earthquake can affect almost all residents of a city. Given countries' different levels of economic development, the absolute impact on production can be magnitudes higher in developed countries than in emerging markets. The Tokyo-Yokohama region has 37 million inhabitants, of which 80% or 29 million could be potentially affected by a very large earthquake. Of all 616 metropolitan areas studied, it has the highest value of working days lost and so carries an index value of 1 on the x-axis (figure 5).

Figure 5: Metropolitan areas at risk from earthquakes



Japan, however, has several other urban centres which sustain the country's economy. By contrast, an earthquake of a similar magnitude would have a much more severe impact on the national economy of a country like Costa Rica. Some 2.2 million inhabitants live in the capital of San Jose, which makes up a high proportion of the country's total population. Almost all of them are exposed to significant earthquake risk. San Jose is the economic hub of Costa Rica. The potential costs of an earthquake makes San Jose the city with the highest potential fallout for a country's national economy, indicated by an index value of 1 on the y-axis.

We can draw some interesting conclusions from this. Smaller urban areas are more broadly affected than larger areas (eg Lima ranks higher than Jakarta). But a high number of people potentially affected does not automatically mean a high global rank when measured in terms of production lost (eg Jakarta is 25 times less affected than Los Angeles). Less obvious perhaps is that although Los Angeles and San Francisco are widely considered at high risk of earthquakes, they are from a national perspective lower ranked than cities like Manila or Lima. Finally, the difference in production losses can be huge. For example, the national impact of an earthquake in Yerevan (Armenia) and Tokyo-Yokohama is similar, but the absolute impact in Tokyo is more than 300 times higher.

Figure 6: Metropolitan areas at risk from river flooding

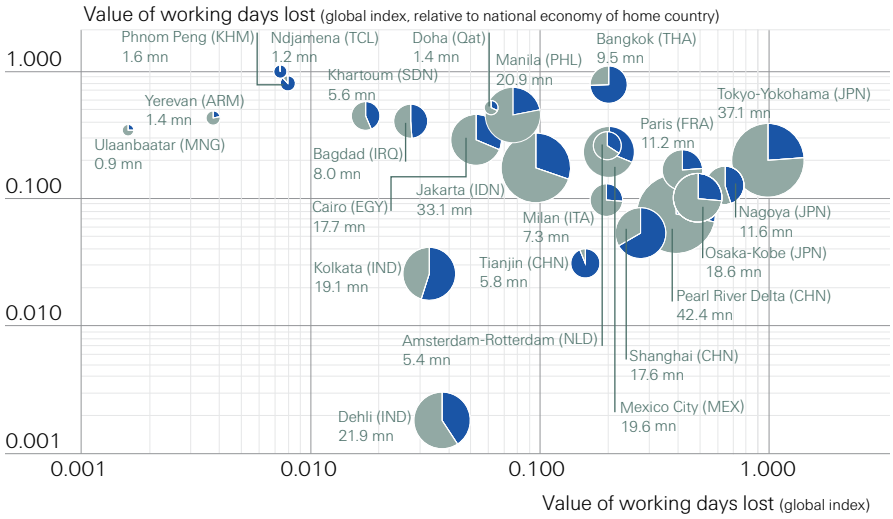
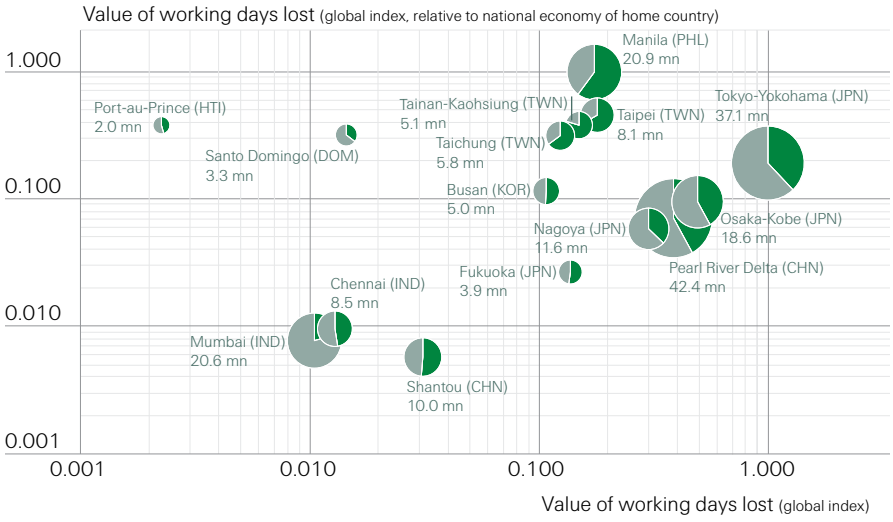


Figure 7: Metropolitan areas at risk from storms



River floods

The flood rankings of metropolitan areas in figure 6 show a somewhat different picture compared to earthquakes. Metropolitan centres with more than 50% of the population potentially affected are exceptions and are mainly located in eastern China. Yet, a number of cities appear in the rankings which are not known to be particularly exposed to flooding, such as Mexico City, Baghdad, Paris or Doha.

The analysis shows that Bangkok is highly exposed to river flooding with potentially massive impacts to the national economy. This was tragically confirmed by the 2011 Chao Phraya River flood, the largest insured fresh water flood event ever recorded. The total loss amounted to around 10% of national GDP, which highlights the critical importance of flood protection measures for the Thai government.

Storms

Fewer metropolitan areas are exposed to heavy damage from storms than by earthquakes or floods. The cities potentially most affected by high wind speeds are located along the coastlines of Asia, such as Tokyo-Yokohama, Manila, Taipei and the Pearl River Delta.

As Figure 7 shows, only three of the most exposed metropolitan areas are outside Asia: Havana (Cuba), Port-au-Prince (Haiti) and Santo Domingo (Dominican Republic). All three Caribbean cities play an essential role in the functioning of their small island economies. Perhaps surprisingly, big US cities known to be exposed to storm and hurricane risk – such as Miami or New York – do not feature in the world top 10 for this peril, ranking 23rd and 45th respectively.

Multiple perils – a global ranking

Many of the world's metropolitan areas are threatened by more than just one natural peril, and some even face the risk of being hit by several perils at once. The 2011 Tohoku earthquake, for example, triggered a massive tsunami wave which led to extensive flooding across the north-eastern seaboard of Japan. Flooding was also brought on by Hurricane Sandy in 2012 and submerged vast parts of New York City while wind damage was minor in this case.

Natural perils have different physical characteristics and probabilities. For example, the chance of a major earthquake and a typhoon happening at the same time is extremely low. Nevertheless, to create a globally consistent risk index it makes sense to look at the aggregated risk that all the perils pose to an urban community. To do so, we added up the results for all five perils for each city. Accordingly, the index value of working days lost can add up to a maximum of 5.

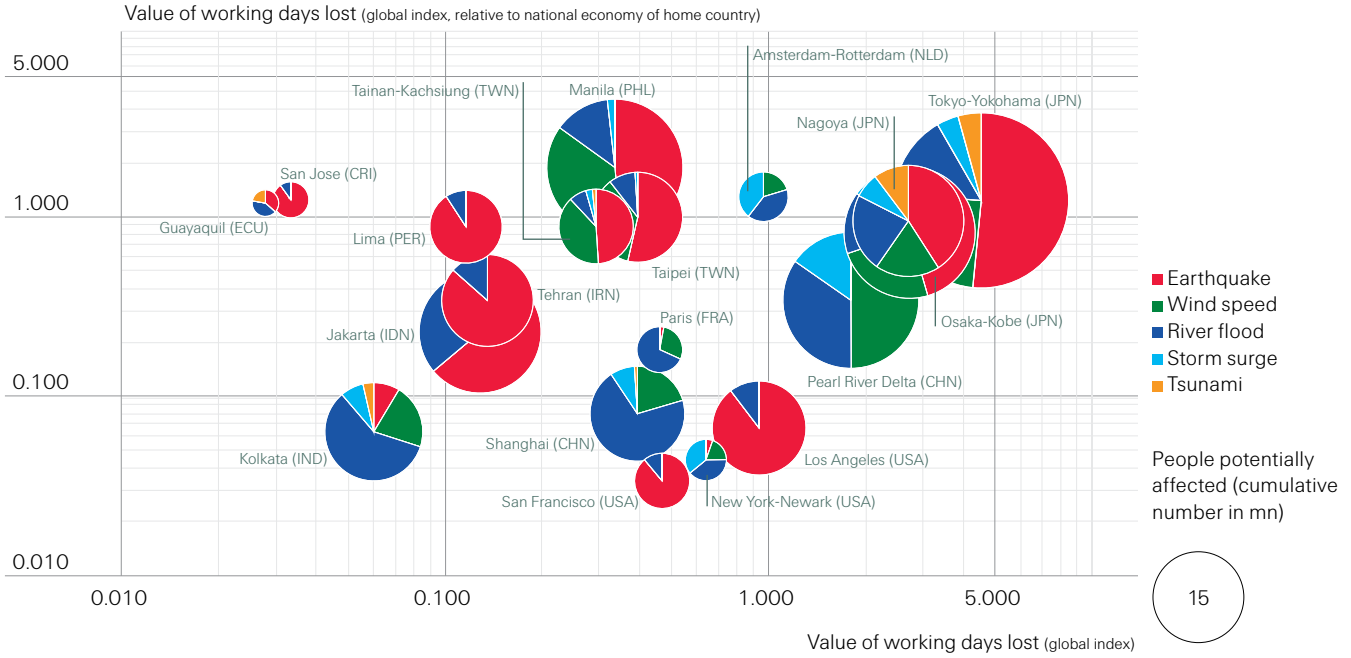
Urban residents who are threatened by multiple perils are more likely to be hit by a natural catastrophe in their lifetime than those confronted with only one peril. In our statistics, these residents are counted more than once. The aggregate number of people potentially affected by multiple perils can therefore exceed the actual size of a city's population. The more it does, the more probable it is that local residents will at some point have to cope with a natural disaster.

Table 5 shows aggregated rankings for all five perils. They list the absolute number of people potentially affected; the value of working days lost in relation to the local and national economy. In smaller, densely populated metropolitan areas, earthquakes and storms could affect virtually the entire population. Although more common than any other natural disaster, river floods typically only affect a limited part of a metropolitan area. Storm surges and tsunamis only affect people living near the coast.

Table 5: Top ten city rankings by analysis for all aggregated perils

Metro area	Ranking: people potentially affected (aggregate for all 5 perils)	Metro area	Ranking: value of working days lost (global index, aggregated for all 5 perils)	Metro area	Ranking: value of working days lost relative to national economy (global index, aggregated for all 5 perils)
Tokyo-Yokohama (JPN)	57.1 mn	Tokyo-Yokohama (JPN)	4.50	Manila (PHL)	1.95
Manila (PHL)	34.6 mn	Osaka-Kobe (JPN)	2.71	Amsterdam-Rotterdam (NLD)	1.31
Pearl River Delta (CHN)	34.5 mn	Nagoya (JPN)	2.69	Tokyo-Yokohama (JPN)	1.29
Osaka-Kobe (JPN)	32.1 mn	Pearl River Delta (CHN)	1.78	San Jose (CRI)	1.26
Jakarta (IND)	27.7 mn	Amsterdam-Rotterdam (NLD)	0.96	Guayaquil (ECU)	1.20
Nagoya (JPN)	22.9 mn	Los Angeles (USA)	0.93	Taipei (TWN)	1.02
Kolkata (IND)	17.9 mn	New York-Newark (USA)	0.62	Ndjamena (TCL)	1.00
Shanghai (CHN)	16.7 mn	San Francisco (USA)	0.47	Nagoya (JPN)	0.97
Los Angeles (USA)	16.4 mn	Paris (FRA)	0.46	Tainan-Kaohsiung (TWN)	0.90
Tehran (IRN)	15.6 mn	Taipei (TWN)	0.39	Lima (PER)	0.90

Figure 8: Impact of all perils by metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis). Residents are counted multiple times when affected by more than one peril because each peril is accounted for individually.



With some exceptions, the world's riskiest metropolitan areas are located in Asia, especially in China, Taiwan, the Philippines and Japan. Hosting several million people in densely populated conurbations, Asia's cities are likely to be the hardest hit by natural catastrophes, both in terms of absolute numbers of potentially affected people and economic impact.

Figure 8 shows an overview of the most exposed cities worldwide. Because earthquakes can affect the majority of the population, their share dominates the pie chart in seismically active or exposed regions. In locations with a multi-hazard risk, the probability of an event increases substantially. Tokyo-Yokohama, Osaka-Kobe and Nagoya in Japan as well as the Pearl River Delta in China, Taichung, Taipei and Tainan-Kaohsiung in Taiwan and Manila in the Philippines face a high likelihood of being impacted by different perils. This amplifies the threat to their inhabitants and economies.

When considering the relative importance of a metropolitan area to the national economy of a country, other cities move up the rankings: Amsterdam-Rotterdam (Netherlands), San Jose (Costa Rica), Lima (Peru) and Guayaquil (Ecuador).

The following chapter presents the global results by continent. We chose to only display the top ten per continent. Locations shown in this chapter reappear along with cities not represented in the global rankings.

Two men stand among the debris from the March 2011 earthquake and tsunami in the Japanese city of Kesennuma. The magnitude 9.0 quake off the coast of Japan is considered the costliest natural disaster in history, causing an estimated USD 235 billion in total losses.

Part III – Regional findings

Asia and Oceania

Figure 9: Impact of all perils by metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis).

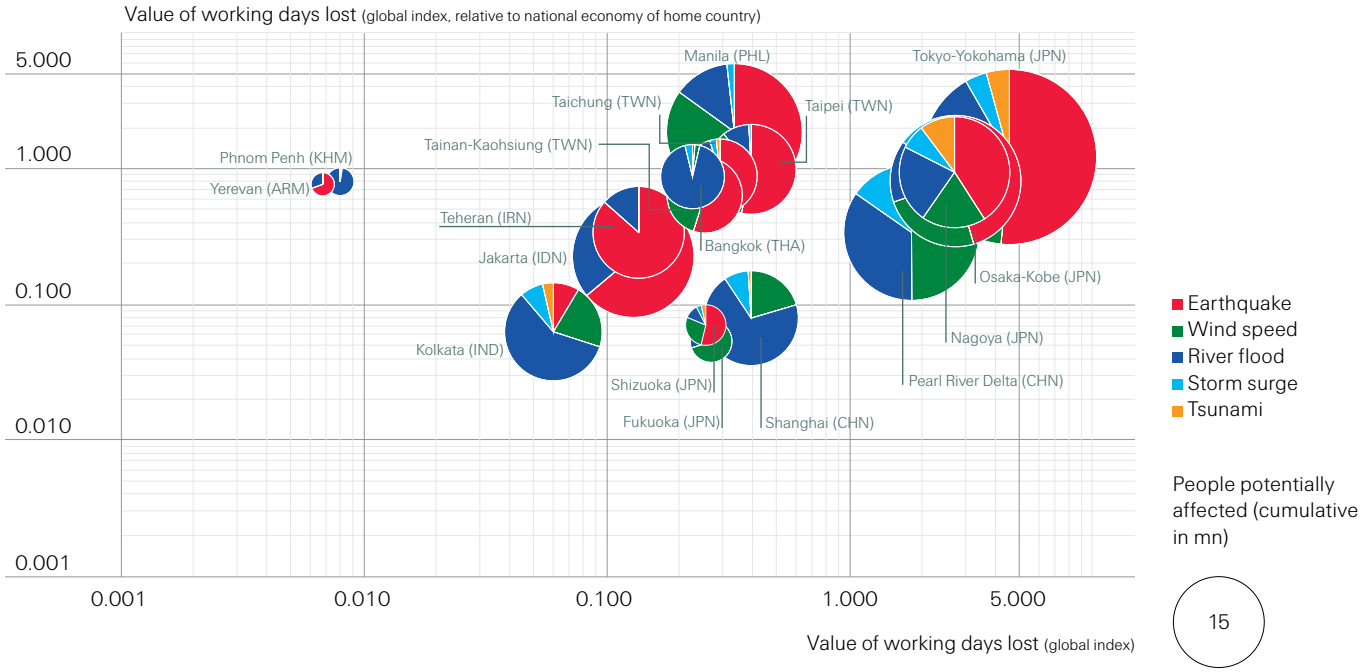


Table 6: Asia and Oceania at a glance

Metropolitan areas analysed	334
– total population	989.0 mn
– total combined GDP	USD 12.6 trn
Most people endangered by single scenario	29.4 mn earthquake Tokyo-Yokohama, 17.7 mn earthquake Jakarta, 17.2 mn wind Pearl River Delta
Top 3 all perils: people potentially affected	Tokyo-Yokohama, Manila, Pearl River Delta
Top 3 all perils: absolute value of working days lost (global index)	Tokyo-Yokohama (4.50), Osaka-Kobe (2.71), Nagoya (2.69)
Top 3 all perils: relative value of working days lost (global index relative to national economy)	Manila (1.95), Tokyo-Yokohama (1.29), Taipei (1.02)

Asia and Oceania host many large, economically vibrant metropolitan areas. Compared to all other continents, cities in Asia and Oceania stand out as being most exposed to natural disasters. Many of them also appear in the top 10 global rankings. In general, Asia's metropolitan areas are threatened by the widest mix of all perils with many of them endangered by all five perils included in this study. The risks of earthquakes, typhoons and river flooding dominate in the northern hemisphere. This is illustrated in the charts by the large bubble sizes and the clusters in the upper right-hand corner as well as the colour scheme.

Australia and New Zealand are also exposed to natural catastrophes, but they have smaller cities and therefore do not feature in the top ten riskiest cities.

Other countries may play a lesser role in the world economy, but their economies depend heavily on a handful of cities that function as centres of economic production. Here we find metropolitan areas such as Bishkek (Kyrgyzstan), Almaty (Kazakhstan) or Yerevan (Armenia), where a larger earthquake or river flood could be disastrous for the entire country's economic production.

North and Central America

Figure 10: Impact from all perils per metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis).

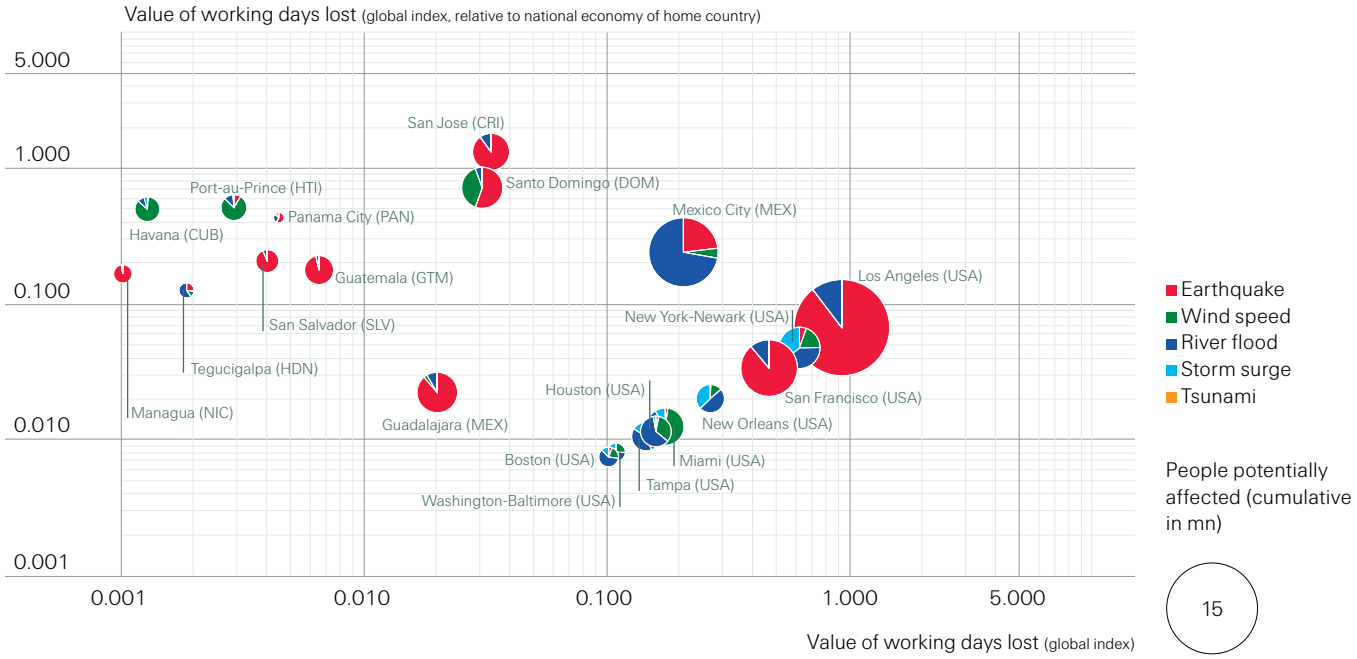


Table 7: North and Central America at a glance

Metropolitan areas analysed	83
– total population	222.7 mn
– total combined GDP	USD 10.5 trn
Most people endangered by single scenario	14.7 mn earthquake Los Angeles, 6.1 mn river flood Mexico City, 5.0 mn earthquake San Franciso
Top 3 all perils: people potentially affected	Los Angeles, Mexico City, San Franciso
Top 3 all perils: absolute value of working days lost (global index)	Los Angeles (0.93), New York-Newark (0.62), San Francisco (0.47)
Top 3 all perils: relative value of working days lost (global index)	San Jose (1.26), Santo Domingo (0.69), Port-au-Prince (0.49)

North and Central America comprise a region threatened by earthquakes along the Pacific coast as well as by hurricanes and storm surges from the Atlantic. River flooding can happen practically anywhere. A key difference between North and Central America, however, is in their distribution of economic production sites.

While the economies of the smaller countries of Central America are highly dependent on just a few metropolitan areas, the US, Canada and Mexico have more urban centres. The difference in economic geography is reflected on the chart by the fact that North America's cities are located in the lower right-hand corner while Central American cities are found in the upper left-hand corner.

From the perspective of the national economy, the Central American capitals of San Jose (Costa Rica) and Santo Domingo (Dominican Republic) rank highest. A catastrophe in either of these two locations would heavily affect the entire country. The deadly earthquake that ravaged Haiti in January 2010 is remembered as one of the worst disasters to hit the impoverished island nation. But it is worth noting that Santo Domingo has an even higher earthquake risk than Port-au-Prince (Haiti).

In contrast to Central America, metropolitan areas of the United States are numerous and highly developed. They are ranked higher in terms of the absolute value of working days lost when compared to all other cities in the world.

Europe

Figure 11: Impact from all perils per metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis).

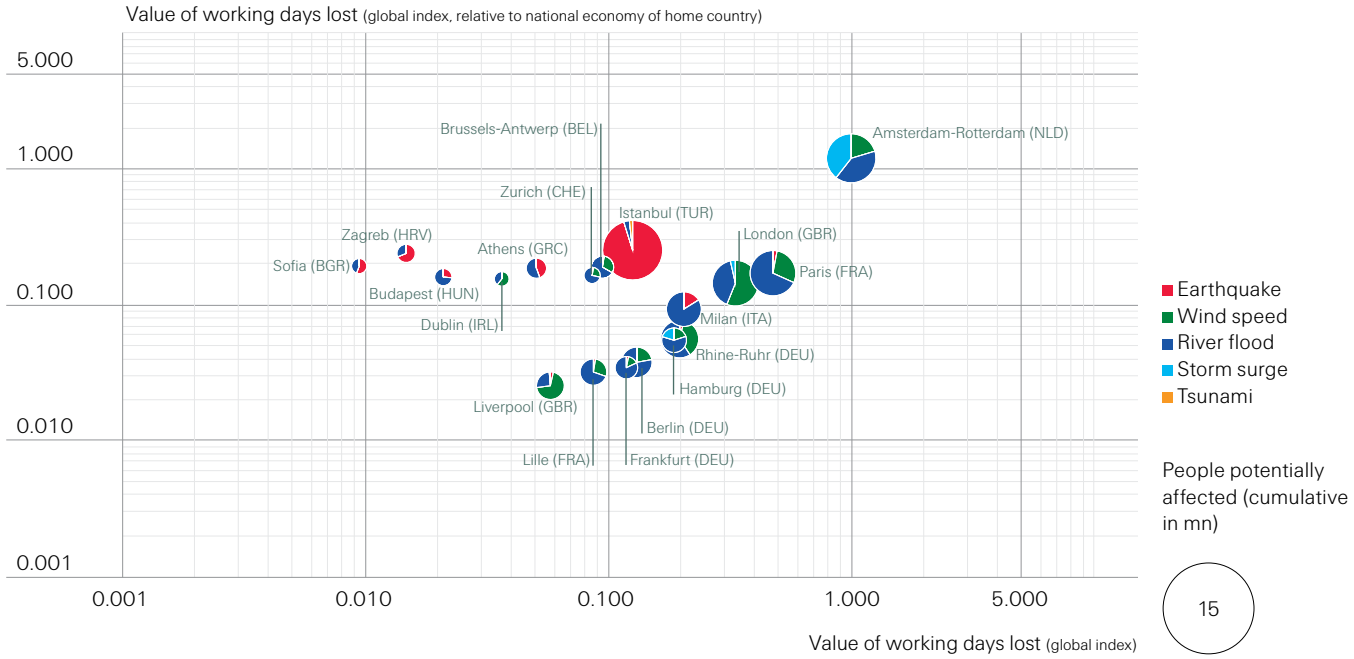


Table 8: Europe at a glance

Metropolitan areas	91 (incl. Istanbul)
– total population	206.4 mn
– total combined GDP	USD 8.2 trn
Most people endangered by single scenario	6.4 mn earthquake Istanbul, 2.7 mn river flood Paris, 2.2 mn winter storm London
Top 3 all perils: people potentially affected	Istanbul, Amsterdam-Rotterdam, London
Top 3 all perils: absolute value of working days lost (global index)	Amsterdam-Rotterdam (0.96), Paris (0.46), London (0.32)
Top 3 all perils: relative value of working days lost (global index)	Amsterdam-Rotterdam (1.31), Istanbul (0.27), Zagreb (0.26)

The vulnerability of Europe's cities to natural disasters varies from region to region. Countries in eastern and southern Europe face risks from earthquakes. Wind becomes more important as a natural peril when moving towards central Europe, while the hazard from river flooding is present almost everywhere. Metropolitan areas of central Europe are not widely spread on the chart. However, although many eastern European metropolitan areas still have a GDP per capita below the European average, they can be even more important for their country's national economy.

One likely scenario could be a strong winter storm in the North Sea that pushes a storm surge towards Amsterdam-Rotterdam and causes wind storm damage at the same time. While flood protection measures are generally well developed in Europe, most defences are designed to protect against local river floods expected once every 50 to 100 years. As a result, only large flood events should trigger major damage, at least if the dams do not fail at lower water levels.

A major winter storm, which has the largest expanse of all perils covered in this study, or a flood can affect several cities heavily. This is particularly true in Europe where cities are located closer together than elsewhere. This has to be taken into account when Europe is compared to other regions. Istanbul, a huge urban sprawl highly endangered by earthquakes, is also covered in the regional overview of Asia, but does not feature in the top 10.

South America

Figure 12: Impact from all perils per metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis).

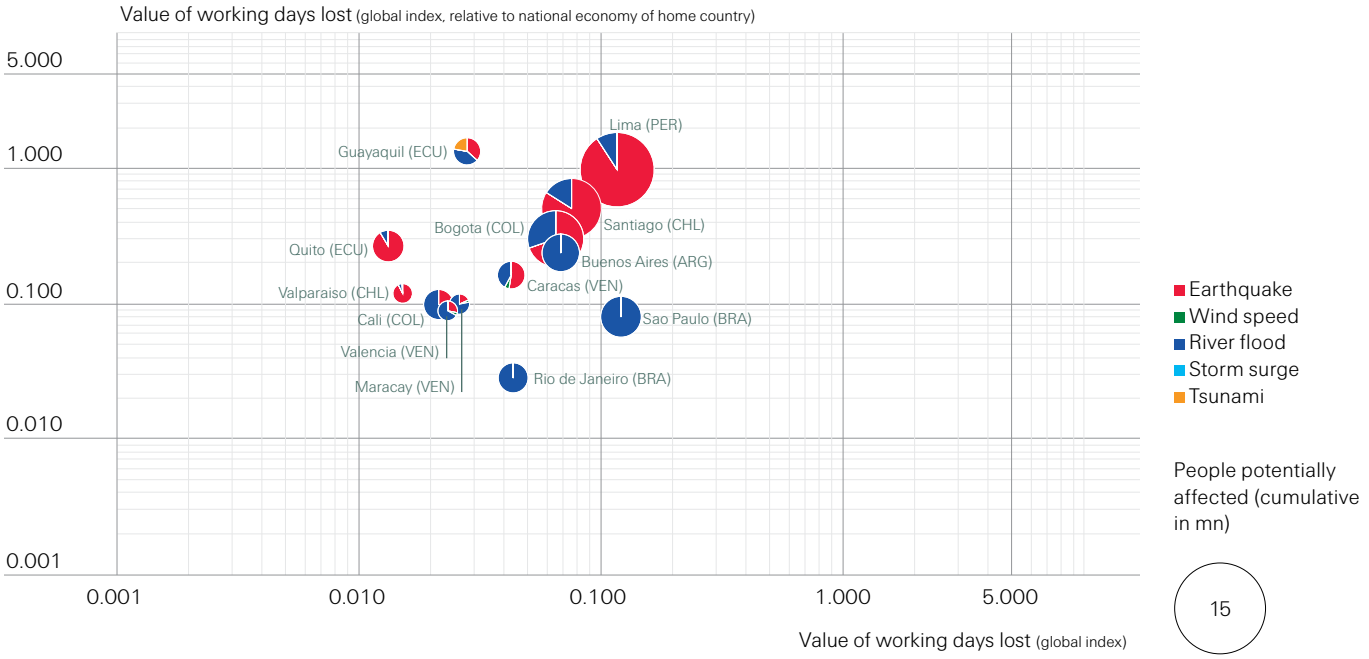


Table 9: South America at a glance

Metropolitan areas	49
– total population	148.5 mn
– total combined GDP	USD 2.1 trn
Most people endangered by single scenario	8.9 mn earthquake Lima, 5.3 mn earthquake Santiago, 3.9 mn earthquake Bogota
Top 3 all perils: people potentially affected	Lima, Santiago, Bogota
Top 3 all perils: absolute value of working days lost (global index)	Sao Paulo (0.12), Lima (0.12), Santiago de Chile (0.07)
Top 3 all perils: relative value of working days lost (global index)	Guayaquil (1.20), Lima (0.90), Santiago de Chile (0.47)

On a global scale, the economic production in South America is relatively evenly distributed among the countries ranging in the mid-scale. This results in a very dense cluster for the top 10 ranks.

Adequate building standards to improve earthquake damage resistance as well as flood risk maps with consecutive planning measures would improve the resilience of many metropolitan areas in the region.

South America faces little risk of extended and high wind speeds, apart from a few exceptions close to the Caribbean and East Brazilian coast line. But other hazards are clearly present. We can see earthquakes in combination with some river flooding in the west, whereas eastern metropolitan areas of Brazil and Argentina face river flood as the dominant peril. Tsunami hazards accompany seismically endangered metropolitan areas along the western coastline at times.

Africa

Figure 13: Impact from all perils per metropolitan area – Top 10
The chart includes the aggregate number of people potentially affected by all relevant perils (bubble size) and global rankings by the value of working days lost, in absolute terms (x-axis) and in relation to the country's national economy (y-axis).

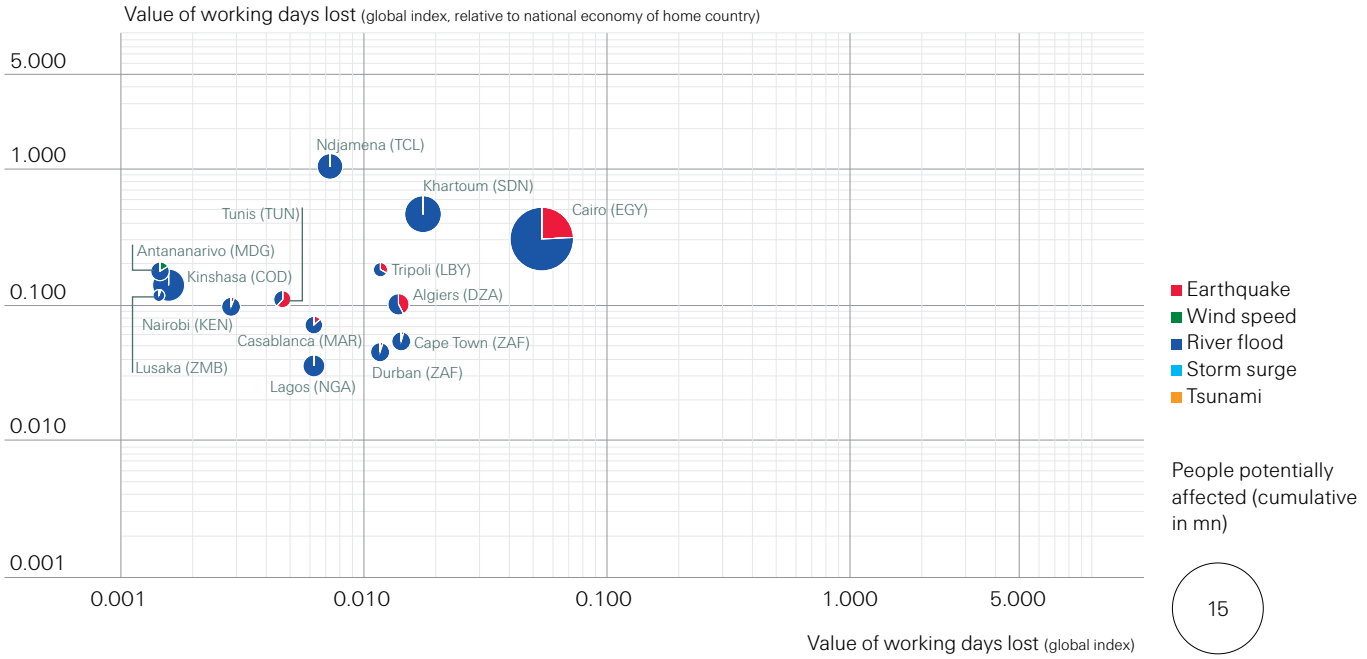


Table 10: Africa at a glance

Metropolitan areas	60
– total population	155.7 mn
– total combined GDP	USD 0.7 trn
Most people endangered by single scenario	5.5mn river flood Cairo, 2.5mn river flood Khartoum, 1.8mn river flood Kinshasa
Top 3 all perils: people potentially affected	Cairo, Khartoum, Kinshasa
Top 3 all perils: absolute value of working days lost (global index)	Cairo (0.05), Khartoum (0.02), Kinshasa (0.01)
Top 3 all perils: relative value of working days lost (global index)	Ndjamena (1.00), Khartoum (0.45), Cairo (0.30)

Africa's cities are almost exclusively threatened by river flooding alone. Africa is relatively safe when it comes to natural hazards analysed here. The only areas threatened by earthquakes are situated along the Mediterranean Sea and along the African rift system, from Cairo down to Tanzania. Tropical cyclones only pose a risk to communities along the southeastern coastline.

On a global scale, the economic output of Africa's cities is comparatively low. This is illustrated by the positions of the metropolitan areas on the left-hand side of figure 13. On the other hand, the individual impact on a country can be enormous in Africa.

For example, a major river flood in Ndjamena (Chad) or Khartoum (Sudan) would affect virtually the entire population and significantly disrupt their countries' national economies. In absolute terms, Cairo – which faces risks from earthquakes and river floods – ranks highest among Africa's cities, both by working days lost and people potentially affected.

Conclusion

Building city resilience is critical

Millions of people live in the world's big metropolitan centres, and they are being joined by many more people who flock to the cities for economic pursuits. A major natural catastrophe can cause tremendous suffering and disruption. The threat to city residents and local economies is real, and it is mounting relentlessly as megacities continue to expand and risk management practices fail to keep up with the pace of change.

As the findings of this study show, there are substantial differences in risk exposure across regions. Asia's cities are most at risk from natural hazards, followed by cities in North America. They also show that many of the smaller and often lesser known metropolitan areas deserve more of our attention. Not only are these centres developing rapidly, but in our rankings they already appear alongside cities typically mentioned as natural catastrophe hot spots, such as Tokyo, San Francisco, Miami or, more recently, New York.

Saving lives is and should be the highest priority in risk mitigation efforts. However, higher living standards in many cities mean that demand for better protection measures is also set to increase, especially in the world's high growth markets. Combining such measures with insurance covers for residual risk is the most cost-effective and recommended approach.

Making cities more resilient

Risk transfer solutions – the example of Mexico's MultiCat
Mexico's MultiCat catastrophe bond programme, which was designed by the World Bank and the Mexican government with support from Swiss Re, forms a key part of Mexico's sovereign disaster risk transfer strategy. The programme combines risk mitigation, risk modeling, and traditional and parametric insurance to allow the government to financially prepare for disasters. It covers earthquake and hurricane risk.

The transaction highlights Swiss Re's long-standing commitment to helping countries and local communities build resilience through innovative insurance solutions and the public-private partnership model. Swiss Re was the first global reinsurance company to dedicate a team of experts to work with national and municipal governments on their risk management needs. The success of MultiCat highlights the growing demand within the public sector for these solutions.

Economics of Climate Adaptation – tackling climate risk locally
Climate adaptation is an urgent priority for national and city authorities. While many adaptation measures are available to make cities more resilient to the impact of climate change, decision-makers need to identify the most cost-effective investments. The Economics of Climate Adaptation (ECA) methodology gives them the facts to do so in a systematic way. It helps them assess the local impact of climate change and take actions to minimise that impact at the lowest cost to society. With its partners, Swiss Re has carried out ECA studies in over 20 locations, including several cities. They all present a strong case for immediate action: it is cheaper to start adapting now than to bear the costs of future disasters tomorrow.
Source:
http://www.swissre.com/rethinking

Yet the majority of urban assets in high growth markets is currently not insured. As a consequence, insured disaster losses in the United States, Canada and Europe are still significantly bigger. As China and other economies catch up, Asia is set to emerge as the region with the highest economic loss potential and the biggest gap between economic and insured losses within the next decades.

Investments in infrastructure are vital to strengthen the resilience of metropolitan areas. The potential damage that a large natural disaster can cause to roads, bridges, telecommunications and other essential infrastructure is perhaps nowhere more apparent than in the world's big cities. This is why strengthening urban resilience is also a prime concern for the insurance industry. As an ultimate risk taker, the insurance industry has a vested interest in new infrastructure investments, upgrades to ageing infrastructure and adaptation measures.[6]

Natural disasters, along with other shocks such as human pandemics and acts of terrorism, are likely to materialise in urban locations and affect millions of residents. Strengthening the resilience of the world's cities is therefore an urgent priority.

Investments in infrastructure would also help cities to cope better with natural disasters and other shocks such as human pandemics and acts of terrorism. As many of these risks are likely to materialise in urban locations, building resilience in the world's cities is an urgent priority. But resource limitations and budget constraints make this a challenging task for mayors, city planners and local disaster risk managers. This study aims to support their work by providing new insights into the potential impact of natural disasters on urban communities.

Since people and economies are interconnected, comparisons across cities and regions are relevant to city authorities. However, more specific assessments of local conditions have to be made to give them an accurate basis for decision-making. In its publication 'Making Cities Resilient,' the United Nations Office for Disaster Risk Reduction (UNISDR) provides guidelines and best case examples for such planning.[7] The OECD also provides a detailed G20/OECD framework on the integration of risk finance and insurance into disaster risk management.[8]

The impact of a large natural catastrophe can only ever be avoided to a certain extent. There will always be costs for relief, recovery and reconstruction efforts, and they will constitute a financial burden for the affected region. However, insurance can help soften the impact by offering risk transfer products that help narrow the wide gap between economic and insured losses.

Swiss Re works with local and national governments, businesses and many other stakeholders to strengthen risk management and disaster preparedness. It does so by assessing, taking and sharing risks, providing capital to the real economy and paying out claims when disasters happen. Further strengthening these partnerships can go a long way towards making urban communities more resilient and supporting them to recover faster when disaster strikes.

6 See Swiss Re Private Equity Partners (2010): An introduction to infrastructure investing, Swiss Re Centre for Global Dialogue (2012): Integrative Risk Management: Fostering Infrastructure Resilience.
7 UNISDR (2013): Making Cities Resilient: Summary for Policymakers A global snapshot of how local governments reduce disaster risk.
8 OECD (2012): Disaster Risk Assessment and Risk Financing – A G20/OECD Methodological Framework.

Appendix

Tables 11–15: Top 10 ranks per peril for the three analyses: (1) people potentially affected; (2) value of working days lost, global index; (3) Value of working days lost, relativ to national economy, global index

Earthquake ranking (see figure 5)

	Metro area	Area (km²); population (mn)	People potentially affected (mn)	Metro area	Area (km²); population (mn)	Value of working days lost (global index 0–1)	Metro area	Area (km²); population (mn)	Value of working days lost, relativ to national economy (global index 0–1)
1	Tokyo-Yokohama (JPN)	16 300 37.1	29.4	Tokyo-Yokohama (JPN)	16 300 37.1	1.00	San Jose (CRI)	1 000 2.2	1.00
2	Jakarta (IDN)	11 600 33.1	17.7	Los Angeles (USA)	14 400 15.4	0.79	Lima (PER)	2 600 8.9	0.73
3	Manila (PHL)	2 900 20.9	16.8	San Francisco (USA)	5 300 5.0	0.40	Taipei (TWN)	2 100 8.1	0.41
4	Los Angeles (USA)	14 400 15.4	14.7	Osaka-Kobe (JPN)	13 600 18.6	0.32	Bishkek (KGZ)	1 600 1.0	0.36
5	Osaka-Kobe (JPN)	13 600 18.6	14.6	Nagoya (JPN)	15 600 11.6	0.24	Manila (PHL)	2 900 20.9	0.36
6	Tehran (IRN)	11 000 15.1	13.6	Taipei (TWN)	2 100 8.1	0.15	Yerevan (ARM)	1 800 1.4	0.34
7	Nagoya (JPN)	15 600 11.6	9.4	Lima (PER)	2 600 8.9	0.10	Almaty (KAZ)	2 200 1.7	0.32
8	Lima (PER)	2 600 8.9	8.9	Shizuoka (JPN)	2 100 1.6	0.10	Santo Domingo (DOM)	800 3.3	0.28
9	Taipei (TWN)	2 100 8.1	8.0	Taichung (TWN)	5 700 5.8	0.09	Santiago (CHL)	3 800 6.2	0.26
10	Istanbul (TUR)	4 100 11.5	6.4	Istanbul (TUR)	4 100 11.5	0.09	Taichung (TWN)	5 700 5.8	0.24

Storm ranking (see figure 7)

	Metro area	Area (km²); population (mn)	People potentially affected (mn)	Metro area	Area (km²); population (mn)	Value of working days lost (global index 0–1)	Metro area	Area (km²); population (mn)	Value of working days lost, relativ to national economy (global index 0–1)
1	Pearl River Delta (CHN)	20 600 42.4	17.2	Tokyo-Yokohama (JPN)	16 300 37.1	1.00	Manila (PHL)	2 900 20.9	1.00
2	Tokyo-Yokohama (JPN)	16 300 37.1	14.1	Osaka-Kobe (JPN)	13 600 18.6	0.49	Taipei (TWN)	2 100 8.1	0.46
3	Manila (PHL)	2 900 20.9	12.6	Pearl River Delta (CHN)	20 600 42.4	0.39	Tainan-Kaohsiung (TWN)	3 100 5.1	0.38
4	Osaka-Kobe (JPN)	13 600 18.6	7.8	Nagoya (JPN)	15 600 11.6	0.30	Port-au-Prince (HTI)	300 2.0	0.38
5	Taipei (TWN)	2 100 8.1	5.4	Taipei (TWN)	2 100 8.1	0.18	Havana (CUB)	500 2.0	0.34
6	Shantou (CHN)	5 200 10.0	5.1	Manila (PHL)	2 900 20.9	0.17	Santo Domingo (DOM)	800 3.3	0.32
7	Nagoya (JPN)	15 600 11.6	4.3	Tainan-Kaohsiung (TWN)	3 100 5.1	0.15	Taichung (TWN)	5 700 5.8	0.31
8	Mumbai (IND)	2 600 20.6	4.3	Fukuoka (JPN)	2 900 3.9	0.14	Tokyo-Yokohama (JPN)	16 300 37.1	0.19
9	Chennai (IND)	1 600 8.5	4.0	Taichung (TWN)	5 700 5.8	0.12	Busan (KOR)	2 500 5.0	0.12
10	Tainan-Kaohsiung (TWN)	3 100 5.1	4.0	Busan (KOR)	2 500 5.0	0.11	Osaka-Kobe (JPN)	13 600	0.10

River flood ranking (see figure 6)

	Metro area	Area (km²); population (mn)	People potentially affected (mn)	Metro area	Area (km²); population (mn)	Value of working days lost (global index 0–1)	Metro area	Area (km²); population (mn)	Value of working days lost, relativ to national economy (global index 0–1)
1	Pearl River Delta (CHN)	20 600 42.4	12.0	Tokyo-Yokohama (JPN)	16 300 37.1	1.00	Ndjamena (TCL)	800 1.2	1.00
2	Shanghai (CHN)	8 000 17.6	11.7	Nagoya (JPN)	15 600 11.6	0.64	PhnomPenh (KHM)	500 1.6	0.81
3	Kolkata (IND)	3 200 19.1	10.5	Osaka-Kobe (JPN)	13 500 18.6	0.48	Bangkok (THL)	4 500 9.5	0.80
4	Jakarta (IDN)	10 600 33.1	10.0	Paris (FRA)	13 600 11.2	0.42	Doha (QAT)	1 000 1.4	0.52
5	Delhi (IND)	5 700 21.9	8.9	Pearl River Delta (CHN)	20 600 42.4	0.40	Manila (PHL)	2 900 20.9	0.46
6	Tokyo-Yokohama (JPN)	16 300 37.1	8.9	Shanghai (CHN)	8 000 17.6	0.28	Khartoum (SDN)	2 600 5.6	0.45
7	Bangkok (THL)	3 500 9.5	7.1	Mexico City (MEX)	4 500 19.6	0.20	Yerevan (ARM)	1 800 1.4	0.43
8	Mexico City (MEX)	4 500 19.6	6.1	Bangkok (THL)	4 500 9.5	0.20	Baghdad (IRK)	4 500 8.0	0.41
9	Cairo (EGY)	3 500 17.7	5.5	Amsterdam-Rotterdam (NDL)	10 800 5.4	0.20	Ulaanbaatar (MNG)	1 000 0.9	0.35
10	Tianjin (CHN)	2 600 5.8	5.5	Milan (ITA)	14 900 7.3	0.20	Cairo (EGY)	3 500 17.7	0.29

Storm surge ranking

	Metro area	Area (km²); population (mn)	People potentially affected (mn)	Metro area	Area (km²); population (mn)	Value of working days lost (global index 0–1)	Metro area	Area (km²); population (mn)	Value of working days lost, relativ to national economy (global index 0–1)
1	Pearl River Delta (CHN)	20 600 42.4	5.3	Pearl River Delta (CHN)	20 600 42.4	1.00	Amsterdam-Rotterdam (NDL)	10 800 5.4	1.00
2	Osaka-Kobe (JPN)	13 500 18.6	3.0	Amsterdam-Rotterdam (NDL)	10 800 5.4	0.73	Ho Chi Minh (VNM)	2'000 9.1	0.32
3	Mumbai (IND)	2 600 20.6	2.6	Osaka-Kobe (JPN)	13 500 18.6	0.73	Pearl River Delta (CHN)	20 600 42.4	0.20
4	Tokyo-Yokohama (JPN)	16 300 37.1	2.3	Tokyo-Yokohama (JPN)	16 300 37.1	0.61	Osaka-Kobe (JPN)	13 500 18.6	0.15
5	Amsterdam-Rotterdam (NDL)	10 800 5.4	1.8	Nagoya (JPN)	15 600 11.6	0.51	Tokyo-Yokohama (JPN)	16 300 37.1	0.13
6	Nagoya (JPN)	15 600 11.6	1.7	New York-Newark (USA)	11 900 16.5	0.46	Manila (PHL)	2 900 20.9	0.13
7	Shanghai (CHN)	8 000 17.6	1.4	New Orleans (USA)	2 700 1.0	0.18	Nagoya (JPN)	15 600 11.6	0.11
8	Kolkata (IND)	3 200 19.1	1.4	Hamburg (DEU)	6 000 2.3	0.09	Rangoon (MMR)	1 100 4.2	0.10
9	Ho Chi Minh (VNM)	2 000 9.1	1.3	Shanghai (CHN)	8 000 17.6	0.07	Bangkok (THL)	3 500 9.5	0.09
10	New York-Newark (USA)	11 900 16.5	1.1	Fukuoka (JPN)	3 000 3.9	0.06	Havana (CUB)	500 2.0	0.08

Tsunami ranking									
	Metro area	Area (km²); population (mn)	People potentially affected (mn)	Metro area	Area (km²); population (mn)	Value of working days lost (global index 0–1)	Metro area	Area (km²); population (mn)	Value of working days lost, relativ to national economy (global index 0–1)
1	Tokyo-Yokohama (JPN)	16 300 37.1	2.4	Nagoya (JPN)	15 600 11.6	1.00	Guayaquil (ECU)	900 2.4	1.00
2	Nagoya (JPN)	15 600 11.6	2.4	Tokyo-Yokohama (JPN)	16 300 37.1	0.88	Nagoya (JPN)	15 600 11.6	0.63
3	Osaka-Kobe (JPN)	13 500 18.6	1.8	Osaka-Kobe (JPN)	13 500 18.6	0.68	Tokyo-Yokohama (JPN)	16 300 37.1	0.55
4	Shantou (CHN)	5 200 10.0	0.7	Busan (KOR)	2 500 5.0	0.06	Osaka-Kobe (JPN)	13 500 18.6	0.43
5	Kolkata (IND)	3 200 19.1	0.6	Izmir (TUR)	1 400 2.7	0.06	Panama City (PAN)	600 1.1	0.33
6	Dhaka (BGD)	1 800 12.9	0.4	Kagoshima (JPN)	500 0.6	0.04	Izmir (TUR)	1 400 2.7	0.28
7	Izmir (TUR)	1 400 2.7	0.4	Shizuoka (JPN)	2 100 1.6	0.04	Busan (KOR)	2 500 5.0	0.21
8	Jiaojing (CHN)	2 700 3.1	0.3	Shantou (CHN)	5 200 10.0	0.04	Tainan-Kaohsiung (TWN)	3 100 5.1	0.21
9	Guayaquil (ECU)	900 2.4	0.3	Tainan-Kaohsiung (TWN)	3 100 5.1	0.03	Jaffna (LKA)	800 0.7	0.15
10	Chennai (IND)	1 600 8.5	0.2	Istanbul (TUR)	4 100 11.5	0.02	Dhaka (BGD)	1 800 12.9	0.13

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