Risks of Exposure and Vulnerability to Cyclones for World's Major Coastal Cities

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Using the data from the 2018 Revision of the UN World Urbanization Prospects (WUP) and the spatial hotspot data on cyclone risk, we show that 169 of 616 world's major coastal cities with 300,000 inhabitants or more on mid-2018, or 1.1 billion people, face a relatively high risk of exposure to cyclones. This represents 27% of 616 coastal cities and 33% of 1.1 billion people in these cities. About 40-44% of coastal cities and 48% of city populations are highly vulnerable to cyclone-related deaths and economic losses. Overall, we show that cyclones have been a major threat to many major coastal cities worldwide and that the population in cyclone highly affected areas has grown faster than that in non-affected areas and such a growth trend is likely to continue in the coming decades. Improving risk reduction management and capacity is a challenge, especially for fast growing cities most at risk.

Extended abstract (draft)

1. INTRODUCTION

In 2018, about 55 per cent of the world's population lived in urban areas (United Nations, 2018), an increase from 43 per cent in 1990. By 2050, two-thirds of the world's population is projected to reside in urban settlements. The increasing concentration of population in urban areas, together with the high density of assets and the socio-economic and spatial vulnerabilities that characterize many cities, could make urban centres more susceptible to the risk of being severely affected by natural hazards such as cyclones than rural settings (Gencer, 2013). According to the *2011 Global Assessment Report on Disaster Risk Reduction,* over 80 per cent of disasters reported by national sources occurred in urban areas (UNISDR, 2011).

Global empirical records have shown that about 1/4 -1/3 of numbers of natural disasters are related to tropic storms and cyclones (hurricanes, typhoons) (Munich RE, 2017). According to estimates provided by the United Nations Inter-governmental Panel on Climate Change (UNIPCC), while the overall frequency of tropical cyclones is expected to either decrease or remain unchanged globally in the 21st century, it is almost certain that there will be increases in the average maximum wind speed of tropical cyclones and increases in total rainfall associated with tropical cyclones (UNIPCC, 2012).

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

Coastal cities were much more likely to be located in areas that were at high risk of exposure to cyclones compared to inland cities (27 versus 6 per cent), although the former was less likely to be located in areas that were at high risk of exposure to drought (Gu et al., 2015). 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 coastal cities, the potential risks of exposure, economic losses and mortality due to natural disasters, environmental degradation and climate change.

The main objective of this technical paper is to provide a global overview of the potential risks of exposure and vulnerability to cyclones for the world's major coastal cities. In the global context of rapid growth of urban populations exposed to natural disasters, the paper aims to raise awareness about cyclones-related risks of exposure and vulnerability faced by major coastal urban areas so as to develop sound management for risk reduction and improved policy frameworks. The paper 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.

2. DATA SOURCES AND METHODS

We used five major datasets for this research. The first was the time series on city populations from the *2018 Revision* of the World Population Revision, which contained population estimates and projections from 1950 to 2035 for 1,860 cities of the world 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 of 4.5 billion. The term “city” in this paper was used in a non-precise way, and may refer to a city proper, an urban agglomeration or a metropolitan area.

As the *2018 Revision* of *World Urbanization Prospects* only included the geographic coordinates of the centroid point for each city, and did not identify the total land area included in each city’s boundaries. In oder to reflect the boundary of the city (or urban extent), we applied second datasets, which is from the official urban extents collected by the United Nations Population Division (UNPD) from Member States to define the urban extent of each city. In the current version of the official urban extents datasets generated by the UNPD, there were about 40 countries, including most European countries, USA, Canada, Brazil, Columbia, Mexico, Japan, Australia, New Zealand, and so forth. For remaining countries or areas without official urban extents, we used the buffered zone of a city to approximately represent its urban extent. The buffer zone was generated around each city centroid to reflect approximately its possible urban extent. The buffer zone was a circle with radius proportional to the population size estimated for mid-2018, using the statistical relationship between city population size and urban extents from MODIS 500 meter resolution remote sensing global urban maps for 3,646 urban areas with 100,000 inhabitants or more in 2000 (see Appendix A).

The third dataset was from the Millennium Ecosystem Assessment, which provided information related to the geographic classification of cities according to whether they were coastal cities or inland cities. The coastal areas were defined as areas between 50 meters below mean sea level and 50 meters above the high tide level or extending landward to a distance of 100 kilometres from shore, including coral reefs, intertidal zones, estuaries, coastal aquaculture, and sea grass communities (Millennium Ecosystem Assessment, 2003: 54). If a city’s official polygon or buffered zone was located in a coastal area, the city was considered a coastal city. Otherwise, it was considered an inland city. With the definition, out of 1,860 cities with inhabitants over 300,000 on 1 July, 2018, 616 cities were classified as coastal cities.

The fourth dataset was the spatial hotspot data on risks of exposure and vulnerability to disaster of cyclones produced by the Center for International Earth Science Information Network (CIESIN) (http://www.ldeo.columbia.edu/chrr/research/hotspots/). The cyclone data covers the period 1980-2000. Data for the period 2000-2012 from the United Nations International Strategy for Disaster Reduction (UNISDR) were also used, especially those data of risk of cyclones for different return periods to investigate future possible attacks by cyclones for coastal cities.

In both datasets from CIESIN and from the UNISDR, the resolution of the events of cyclones was on a 30 by 30 arc *second* grid (about 1 km at the equator). Grid cells with population density less than 5 persons per square kilometre and without significant agricultural activities were excluded from these database. For each each grid cell, the spatial hotspot dataset records the frequencies of events, as well as the severity or scale of the impact of each event, with respect to both mortality and economic losses. All grid cells with data on the frequencies and the scales of cyclones were apportioned into deciles. An area was classified as being at high risk of exposure to cyclones if it was located in grid cells ranking in the top three deciles of the global risk distribution in terms of frequency of occurrences of cyclones. An area was classified as being at medium level of risk if it was located in grid cells ranking from the 5^{th} to the 7^{th} deciles and at low level of risk if it was located in grid cells ranking from the 1^{st} to the 4^{th} deciles (Dilley et al., 2005: 33).

The classification of the relative risk of vulnerability to cyclone-related mortality or economic losses was performed similarly to the classification of the relative risk of exposure to natural hazards described above. Specifically, 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 cyclones. 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 of the global risk distribution in terms of the mortality rate or level of economic losses associated with cyclones. An area was classified as being at medium risk if it was located in grid cells ranking from the 5th to the 7th deciles and at low risk if it was located in grid cells ranking from the 1st to the 4th deciles (Dilley et al., 2005).[1] As there are two indicators refer to economic losses: relative losses (to nation's GDP) and total losses. Unless otherwise stated, the risks of economic losses refer to total economic losses.

The fifth source consisted of several sources that produced global urban extents, such as MODIS Landcover 500 meters (Friedl et al., 2010) and GRUMP urban extents (CIESIN, 2011). These two datasets were mainly used to for the purpose of sensitivity analysis that examined the difference in outcomes if we alternatively used these criteria for definition of urban extents. We found that the results from different criteria for urban extents produced very similar results (see Appendix B).

In classifying the degree of risk exposure and vulnerability of a city to cyclones, we took all of the grid cells that fell fully or partially within the city official urban extent and the buffer zone and then took the maximum cell value to represent the level of exposure/vulnerability risk.

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

3. MAJOR FINDINGS

3.1. Although the coastal cities had a similar faster growth from 1950 to 2018 than inland cities, the fastest growing cities are always found in coastal areas.

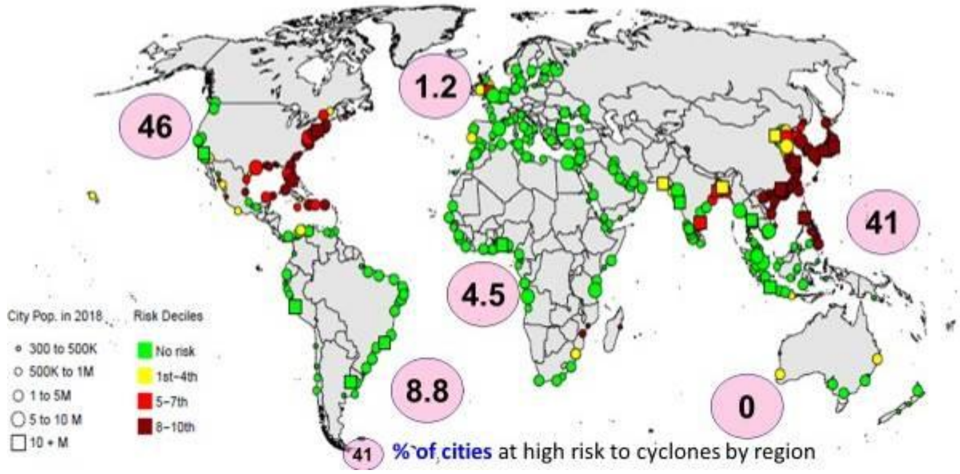
The average annual growth rates for 10 fastest growing inland cities from 1950 to 2018 lied in 7.6-10.2%, whereas the rates for 10 fastest growing coastal cities in the same period were 8.0-16.7%.

3.2. In 2018, nearly 27 per cent of 616 large coastal cities, representing 33 per cent of city dwellers worldwide, were at high risk of exposure to cyclones.

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

(1) Risk of exposure to cyclones

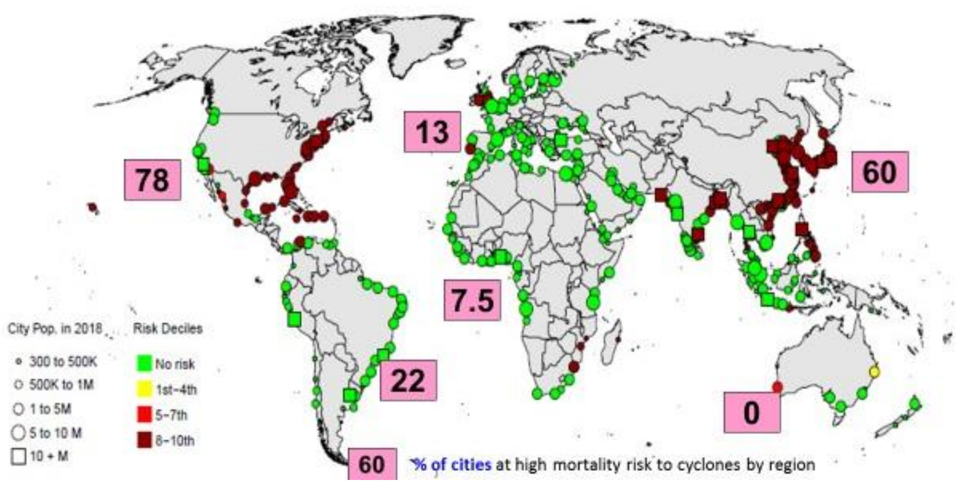
- In 2018, **169 of 616** coastal cities (27%) or **359mn of 1.1 bn** city pop (33%). worldwide were at high risk of exposure to cyclones
  - **Low risk**: **55** cities (~9%) , **100 mn** (~9%)
  - **Medium risk: 58** cities (~10%), **98 mn** (~9%);



3.3. Globally, in 2018, about 40-45 per cent of large coastal cities, representing approximately 48 per cent of the total city population, were exposed to high mortality vulnerability or economic losses from cyclones.

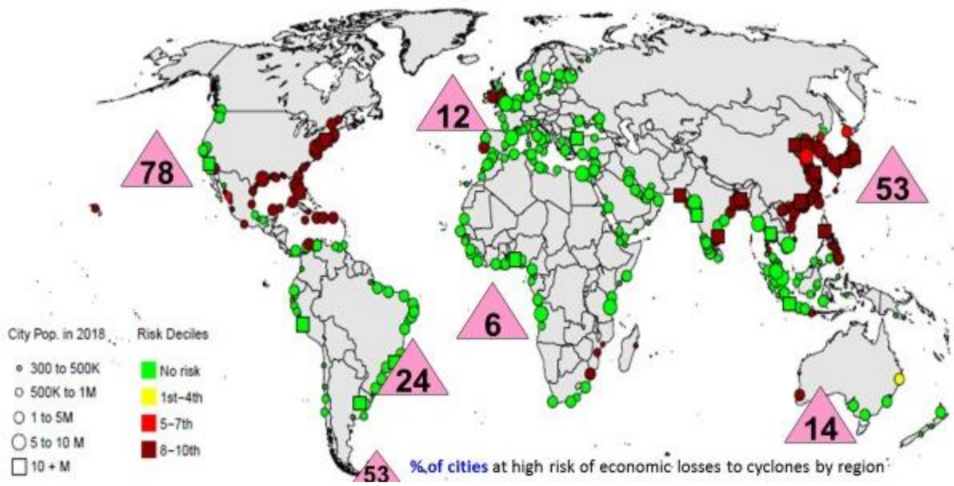
- **270** of 616 cities (43.8%) or **524 mn** of city populations (47.8%) were at high mortality vulnerability to cyclones;

- **Low/medium risk: 9** cities (~1.4%) or **8 mn** (<1%)

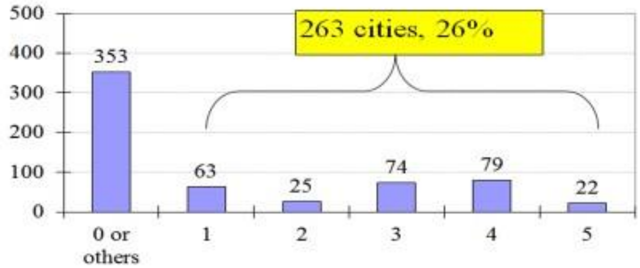


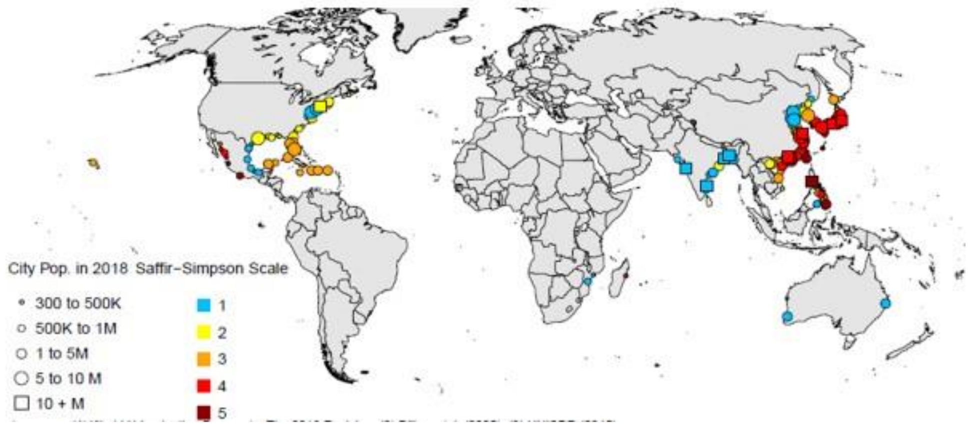
- **246** of 616 cities (40%) or **524 mn** of city populations (48%) were highly vulnerable to economic losses from cyclones.

- **Low/Medium risk**: **34** cities (<6%) or **31mn** people (<3%)

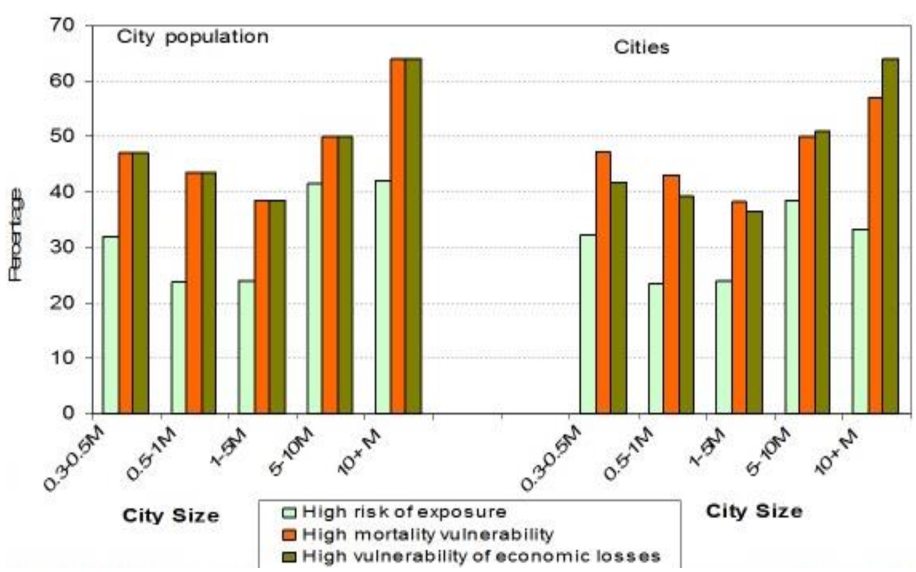


3.4 About 1/4 of large coastal cities at risk of attacking by cyclones with SSS category 1-5.

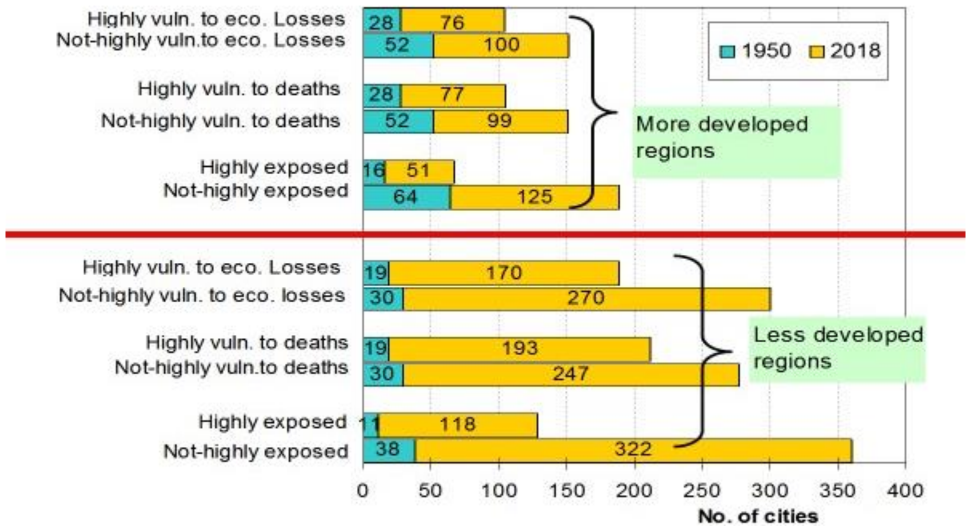




3.5. Megacities were more likely to be highly exposed to cyclones and were more vulnerable than cities of other sizes.

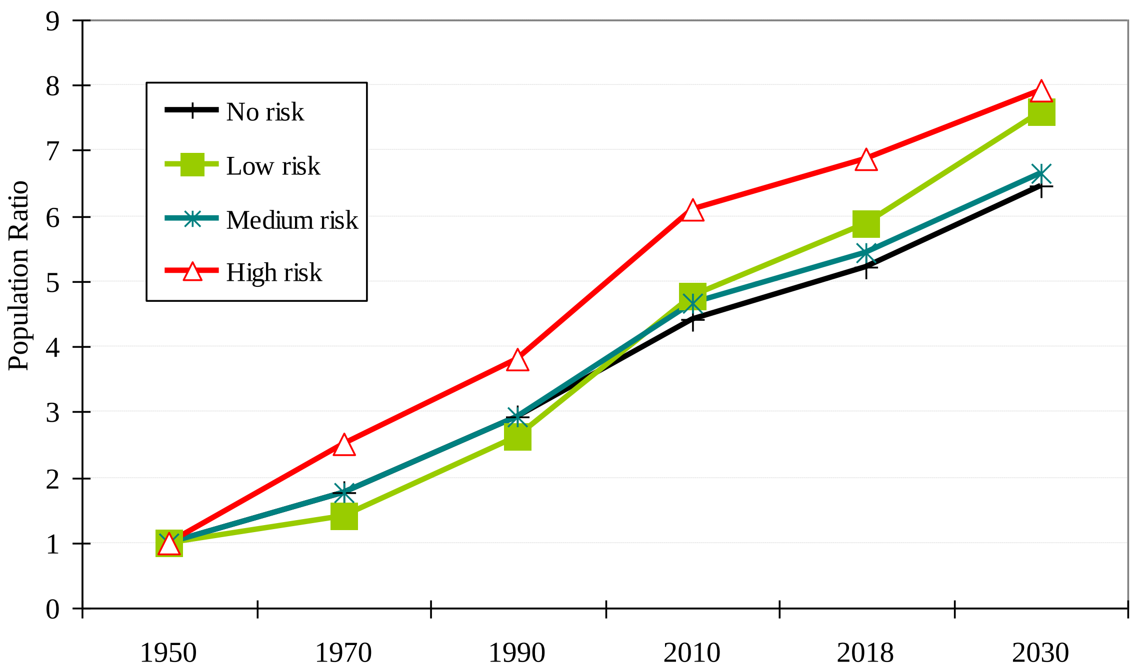


3.6. Cities in the less developed regions, which, on average, were experiencing faster growth than cities elsewhere, were more likely to be exposed to both the risk of cyclones and the potentially adverse consequences of this type of disaster.

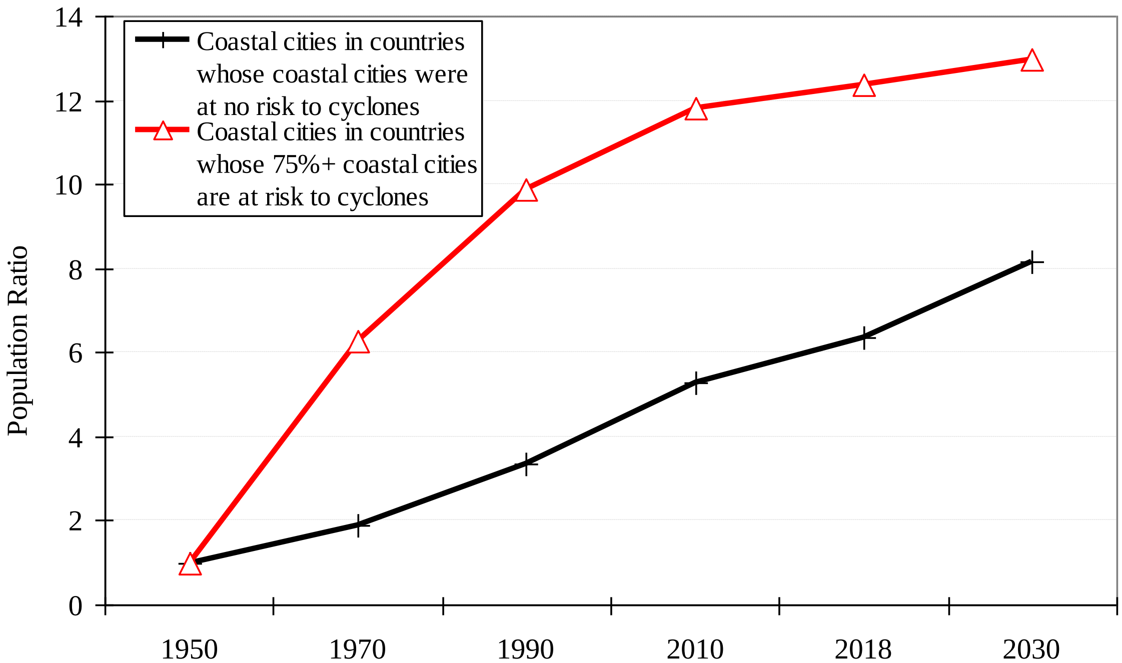


3.7. The population of cities in areas highly exposed and vulnerable to cyclones grew rapidly between 1950 and 2018

Population in coastal cities located in high risk areas grew fasters than coastal cities located in no or lower risk areas.



Population in coastal cities in countries with at least 75% of their coastal cities at risk to cyclones had a faster growth than coastal cities in countries without any city at risk to cyclones.



4. CONCLUDING REMARKS

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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[2] and FuzzyG UN/EC Common Gazetteer[3]). 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[4] Level 0 at 1:1 million scale) and the urban extents from the Global Rural-Urban Mapping Project (GRUMP)[5] for each city in the *2014 Revision* of the *World Urbanization Prospects*. Finally, Google Earth with remote sensing imagery was used to resolve discrepancies and to obtain centroid coordinates consistent with land features (i.e., excluding rivers and lakes) and coastlines.

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

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

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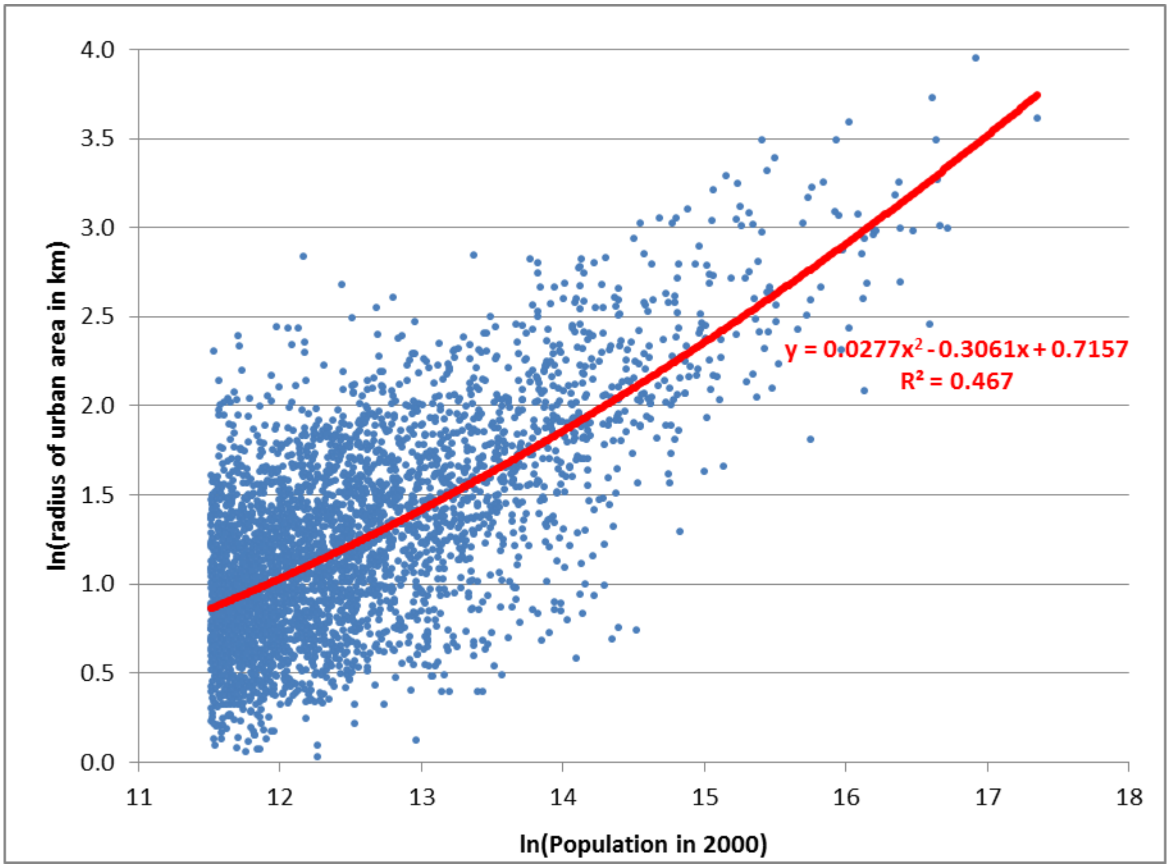
[2] Geonames Gazetteer. http://www.geonames.org. Retrieved 4 March 2014.

[3] FuzzyG is a service of the Joint Research Centre of the European Commission and the Cartographic Section of the United Nations. http://dma.jrc.it/services/gazetteer/ Retrieved 4 March 2014.

[4] UN Cartographic Section (UNCS).UNmap. http://ggim.un.org/projects.html. Retrieved 19 July 2013.

[5] Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Center International de Agriculture Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4GH9FVG. accessed 14 April 2014.

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



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

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

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

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

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

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