THE FUTURE WE DON'T WANT

How Climate Change Could Impact the World's Greatest Cities

UCCRN Technical Report

February 2018

Mexico City

C40 CITIES

GLOBAL COVENANT of MAYORS for CLIMATE & ENERGY

UCCRN URBAN CLIMATE CHANGE RESEARCH NETWORK

ACCLIMATISE building climate resilience

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1. INTRODUCTION

A. ABOUT THE FUTURE WE DON'T WANT

The Future We Don't Want project is a collaboration between C40 Cities, Global Covenant of Mayors, Acclimatise, and the Urban Climate Change Research Network (UCCRN) aimed at understanding and communicating key challenges cities are facing, and will continue to face, as a result of climate change. These four organisations have come together to illustrate the unique risks that climate change poses to cities through a scientific global data analysis, as well as to share urban responses to those risks through case study examples from real-world urban experiences and narrative story lines.

This Technical Report highlights the data analysis and case studies developed by the Urban Climate Change Research Network for this project. It serves as a foundation for building narratives and key communication tools around global impacts of climate change on cities and their responses that will serve as an inspiration for other cities looking to build their own resilience plans.

B. WHY CITIES?

Every year sees the addition of 67 million new urban dwellers. A bulk of this rapid urbanisation is taking place in developing countries. By 2030, an estimated 60 percent of the world's population will be living in urban areas. That figure will keep rising until mid-century when over 65 percent of the world's population is projected to live in cities (IPCC, 2014). This rapid, unprecedented urban growth, poses many urban challenges, even without the added pressure of climate change. However, while the world's urban population keeps growing, cities and the people who live in them will be increasingly vulnerable to climate extremes including more frequent, longer and more intense heat waves, exacerbated inland flooding from heavy downpours, and extended coastal flooding due to sea level rise.

Climate change is already underway and it is increasingly necessary for cities to plan and implement solutions in response to a range of climate hazards that risk impacting the health and well-being of residents as well as urban economies and infrastructural systems. 70 percent of cities are already dealing with the effects of climate change, and nearly all are at risk. For instance, over 90 percent of all urban areas are coastal, which puts most cities across the globe at risk of flooding from sea level rise and powerful storms. The financial effects of climate change can be just as devastating as the physical ones and unexpected disruptions from storms, flooding, and drought can lead to major disruptions in city government and business operations. In light of this global challenge, many urban areas have started developing resilience strategies that encompass integrated structural, behavioural, programmatic, and nature-based approaches.

City leaders are in the right position to deal with this climate challenge for two key reasons: first, cities are big users of energy, consuming 2/3 of the world's energy while creating over 70 percent of greenhouse gases. Second, city mayors in many countries are directly accountable to their constituents for their decisions that affect global developments as well as every-day life.

Key city networks and international organisations are aiding such city action by providing resources, advocacy, and partnerships. As part of the research project, C40 Cities, Global Covenant of Mayors, Acclimatise, and the Urban Climate Change Research Network (UCCRN) have come together to illustrate the unique risks that climate change poses to cities by generating global-scale data on climate impacts and highlighting examples of urban responses to those risks through relevant case studies. This Technical Report highlights the data analysis and case study foundation developed by the Urban Climate Change Research Network for the project.

The UCCRN[1] Second Assessment Report on Climate Change and Cities (ARC3.2) provides a basis for the Future We Don't Want analysis by presenting climate projections for approximately 153 cities and cataloguing urban disasters and risks, along with the effects on human health in cities (UCCRN, 2018). ARC3.2 provides concrete solutions to cities with regard to mitigation and adaptation; urban planning and design; equity and environmental justice; economics, finance, and the private sector; as well as for urban sectors such as energy, water, transportation, housing and informal settlements, solid waste management, and climate governance. The ARC3.2 also includes a Case Study Docking Station (CSDS) that documents city examples and on-the-ground responses to resilience and climate change in 153 UCCRN cities (this approach is further elaborated in Section 4). Of the 153 UCCRN cities, 35 percent are C40 cities, and 45 percent are Global Covenant cities who have all pledged to achieve the goals of the Paris Agreement. The urban case studies from the CSDS form the basis for the examples of climate impacts and solutions that are shared throughout this Technical Report.

The Future We Don't Want aims to highlight the critical risks that cities, and their residents will encounter as a result of climate change. It also provides tangible lessons learned from cities that are investing in actions to build resilience in the face of these risks. By analysing the urban vulnerability to climate change, The Future We Don't Want aims to generate an awareness around what cities will be facing if we don't take drastic action to reduce global emissions. At the same time, our research aims to facilitate urban collaboration where cities can learn from each other and take the right climate actions to meet the adaptation goals of the Paris Agreement. Through increased awareness and ambitious action, city leaders can ensure the continued resilience and sustainable development of urban areas in the age of climate change.

C. ABOUT THE TECHNICAL REPORT

The Technical Report presents the work done by UCCRN for the Future We Don't Want project. The Report contains results from the data analysis of six major global urban vulnerabilities to climate change based on several key hazards, as well as case studies that present examples of how cities are responding to these challenges.

The report presents the background of the technical data analysis and an overview of the UCCRN Case Study Docking Station on which the case study analysis is based. The report then details each of the six vulnerabilities individually. An overarching headline finding for each is presented, along with a map of the global urban outlook for that vulnerability, and the methodology used to develop that information. Then, an overview of that particular vulnerability and the overall findings of the data analysis are discussed. For each impact area, three case study cities have been selected, highlighting examples of how urban decision-makers are experiencing and responding to that particular challenge. The report concludes with a summary and overall key messages for how cities can use this information to prepare for a changing climate.

[1] *UCCRN is a network of cities dedicated to providing the information that city leaders–from government, the private sector, non-governmental organisations, and the community—need in order to assess current and future risks, make choices that enhance resilience to climate change and climate extremes, and take actions to reduce greenhouse gas emissions.*

D. SUMMARY OF RESULTS

SUMMARY OF GLOBAL NUMBERS

Vulnerability	Time Period	Population Estimate	City Estimate
EXTREME HEAT	Present Day	Over 200 million people	Over 350 cities
	2050s	Over 1.6 billion people	Over 970 cities
EXTREME HEAT AND POVERTY	Present Day	Over 26 million people	Over 230 cities
	2050s	Nearly 215 million people	Over 490 cities
WATER AVAILABILITY	2050s	Over 650 million people	Over 500 cities
FOOD SECURITY	2050s	Over 2.5 billion people	Over 1,600 cities
SEA LEVEL RISE	2050s	Over 800 million people	Over 570 cities
SEA LEVEL RISE AND POWER PLANTS	2050s	Over 450 million people	Over 230 cities

Extreme Heat: The total number of people living in cities where they are regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F) in the present day and in the 2050s.

Extreme Heat and Poverty: The total number of people living in poverty in cities where they are regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F) in the present day and in the 2050s.

Water Availability: The total number of people living in cities where freshwater availability from stream-flow is projected to decline by at least 10 percent by the 2050s, compared to the present day.

Food Security: The total number of people living in cities where their national yield of at least one of four major crops (maize, rice, soy, or wheat) is projected to decline by at least 10 percent by the 2050s, compared to the present day.

Sea Level Rise: The number of people living in coastal cities where sea level is projected to rise by at least 0.5 metres by the 2050s compared to the present day. Coastal cities are defined as those within 10 kilometres from the coast and have an average elevation below 5 metres.

Sea Level Rise and Power Plants: The number of people living in cities where nearby power supply facilities within 50 kilometres of the city are projected to be vulnerable to 0.5 metres of sea level rise by the 2050s, compared to the present day. Coastal power plants are defined as those within 5 kilometres from the coast and have an average elevation below 5 metres.

2. APPROACH TO TECHNICAL ANALYSIS

The technical analysis performed by UCCRN includes three major components: 1) A global-scale data analysis of six major urban vulnerabilities to climate change; 2) Case studies that contextualise the six major vulnerabilities and how cities are responding to them; and 3) A global GIS database that includes map layers by which these six hazards can be viewed globally across different cities. This technical report includes the global-scale data analysis results, global maps of cities projected to experience the vulnerabilities, and the case studies that ground the research in tangible urban experiences.

A. DATA ANALYSIS

The Future We Don't Want data analysis calculates urban vulnerability to climate change, focusing on six major topics. While these are not the only vulnerabilities that cities are facing as a result of the changing climate, these six areas highlight overarching risks that most cities will encounter and therefore they provide a broad context that encompass almost every city across the globe.

The six key climate vulnerability conditions studied in the Future We Don't Want analysis are:

- Heat extremes
- Poverty and heat extremes
- Water availability
- Food security
- Coastal flooding and sea level rise
- Energy supply and sea level rise

At the foundation of the data analysis, for each of these climate vulnerability conditions, is the estimated urban population facing these hazards. Figure 1 below illustrates the global cities that were considered in this analysis, estimating their total population levels, today and in the future.

Population estimates in the base period, for the 2000s, are from Natural Earth Populated Places Dataset[2] for cities with over 100,000 residents. Population estimates for the 2050s are based on population growth rates through the 2050s derived by applying the growth rate from the Global Rural-Urban Mapping Project (GRUMP)[3] urban population extents to the baseline population for cities within the Natural Earth Dataset of cities over 100,000 residents (Marcotullio, personal communication).

Cities were categorised by population size into five classes: a) 100,000 – 500,000; b) 500,001 – 1,000,000; c) 1,000,001 – 5,000,000; d) 5,000,001 – 10,000,000; and e) 10,000,000+. This methodology for population was applied to each of the six climate vulnerability analyses and are reflected in the maps throughout the report.

The total number of cities in the population dataset, and therefore the total number of cities included in this analysis, are 2,586. The total estimated urban baseline population of all of the cities in the Natural Earth Dataset in the 2000s is approximately 1.4 billion (1,435,802,343) people. The total estimated future urban population in the 2050s for all of the cities in this analysis is approximately 3.5 billion (3,547, 807,209) people. Figure 1 highlights the growth in city population size over the five decades between 2000 and 2050, as is indicated by the presence of far more highly-populated cities with over 1 million, 5 million, and 10 million residents compared to the base period.

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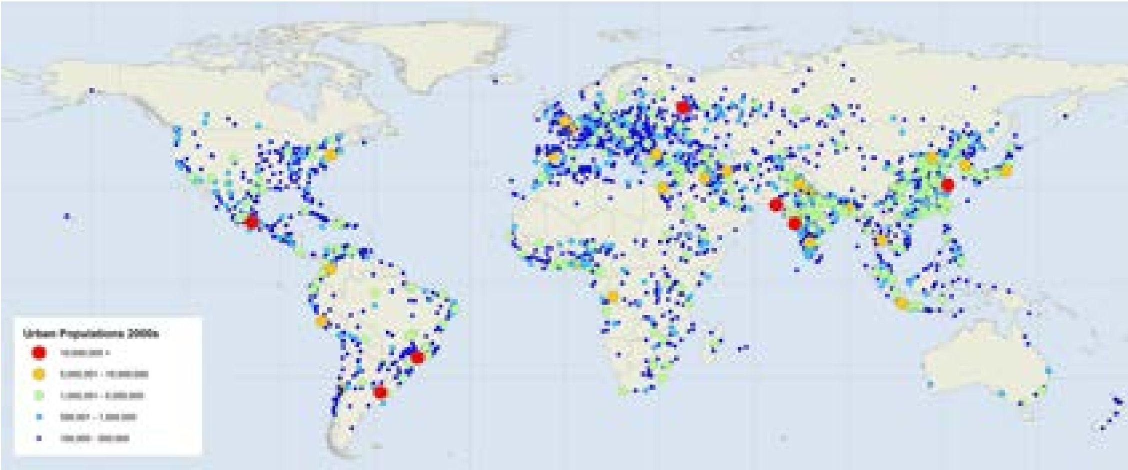
[2] *Natural Earth Populated Places Dataset - http://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-populated-places/*

[3] *GRUMPv1 - http://dx.doi.org/10.7927/H4C53HSR*

Urban populations **2000s**



Urban populations **2050s**

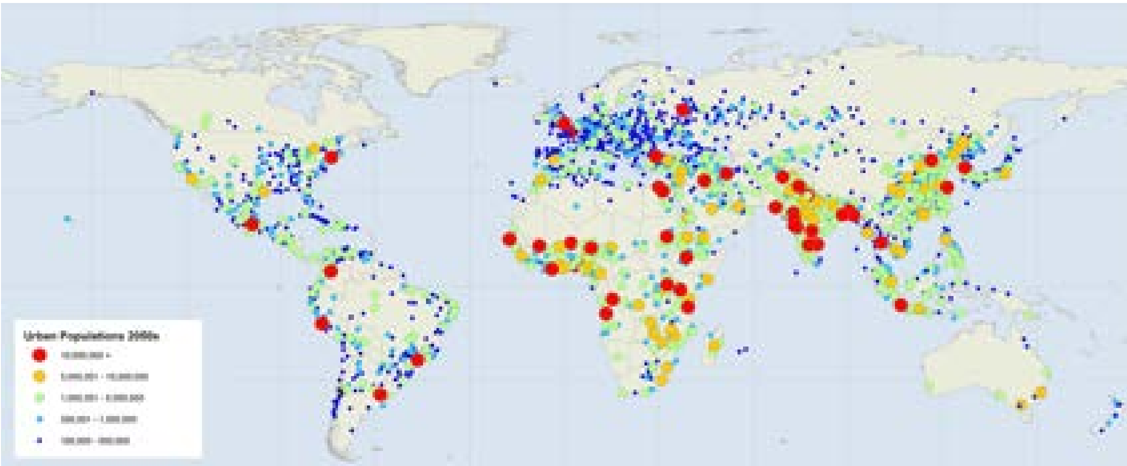


Figure 1. *Global cities with populations 100,000 and greater in the 2000s (top) and estimated urban populations in the 2050s (bottom). Data source for baseline population in 2000s from Natural Earth Dataset. Data source for population in the 2050s estimated from the GRUMP population growth estimates applied to the baseline population data in the 2000s Natural Earth Dataset (Center for International Earth Science Information Network (CIESIN), Columbia University, 2017).*

Center for International Earth Science Information Network (CIESIN), Columbia University. 2017. Documentation for the Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extent Polygons, Revision 01. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4C53HSR

B. CASE STUDIES

Each section of the Technical Report presents case studies that highlight how cities are addressing the six climate vulnerabilities on the ground. The content for these case studies comes from the UCCRN Case Study Docking Station (CSDS), which was developed as a part of the Second Assessment Report on Climate Change and Cities (ARC3.2) by local experts and practitioners (Rosenzweig et al., 2018). The UCCRN Case Study Docking Station includes climate projections for approximately 150 cities (Bader et al., 2018), and documents experiences of UCCRN cities and their strategies to improve resilience to climate change. Figure 2.a illustrates the CSDS search engine, and figure 2.b provides an example of a CSDS search. Of the nearly 150 UCCRN cities in the CSDS, 35 percent are also C40 cities, and 45 percent are also Global Covenant cities, who have all pledged to achieve the goals of the Paris Agreement. All case studies included in this report are both C40 cities and UCCRN cities. In addition, information in the case studies throughout the report is supplemented by interviews conducted by C40 and Acclimatise with city stakeholdersand experts.

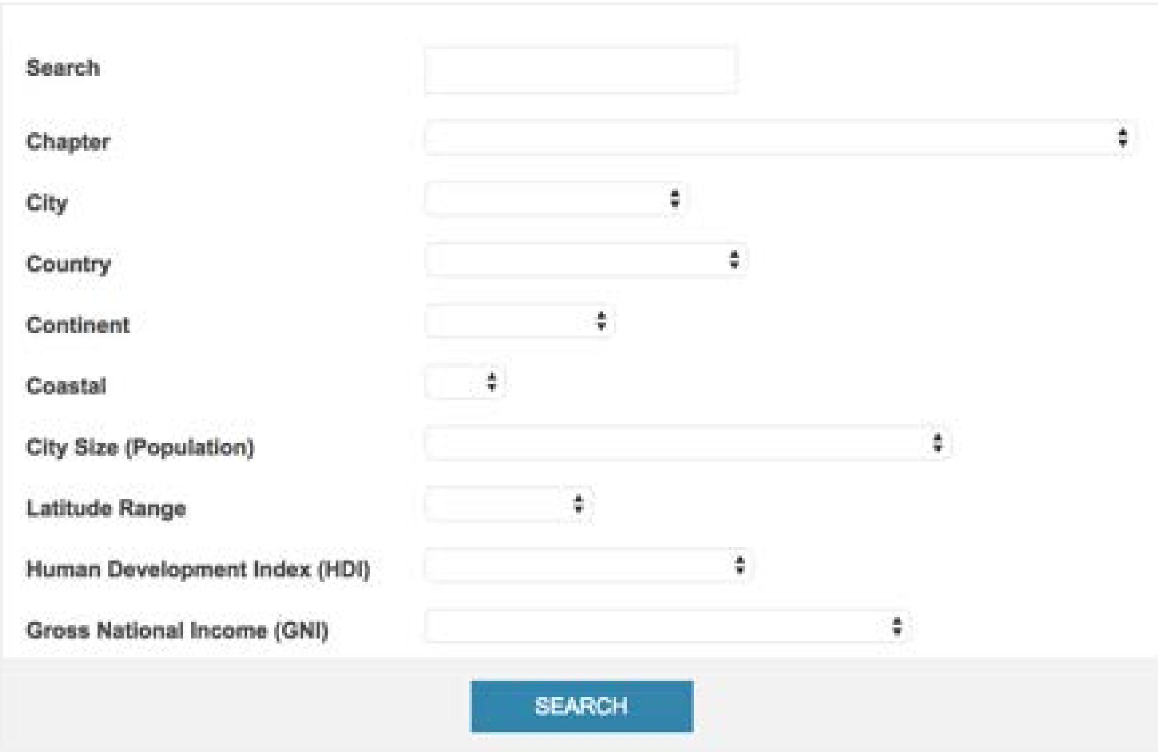


Figure 2.a. *ARC3.2 Case Study Docking Station (CSDS) search engine. See: http://uccrn.org/casestudies/*

CHAPTER	COUNTRY	CITY	CASE STUDY TITLE	CASE STUDY NUMBER	EXECUTIVE SUMMARY	CASE STUDY FILE
Coastal Zones in Urban Areas	United States (USA)	New York City	Preparing for Sea Level Rise, Coastal Storms, and other Climate Change-Induced Hazards	9.8	As a major center of global finance and international trade, New York City stands to lose a lot from ...	CS 9.8 - New York, United States.pdf
Economics, Finance, and the Private Sector	United States (USA)	New York City	Public Enabling of Private Real Estate in NYC	7.2	A variety of strategies developed by New York City (NYC) agencies advance the adaptive capacities of ...	CS 7.2 - New York, United States.pdf
Energy Transformation in Cities	United States (USA)	New York City	Consolidated Edison After Sandy: Planning for Energy Resilience	12.A	Con Edison, the electric power company in New York City, suffered major damage in Superstorm Sandy ...	CS 12.A - New York, United States.pdf
Energy Transformation in Cities	United States (USA)	New York City	Renewable Gas Demonstration Projects in New York City	12.3	In New York City, the development of the Newtown Creek Renewable Natural Gas Project is estimated to ...	CS 12.3 - New York, United States.pdf

Figure 2.b. *Example of search for New York City in the ARC3.2 CSDS (UCCRN, 2018).*

C. GLOBAL GIS DATABASE

UCCRN is developing an online, collaborative, web-based global geographic information system (GIS) that allows users to create, use, and share maps, scenes, apps, layers, analytics, and data. This enables UCCRN to integrate datasets and mapping products from individual projects in a consistent manner and facilitates visual representation of the work worldwide that cities are spearheading in their efforts to adapt to and mitigate climate change. Furthermore, meaningful insights can be drawn that inform stakeholders about climate change impacts on urban communities.

In order to complete the data analysis undertaken to support the project, a global GIS database has been developed that allows for visualisation and spatially consistent assessments of relative vulnerability to climate hazards in urban areas worldwide. GIS data layers associated with climate hazards have been put together with a map document (.mxd) into one convenient, portable file known as a 'map package.' Map packages are supported by Environmental Systems Research Institute, Inc (ESRI) ArcGIS® for Desktop version 10.0 onwards. Map packages will fail to open with older versions (9.3.1 or older).

The data layers in the database are ESRI shapefiles that include a main file (.shp), an index file (.shx), and a standard database file used to store attribute data and object IDs (.dbf). The .prj file included with each data layer is an optional file that contains the metadata associated with the shapefiles coordinate and projection system. In addition, an optional spatial index file (.sbn) is included that is utilised for spatial queries. The main file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The database table contains feature attributes with one record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the database file must be in the same order as records in the main file (ESRI, 1998).

Note: *Like all projections, these climate and vulnerable population projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some processes. In this report, the average climate projections are characterised using state-of-the-art climate models, one scenario of future greenhouse gas concentrations, and recent peer-reviewed literature. The potential for error should be acknowledged.*

HEAT EXTREMES

Bangkok

Today

- **Roughly 350 cities on earth experience extreme heat conditions in the form of 3-month average maximum temperatures reaching at least 35°C (95°F).**
- **Just over 200 million people in cities are living under extreme heat conditions.**
- **14 percent of the global urban population lives under high heat conditions.**

By the 2050s

- **Over 970 cities will be regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F).**
- **More than 1.6 billion people in cities will be living with extreme high summer temperatures.**
- **45 percent of the global urban population will be living in cities with high summer temperatures.**
- **The number of people living in cities regularly exposed to heat extremes will increase by 700 percent compared to today.**

A. INTRODUCTION AND JUSTIFICATION

As average global temperatures increase over the coming decades, extreme high temperatures are projected to increase in frequency, intensity, and duration. Cities are particularly at risk because of the urban heat island effect (UHI). The urban heat island effect is a phenomenon where cities tend to be warmer than surrounding suburban and rural areas as a result of a built environment characterised by a high degree of hard surfaces. This makes urban centers more susceptible to heat extremes which can worsen air quality (Foobot, 2017), cause dehydration, heat strokes, cardiovascular complications, kidney diseases, and death (Knowlton et al., 2014). Certain groups of people – including children, the elderly, the sick, and the poor – are particularly vulnerable to persistent heat extremes.

As climate change causes average global temperatures to increase over the coming century, higher extreme temperatures during the hottest times of the year will also become more intense. Today, many urban dwellers in lower latitudes are already familiar with extremely high temperatures for sustained periods of time. In the future, urban populations will continue to grow and more cities will experience higher temperatures. Cities in higher latitudes will therefore face heat extremes that they have not dealt with previously. Understanding how extreme heat situations are expected to change in the coming decades will help city leaders protect the health of city residents, increase infrastructure resilience, and prepare for demands on their energy systems.

B. METHODOLOGY

Extreme heat is defined in this analysis as the warmest 3-consecutive month period (defined using average monthly maximum temperature) in a given location. Climate scenarios used are from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange, and distributed by the NASA Center for Climate Simulation (NCCS) (NASA, 2017). The NEX-GDDP dataset is made available by NASA to assist the science community in conducting studies of climate change impacts at local to regional scales, and to enhance public understanding of possible future global climate patterns at the spatial scale of individual towns, cities, and watersheds.

Using outputs from four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M) in the NEX-GDDP dataset, monthly maximum temperatures were averaged over 3-consecutive months to find the hottest 3-month periods for each 0.25 by 0.25 degree grid cell. This analysis was conducted for both the historical model base period (1980-2005) as well as the future 2050s time frame (defined as 2041-2070).

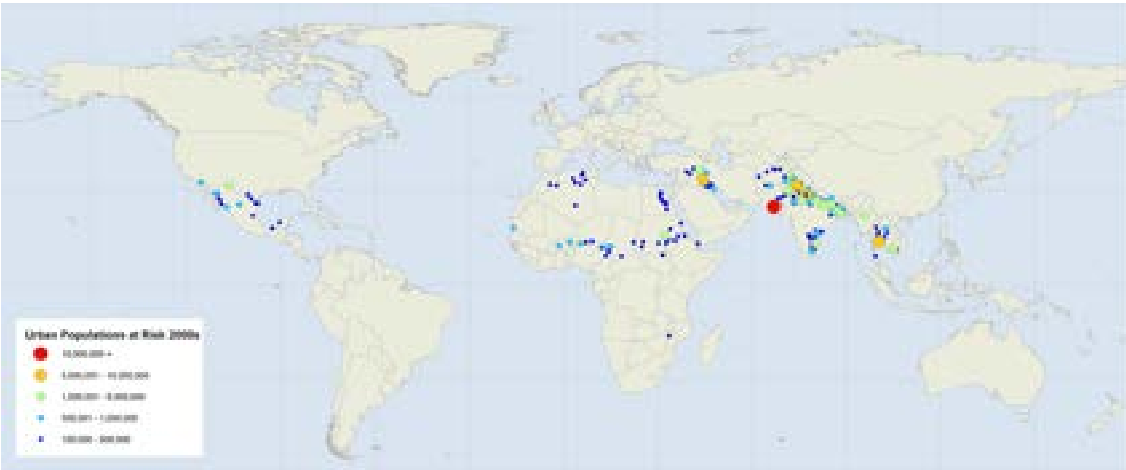
A temperature threshold of 35°C (95°F) was applied to multi-model means across all grid cells to identify the urban areas most vulnerable to extreme heat. That is a temperature when it is possible to, for example, experience heat cramp or exhaustion. The analysis was conducted for cities with populations greater than 100,000 during the base period and in the 2050s. The historical and projected populations of cities that exceed the extreme heat threshold are summed to develop a global estimate of the urban population vulnerable to extreme heat during the base period and in the 2050s.

C. DISCUSSION AND FINDINGS

Today, over 200 million people living in more than 350 cities, mostly in the lower latitudes, regularly experience their hottest 3-month average maximum temperatures reaching at least 35°C (95°F). Global urban populations are estimated to be 1.4 billion people in the base period - implying that 14 percent of all urban residents already face heat extremes.

As urban populations and average temperatures increase globally, over 1.6 billion people will be living in more than 970 cities where they will be exposed to these temperature extremes by mid-century (Figure 3). To put that in perspective, with urban populations in the 2050s projected to reach 3.5 billion people, 1.6 billion, or 45 percent of the total global urban population will be living under these heat conditions. This is an eight-fold increase in the number of urban residents facing sustained heat stress.

Extreme Heat **Baseline Period**



Extreme Heat **2050s**

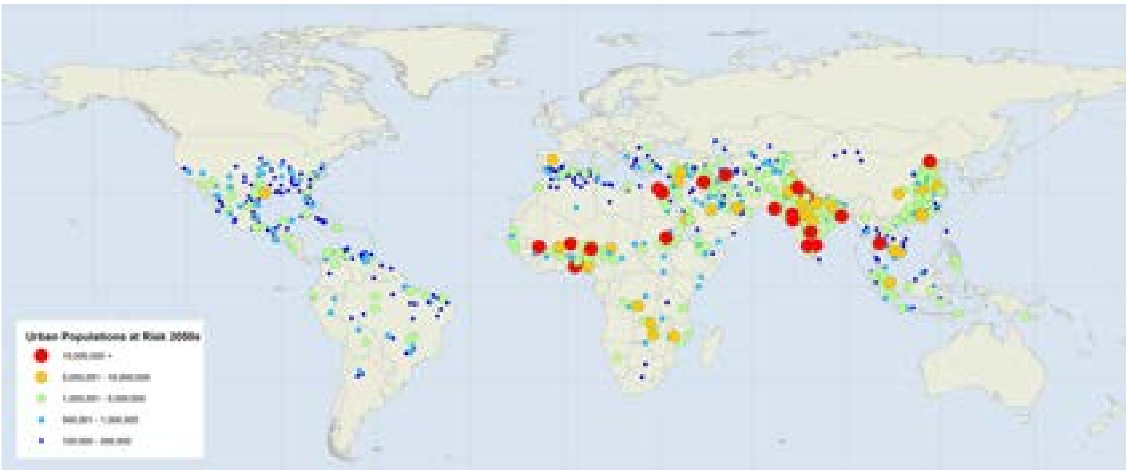


Figure 3. *Urban populations at risk to extreme heat. Data source: Cities with a three month period (consecutive months) where average maximum temperatures exceed 35°C in the baseline period (top) compared to those that are projected to experience these temperature extremes by the 2050s (bottom). Multi-model mean temperature is derived from the NASA NEX-GDDP dataset with four GCMs (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M); Average monthly (hottest three consecutive months) maximum temperature for 1980-2005 baseline period is compared to 2041-2070 under RCP 8.5; Population estimates in the baseline period are from the Natural Earth Dataset for cities over 100,000 residents, and population growth rates for the 2050s are derived by applying the growth rate from the Global Rural-Urban Mapping Project (GRUMP) urban population extents to cities within the Natural Earth Dataset.*

The Future We Don't Want analysis shows that Asia, and the Middle East, are already home to many cities that experience extreme temperatures. By 2050, the number of exposed cities in these regions will increase significantly with hundreds more cities at risk. The research also shows that regions that currently have few cities that deal with extreme heat, will see exposure rise dramatically. Eastern China; southern, western and northern Africa; North America and parts of South America will be especially affected. Rising urban populations in these regions is partially to blame for the increased exposure over the next 30 years when 90 percent of urbanisation is expected to be concentrated in Asia and Africa alone (United Nations, 2014).

D. IMPLICATIONS FOR CITIES

Past heat waves offer a window into the future for cities expecting temperatures to rise. Today, nearly one third of the world's population is exposed to life-threatening heat extremes for 20 days a year or more (Mora et al, 2017). Events such as the 2003 heatwave in Europe, which claimed over 70,000 lives, and the 2015 heatwave in South Asia, that resulted in 3,500 deaths, will become more frequent and severe by the 2050s.

In the United States, heat waves pose a major climate-related risk to cities because more fatalities occur from heat waves than from any other climate hazard, (NOAA, 2016). For example, out of 4,564 reported fatalities between 2006 and 2015 related to hazards such as tornadoes, floods, lightning, winter storms, and hurricanes, a total of 1,130 fatalities were related to heat, representing almost 25 percent of the fatalities reported. Although, it's worth noting that the number shown does not capture the full-extent of heat-related deaths because many fatalities associated with heat extremes are not identified as such by medical examiners (NOAA, 2016).

By 2050, people who already live in hot places will have to adapt to even longer periods of sweltering heat; while people who live in cooler cities will be exposed to levels of extreme heat to which they are unaccustomed. Cities will therefore need to plan for temperatures that make it difficult and exhausting for citizens to move around and work safely outdoors, as well as unbearable to stay indoors without air-conditioning and sufficient ventilation. Ozone production is accelerated at high temperatures and short-term exposure to ozone has been linked to adverse health effects. High levels of ozone have also been related to exacerbated chronic lung disease and increased mortality rates (Bell et al., 2004). Children, the elderly, the sick, and the poor in urban areas are particularly vulnerable to persistent heat extremes during the hottest times of the year (Wilhelmi et al., 2004).

Direct heat stress is particularly harmful when nighttime temperatures are high. This prevents the human body from rest and regeneration as a rise in body temperature under heat wave conditions will severely decrease the heat loss needed to adjust internal mechanisms that regulate body temperature. Such conditions can lead to excessive strain on the body and ultimately cause heat illness and an increase in heat-excess related mortality and morbidity (Amengual et al., 2014). Indirect heat-related effects on health arise through the interaction of heat and other environmental factors, particularly air and water pollution. For example, air pollutants and heat can cause higher ozone concentrations, which can irritate the respiratory system and reduce lung function. As a result, heat waves can cause heart attacks and aggravate asthma, bronchitis, and other cardiopulmonary diseases, leading to premature death (Franchini and Mannucci, 2015).

Given the complex interaction between heat extremes and the physiological factors outlined above, any city's heat action strategy will have to account for a broad range of causes and impacts in order to strengthen resilience to future extreme heat. In a warming world, it is critical that adaptation strategies are supported by wider efforts to improve urban infrastructure and services. A resilient city needs accessible and affordable healthcare, reliable public transport, uninterrupted electricity supplies, clean drinking water, and well-functioning sanitation systems. By reducing emissions, cities around the world can work together to make sure that the Future We Don't Want scenarios - where 1.6 billion people living in over 970 cities would be exposed to extreme temperatures by mid-century - are not realised; while simultaneously planning for the possibility that they are.

E. URBAN RESPONSES TO EXTREME HEAT

The technical data analysis for extreme heat in The Future We Don't Want is supplemented with three case study examples from cities that are already facing high temperatures.

CASE STUDIES

Delhi, India

UCCRN City • C40 City

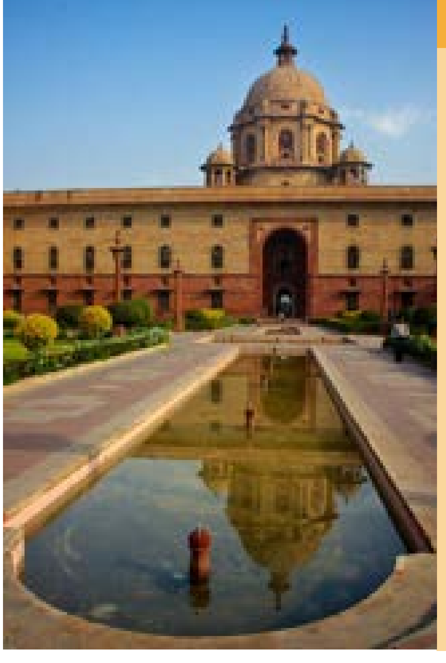


Image Source: Edmund Gall, CC BY-SA 2.0

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	**+1.5 to 3.3°C**
Precipitation	**-13 to +28 percent**

- In India, heatwave deaths have almost doubled over the past 20 years.
- Over 2,000 deaths were recorded during the North India heat wave of 2015.
- Outdoor workers and people in low-income homes suffer the most during heat extremes. In homes with tin-roofs, temperatures can cross 50ºC (122ºF), during heatwaves in Delhi.
- Spikes in heat-related afflictions lead to increased pressures on health services. Patients reporting dehydration, diarrhea and heat cramps almost double in hospitals during heat waves.

SOLUTIONS

- 30 cities and 11 states in India have developed a "Heat Action Plan" that incorporates early warning systems, suggests changes in outdoor work-hours, outlines improvements in health service responses, and promotes mass-media campaigns to sensitise communities.
- Early warning systems alert residents and city officials one week before a heatwave, allowing city officials to plan their response.
- Mortality rates have dropped from 2,600 people in 2015 to less than 200 in 2017, owing to better coordinated action by the Meteorological and Disaster Management Departments.
- Delhi is the 12th city that will develop a Heat Action Plan in 2018.

Seoul, South Korea

UCCRN City • C40 City • Global Covenant City

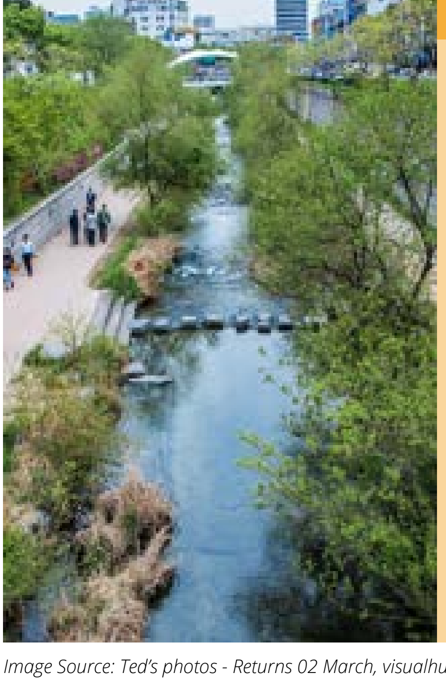


Image Source: Ted's photos - Returns 02 March, visualhunt.com, CC BY-NC-SA

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	**+1.5 to 3.4°C**
Precipitation	**+1 to +19 percent**

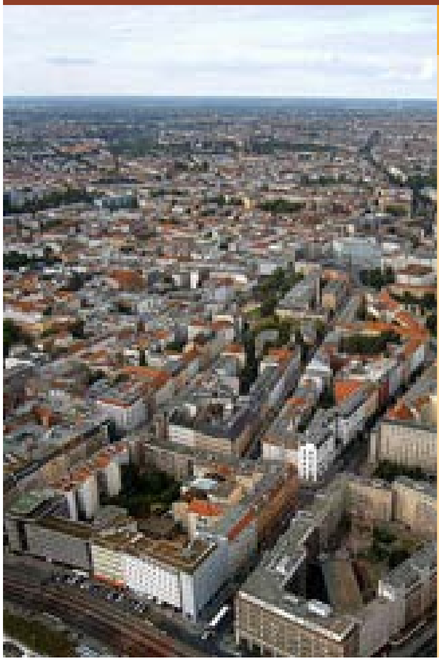
- In Seoul, the minimum temperature during winter has increased at an average rate of 0.5°C per decade.
- During heatwave days, there is an 8.4 percent increase in total mortality compared to non-heatwave days.
- The first heatwave of the summer has had a larger estimated mortality effect than later heatwaves.
- During the 2013 heatwave, city authorities had to restrict use, and turn-off air conditioning in government buildings, to prevent a power outage.

SOLUTIONS

- Heatwave advisories are issued when temperature highs reach 33°C (91°F) for 2 consecutive days.
- Companies are advised to allow outdoor workers to take breaks during the hottest hours of the day.
- Cooling shelters are provided in public locations throughout the city, which allows residents without air conditioning to find respite from the heatwave.
- As a long-term effort to improve Seoul's resilience to heat, and other climate hazards, the city has planted 16 million trees and expanded its green space by 3.5 million m².

Berlin, Germany

UCCRN City • C40 City • Global Covenant City



IMPACTS

ARC 3.2 Climate Projections – 2050s

Temperature	+1.3 to 3.6°C
Precipitation	-2 to +16 percent

- Days of extreme heat have become more common, leading to increased rates of mortality during intense heat waves.
- Rapid urbanisation and the growing number of elderly have increased the city's vulnerability to heat extremes.
- Heat-related mortality rates are particularly high in Berlin's most densely built-up districts.
- Extreme heat has also affected the transport system, for example, by making train carriages without proper ventilation too hot to use.

SOLUTIONS

- Berlin aims to become a 'Sponge City' that replaces hard surfaces with green space and water-permeable surfaces to combat the urban heat island effect as well as enable the city to adapt to heavy rains.
- By planting rooftops with mosses or grasses, the ability to absorb water increases while an evaporative cooling effect is achieved.
- Berlin has monitoring systems for climate change that aim to strengthen the resilience of ecosystems, public health and urban infrastructure.
- The city is working on improving communication to communities about upcoming risks and action.

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HEAT EXTREMES AND POVERTY

Auckland

Today

- **Over 26 million people are living in poverty in more than 230 cities where they are regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F).**

By the 2050s

- **Nearly 215 million people will be living in poverty in 495 cities where they will be regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F).**
- **There will be an eight-fold increase in the number of people living in poverty in these extreme heat conditions compared to today.**

A. INTRODUCTION AND JUSTIFICATION

Impacts of climate change differ among people and groups because of varying socio economic factors. People with lower incomes and limited assets; people who are discriminated on the basis of race, ethnicity, gender, age, poor health will be hit the hardest (Reckien et al., 2018). These social characteristics influence where people live and how severely they are affected. Impoverished populations are particularly vulnerable to climate change because they lack access to resources that could help them withstand extreme events. For example, during extended heat events, people living in poverty face additional risks compared to other populations because they may lack access to adequate drinking water, shelter, air conditioning, and medical assistance. As urban populations continue to grow, the number of people vulnerable to climate change will also also continue to rise.

B. METHODOLOGY

Extreme heat is defined in this analysis as the warmest 3-consecutive month period (defined using average monthly maximum temperature) in a given location. Climate scenarios are from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange, and distributed by the NASA Center for Climate Simulation (NCCS). The NEX-GDDP dataset is made available by NASA to assist the science community in conducting studies of climate change impacts at local to regional scales, and to enhance public understanding of possible future global climate patterns at the spatial scale of individual towns, cities, and watersheds.

Using outputs from four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M) in the NEX-GDDP dataset, monthly maximum temperatures were averaged over 3-consecutive months to find the hottest 3-month periods for each 0.25 by 0.25 degree grid cell. This analysis was conducted for both the historical model base period (1980-2005) as well as the future 2050s time frame (defined as 2041-2070).

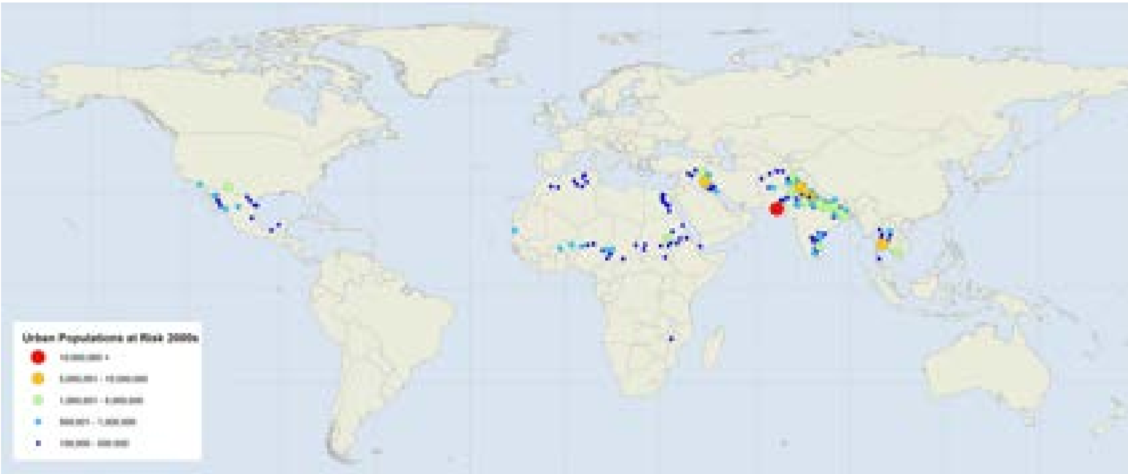
A temperature threshold of 35°C (95°F) was applied to multi-model means across all grid cells to identify the urban areas most vulnerable to extreme heat with GIS software. The analysis was conducted for cities with populations greater than 100,000 during the base period or the 2050s. The historical and projected populations of cities (with populations greater than 100,000) that exceed the extreme heat threshold are summed to develop a global estimate of the urban population vulnerable to extreme heat during the base period and in the 2050s respectively.

Poverty rates are derived from national Urban Poverty Headcount Ratios developed by the World Bank, Global Poverty Working Group. Data are compiled from official government sources or are calculated by World Bank staff using national (i.e., country-specific) poverty definitions (World Bank, 2017). The Urban Poverty Headcount Ratio (i.e., national urban poverty rate) is the percentage of the urban population living below the national poverty line. This dataset includes poverty rates for 97 countries. The rate of poverty was applied to the total urban population estimates for the baseline and future periods in this analysis. The total urban population in poverty facing heat extremes was determined by applying national urban poverty rates to cities projected to be vulnerable to extreme heat in the 2050s.

C. DISCUSSION AND FINDINGS

Today, over 26 million people across 230 cities live in poverty and are regularly exposed to sustained high temperatures. As urban populations and average temperatures increase over the coming decades, the analysis estimates an 700 percent increase in the number of urban poor living in these extreme heat conditions. The projections indicate that over 215 million people will be living in poverty spanning across nearly 500 cities in the 2050s time period (Figure 4). In particular, cities in Southeast Asia as well as West Africa are particularly vulnerable to these changing conditions with high rates of poverty, rapid urbanisation, and already-existing high heat conditions.

Extreme Heat and Poverty | Baseline Period



Extreme Heat and Poverty | 2050s

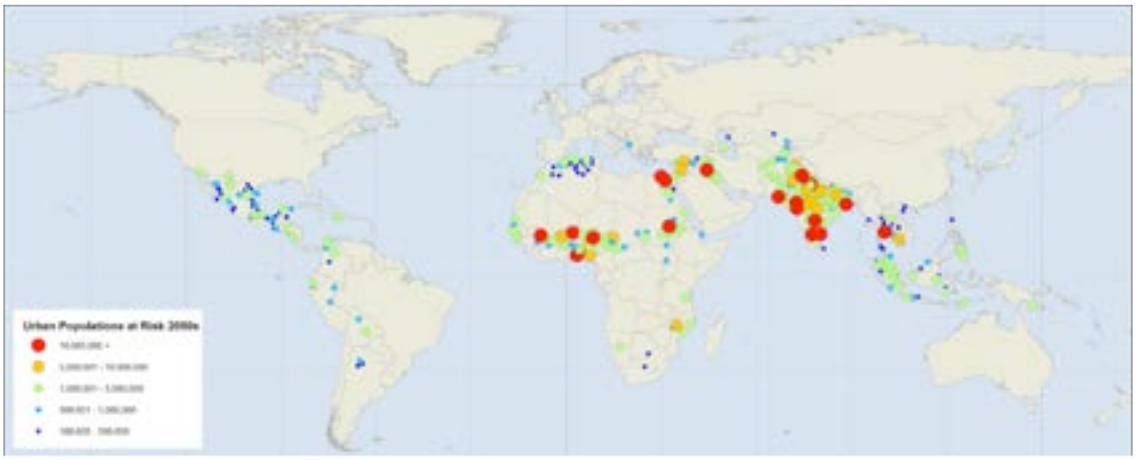


Figure 4. Urban populations in poverty at risk to extreme heat. *Data Source: Cities within countries for which the World Bank has developed national urban poverty ratios are shown (if they are at risk to extreme heat). Cities with a three-consecutive-month period where average maximum temperatures exceed 35°C (95°F) in the baseline period (top) are compared to those that are projected to experience these temperature extremes by the 2050s (bottom). Multi-model mean temperature is derived from the NASA NEX-GDDP dataset with four GCMs (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M); Average monthly (hottest three consecutive months) maximum temperature for 1980-2005 baseline period is compared to 2040-2071 under RCP 8.5; Population estimates in the baseline period are from the Natural Earth Dataset for cities over 100,000 residents, and population growth rates for the 2050s are derived by applying the growth rate from the Global Rural-Urban Mapping Project (GRUMP) urban population extents to cities within the Natural Earth Dataset. The same World Bank poverty rate in the baseline period is applied to the total projected urban population levels in the future time period to obtain a projected estimate of total urban residents in poverty in the 2050s.*

D. IMPLICATIONS FOR CITIES

The Future We Don't Want research shows that, cities that face average summertime temperature highs of 35˚C (95˚F) by 2050, will also have significant proportions of their populations living in poverty. Booming population growth in cities in Africa and Asia will drive much of the increase in the numbers of urban poor exposed to high temperatures.

Social characteristics, such as low income; limited assets; and discrimination on the basis of minority status, race or ethnicity, sex and gender, age, poor health, and impaired mobility, influence where people live, and how severely they are affected by climate impacts (Reckien et al., 2018; Satterthwaite 2008; Williams et al., 2010). However, it is not just the most vulnerable who are impacted. Regularly occurring events can gradually undermine the resource base of more resilient groups in society, which ultimately leads to increases in the scale and depth of urban poverty (Tyler and Moench, 2012; Tompkins et al., 2013). The research also stresses that climate change will have a downward pull on the financial resources of many residents currently not considered to be especially poor. Should cities face extreme climate events more frequently, leaving little time for recovery, this could ultimately increase overall levels of urban poverty (Reckien et al., 2018; Tyler and Moench, 2012).

Differentials in the scale and nature of risks among informal settlements relate to the extent of infrastructure and services provision that is present in a given location. Differentials in risk, arising from inadequate or no infrastructure, and a lack of access to services, can emerge due to factors such as age, sex, and health status. For example, the 1991 cyclone in Bangladesh killed 138,000 people, many of whom were women older than 40 years (Dankelman et al., 2008). An analysis of the impacts of the 2011 floods in Lagos similarly revealed differences in vulnerability among low-income women based on gender relations and gender roles in household structure, occupation, and access to health care (Ajibade et al. 2013). Differentials in risk can also arise from the lack of voice for particular groups, such as informal settlers, and a lack of accountable government agencies in certain areas (Huq et al., 2007).

Many cities that are affected by higher than average climate change impacts also show particularly high growth rates; especially those in low-income countries of Asia and Africa where nearly 90 percent of the increase in urban population between now and 2050 is expected to take place (UNDESA, 2014). These demographic trends put ever-increasing numbers of people at risk from climate change and will potentially amplify equity and environmental justice issues. It is likely that rapid population growth in developing country cities will correspond with an increase in slum populations, which is often associated with unplanned and unregulated settlements in risk-prone areas (UN-Habitat, 2013; Revi et al., 2014). Currently, 62 percent of the population in Africa, and about 30 percent in Asia live in slums, and rapid urban growth poses a major challenge for city governments.

Mobilising resources to improve equity and environmental justice under changing climatic conditions requires the participation of impacted communities and the involvement of civil society. A key need is to learn how to tap non-traditional sources of finance, including partnerships with the private sector and community contributions. Governance also needs to be strengthened in regard to adherence to principles of transparency in spending, monitoring, and evaluation (Reyes 2013; Newell 2005).

Working with environmental justice groups can make an important contribution to increasing awareness, bringing equity issues to the forefront, and promoting the inclusion of equity into city plans and policies (Reckien et al., 2018). Particular attention should be paid to the need for equity between women and men because gender inequality is often overlooked in climate change studies, disaster-relief programmes, and mitigation and adaptation policies (Gencer et al., 2018).

If the Future We Don't Want scenarios are realised, and the number of urban poor in developing countries that are exposed to the worst heat extremes rise by around 200 million people by mid-century, it is important to remember that the poor are often best positioned to protect their neighbourhoods from worsening climate impacts. As the UN notes, "the urban poor have a proven capacity to improve and invest in their communities" (United Nations Momentum for Change, 2014). Cities that engage in an open dialogue with vulnerable communities can often find innovative, sustainable ways to build climate resilience (Rosenzweig et al., 2018). Ensuring that development policies and climate adaptation plans are developed not just with the poor in mind, but on board, is essential for climate policies to be effective over the long term.

E. URBAN RESPONSES

The technical data analysis for extreme heat and poverty in The Future We Don't Want is supplemented with three case study examples from cities that are already facing this scenario.

CASE STUDIES

Cairo, Egypt

UCCRN City • C40 City

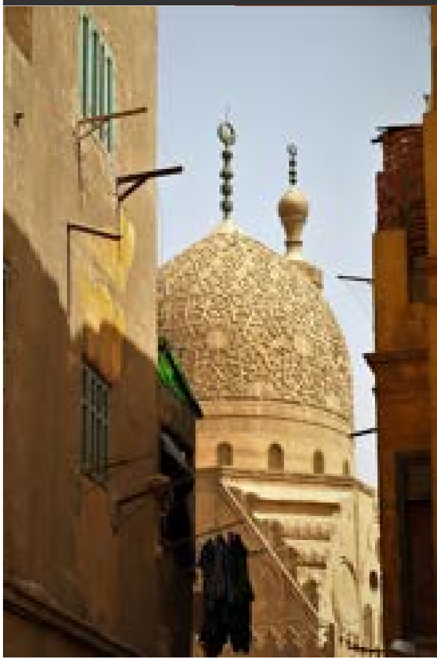


Image Source: pixabay.com, CC0

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	**+1.5 to 3.4°C**
Precipitation	**-31 to +9 percent**

- Cairo is already experiencing periods of extreme heat today, and the heatwaves will increase in intensity and frequency by mid-century.
- The city's informal areas, home to millions of residents, are anticipated to be highly vulnerable to increasing heat waves.
- Besides being vulnerable to heat, residents in informal areas will also be vulnerable to water scarcity.

SOLUTIONS

- In an effort to better understand the conditions and challenges in vulnerable neighbourhoods, the Eco-citizen World Map Project (EWMP) crowdsourced urban data to holistically assess local conditions in Cairo's Imbaba neighbourhood.
- Participatory community-mapping, that connected local residents with academic institutions and multilateral organisations, enabled water efficiency and conservation measures.
- The EWMP helps ensure grassroots interventions aimed at reducing the Imbaba neighborhood's vulnerability to climate change.

Accra, Ghana

UCCRN City • C40 City • Global Covenant City

Image Source: Ted's photos - Returns 02 March, visualhunt.com, CC BY-NC-SA

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	**+1.2 to 2.4°C**
Precipitation	**-12 to +11 percent**
Sea Level Rise	**+17 to 58 cm**

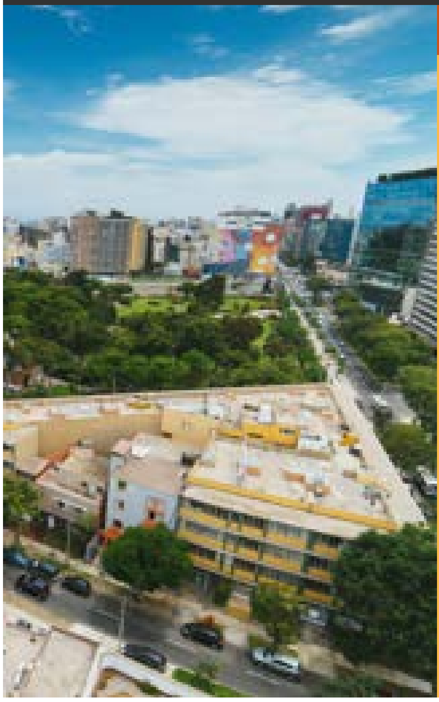
- Dwellings in informal settlements with corrugated iron roofs get exceedingly hot during periods of extreme heat, which can cause heat-related illnesses.
- Many informal settlements are highly vulnerable to flooding, with water pouring into houses from above and below due to leaking roofs and a lack of drainage.
- Recurring climate impacts force residents of informal settlements to use their small savings for continuous repairs.

SOLUTIONS

- The People's Dialogue on Human Settlements is a project set up by a network of community-savings groups in poor neighbourhoods.
- The initiative has resulted in a series of joint projects between communities and the local government that aim to address urban poverty, unemployment, and homelessness.

Lima, Perú

UCCRN City • C40 City • Global Covenant City



IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.4 to 2.9°C
Precipitation	-7 to +33 percent
Sea level Rise	+14 to 55 cm

- Large-scale rural to urban migration over the past decades have caused many settlements to be built on desert plains, riverbeds, and steep hills, leaving them exposed to climate impacts such as heat, flooding, and landslides.
- 600,000 homes across the city are built in areas at high risk of negative climate impacts.
- When Lima suffered severe rainfall in 2017, it caused widespread flooding and triggered landslides. 210,000 homes were damaged or destroyed and 150,000 urban residents were displaced.

SOLUTIONS

- Through the programme Barrio Mío, a poverty map of the city has been developed, and priority is given to projects in underserved areas.
- As a result of Barrio Mío, 36,430 people have been trained in risk management and 315 community committees have been created.
- The city of Lima has also planted 42,600 trees to help stabilise hills and improve environmental quality and livability, including the restoration of public spaces.

Image Source: Dan Gold on unsplash.com

WATER AVAILABILITY

By the 2050s

- **Over 650 million people living in over 500 cities will be vulnerable to reduced freshwater availability in the 2050s due to declines in streamflow of 10 percent or more.**
- **Global water demand is expected to increase by 55 percent.**

A. INTRODUCTION AND JUSTIFICATION

With respect to climate change, water is both a resource and a hazard. As a resource, good-quality water is basic to the well-being of the ever-increasing number of people living in cities. However, drought or excess precipitation can lead to hazards such as flood-related damage to physical assets, decreased water quality (with negative health consequences), and lack of adequate water flow for sewerage. As cities grow, demand and competition for limited clean water resources will therefore increase, and climate-linked impacts are very likely to make these pressures worse in urban areas across the globe (Vicuña et al., 2018).

In response to warming, evaporation is projected to increase over most land surfaces globally, except primarily in southern Africa and Australia, where declines in soil moisture availability are sufficient to reduce overall evaporation (Collins et al., 2014). Net water deficits (i.e., evapotranspiration minus precipitation) are projected to increase over most subtropical to mid-latitude regions, and decline over the higher latitudes, with precipitation increases compensating for increases in evaporation caused by warming temperatures (Kirtman et al., 2014). In most regions where net deficits increase, run-off and recharge may be expected to decline such that water availability is likely to suffer. Even in regions where net deficits decline somewhat, the amount of run-off and recharge derived from each unit of precipitation will likely decline due to enhanced evapotranspiration (Das et al., 2011; Georgakakos et al., 2014).

Warming-induced declines in snowpack, glaciers, and less seasonally persistent snowpack (e.g., earlier snowmelt) are expected to change the timing of water availability for 70 percent of major rivers and for water supplies around the world that depend on mountain-based seasonal snows as their source (Vuviroli and Weingartner, 2008). This alters the natural storage of water from cooler seasons with low water demands to warm seasons when demands are commonly highest. This shift in the seasonal timing of water availability is expected to challenge water management systems in many parts of the world (Barnett et al., 2005; Oberts, 2007; Kenney et al., 2008; Wiley and Palmer, 2008; Meza et al., 2014; Buytaert and De Bièvre, 2012).

Climatic pressures will interact at different spatial scales and have a synergistic impact on water availability, which depends not only on the amount of water at different sources, but also on water quality, infrastructural integrity, arrangements among competing users, and strength of institutions. Governance systems have largely failed to adequately address the challenges that climate change poses to urban water security. Failure is often driven by a lack of coherent and responsive policy, limited technical capacity to plan for adaptation, limited resources to invest in projects, lack of coordination, and low levels of political will and public interest (Vicuña, et al., 2018).

B. METHODOLOGY

The purpose of this analysis is to explore and synthesise the current state of knowledge about the impact of climate change on renewable water resources at the global scale. The map shows cities that are located in areas where the multi-model ensemble mean of streamflow is projected to decline by at least 10 percent in the 2050s (2041-2070) compared to the baseline period (1980-2005). From the framework created by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP Fast Track), a set of two global hydrological models (GHMs) – JULES and LPJmL – have been applied using bias-corrected forcing from four different global climate models (GCMs) – IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M – under representative concentration pathway 8.5 (ISIMIP, 2018; Best et al., 2011; Bondeau et al., 2007).

ISIMIP offers a consistent framework for cross-sectoral, cross-scale modelling of the impacts of climate change. The key goal of ISIMIP is to contribute to the comprehensive (cross-sectoral) understanding of the impacts of politically and scientifically-relevant climate-change scenarios. The first ISIMIP simulation round, the ISIMIP

Fast Track, ran from early 2012 until 2013, with a focus on providing cross-sectorally consistent projections of the impacts of different levels of global warming in the 21st century.

By using naturalised flows (i.e., modelled streamflow without the interference of man-made structures), it is possible to isolate the impact of climate change on water availability. Note that the Future We Don't Want analysis has not taken into account water resources available in man-made reservoirs, in underground water storages, or from desalination plants; nor did we include any infrastructure for the transfer of water between river basins. Water availability estimates utilised within this analysis should therefore be interpreted as conservative (i.e., lower-end estimate) (Veldkamp et al. 2016).

C. DISCUSSION AND FINDINGS

Half a billion people already face severe water scarcity all year round (Mekonnen and Hoekstra, 2016). In the 2050s, the analysis shows that 650 million people in over 500 cities may face more than a 10 percent decline in streamflow compared to present day levels (Figure 5). Due to the uncertainty around groundwater resources, globally we only consider streamflow (discharge) to assess water availability risks, even though some cities rely on both surface and groundwater extraction. We therefore systematically underestimate water availability, but one should keep in mind that groundwater extraction often occurs at higher rates than can be compensated for by natural recharge (Wada et al. 2010). Groundwater extraction, therefore, rarely corresponds to sustainable use of resources, and within the long-term focus of our study, surface water provides the main source for sustainable water consumption. The omission of groundwater therefore makes our assessment of water availability risk conservative (Orlowski et al. 2014).

By 2050, the global population is expected to reach nine billion, and global water demand is expected to increase by 55 percent (UNESCO, 2015). These projections put a considerable strain on existing water resources. The Future We Don't Want research now suggests that climate change will aggravate the problem dramatically. The findings show that urban areas of the Middle East and North India, as well as South America will be particularly vulnerable to reduced streamflow by the 2050s.

Decline in freshwater **2050s**

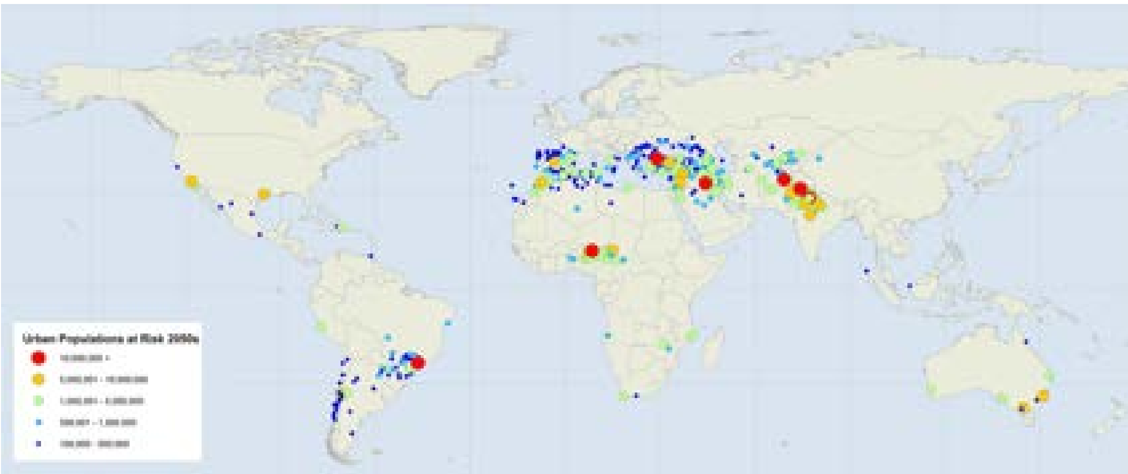


Figure 5. Cities projected to experience at least a -10 percent decline in streamflow in the 2050s compared to current levels. *Data source: Two GHMs (JULES and LPJmL) and four GCMS (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) utilised to develop a multi-model mean.*

D. IMPLICATIONS FOR CITIES

Warmer temperatures result in a greater demand for water in many cities (Schleich and Hillenbrand, 2009). The extent of this temperature sensitivity, however, depends considerably upon climate, land use, and energy dependency within cities (Zhou et al., 2000; Ruth et al., 2007; O'Hara and Georgakakos, 2008; House-Peters and Chang, 2011; Almutaz et al., 2012; Breyer, 2014; Donkor et al., 2014; Stoker and Rothfeder, 2014). For example, climate change may have a larger impact in cities that are reliant on older, less water-efficient, and coal-based thermoelectric plants than in cities that rely on newer, more water-efficient, natural gas combined-cycle thermoelectric plants (Scanlon et al., 2013a, 2013b).

Cities often draw water from sources that are located much further away from their local water supply (McDonald et al., 2014). Therefore, urban water supply is highly dependent on climatic changes in surrounding areas, in addition to climate pressures on supplies located within cities.

Different water uses and users in urban settings have different requirements for water supply, wastewater, and sanitation. In urban centers, critical services like healthcare, food supply, transportation, energy systems, schools and retail share interdependencies with water. Projected deficits in the future of urban water supplies will likely have a major impact on both water availability and costs. Decisions taken now will have an important influence on future water supply for industry, domestic use, and agriculture.

Adaptation strategies for urban water resources will be unique to each city since they depend heavily on local conditions. Understanding the local context is therefore essential to adapting water systems in ways that address both current and future climate risks. A lack of urban water security, particularly in lower income countries, is an ongoing challenge. As a result, water scarcity is also often a catalyst for conflict. In South India, inter-state disputes on water sharing have repeatedly triggered riots (New Indian Express, 2016). A number of news reports now link recent protests and civil unrest in Iran to persistent water scarcity in the country, which, experts say, is linked to both climate change and poor water management (New York Times, 2018).

Many cities struggle to deliver even basic services to their residents, especially those living in informal settlements. As cities grow, demand and competition for limited water resources will increase, and climate changes are likely to make these pressures worse in many urban areas. Acting now can minimise negative impacts in the long term. Master planning should anticipate projected changes over a time frame of more than 50 years. Yet, in the context of an uncertain future, finance and investment should focus on low-regret options that promote both water security and economic development, and policies should be flexible and responsive to changes and new information that come to light over time.

Urban governance systems will have to adequately address the challenges that climate change poses to urban water security. Doing so requires coherent and responsive policy, sufficient technical capacity to plan for adaptation, resources to invest in projects, coordination between and within governmental organisations, along with political will, public knowledge, and interest (Tanner et al., 2009).

Water availability is often the first casualty of any climate impact. If city governments do not act swiftly to meet their mitigation and adaptation commitments under the Paris Agreement, water scarcity affecting over half a billion people living in 500 cities would lead to cascading socioeconomic impacts, hurting urban economies and threatening their stability.

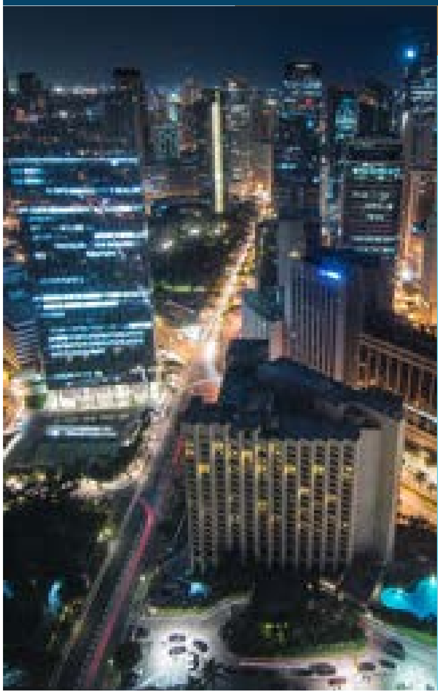
E. URBAN RESPONSES

It is important to develop adaptation measures that minimise the negative impact of water scarcity on the built, social, and ecological environments of cities.

CASE STUDIES

Manila, Philippines

UCCRN City • Global Covenant City



IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.1 to 2.1°C
Precipitation	-3 to +14 percent
Sea Level Rise	+14 to 60 cm

- High population density and moderate adaptive capacity make the city more susceptible to negative climate impacts.
- Manila is projected to experience increased frequency and intensity in tidal surges, typhoons, storms, and droughts. 16 million people are threatened by around 9 tropical storms that make a landfall each year, resulting in floods, displacement, and disease.
- Water supply systems are inefficient and burdened with debt.

SOLUTIONS

- Metro Manila's adaptation strategies cover vulnerability assessments, climate resilient assets, disaster risk reduction and management, and water source protection and development.
- The development of water safety Plans (WSPs) have helped decision-makers identify risks and prioritise investments.
- Community partnerships like "Tubig Para sa Barangay" (Water for the Poor) have made safe drinking water available to individual households.
- There is now a standard procedure of constructing water impounding facilities (rainwater collection systems) underneath shopping centers.

Image Source: PhotosThroughMyEyes on Visualhunt.com / CC BY-NC-SA

Tehran, Iran

UCCRN City

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.9 to 3.6°C
Precipitation	-12 to +11 percent

- In 2014, Tehran suffered a prolonged drought with annual rainfall estimated at below 80 percent of the long term average. Less precipitation, a growing population, and poor water management have led to a severe water crisis.
- Inadequate water distribution infrastructure and low water prices have resulted in urban over-consumption of water.
- In less than 25 years, 60 percent of the country's population risk needing to leave if current water conditions persist, according to Iran's former agriculture minister.

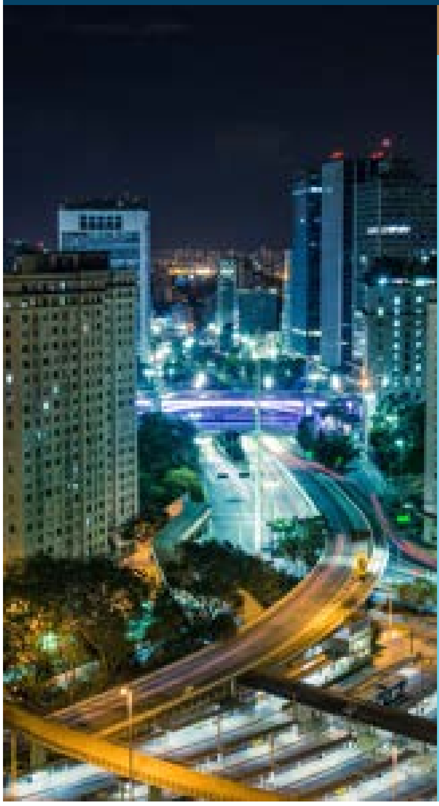
SOLUTIONS

- Due to the lack of permanent surface water resources, several dams transfer water to Tehran.
- Alternative technological solutions (e.g., inter-basin water transfer and desalination) are being explored.
- In 2016, the Tehran government developed information-based advisories to try and change consumption patterns among residents and businesses.

Image Source: nima; hopographer on Visualhunt / CC BY-NC-SA

São Paulo, Brazil

UCCRN City • C40 City • Global Covenant City



IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.2 to 2.6°C
Precipitation	-6 to +13 percent

- The water systems that are in place are not capable of ensuring the necessary flow in the medium and long term.
- When a prolonged drought hit São Paulo in 2014, it affected all parts of the city, but impacted low-income communities in peripheral and high altitude settlements most significantly.
- Climate change may further impact water supply, stressing the city's water security.

SOLUTIONS

- During the drought in 2014, the state water utility, Sabesp, set up a reward scheme that incentivised reduced consumption, combined with information campaigns to encourage decreased water usage.
- Sabsep is now making structural changes, such as connecting various supply sources, setting up a Water Resources Fund and plugging inefficient pipelines.
- Long-distance channels to transport water are under construction, as are wells in the Guarani Aquifer and the transposition basins.
- The preservation of ecosystem services and biodiversity in the Tiete River Basin is further benefiting the water quality.
- Community based initiatives like Movimento Cisternas Já or "Cisterns Movement Now" aim to increase poor households' resilience to water shortages.

Image Source: Vanessa Bumbeers on unsplash.com

FOOD SECURITY

Singapore

By the 2050s

- **Around 2.5 billion people will be living in over 1,600 cities where national yields of a major crop are projected to decline by at least 10 percent below present-day levels.**

A. INTRODUCTION AND JUSTIFICATION

Cities house more than half of the world's population, but produce very little of what is consumed. Cities, therefore, require complex systems to feed their growing populations. While much of the world's food supply comes from traded commodities, a high portion of the food consumed by urban dwellers comes from national sources. Since climate change is projected to result in crop yield declines in many parts of the world, these declines will affect the food security of many people living in cities (Rosenzweig et al., 2013).

Climate change raises concerns about agricultural production and its effects on urban populations through changes in food security. The four pillars of food security – its availability, accessibility, utilisation, and stability – will all be affected by projected changes in climate (Rosenzweig and Hillel, 2018). Declines in crop yields will decrease food availability in cities and affect its accessibility through increased prices (Porter et al., 2014; Nelson et al., 2014). The well-being of urban citizens will thus be affected in multiple ways.

As part of the Future We Don't Want analysis, an index has been developed that represents the number of people living in cities within a nation that is projected to undergo a 10 percent, or greater, decline in crop yields. The crops included in the index are maize, rice, soybean, and wheat.

B. METHODOLOGY

The Future We Don't Want analysis of the implications of climate change on urban food security examined projected national rain fed yield decline of the "Big Four Crops" – maize, rice, soybean, and wheat. Globally, these crops rank as the highest produced and consumed crops, and therefore are indicators of global food security. The projected change in the national rain fed yield for the most important crop (identified here as the crop with the most harvested area) in each country is assessed for this analysis. Only countries that have significant area (i.e., at least the 10th percentile of harvested area) dedicated to one of the big four crops are included in this analysis.

Figure 6 highlights the cities that are located in countries where national rain fed yields for the most important Big Four Crop is projected to decline by at least 10 percent by the 2050s compared to current rain fed yield levels. These model projections are produced as part of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), in coordination with Agricultural Model Intercomparison and Improvement Project (AgMIP), using multiple global climate models (GCMs) under representative concentration pathway (RCP) 8.5, and multiple global gridded crop models (GGCMs), as part of the ISIMIP Fast Track project (Rosenzweig et al., 2013). AgMIP is a major international collaborative effort to improve the state of agricultural simulation and to understand climate impacts on the agricultural sector at global and regional scales (Rosenzweig et al., 2013).

Yield projections are developed with a 5 GGCM (PEGASUS, pDSSAT, GEPIC, LPG-GUESS, EPIC) / 4 GCM multi-model mean utilising four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M); Spatial Production Allocation Model crop area estimates are utilised. The yield change is weighted based on the acreage of rain fed maize, wheat, rice, and soy production within each grid cell. The baseline period utilised is 1980-2005 while the future period projected is 2041-2070. Grid cells with less than 2 tons/ha/year of yield are not included in this analysis.

C. DISCUSSION AND FINDINGS

Food supply may become an increasing concern for urban residents over the coming decades. The Future We Don't Want analysis shows that 2.5 billion people will be living in cities where national yields of one of the four major global crops (maize, rice, soy, or wheat) will decline by at least 10 percent by the 2050s compared to present day levels. At the same time, agricultural output will need to increase by approximately 50 percent by 2050 to meet the demand of growing urban populations (Figure 6).

National Yield Decline in Maize, Rice, Soybean, and/or Wheat **2050s**

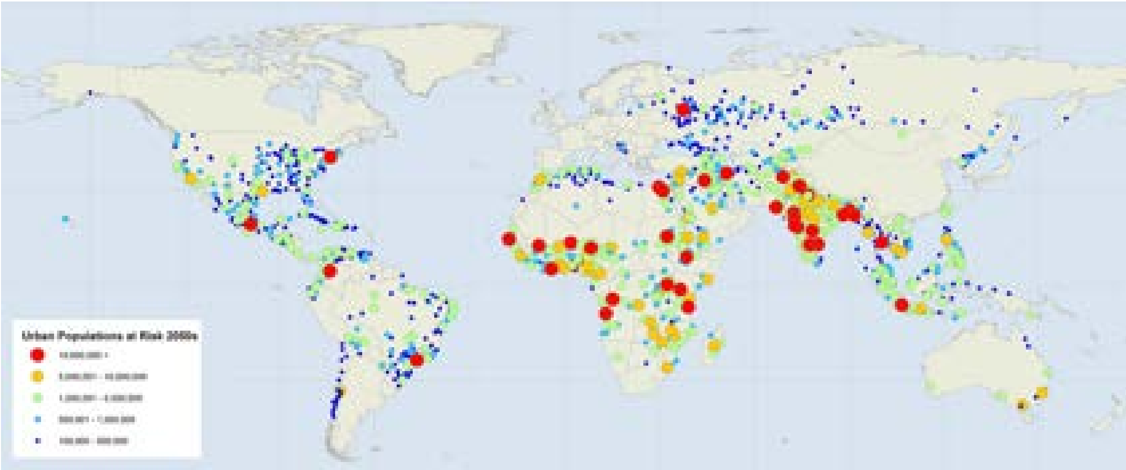


Figure 6. Cities that are located in countries where national rainfed yield of maize, rice, soybean, and/or wheat is projected to decline by at least -10 percent below current levels by the 2050s.

Data source: Multi-model man yield projections are developed with 6 GGCMs (LPJmL, PEGASUS, pDSSAT, GEPIC, LPG-GUESS, and EPIC) and 4 GCMs utilising four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M); Spatial Production Allocation Model crop area estimates are utilised; Yield change weighted based on the acreage of rainfed maize, wheat, rice, and soy production within .5 degree grid cell.

D. IMPLICATIONS FOR CITIES

With increasing urbanisation, cities need to address the triple challenge of mitigating climate emissions, adapting to climate change, and providing basic services, including food, to residents. The world is already seeing the effects of climate change, with global average temperatures being 1 degree centigrade warmer than before the industrial revolution. The results are bigger variations in rainfall, droughts, and other extreme events that have impacted agricultural output and quality.

Should crop yields decline and prices rise in line with the Future We Don't Want forecast, it will amount to a significant challenge for residents and local authorities in cities around the world. Urban populations are expected to rise, especially in developing countries, between now and 2050. Hence, estimates suggest that agricultural production will need to increase by between 50 to 60 percent in order to provide sufficient food by 2050 (Reardon, 2016).

In a world where climate change will have more significant and unpredictable impacts everywhere, and where the competition over water resources, declining harvests, as well as between domestic consumption and agricultural exports will increase, urban food supply systems must factor in a range of climate disruptions that can quickly lead to food shortages.

Climate change can affect agricultural production and urban food security in several ways. Drought and rainfall that is not aligned to the agricultural growing season, can result in water shortages that result in crop failures, and increasing urban food prices. This will have especially negative consequences for low-income populations.

Food scarcity can also lead to conflict. When the price of staple crops like wheat, maize, and rice rose substantially between 2007 and 2008, it sparked unrest in many countries. In Bangladesh, thousands of workers rioted near Dhaka and there were instances of protests in fifteen countries across Africa, South America and Asia owing to food price hikes (Reuters, 2008).

Poor urban consumers are extremely sensitive to price variations caused by climatic impacts on food production and/or distribution because they rarely produce their own food (Porter et al., 2014). Given price increases, families may therefore be forced to either limit the quantity or quality of food consumed, with strong potential impacts for human health. Women are likely to be disproportionately impacted because they often belong to the poorest of the poor, representing 70 percent of the 1.3 billion poor worldwide. Women are especially prone to reduce food intake compared with other family members, if food is scarce and/or expensive. Currently, 50 percent of the women and children in developing countries are anemic (GGCA, 2009). As for children, food scarcity and malnourishment can cause wasting or stunting.

The future upscaling of urban agriculture will need new urban design concepts and the development of city plans that recognise urban agriculture as an accepted, permitted, and encouraged form of land use. While cities need to take a leading role in coordinating this shift in agriculture as it relates to the city, the involvement of regional or provincial governments are key since they can address agriculture and land-use planning at larger scales, facilitate access to financing, and develop regional policies that accompany city-level strategies.

In a world characterised by rising temperatures, droughts, variations in precipitation, and other extreme climate events, ensuring food security is a matter of health, public security and social justice. As climate impacts become more apparent, urban food systems need to become more resilient and city governments have a significant stake in ensuring that they are.

E. URBAN RESPONSES

The technical data analysis for food security in The Future We Don't Want is supplemented with three case study examples from cities that are already addressing some of these issues.

CASE STUDIES

Medellín, Colombia

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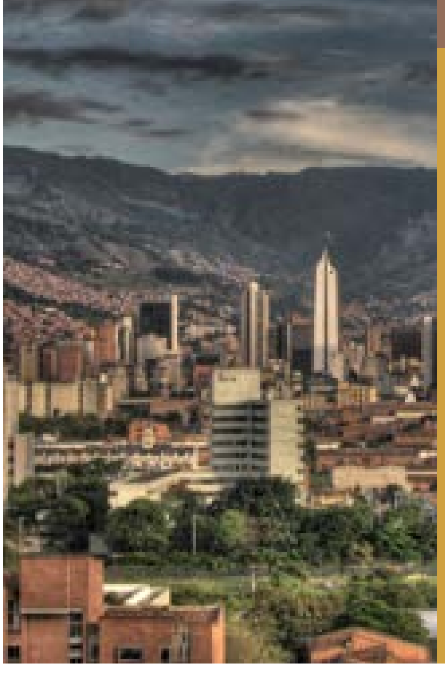


Image Source: flickr.com/ david peña CC BY-SA 2.0

IMPACTS

ARC3.2 Climate Projections – 2050s
Temperature +1.4 to +2.8°C
Precipitation -4 to +14 percent

- Medellín is vulnerable to market fluctuations and supply-chain disruptions.
- Heavy rainfall can cause mudslides that impacts the transportation of agricultural products into Medellín, resulting in shortages and higher prices.
- Droughts have raised the prices of basic goods such as milk.
- Poorer neighbourhoods are particularly vulnerable by high prices and have limited access to high quality produce.

SOLUTIONS

- The city government is working to strengthen regional rural-urban supply chains.
- By establishing food markets in poor neighborhoods, that are managed by local associations, low-income urban consumers are connected to low-income rural suppliers.
- New urban food markets provide access to local, organic produce at controlled prices.
- Medllín's programme has enabled small-scale peri-urban farmers to provide produce and reduce transportation and distribution costs.
- New distribution centers and monitoring systems have been established to match supply and demand of specific goods.

Paris, France

UCCRN City • C40 City • Global Covenant City

Image Source: Photo by Anthony DELANOIX on Unsplash

IMPACTS

ARC3.2 Climate Projections – 2050s
Temperature +1.3 to 3.2°C
Precipitation -6 to +8 percent

- Paris is susceptible to heat extremes and flooding.
- Over the coming decades, Paris expects greater competition for water sources in the North of France from other regions, as well as from agriculture and industry.
- The city aims to decrease its exposure to climate shocks, at home and abroad, and safeguard its long-term water supply while reducing agricultural emissions.

SOLUTIONS

- Paris engaged external experts in a year-long survey to assess its vulnerabilities and opportunities with regard to climate change and resources depletion (water, energy, food, biodiversity).
- Paris aims to use its procurement more strategically to influence food security and sustainable agriculture while reducing emissions.
- The city has established low-cost markets for locally grown, organic produce.
- Paris plans to establish 33 hectares of urban agriculture within the city's boundaries by 2020. By 2050, 25 percent of the city's food supply will be produced in the Île-de-France region.

Quito, Ecuador

UCCRN City • C40 City • Global Covenant City

IMPACTS

ARC3.2 Climate Projections – 2050s
Temperature **+1.3 to 2.6°C**
Precipitation **-4 to +19 percent**

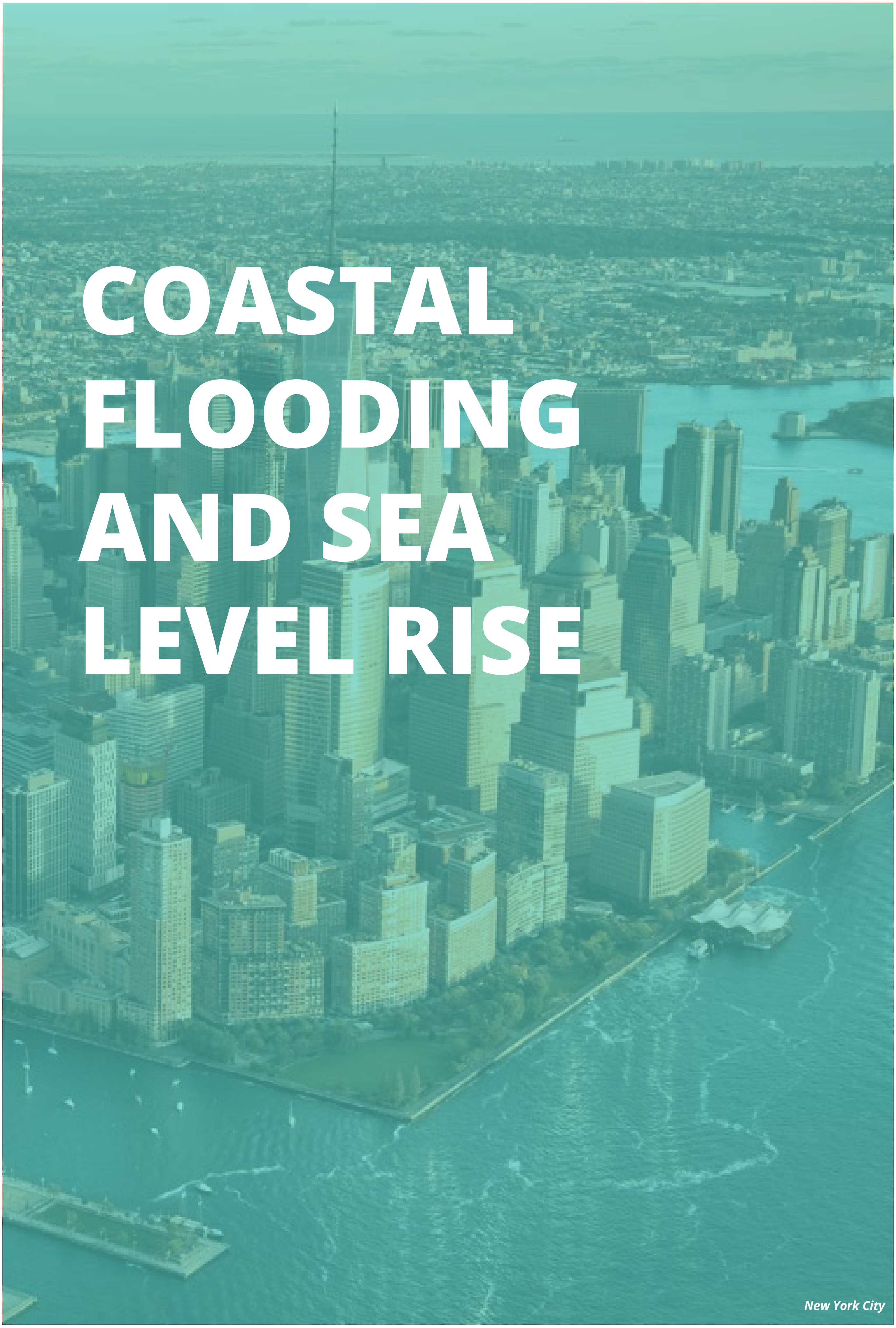
- In recent years, extreme weather events have affected Ecuador's infrastructure, neighbourhoods, agriculture, and forests, while the loss of glaciers and highland ecosystems have impacted food security, water, and hydropower supplies.
- Quito has experienced rapid population growth and low-density sprawl, which has resulted in increased food scarcity among poorer communities that live further away from the city's basic service net.

SOLUTIONS

- Quito adopted a Climate Change Strategy in 2009, followed by an Action Plan in 2012 that addresses adaptation and mitigation in an integrated way.
- The programme AGRUPAR (Agricultura Urbana Participativa, 2018) aims to strengthen the management skills and micro-enterprises of Quito's urban farmers (Conquito, 2018). AGRUPAR provides seeds and seedlings, as well as free spaces within the city where local farmers can sell their produce.
- Quito's goal is to produce 30-40 percent of its food locally over the next few decades, mostly in the region's rural areas.

Image Source: MastaBaba on Visual hunt / CC BY-NC

COASTAL FLOODING AND SEA LEVEL RISE



New York City

By the 2050s

- **Over 800 million people will be living in more than 570 coastal cities that are at risk to at least 0.5 metres of sea level rise and coastal flooding.**

A. INTRODUCTION AND JUSTIFICATION

Sea level rise coupled with rapid urban development have significantly amplified risks in coastal cities. Coastal settlements are susceptible to climate hazards such as sea level rise, storm surges, shoreline erosion, and saltwater intrusion. Ten percent of the world's total population and 13 percent of the urban population resides in Low Elevation Coastal Zones, defined as contiguous land areas along the coast that are within 10 metres of sea level. (McGranahan et al., 2007). The majority of megacities are coastal and vital to shipping, fisheries, and international commerce (UNDESA, 2012). Rising sea levels threaten increasing coastal populations, critical infrastructure, and valuable assets that lie within coastal floodplains.

Global sea level rose by approximately 1.7 mm/yr between 1900–2010 (Wong et al., 2014; IPCC, 2013). Since 1993, both satellites and tide gauges register a sea level rise of about 3.2 mm/year (IPCC, 2013; Masters et al., 2012). Globally, many cities face faster local sea level rise than the global average due to subsidence caused by sediment compaction and groundwater withdrawal (Syvitski et al., 2009).

B. METHODOLOGY

In the Future We Don't Want analysis, coastal cities most vulnerable to sea level rise were defined as those which had any portion of their GRUMP urban extent area falling within 10 km of the coast, and that had an average elevation of less than 5 metres. Only cities that are projected to experience at least 0.5 metres of sea level rise or more by the 2050s under a high end RCP 8.5 scenario relative to the 2000-2004 base period were selected for the analysis.

The model-based components of the sea level rise projections are the ensemble mean of three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) at a 1 degree grid scale. These components are part of a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, and land-based ice sheets (global) and land water storage (global) (Bader et al., 2018). Cities were selected if any of the neighboring grid cells near the city were identified as experiencing at least 0.5 metres of sea level rise by the 2050s. To determine average elevation, the GMTED Global Grids elevation dataset at a spatial resolution of 15 arc-seconds of longitude and latitude is utilised. The number of people vulnerable to coastal flooding and sea level rise in urban areas in the 2050s is determined by tallying the total projected urban population of all global coastal cities vulnerable to 0.5 metres of sea level rise.

C. DISCUSSION AND FINDINGS

Approximately 800 million people living in more than 570 coastal cities are projected to experience at least 0.5 metres of sea level rise by the 2050s under a high greenhouse gas emissions scenario (Figure 7). This risk is not particularly unique to any one region of the globe. Rather, sea level rise and coastal flooding can impact coastal cities across the globe. As populations in these areas continue to grow, governments will need to protect its citizens and the infrastructure vulnerable to climate-linked coastal impacts.

Sea level rise 0.5 metres 2050s

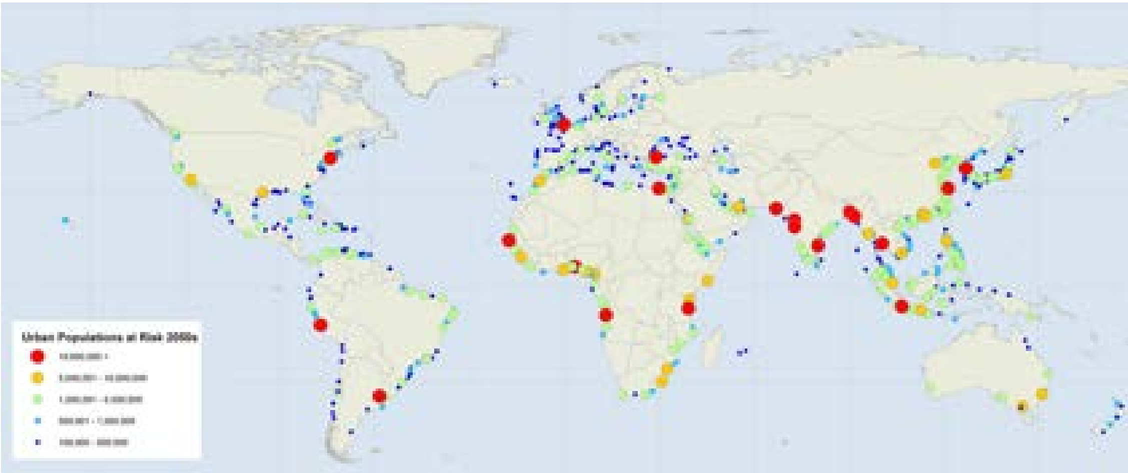


Figure 7. Cities projected to experience at least 0.5 metres of sea level rise by the 2050s under RCP8.5.

Data source: Projections are shown for the 2050s under the high end RCP 8.5 scenario relative to the 2000–2004 baseline period. The model-based components are the ensemble mean of three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) and are accompanied by a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, land-based ice sheets (global), and land water storage (global).

D. IMPLICATIONS FOR CITIES

Major coastal cities often locate valuable assets along the waterfront or within the 100-year flood zone, including port facilities, transport and utilities infrastructure, schools, hospitals, and other long-lived structures. These assets are potentially at risk from both short-term flooding and permanent inundation. Estimates suggest that the global economic costs to cities, from rising seas and inland flooding could amount to $1 trillion annually by mid-century (Hallegatte et al., 2013). By the 2070s, asset exposure to climate change could increase more than tenfold and encompass approximately 9 percent of projected global GDP due to the combined effects of sea level rise, land subsidence, population growth, and increasing urbanisation.

Urban centers built on low-lying deltas are especially vulnerable as higher coastal storm surges will pose a greater risk to life and property. The surge-related threat will be exacerbated by rising sea levels, because a higher sea level will allow storm surges to reach further inland. These risks are exacerbated in many coastal cities by land subsidence (i.e., land sinking) caused by groundwater overdraft and sediment compaction. Jakarta, for example, is especially susceptible to sea level rise and high tides since it is also experiencing one of the fastest land subsidence rates in the world. The digging of illegal wells is emptying out the city from below, while the weight of urban sprawl adds additional pressure, causing the land to sink by 25 cm per year (Simarmata et al., no date).

Moreover, sea level rise-induced saltwater intrusion upstream and into coastal aquifers can jeopardise urban drinking water supplies and contaminate agricultural soils. Sea level rise can also increase the risk of groundwater flooding. A rise in sea level will simultaneously raise water tables, saturate the soil, expand wetlands, and increase flooding during heavy rainfall events (Rotzoll and Fletcher, 2013). High waves and/or water levels during intense storms can cause beach erosion and retreating shorelines. Around developed areas, such erosion can disrupt sediment movements and result in a coastal squeeze, with associated loss of land and environmental degradation.

A long-term integrated approach to coastal management and inclusive governance is essential to adapt to climate change impacts and manage cities in the coastal zone (Nicholls et al., 2015). Actions to reduce exposure to natural hazards include moving people and infrastructure out of harm's way, building "hard" engineering protection (e.g., the Maeslantkering and Delta Work storm surge barrier in The Netherlands) and "soft" solutions (e.g., planting and protecting mangroves and other natural vegetation (Möller et al., 2014). Other adaptive strategies include accommodating structures and lifestyles to a more aquatic presence, and it may ultimately become impossible to protect further development in extremely high-risk areas.

Sea level rise and coastal flooding will have diverse impacts based on a city's geography, urban development patterns, economic make-up, and social structure. Despite these variations, however, the broader experience of sea level rise and coastal flooding under a high greenhouse gas emissions scenario will be shared by over 570 cities throughout the world, from Miami to Guangzhou to Mumbai. In cities that are rich and poor, dense and sprawling, hot and cold, the Future We Don't Want research shows that unabated climate change will expose 800 million people and trillions of dollars in assets (Hallegatte, S. et al., 2013) to ever harsher and more frequent climate hazards.

E. URBAN RESPONSES

The technical data analysis for sea level rise and coastal flooding in The Future We Don't Want is supplemented with three case study examples from cities which are already facing rising seas.

CASE STUDIES

New York City, USA

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IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	**+1.7 to 3.7°C**
Precipitation	**+1 to +13 percent**
Sea level rise	**+16 to 71 cm**

- Critical city assets lie along the waterfront or within the 100-year flood zone.
- Coastal wetlands that serve as a buffer against storm surges have deteriorated within the past few decades, increasing New York City's vulnerability.
- The city's poor, aged, and disabled citizens are more vulnerable and less able to cope with natural disasters.
- Hurricane Sandy in 2012 acted ass a wake up call that the city's coastal residents and assets are at risk to climate change.

SOLUTIONS

- New York City has established an independent panel of scientists called the New York City Panel on Climate Change (NPCC) that advises the Mayor's office on climate change projections specific to the region.
- The city is improving coastal flood mapping, updating and refining local climate projections, and strengthening coastal defenses.
- Smaller, strategically placed local storm surge barriers are being built around New York City.
- New design guidelines that account for resilience to future climate impacts have been developed.
- A city task force has been established to better engage community organisations in city-preparedness planning.

Image Source: Stig Ottesen on Unsplash

Dar es Salaam, Tanzania

UCCRN City • C40 City • Global Covenant City

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature:	**+1.2 to 2.1°C**
Precipitation:	**-14 to +13 percent**
Sea Level Rise:	**+15 to 60 cm**

- 70 percent of the city's population lives in informal settlements.
- 8 percent of the city lies below sea level.
- Rapid population growth of 5.3 percent per year has expanded informal settlements in flood-prone areas.
- Residents' vulnerability is heightened by inadequate storm water drainage, sewage and piping systems that cause public health hazards during floods.
- Flooding disrupts the city's transport system and causes regular blackouts, resulting in economic losses.

SOLUTIONS

- Dar es Salaam is developing methodologies for designing adaptation initiatives.
- Policies are being developed to support coastal peri-urban dwellers, who depend on natural resources, in their efforts to adapt to climate change.
- The city has formalised property rights in low-risk areas to incentivise residents in high-risk areas to relocate.
- Dar es Salaam is also improving local services in more vulnerable areas, such as strengthening stormwater drainage, water supply, waste collection and transport links, to reduce vulnerability.

Image Source: Roland | Wikimedia Commons (CC BY 2.0)

Jakarta, Indonesia

UCCRN City • C40 City • Global Covenant City

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.2 to 2.5°C
Precipitation	-11 to +12 percent
Sea Level Rise	+14 to 58 cm

- The northern coast of Jakarta is at risk of flooding from sea level rise, high tides, and extreme rainfall.
- Close to 90 percent of the metropolitan region already lies below sea level.
- Jakarta is experiencing one of the fastest land-subsidence rates in the world due to the digging of illegal wells and weight of urban development.
- More than 60 percent of Jakarta's population lives in informal settlements, Kampungs, that are vulnerable to flooding.

SOLUTIONS

- Jakarta is developing a Sea Defense Wall Master Plan.
- Adaptive building regulations and integrated disaster evacuation spaces are being developed.
- The city plans to relocate close to 400,000 residents from riverbanks and reservoirs through the "Socially Inclusive Climate Adaptation for Urban Resilience" project.
- Jakarta encourages competition between local community leaders to upgrade and expand green spaces through the Kampung Climate initiative, which will allow water-levels to recede more rapidly faster after flooding.
- The city is capitalising on residents' existing knowledge and experience of flood impacts, without having to spend additional government funds on external expertise and costly risk assessments.

Image Source: flickr.com/ Ferry Octavian (CC BY-NC-ND 2.0)

SEA LEVEL RISE AND ENERGY SUPPLY

Yokohama

By the 2050s

- **Over 450 million people will be living in more than 230 cities in which nearby power supply will be vulnerable to at least 0.5 metres of sea level rise under a high greenhouse gas emissions scenario.**
- **By 2050, 270 power plants producing a total of 182,902 megawatts electricity will be vulnerable to at least 0.5 metres of sea level rise.**
- **Energy disruptions in cities can impact electricity, heating, healthcare, water, transportation, and other critical services.**
- **Coastal energy infrastructure is particularly vulnerable to climate change.**

A. INTRODUCTION AND JUSTIFICATION

Urban energy systems are both directly and indirectly vulnerable to climate change impacts, including the effects of heatwaves, drought, and flooding. Sea level rise poses a particular risk to power supply, because infrastructure systems that are built to support energy networks are often in place for decades. As sea levels continue to rise, power plants located along the coast will be increasingly vulnerable to coastal flooding. Many cities depend on energy from power plants located in these low-lying coastal regions. Flooding to power generation, transmission, and distribution networks can lead to cascading impacts on urban residents and key infrastructure systems. Once in place, power networks are expensive to relocate and, depending on land use decisions in the metropolitan region, it may not be feasible. Understanding the risks that sea level rise will pose to power networks before new infrastructure is put in place can help limit costs for repairs or relocation in the coming decades, as coastal flooding events become more frequent.

B. METHODOLOGY

The Future We Don't Want analysis pertaining to the sea level rise and energy supply is focused on cities near power plants that may be vulnerable to at least 0.5 metres of sea level rise in the 2050s. Only power plants that are located at an average elevation below 5 metres were identified using the GMTED Global Grids elevation dataset at a spatial resolution of 15 arc-seconds of longitude and latitude. Using the Knoema power plant data set (Knoema, 2016), all power plants within 5 km from the coast that fall within the 5 metres elevation threshold and whose neighboring grid cell in the 2050s is projected to experience at least 0.5 metres of sea level rise relative to the 2000-2004 base period under a high end RCP8.5 greenhouse gas emissions scenario were identified. Cities whose GRUMP urban extent boundaries are located within 50 km of power plants that met this criteria were then identified, and the total urban population then calculated.

The model-based components of the sea level rise projections are a combination of the ensemble mean of three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) at a 1 degree grid scale and a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, land-based ice sheets (global), and land water storage (global).

C. DISCUSSION AND FINDINGS

There are 270 power plants, located close to cities, producing a total of 182,902 megawatts of energy which are vulnerable to at least 0.5 metres of sea level rise by the 2050s. These power plants will potentially provide power for over 450 million people and more than 230 cities (Figure 8). While many coastal power plants are at risk of flooding from sea level rise, the Future We Don't Want analysis highlights urban areas where nearby power supply is most vulnerable by limiting the analysis to power plants that are located in regions where at least 0.5 metres of sea level rise is projected to occur under a high emissions scenario by mid-century. The results show that cities in Asia, Europe, and the east coast of North America have nearby power supplies that lie in areas that may be particularly susceptible to higher than average sea level rise.

Sea level rise and power plants **2050s**

Figure 8. Cities whose nearby power plants are vulnerable to coastal flooding as a result of 0.5 metres of sea level rise in the 2050s.

Data source: Knoema World Power Plant Database, 2016; CMIP5. Projections are shown for the 2050s under the high end RCP 8.5 scenario relative to the 2000–2004 baseline period. The model-based components are the ensemble mean of three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) and are accompanied by a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, land-based ice sheets (global), and land water storage (global). Map re lects power plants that are located at an elevation below 5 metres, less than 5 km from coast, and less than 10 km from a sea level rise grid cell greater than or equal to 0.5 metres in the 2050s time frame.

D. IMPLICATIONS FOR CITIES

Energy supply is intrinsic to global economic and social progress and is a critical component of urban security and resilience. Cities in particular, account for more than 75 percent of global primary energy use and have the most to lose from climate-linked energy disruptions (UN Habitat, 2012). Such disruptions in cities can affect the provision of electricity, transportation, water, healthcare and other critical services, and cause cascading failures across the entire economy of a city and a country.

In the coming decades, rapid population growth, urbanisation, and climate change will intensify stresses on existing and planned energy infrastructure. Going forward, energy choices will need to factor local air quality, greenhouse gas emissions, energy equity, energy security, and climate resilience. Local governments will need to conduct vulnerability assessments and plan for varied climate events and their impacts on the energy supply chain.

Coastal energy infrastructure is particularly vulnerable to climate change. More frequent extreme weather events such as hurricanes, storm surges, and coastal flooding are expected to result in recurring energy disruptions to the power network, decreased reliability of production and transmission, higher costs for cities and consumers, and in the long run, stranded energy assets that dot the shores of increasingly exposed coasts (Azevedo de Almeida and Mostafavi, 2016).

Across the world more than 6,700 power generation plants, accounting for almost 15 percent of power generation in 2009, are located within the Low Elevation Coastal Zone. Areas heavily dependent on different types of biomass as primary energy feedstocks may also be vulnerable if sea level rise affects the availability of material. Oil and gas drilling operations and refineries in coastal areas are also susceptible to extreme events, including flooding and high winds.

Energy supply is a critical resilience priority; if energy systems fail, they add additional stresses on the ability to provide potable water supply, food, transportation, sanitation, communications, and health care, etc. Energy supply disruptions can lead to cascading failures across the economy, impacting the functioning of the government, businesses, and local communities. For example, this level of extreme disruption of power loss on the community was seen in Puerto Rico following Hurricane Maria in 2017. Similarly, better access to electricity can lower costs for businesses, increase trade and investment, drive economic growth, and help reduce poverty. To prevent destabilising disruptions to electricity supply that can, in turn, impact public transport, water, and healthcare systems; cities need to assess their local risks and plan for climate resilient energy systems.

E. URBAN RESPONSES

It is important to develop adaptation measures that will minimise the negative impact that extreme climate events can have in the built, social, and ecological environment. The technical data analysis for impacts of climate change on energy supply for urban areas in The Future We Don't Want is supplemented with three case study examples from cities that are already facing this challenge.

CASE STUDIES

Seattle, Washington

UCCRN City • C40 City • Global Covenant City

Image Source: skeeze on pixabay

IMPACTS

ARC3.2 Climate Projections – 2050s

Temperature	+1.4 to 3.7°C
Precipitation	-3 to +10 percent
Sea Level Rise	+14 to 56 cm

- Seattle's hydropower is vulnerable to variability in the supply of water from mountain snowpack, earlier and faster spring melt of mountain snowpack, and reduced summer river levels.
- Climatic change has reversed the energy demand trajectory in the city; there is less demand in the winter for heating, and more demand in the summer for cooling.
- Higher energy demand in the summer and de-rating of the overhead lines leads to reduced transmission capacity.
- A climate vulnerability assessment by local energy utility, Seattle City Light, projects increased risks for energy supply from sea level rise and tidal flooding. This could result in equipment damage, frequent transmission and distribution outages, and "financial consequences" for the utility.

SOLUTIONS

- Seattle City Light is the first large electric utility in the U.S to become carbon neutral, and it is developing a utility-wide adaptation plan.
- Seattle is leveraging existing tools to plan for hydro-climatic variability and prepare for high winds and storms.
- A rate stabilisation fund is being established and the city is installing new equipment built to withstand landslides and lightning.
- A newly introduced building efficiency programme in Seattle aims to reduce 81,000 metric tons of greenhouse gas emissions from the building sector.

London, United Kingdom

UCCRN City • C40 City • Global Covenant City

Image Source: pixabay.com

IMPACTS

ARC 3.2 Climate Projections – 2050s

Temperature	+1.0 to 2.7°C
Precipitation	-4 to +10 percent
Sea level rise	+17 to 70 cm

- London lies in the Low Elevation Coastal Zone and faces risks of tidal flooding from the North Sea, fluvial flooding from the Thames and its tributaries, and surface water flooding due to heavy rainfall.
- The city is also vulnerable to overheating and drought-like conditions.
- Hotter summers increase the demand for mechanical cooling, resulting in higher energy demand.
- The United Kingdom's nuclear, coal, and oil and gas fired power stations are located along the coast and are vulnerable to tidal flooding, which can, in turn impact London's power supply. London also has electricity substations that are vulnerable to local flooding.
- Climate impacts put assets worth £200 billion at risk, as well as 1.25 million people living along the Thames river in London and surrounding areas.

SOLUTIONS

- London is supporting the development of decentralised energy systems, including the use of low carbon and renewable energy, and energy generated from waste.
- The city is reducing the energy consumption of existing building stock and moving towards zero emission transport.
- The city has developed its Sustainable Drainage Action Plan to improve city-wide drainage infrastructure to withstand heavy flooding.
- The draft London Environment Strategy and the draft London Plan focus, among other things, on, tackling extreme weather events and interdependencies across multiple sectors.

Rio de Janeiro, Brazil

UCCRN City • C40 City • Global Covenant City

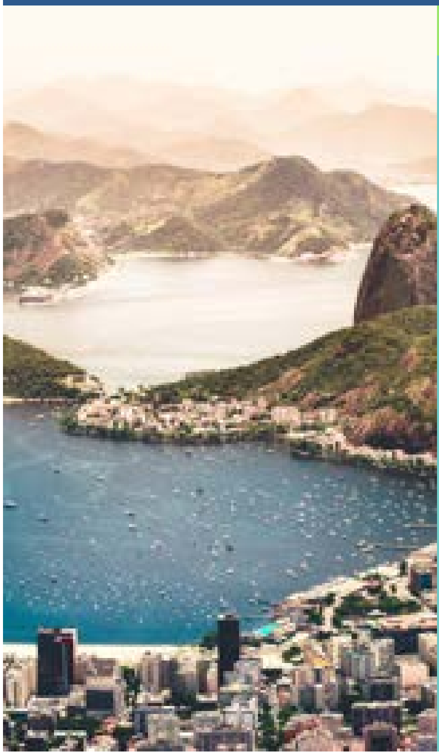

Image Source: Agustín Diaz on Unsplash

IMPACTS

ARC 3.2 Climate Projections – 2050s

Temperature	+1 to 2.1°C
Precipitation	-14 to +10 percent
Sea level rise	+15 to 56 cm

- Around 70 percent of Brazil's energy comes from hydropower plants and most of Rio de Janeiro's power comes from the central grid.
- Climate projections indicate that drought-like conditions in the summer can lead to electricity shortages as the hydropower supply is sensitive to water disruptions.
- Coastal surges and heavy precipitation events could result in more intense disruptions in the future, with cascading impacts in other critical sectors.
- Brazil's only nuclear plant is located along the coast, and susceptible to tidal flooding.

SOLUTIONS

- The city is looking to source more of its energy from decentralised renewable sources to reduce greenhouse gas emissions, lessen its dependency on water intensive energy sources, and reduce its vulnerability to droughts and sea level rise.
- One of the key objectives of the city's resilience plan is to develop and implement a solar energy strategy. Solar thermal systems are mandatory for new and renovated buildings (Global Solar Thermal Energy Council).
- Government policies range from energy loss prevention to emission reduction through local government operations.
- Light Sociedade Anónima (Light S.A.) has formalised a smart grid program to implement remote metering solutions in its concession area.
- The Inova Energia programme supports the development of smart city pilots in the country.

SUMMARY

By the 2050s, cities across the globe will be faced with broad challenges as a result of climate change. More people will be at risk to these impacts as urban populations more than double from 1.4 billion people today to over 3.5 billion people by mid-century. Key findings from the Future We Don't Want analysis show that millions of urban residents will be vulnerable to changing climate conditions and thousands of urban decision makers will need to make their cities more resilient to withstand these challenges.

The Future We Don't Want research was conducted to highlight what cities need to be prepared for over the next three decades, according to the best available science. There are six key findings for cities across the globe:

By the 2050s,

1. Over 1.6 billion people, living in more than 970 cities, will face sustained extreme heat conditions of over 35°C (95°F) for 3 consecutive months.
2. Nearly 215 million highly vulnerable people, living in poverty in more than 230 cities, will face sustained extreme heat conditions over 35°C (95°F) for 3 consecutive months.
3. Over 650 million people, living in more than 500 cities, may face at least a 10 percent decline in freshwater availability from streamflow.
4. Over 2.5 billion people, living in more that 1,600 cities, may face at least a 10 percent decline in national yields of major crops.
5. Over 800 million people, living in more than 570 coastal cities, will be at risk of coastal flooding from at least 0.5 metres of sea level rise.
6. Over 450 million people will be living in more than 230 cities, where nearby power supply is at risk of coastal flooding from at least 0.5 metres of sea level rise.

While these six areas are not the only vulnerabilities that cities will encounter as a result of climate change, these findings highlight significant risks for people in urban areas in the coming decades. As shown by examples in the case studies throughout this report, city leaders are already taking action to deal with these risks. The scientific foundation that The Future We Don't Want offers allows cities to see within what time-frames they should be preparing for particular risks.

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APPENDIX: DATA SOURCES

DATA	DESCRIPTION OF DATA AND LINK TO SOURCE
Population Baseline	**Name of data source:** Natural Earth Data Populated Places **Entity:** Oakridge National Laboratory **Link to data:** http://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-populated-places/ **Year created:** 2017 **Description of data:** Urban population estimates for the present day (2016-17), version 4.0.0
Population Future	**Name of data sources:** Natural Earth Data; Global Rural-Urban Mapping Project (GRUMP) **Entity:** Oakridge National Laboratory; NASA Socioeconomic Data and Applications Center (SEDAC) and Center for International Earth Science Information Network (CIESIN) at Columbia University **Link to data:** Natural Earth Dataset - http://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-populated-places/ GRUMP - http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-ext-polygons-rev01/docs **Year created:** 2017 **Description of data:** Urban population estimates for the 2050
Extreme Temperature Baseline	**Name of data source:** NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset **Entity:** NASA **Link to data:** https://cds.nccs.nasa.gov/nex-gddp/ **Year created:** 2012 **Description of data:** Model mean of four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) in the base period (1980-2005)
Extreme Temperature Future	**Name of data source:** NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset **Entity:** NASA **Link to data:** https://cds.nccs.nasa.gov/nex-gddp/ **Year created:** 2012 **Description of data:** Model mean of four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) in the 2050s (2041-2070)

DATA	DESCRIPTION OF DATA AND LINK TO SOURCE
Extreme Temperature and Poverty Baseline	**EXTREME HEAT** **Name of data source:** NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset **Entity:** NASA **Link to data:** https://cds.nccs.nasa.gov/nex-gddp/ **Year created:** 2012 **Description of data:** Model mean of four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) in the base period (1980-2005) hottest 3-month maximum average temperature **POVERTY** **Name of data source:** National Urban Poverty Headcount Ratios **Entity:** World Bank **Link to data:** https://datacatalog.worldbank.org/dataset/world-development-indicators **Year created:** 2017 **Description of data:** National urban poverty rates expressed as a percentage of total national urban population
Extreme Temperature and Poverty Future	**EXTREME HEAT** **Name of data source:** NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset **Entity:** NASA **Link to data:** https://cds.nccs.nasa.gov/nex-gddp/ **Year created:** 2012 **Description of data:** Model mean of four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) in the 2050s (2041-2070) hottest 3-month maximum average temperature **POVERTY** **Name of data source:** National Urban Poverty Headcount Ratios **Entity:** World Bank **Link to data:** https://datacatalog.worldbank.org/dataset/world-development-indicators **Year created:** 2017 **Description of data:** National urban poverty rates expressed as a percentage of total national urban population
Water Availability Future	**Name of data source:** ISIMIP Fast Track **Entity:** Inter-Sectoral Model Impact Intercomparison Project (ISIMIP) **Link to data:** https://esg.pik-potsdam.de/search/isimip-ft/ **Year created:** 2018 **Description of data:** Two GHMs (JULES and LPJmL) and four GCMS (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M) utilised to develop multi-model mean.
Food Security Future	**Name of data source:** ISIMIP Fast Track **Entity:** Inter-Sectoral Model Impact Intercomparison Project (ISIMIP) **Link to data:** https://www.isimip.org/outputdata/ **Year created:** 2018 **Description of data:** 5 GGCM (PEGASUS, pDSSAT, GEPIC, LPG-GUESS, EPIC) / 4 GCM multi-model mean utilising four global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M); Spatial Production Allocation Model crop area estimates are utilised

DATA	DESCRIPTION OF DATA AND LINK TO SOURCE
Sea Level Rise Future	**SEA LEVEL RISE** **Name of data source:** CMIP5 **Entity:** World Climate Research Programme **Link to data:** https://cmip.llnl.gov/cmip5/ **Year created:** 2013 **Description of data:** Projected ensemble mean increase in sea level relative to the 2000-2004 base period level from three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M) at 1 degree grid scale and a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, and land-based ice sheets (global) and land water storage (global). **ELEVATION** **Name of data source:** Global Multi-resolution Terrain Elevation Data **Entity:** United States Geological Survey **Link to data:** https://topotools.cr.usgs.gov/gmted_viewer/gmted2010_global_grids.php **Year created:** 2010 **Description of data:** Mean statistic, 15 arc-seconds
Sea Level Rise and Energy Future	**POWER PLANT** **Name of data source:** World Power Plants Database, 2016 **Entity:** Knoema **Link to data:** https://knoema.com/WGEOPPD2016/world-power-plants-database-2016 **Year created:** 2016 **Description of data:** database of global power plants by location, size, type, and capacity. **SEA LEVEL RISE** **Name of data source:** CMIP5 **Entity:** World Climate Research Programme **Link to data:** https://cmip.llnl.gov/cmip5/ **Year created:** 2013 **Description of data:** Projected ensemble mean increase in sea level relative to the 2000-2004 base period level from three global climate models (IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M) at 1 degree grid scale and a four-component approach that incorporates both local and global factors related to changes in ocean height (local), thermal expansion (global), loss of ice from glaciers, ice caps, and land-based ice sheets (global) and land water storage (global). **ELEVATION** **Name of data source:** Global Multi-resolution Terrain Elevation Data **Entity:** United States Geological Survey **Year created:** https://topotools.cr.usgs.gov/gmted_viewer/gmted2010_global_grids.php **Year created:** 2010 **Description of data:** Mean statistic, 15 arc-seconds

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