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Published in:
Environmental Research

Link to article, DOI:
10.1016/j.envres.2020.110435

Publication date:
2021

Document Version
Peer reviewed version

Research Article – Environmental Research (Accepted 3 November 2020)

Piloting a City Health Adaptation Typology in climate-engaged cities: Toward identification of an urban health adaptation gap

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Author contributions: Mary C. Sheehan: conceptualization, methodology, writing – original draft preparation, review and editing; **Mila Freire:** conceptualization, writing – review; **Gerardo Sanchez Martinez:** conceptualization, methodology, writing – review and editing.

Words: abstract plus highlights ~ 300; main text plus tables and figures ~7,300

Supplementary Materials: 5 appendices (A-E)

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest: The authors declare no conflict of interest.

Running title: City Health Adaptation Gap

Piloting a City Health Adaptation Typology in climate-engaged cities: Toward identification of an urban health adaptation gap

Abstract: Climate change has important population health impacts, and cities are often on the frontlines. However, health is reported to be less active in climate adaptation than other sectors. To better understand urban health adaptation efforts and identify gaps we developed a City Climate Health Adaptation Typology and tested it with adaptation actions of 106 large world cities (population > 1 million) reported to a large publicly-available adaptation database. We found two-thirds of actions of these active adapter cities were health-associated. Half were information activities (e.g. hazard mapping, early warnings); and nearly one-third addressed climate-relevant health determinants in the urban built environment. Forty percent were in low- or middle-income countries. Our proposed typology provides a systematic framework for monitoring and comparing city health adaptation actions. Reported city actions are suggestive of greater depth and breadth of urban health-associated adaptation than previously reported. However, even among these highly adaptation-engaged cities, a health adaptation gap was apparent in key climate health services (e.g., mental health), and in governance and capacity building in climate-related public health. The COVID-19 pandemic has demonstrated pressing need for strong public health institutions. We recommend better integration of public health agencies into local climate action planning, enhanced modes of collaboration between health and non-health agencies and with non-governmental actors, and strengthening of city public health adaptive capacity including through networking.

Highlights:

- We propose a five-part typology to support consistent urban health adaptation monitoring
- Applying it to >100 large climate-active cities suggests health share is substantial
- Health adaptation in these cities centers on hazard mapping and urban heat management
- However, a health adaptation gap exists in services, governance and capacity building
- Local health agencies should be strengthened and integrated into city climate planning

Keywords: climate change; adaptation; public health; cities

Piloting a City Health Adaptation Typology in climate-engaged cities: Toward identification of an urban health adaptation gap:

1. Introduction

Urgent action to decarbonize the global economy is needed over the next decade to prevent irreversible alterations to Earth's climate, while building population resilience to inevitable climate-related changes (Hansen et al. 2017; IPCC 2018; Steffen et al. 2018). Human health is at the center of this challenge (McMichael et al. 2003). With their concentrated populations, cities are often on the frontlines. Children born today face unprecedented health risks over their lifetimes due to extreme weather, infectious diseases, and water and food insecurity; limiting global warming to well below an incremental 2°C and adapting to changing conditions will help reduce these preventable risks through cleaner air, healthier diets, and better-prepared cities (Watts et al. 2019). Of ten sentinel risk indicators examined by the Intergovernmental Panel on Climate Change (IPCC), several involve direct impacts on urban population health, including mortality and morbidity from extreme heat and flooding (IPCC 2018). However, changing climate parameters also amplify and compound urban health risks through complex pathways, as illustrated by recent wildfires in the American West (Walter et al. 2020). Concerns for economic damages to physical property, though often entailing dire consequences, can mask those to human wellbeing (McMichael & Lindgren 2011). Framing climate challenges with a health lens has the potential to motivate behavior change needed to transition to a clean energy economy and adapt to equitably protect populations (Maibach et al. 2011; Watts et al. 2018).

1.1 The Health Adaptation Gap

Yet health has been less visible in climate planning efforts than some other sectors (Lesnikowski et al. 2011; Fox et al. 2019), and there has been limited research on public health adaptive capacity (Hess et al. 2011). The United Nations Environment Program (UNEP) points to a substantial 'health adaptation gap:' while much climate-related mortality and morbidity is preventable, funding is inadequate and efforts are insufficient to meet needs (Martinez et al. 2018). Action in three priority areas is essential to closing this gap: (i) better integrating health into climate planning while enhancing the capacity of health systems; (ii) addressing the multi-sectoral core determinants of health; and (iii) further developing promising health-adaptive interventions such as early warning systems (Martinez et al. 2018).

Recent initiatives suggest growing recognition of the need to address this gap. The World Health Organization (WHO) has called for a transformative change to focus on upstream determinants of health and climate in an integrated way across sectors, supported by collaborative governance (WHO 2019). The Lancet Countdown aims to "place health at the center of the coming transition" towards a clean economy, monitoring 41 cross-cutting health and climate indicators globally, including tracking of adaptation plans at national and city level (Watts et al. 2019). Integration of health within climate change planning has been addressed in major reports in the US and the EU (USGCRP 2016; EASAC 2019), while international financial institutions have committed to greater health-related adaptation spending (Watts et al. 2019). The COVID-19 pandemic has also raised awareness of the critical economic and social costs of weak public health institutions (Carrington 2020; Evanson 2020; Sheehan & Fox 2020). Some voices in the research and development community are calling for a highly sustainable or net-zero emissions economic recovery from COVID-19 (Allan et al. 2020; Hammer et al. 2020).

1.2 Urban Health Adaptation Challenges

Cities have distinct vulnerabilities to climate hazards, which makes understanding urban health adaptation gaps particularly relevant (Bambrick et al. 2011; Barata et al 2018; Fagliano & Diez Roux 2019). Today, 55% of the world's population is urban and that share is projected to reach 68% by 2050 (UN 2018). Cities are also inherently susceptible to the urban heat island (UHI) effect, and are frequently located on flood-prone coasts or rivers (Hallegatte et al. 2013). Surveys carried out by CDP – an organization that annually tracks and publishes databases recording climate actions of member cities belonging to several large global climate networks – suggest extreme heat, storms and flooding dominate climate-related hazard concerns for many cities (CDP 2013). On the other hand, the Urban Climate Change Research Network (UCCRN) has found that the future climate-relevant health risks of city dwellers are likely to be increasingly indirect, mediated through the urban natural, built, and social environments (Barata et al. 2018). Examples include greater heat and humidity favoring mosquito-borne disease; more frequent droughts and storms reducing water quality and quantity; poorer air quality with extreme heat; cascading impacts of storm- and flood-related infrastructure outages; wildfire-, flood- and storm-related impacts on physical and mental wellbeing; and challenges to the capacity of local healthcare institutions (USGCRP 2016; EASAC 2019; Barata et al. 2018). With these coming challenges, the WHO has called on urban planners to prioritize health in climate-related policy action (Neira 2018).

After focusing on mitigating greenhouse (GHG) emissions, cities have become more active in climate adaptation over the past decade, although evidence suggests urban adaptation remains in its infancy (Kernaghan & da Silva 2013; Reckien et al 2015). A review of large (> 1 million population) city adaptation actions based on publicly-available climate planning documents, found

adaptation actions reported by 73 of 401 world cities (Araos et al. 2016a). A baseline review using the same database found 42 cities, or 10% of total, reported health adaptation actions (Araos et al. 2016b). While governance arrangements for climate-relevant health initiatives vary across cities and by region (Heidrich et al 2016; Austin et al. 2019), cities often have greater institutional and political independence of climate planning and action than national governments (Barata et al. 2018; Rosenzweig et al. 2018). Large cities in particular, with their concentration of knowledge, capacity to innovate and provide services, and practice of networked learning, may have an advantage in delivering health-supportive climate policies and actions (Reckien et al. 2015; Ezzati et al. 2018).

However, there is a dearth of evidence on climate-related health adaptive actions across world cities, and the information available suggests health is often less well-integrated into urban climate planning than other sectors. For example, an international survey of 350 city climate action plans found only 35% had incorporated public health, which was among local government agencies considered "on the margins of urban adaptation" (Aylett 2015). A qualitative review of six US cities' adaptation plans found lack of information on climate-health impacts and exclusion of public health from climate planning in adaptation planning (Shimamoto & McCormick 2017). Analysis of ten world megacities found health accounted for just 2-4% of adaptation spending (compared to 11-13% for transport, 11-15% for water, and over 30% for the built environment), and priorities seemed "largely influenced by market-based responses to protecting physical capital rather than at-risk populations" (Georgeson et al. 2016).

Research on adaptation tracking has found that reliable, meaningful adaptation monitoring requires consistent definitions, comprehensive and comparable data and coherency (Ford & Berrang-Ford 2016). In addition, particularly for cities, monitoring of health adaptation must

inevitably go beyond public health departments (Baum et al. 2014; Patz & Thomson 2018). That population health is determined to a large extent outside the health sector is widely accepted, as underlined by the upstream determinants focus of the recent WHO strategy, and holistic assessment frameworks such as Health-in-All Policies integrating health into broader cross-disciplinary planning (WHO 2019; Baum et al. 2014; de Leewu 2017). Water and sanitation have been at the core of urban public health for centuries; reducing risk of microbial infection remains a critical area of collaboration between health and water agencies (Hoornweg et al. 2011; World Bank 2011). Greening initiatives carried out by urban planning departments can reduce hazardous heat exposures as can other modifications to the built environment at building, city and peri-urban scales (Barata et al. 2018), though it is rare to find they integrate health into decision-making. Public preparedness (emergency response, hospital surge-capacity) is essential to protecting urban dwellers from climate-related epidemics and disasters (McMichael & Lindgren 2011) and is formally considered a 'health-related' field (Watts et al. 2019).

Thus, adaptive actions that contribute to protecting population health and building health resilience in the urban space can be expected to cover a wider range than the climate-related activities carried out by local health departments, or budgeted under their mandates. Some researchers have addressed this by distinguishing between adaptation actions which have an 'explicit' health focus, and those which have an 'implicit' contribution to population health (Lesnikowski et al. 2011). However, a unified and consistent typology of health-associated adaptation actions in the urban space is lacking. Moreover, few efforts have looked comprehensively at a large sample of cities in low-, middle- and high-income countries to identify categories of planned or completed health adaptive action as well as determine deficits. This

makes it difficult to assess progress and needs in a consistent, comparable, comprehensive and coherent way across cities.

1.3 Study Goal: Characterizing Urban Health-Associated Adaptation

The goal of this study is to characterize urban health-associated adaptation by proposing a consistent City Health Adaptation Typology and testing its use with a major public global city database of active adapters. We hypothesized that this close-up view of climate-engaged cities would also enable us to begin to understand more comprehensively the scope and nature of city adaptive actions aimed at safeguarding human health and wellbeing, as well as to move toward mapping the elements of an 'urban health adaptation gap.' The ultimate motivation of this research is to enhance the ability to consistently monitor, evaluate and learn from cities' ongoing and planned health-associated activities as these become more fully integrated into adaptation planning, and as urban climate health challenges become increasingly more complex.

2. Materials and Methods

2.1 Materials

2.1.1 City Health Adaptation Typology

We first developed a City Health Adaptation Typology based on a review and synthesis of over 30 articles from the literature outlining climate adaptation typologies or frameworks that were general, health-related or specific to urban areas. Our review findings are outlined here and we provide the full literature review and describe the typology in Appendix A. Briefly, we found that adaptation is commonly divided into three time-linked phases: (i) planning, (ii) preparation, and (iii) adaptive actions (Lesnikowski et al. 2011); and into ten functional categories: capacity building, management and planning, practice and behavior, policy, information, physical

197 infrastructure, warning or observation systems, green infrastructure, financing, and technology
198 (Biagini et al. 2014).

199 To tailor the above general adaptation framework to health we overlaid it with the WHO's
200 climate resilience framework, which is comprised of blocks for climate health information; climate
201 health service delivery; leadership and governance; and workforce strengthening (WHO 2015).
202 To further refine the framework to the urban space, we built on the recommendation of the UCCRN
203 that city health adaptation plans include early warning systems, preparedness, vulnerability
204 mapping, and linkages with sectors important to health determinants, such as infrastructure, land
205 use management and urban planning (Barata et al. 2018). However, since many actions in the
206 urban built environment potentially support wellbeing, we sought to further refine our typology to
207 distinguish actions aimed primarily at protecting human health or preventing human harms from
208 actions aimed primarily at protecting assets or other goals. To do so we followed analysis of the
209 IPCC (Special Report on 1.5 Degrees, Supplemental Material 4.SM) evaluating the peer-reviewed
210 literature on urban adaptation actions by including those actions which have been shown to provide
211 health benefits or co-benefits (de Coninck et al. 2019). The resulting typology therefore rests on
212 a widely-used general adaptation framework that has been fine-tuned to reflect the urban health
213 context.

214 We propose a typology structured around five groups of health-associated adaptation action
215 categories: (i) organizing climate-related health *governance*; (ii) developing and sharing climate-
216 relevant health *information*; (iii) providing climate-health *services*; (iv) developing infrastructure
217 and policies in support of climate-relevant health *determinants*; and (v) building health adaptive
218 *capacity* (Table 1, Appendix A). These groups are comprised of 16 adaptation action categories
219 for which benefits to urban population health in the context of climate hazards have been well

220 defined in the literature (WHO 2015; Barata et al. 2018; de Coninck et al. 2019). We designated
221 a non-health-associated category for actions aimed primarily at protecting infrastructure assets,
222 preserving biodiversity, strengthening economic or financial sustainability, or carrying out routine
223 activities unrelated to incremental climate hazards.

224 **2.1.2 CDP City Adaptation Actions Database**

225 The CDP (formerly the Carbon Disclosure Project) organization runs a publicly-available
226 Open Data Portal (data.cdp.net) with a global set of databases on climate mitigation and adaptation
227 activities of private companies and local jurisdictions, based on annual surveys (CDP 2019). CDP
228 also serves as the reporting platform for the Compact of Mayors, an international consortium of
229 city climate change networks (COM 2020), and its city databases rely on data from CDP's own
230 city network and those of partners, including C40 Cities, Local Governments for Sustainability
231 (ICLEI), the World Wildlife Fund (WWF) and others. CDP's validated city datasets have been
232 used as a basis for international climate monitoring initiatives, including the Lancet Countdown
233 indicator for number of city-level climate change risk assessments underway or completed (65%
234 of world cities surveyed in 2018) (Watts et al. 2019).

235 The CDP Cities Adaptation Actions database tracks the self-reported planned, ongoing and
236 completed climate adaptation actions of hundreds of world cities (CDP 2019). It reports the
237 following categorical variables for participating cities, based on pre-defined menu options: climate
238 hazards, adaptation actions, operational stage of implementation, country, world region, and city
239 network affiliation (Appendix B). Cities also provide written descriptive entries summarizing the
240 nature of each adaptation action responding to a particular identified climate hazard, as well as
241 numerical population data.

242

2.2 Methods

In order to test our City Health Adaptation Typology using the CDP Adaptation Actions database, we carried out an analysis of the detailed written adaptation action descriptions for the subset of large cities (urban agglomeration populations > 1 million) and allocated them to one of our typology categories. We chose to examine the subset of large cities because they often have greater responsibilities for public health; they are likely to have more extensive adaptation programs; and some research has been done on this category of cities and is available as context. We identified the large city subset using consistent population data (UN 2019).

To prepare our analysis we downloaded the dataset (June 2019 version with data as of end-2018) to an Excel spreadsheet, and cleaned the data to include only cities that reported information on both climate hazards and adaptation actions. Of total, 106 cities had 2018 UN populations greater than one million and reported at least one adaptation action with a sufficient written description to evaluate; these cities reported 589 adaptation actions. We eliminated from consideration 40 actions due to insufficient information (e.g. written responses such as "under implementation"), leaving 549 reported written descriptions for evaluation. We used data analysis functions to calculate descriptive statistics in order to derive characteristics of cities by climate hazard, region, and other variables.

The first step in the analysis was to identify among written adaptation actions which were primarily human health-associated, consistent with our typology. We then allocated these actions to one of the typology categories based on description content. This analysis was performed without regard to the original CDP database category in which actions were reported. We summarized actions in tabular form (total, mean per city, range, share of total) for each typology category by climate hazard, world region, city and country World Bank income category (low-

and middle-income, or high-income) (World Bank 2020). We also identified active health adapters, which we defined as those cities with health-associated actions at or over the 75th percentile. The majority of adaptation action descriptions were in English; we translated those reported in French, Spanish, Portuguese or Chinese.

3. Results

When we reviewed the 549 written adaptation actions of 106 large world cities in the CDP database to allocate them to categories in our typology, we determined 369 actions (67% of total) reported by 98 cities were health-associated (3.8 actions per city, range 1-12); we deemed 180 actions (33%) reported by 73 cities to be not health-associated (2.5 actions per city, range 1-8) (Table 1 and Appendix C). Among health-associated actions, 33% (2.3 per city) were in the sharing information group; 20% (1.7 per city) were in the supporting determinants group; 9.5% (1.5 per city) were in the furnishing services group; 3.3% (1.3 per city) were in the organizing governance group; and 1.3% (1.3 per city) were in the capacity building group (Table 1 and Figure 1.a). Hazard and vulnerability mapping (information group) was the largest single health-associated adaptation action category (83 actions, 1.7 per city); a majority of these actions were identified with flood, storm and landslide hazards (Figure 1.b). Managing the urban heat island effect (determinants group) was the second-largest category (71 actions, 1.3 per city). Early warning (information group) and preparedness and response (services group) were also frequently reported (42 actions, 1.7 per city; and 38 actions, 1.4 per city, respectively).

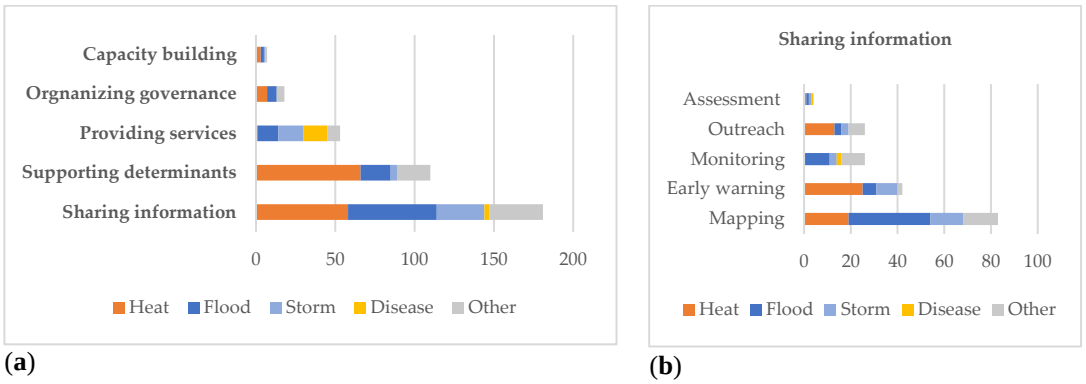
There were few or no actions reported for several categories in the climate-health services group (including climate-sensitive infectious disease, mental health, nutrition or rural-to-urban migration related interventions; Appendix C). Few actions were reported in the climate-health

governance and capacity groups. The largest number of non-health-associated actions was in the protecting physical infrastructure category (104 actions by 60 cities, 1.7 per city).

Category	No. Actions	% of Total	No. Cities[a/]	Actions/City
Governance	**18**	**3.3%**	**14**	**1.29**
Information	**181**	**33.0%**	**78**	**2.32**
- Assessments	4	0.7%	4	1.00
- Mapping	83	15.1%	50	1.66
- Monitoring	26	4.7%	18	1.44
- Community outreach	26	4.7%	21	1.24
- Early warning	42	7.7%	25	1.68
Services	**52**	**9.5%**	**34**	**1.53**
- Vector management	11	2.0%	11	1.00
- Infectious disease	3	0.5%	3	1.00
- Preparedness, response	38	6.9%	28	1.36
Determinants	**110**	**20.0%**	**64**	**1.72**
- UHI management	71	12.9%	53	1.34
- Flood management	21	3.8%	17	1.24
- Water & air quality	18	3.3%	9	2.00
Capacity	**8**	**1.3%**	**6**	**1.33**
Subtotal Health	**369**	**67.2%**	**98**	**3.77**
L- & M- Income	*131*	*23.9%*	*42*	*3.12*
H-Income	*238*	*43.3%*	*56*	*4.25*
Subtotal Non-Health	**180**	**32.8%**	**73**	**2.47**
Total Health and Non-Health	**549**	**100.0%**	**98**	**5.60**
L- & M- Income	*175*	*31.9%*	*42*	*3.5*
H-Income	*374*	*68.1%*	*56*	*6.7*
Insufficient information	**40**	**7.3%**	**12**	**3.33**
Total reported actions	**589**	**107.3%**	**106**	**5.56**

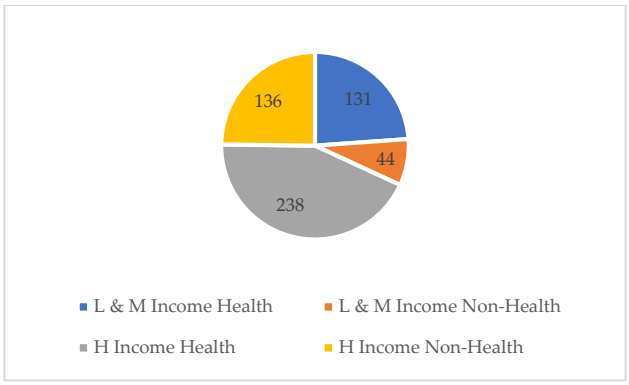
Table 1. Large Cities' Reported Adaptation Actions, Health-associated and non health-associated actions (number, share of total, number of cities, and actions per city), n = 106 cities with 2018 UN populations over one million. [a/]City totals do not add since many cities reported multiple actions.

Of large cities reporting health-associated adaptation actions, 42 were in low- or middle-income and 56 were in high-income countries (Table 1). Cities in high-income countries reported more total actions than those in low- and middle-income countries (Figure 2.a); they also reported more health actions per city (4.3 compared to 3.1). However, cities in low- and middle-income countries reported a higher share of health-associated adaptation actions (75% compared to 64%) (Figure 2.b and Appendix D). One-third of large cities (n=33) were active health adapters, i.e., reporting health-associated actions at or above the 75th percentile, accounting for 62% of total health-associated actions. Three quarters of these active health adapters were in high-income countries.

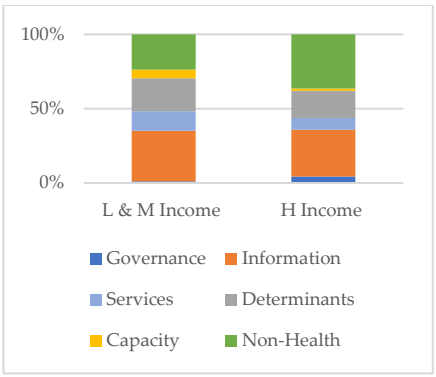


(**a**) (**b**)

Figure 1. Health-associated adaptation actions for 98 large world cities by climate hazard: (**a**) Total health-associated actions (n=369) according to the five typology groups; (**b**) Actions in the sharing information group (n=181) according to typology category.



(**a**)



(**b**)

Figure 2. Total adaptation actions (n=549) for 42 large cities in low- and middle-income countries, and 56 large cities in high-income countries: (**a**) Number of health and non-health actions; (**b**) Share of health and non-health actions.

4. Discussion

In this paper we aimed to contribute to characterizing urban health adaptation actions by developing a City Health Adaptation Typology and testing it with publicly-available data from climate-active cities reporting to the 2019 CDP Cities Adaptation Actions database. When using our five-part typology to classify written adaptation descriptions in the subset of 106 large cities with populations over one million, we identified 67% of actions reported by 98 cities as health-associated. These actions were primarily concentrated in two groups: climate-health adaptive information activities; and infrastructure and policies supporting climate-relevant health determinants. Consistent with our hypothesis, a consistent and urban-health specific typology helped to reveal population health content of city adaptation activities in these large, active adapter cities. However, our typology also helped reveal potential urban health adaptation gaps: In particular, we found markedly lower reported city effort in climate-relevant health service provision, including vector-, water-, air-borne and infectious disease management, and no reporting of efforts in some service areas, such as climate-relevant mental health and nutrition-

related outcomes; moreover, we identified very few activities addressing climate-health governance or workforce capacity building.

4. 1 Comparison With Recent Research

To our knowledge, no previous study has proposed an urban health-specific adaptation typology, or examined the health-associated adaptive actions reported to the CDP Adaptation Actions database. While it did not outline a specific typology of adaptation actions, one recent study mapping adaptation to climate-linked hazards in five large Mediterranean-climate cities also took a health-determinants approach; these authors found all cities had designed heat, flood and water management interventions responding to identified risks in order to protect the health of populations, though in multiple differing ways that did not always specify a role for public health agencies (Paz et al. 2016).

Another study aimed to establish a global baseline of reported health adaptation actions for 401 large world cities using publicly-available climate planning documents and based on general adaptation categories; these authors identified health adaptive actions in 42 cities responding to extreme weather risks in the categories of management, planning and policy, and practice and behavior, however noted few capacity building or information-related activities, or few cities in low- or middle-income countries reporting actions (Araos et al. 2016b).

In contrast, we aimed to propose a tailored urban-health adaptation typology and test it with a fairly sizable sample of highly climate-engaged cities. Using our proposed typology to examine the CDP data we identified a large number of health-associated actions and determined with some specificity the nature of the most frequently-reported health actions. Our findings are suggestive of an increasing trend health-related adaptation, which may be due to the passage of time and shared learning across cities. We noted in particular an intensive effort toward gathering, assessing

and communicating climate adaptive hazard and health risk information. One possible vehicle for this is city networks such as ICLEI and C40 Cities which may have helped scale-up promising information-intensive actions such flood mapping and heat early warning systems (Lee & Van de Meene 2012; Fungfeld 2015; Watts 2017).

Our findings otherwise run largely in parallel with the relatively limited literature on city health adaptation. Consistent with previous research, cities in our study were most concerned with addressing heat/drought, storms and flooding (CDP 2013; Paz et al. 2016; Araos et al. 2016b; Barata et al. 2018). As a result, their health-associated adaptation effort was predominantly directed toward two clusters of adaptive interventions (many cities reported actions in both):

(1) *Reducing population risk due to flooding and storm-related damage* through flood and landslide mapping, flood and storm preparedness and response activities, and flood relocation and re-zoning. One or more of these actions was reported by 84% (n=89) of large cities. Flood mapping was the single most frequently-reported health-associated activity.

(2) *Protecting populations from the health impacts of extreme heat* through structural efforts to minimize the UHI, heat health plans and early warnings, and heat-related community outreach. One or more of these actions was reported by 72% (n=76) of large cities. Managing the UHI effect was the second most frequently-reported health-associated activity.

We were not able to evaluate the role of local public health agencies in these commonly-reported activities. The CDP database did not include as a systematically-collected variable the department responsible for implementing reported actions, and this information was available only in a few of the written adaptation action descriptions (e.g., we identified 17 entries mentioning public health agencies, mainly associated with vector and heat management activities). Based on the literature, flood- and storm-related actions may be led by one or a range of local planning

agencies, regional and/or national engineering, environment, water resources or emergency management agencies (Dhakal & Chevalier 2016; Francesch-Huidobro et al. 2017); the role, if any, for local health departments is likely to be providing vulnerability data, and/or partnering in preparedness or in community outreach. It is more common for local health departments to take a leadership role in issuing heat early warnings and community heat risk messaging, or for these to be carried out as a partnership between health and environment agencies (Lowe et al. 2011); however, involvement of health agencies in bricks-and-mortar UHI management initiatives is rare (Casanueva et al. 2019).

Notably, our large city sample included 42 cities (nearly 40%) from low- and middle-income countries. These cities had a higher health-associated share of adaptation actions than cities in high-income countries, particularly in the providing services group which includes many of the core traditional public health functions. This pattern is consistent with an analysis of adaptation spending in mega-cities in which the health share was larger in cities with lower per capita income (Georgeson et al. 2016). The comparatively strong representation of low- and middle-income countries in our sample represents a change from previous research, and may be due in part to the role in CDP reporting of city networks, several of which have targeted increasing participation of cities in the global South (Kernaghan & da Silva 2013; ACCCRN 2020; UN Habitat 2020).

4.2 City Health Adaptation Gap

The large cities in our sample appear to be undertaking substantial efforts toward two of the three UNEP-identified health adaptation gap priority areas. First, a majority of cities reported one or more health-associated adaptive activities, particularly hazard and vulnerability mapping, early warning actions and alerts, and community outreach (Figure 1.b). Second, large cities are strengthening their emergency preparedness and response efforts, and many also demonstrate

evidence of multi-sectoral actions addressing health determinants, in particular management of the UHI effect and of flooding risks (Figure 1.a). In particular, both for the 42 cities in low- and middle-income countries and for the group of 33 extensive health adapters, our study suggests growing urban health adaptive performance.

However, our results also suggest important deficits, mainly in the third UNEP-identified gap area of better integrating health into climate planning while enhancing the climate-resilience and capacity of health systems (Figure 1.a). The share of the providing services group was less than 10% of total adaptation actions reported, and the bulk of these actions were for preparedness and response. Other than HRI initiatives and a small number of arbovirus surveillance programs, monitoring activities related to climate-sensitive diseases were generally not reported. Few adaptation actions were reported for water- and food-borne disease management, and no health-associated actions at all were reported for climate-relevant nutrition, or mental health outcomes.

Moreover, the share of actions in the governance and capacity building groups combined was less than 5% of total. This may be indicative of wider challenges with integrating health systems into health-protective adaptation under the typical competencies of local governments (Austin et al. 2019). Taking urban planning and heat as an illustration, the potential of public health interventions to influence urban form to minimize the health impacts of heat is often limited; not only are these decisions typically outside health agency mandates, but inter-sectoral coordination mechanisms for public health practitioners to feed health evidence into decision cycles frequently do not exist (Rantala et al. 2014). Exploring the experimental efforts by extensive health adapters may help indicate pathways forward. For example, the Barcelona Public Health Agency (ASPB) has worked with the city planning department under the umbrella of the Barcelona Adaptation Plan to recommend specific at-risk neighborhoods for expanded urban greening activities based

on results of sociodemographic and landscape characteristic heat vulnerability mapping (Villalbi & Ventayol 2016; Xu et al. 2013).

This third gap area suggests that cities may not be anticipating and preparing the needed scale-up in healthcare surge capacity, nor building the robust climate-adaptive health agency capacity needed to address the complex, often indirect health challenges of urban climate hazards of the 21st century. Programs in the US and elsewhere have demonstrated that local health agencies can build capacity and develop collaboration strategies by working through learning networks, often with limited resources (Sheehan et al. 2017; Du et al. 2019; Rudolph et al 2020). The creation of a dedicated network to strengthen urban health agency adaptive capacity, including to build on the recent lessons of the COVID-19 pandemic through a city learning exchange may be a timely initiative (Rudolph et al. 2020; Bai et al. 2020).

4.3 Limitations and Future Challenges

The CDP Cities Adaptation Actions database is a valuable resource for policy-makers and researchers. However, we found several issues that affect its use for our research. First, the selection of participants was based on an opportunistic convenience sample of world cities surveyed through the CDP city network. However, CDP cities data is validated and the dataset is the most important, largest repository of such information, collected in a comparable manner. Second, the cities of Asia and Africa are under-represented which is of concern, as infectious disease and nutrition-related morbidity are on the rise there. Our typology groups and categories helped aggregate reported activities more consistently and comparably into classifications structured to be systematic and relevant to urban health. However, given these limitations our findings quantifying city adaptation actions should be seen as providing a snapshot of currently available reporting from this source.

Typologies should evolve as adaptation advances (Biagini et al. 2014). Among future challenges is defining governance aspects, including the role of public health agencies, and whether adaptation actions are mainstreamed or new public policies, or result from social or private partner activity (Bulkeley & Kern 2006). Successful climate health adaptation is likely to require a mix of these modes, and explicit collaborative arrangements (Hughes 2015; Austin et al. 2016; Austin et al. 2019). Tracking these modes of governance, when the information is available to do so, will be useful. These and other refinements will help ensure increased utility of the proposed typology as well as move toward greater consistency and comparability of data over time.

5. Conclusions

The City Health Adaptation Typology is proposed as a systematic, literature-grounded approach to enhancing the specificity of urban health adaptation action categories in order to contribute to enhanced consistency and comparability in monitoring. In testing the typology with large active adapters in the CDP city database, we found two-thirds of the reported adaptive actions of 98 world cities with populations over one million were aimed at protecting population health and wellbeing from climate change hazards through actions known to have health benefits or co-benefits. While most health adaptation effort was reported by cities in high-income countries, cities in low- and middle-income countries represented 40% of total and reported a higher share of health-associated adaptation than cities in wealthier countries. Health-associated adaptive effort focused largely on reducing risk from and building resilience to extreme flooding, heat and storms.

Reported actions in this group of large cities suggest a strong response in two of three UNEP-identified health adaptation gap areas: adaptive information activities such as hazard mapping, community outreach and early warning; and infrastructure and policies that address

health determinants by reducing the climate-vulnerability of the urban built environment. However, our analysis revealed a deficit among these cities in the third UNEP-identified adaptation gap area of integrating public health into climate planning and building local health adaptive capacity. To remedy this gap, greater attention should be focused on integrating public health agencies into local climate action planning, enhancing and defining collaboration arrangements for climate-relevant health outcomes between health and non-health agencies, and targeted efforts to strengthen the adaptive capacity of city public health agencies including through city networks.

Supplementary Materials. Appendix A: City Health Adaptation Typology (including Appendix A References); Appendix B: CDP Database Main Variable Categories; Appendix C: Large Cities: Analysis of Written Adaptation Action Entries; Appendix D: List of Cities in Large Cities Group.

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Appendix A. City Health Adaptation Typology

For this study, we adopted the IPCC definition of *adaptation* as "the process of adjustment to actual or expected climate and its effects" (IPCC 2020), which is determined by specific climate hazards and their impacts, vulnerability to those hazards, and adaptive capacity (Smit & Wandel 2006). For *health adaptation* we used the WHO definition as "the process of designing, implementing, monitoring and evaluating strategies, policies and programs to manage the risks of climate-relevant health outcomes" (Sanchez Martinez 2018; WHO 2014). We therefore assume that *urban health adaptation* will involve carrying out these actions in response to a city's climate hazards, mediated by its vulnerability factors, and taking into account the adaptive capacity of its health-supportive actors. City public health departments often have a leadership role in these actions. But because of the wide range of sectors that impact population health, and because coordination among government levels, collaboration across city departments, and partnership with non-governmental community and private sector partners is increasingly recognized as central to building climate health resilience (WHO 2019; Austin et al. 2016), we also expect health-associated adaptation actions to involve other city actors.

To formulate a City Health Adaptation Typology we searched the literature for relevant published studies and agency reports proposing climate adaptation typologies or frameworks that were general, health-related or specific to urban areas. We defined adaptation purpose and scope as planned public policy at local level, primarily carried out by government actors. Our objective was to strengthen comparability and consistency of the typology categories by enhancing their precision and urban health-relevance. Consistent with the upstream health determinants approach recommended by the WHO, we interpreted this to include activities local public health authorities

743 typically lead but also those in which they may partner or collaborate with others to safeguard
744 urban health and wellbeing (WHO 2019). We identified over 30 adaptation typology or framework
745 studies and reports, and used the findings to construct our City Health Adaptation Typology, as
746 described below.

747 Various ways of categorizing adaptation have been proposed, evolved over the last two
748 decades, and been tested with real-life adaptation activities. One influential early review of
749 adaptation frameworks focused on modes with respect to fundamental parameters, including:
750 adaptation purpose (naturally occurring or planned as public policy); timing (reactive, concurrent
751 or anticipatory with respect to climate hazards); temporal scope (short and tactical or longer-term
752 and strategic); spatial scope or governance level (local, regional, national, or global); intent (to
753 decrease vulnerability or to modify effects); and form (technological, behavioral, institutional,
754 regulatory, market-based, etc.) (Smit et al. 2000). Since then, much of the climate adaptation
755 typology literature has focused on planned public policies at the national level (Lesnikowski et al.
756 2011; 2013; Biagini et al. 2014; Austin et al. 2016), and more recently, at sub-national level
757 (Bambrick et al. 2011; Reckien et al. 2015; Heidrich et al. 2016; Araos et al. 2016b).

758 Another review and typology of adaptation tracking at national level notes that monitoring
759 outcome-based metrics are constrained by the difficulty of associating specific climate adaptation
760 actions with actual vulnerability reduction; these authors suggest alternatives that instead monitor
761 measurements of adaptation readiness, implementation progress, and impact as proxies (Ford et
762 al. 2013). Influential research on adaptation tracking from this group of authors has also found
763 that reliable, meaningful adaptation monitoring requires consistent definitions, comprehensive and
764 comparable data (across unit of space, time, sectoral focus) and coherency (reflecting substantive,
765 actual adaptation) (Ford & Berrang-Ford 2016).

766 The adaptation typology literature has also recently focused on further refining adaptation
767 timing and form, along with developing greater specificity on monitoring implementation
768 progress. One influential study defined three adaptation phases: (i) recognition of need to adapt
769 (i.e., planning to act); (ii) groundwork or preparatory actions (i.e., that build adaptive capacity);
770 and (iii) actual adaptive actions (i.e., that actually contribute to resilience or reducing
771 vulnerability); and established several adaptation action categories based on analysis of 38 national
772 climate plans: impact and vulnerability assessments, adaptation research, and conceptual tools
773 (preparatory actions); and legislation, infrastructure and technology, public awareness and
774 outreach, and surveillance and monitoring (adaptation actions) (Lesnikowski et al. 2011). These
775 categories were further refined based on experience with multilaterally-financed projects under the
776 Global Environment Facility (GEF) into ten groupings: capacity building; management and
777 planning; practice and behavior; policy; information; physical infrastructure; warning or
778 observation systems; green infrastructure; financing; and technology (Biagini et al. 2014).
779 In addition to published studies, national and international agencies have developed
780 recommendations relevant to constructing a health-specific adaptation typology. The WHO
781 *Operational Framework for Climate-Resilient Health Systems* (WHO 2015) identifies ten building
782 blocks of public health climate resilience (Figure 1.a). According to this framework, climate health
783 information represents a major category of action, and includes the building blocks of
784 vulnerability, capacity and adaptation assessment; integrated monitoring and early warning; and
785 climate health research. Emergency preparedness, climate-informed programs, and activities that
786 address determinants of health are building blocks of another major category, climate-health
787 service delivery. The framework also includes categories for climate-health leadership and
788 governance, finance, technology, and workforce strengthening (WHO 2015). The US CDC's Ten

Essential Public Health Services model as applied to climate change similarly identifies an information-based assessment role (including disease surveillance and risk assessment), and a service-oriented assurance role (including provisioning of health and safety services), as well as a policy development role (Frumkin et al. 2008). Clearer governance arrangements among agencies for health adaptation, more explicit attention to implementation, and integrative learning through tracking and evaluation have been suggested as enhancements to this model (Fox et al. 2019).

The urban environment also presents unique challenges and vulnerabilities that must be reflected in an urban health adaptation typology. Central among them are the UHI and its impacts, which make certain adaptive activities (e.g., heat health action plans, urban forestry programs) high priority for many cities (US EPA 2019). Networked urban infrastructure is another major urban vulnerability; cascading impacts of service interruptions from storms, flooding and other stresses in turn contribute to population health risks which require monitoring and mapping of hazards, vulnerabilities and risks; outreach to the public; and preparedness and emergency response efforts (USGCRP 2016; Clark et al. 2019). Reliance on risk management tools to build resilience and flexibility was seen as key in one literature review of urban adaptation strategies (Hunt & Watkiss 2011). While it does not recommend specific categories of urban health adaptation, the health chapter (Chapter 10) of the *Second Assessment Report on Climate Change and Cities* (ARC3.2) of the Urban Climate Change Research Network (UCCRN) recommends city health adaptation plans, or health components of broader adaptation plans, include the following components: early warning systems; citizen training in preparedness; vulnerability mapping; and mainstreaming of health concerns into other sectors with relevance to health determinants, including food distribution, water and waste management, energy and transport, land use management and urban planning (Barata et al. 2018).

With the health advantages of urban living unevenly distributed over short distances, also vital is vulnerability targeting and addressing inequalities (Ezzati et al. 2018). Ensuring health-related adaptation is equitable, efficient, effective and legitimate will require enhancing involvement of non-governmental stakeholders, as well as providing means for health and vulnerability data to reach non-health actors. Cities are experimenting with such governance arrangements (Anguelovski & Carmin 2010; Castan-Broto & Bulkeley 2013; Hughes 2015). Evidence indicates most city adaptation effort to date is public sector-driven; and that limited private sector engagement seems to be governed largely through partnerships, while rarer cases of citizen engagement is via information provision (Klein et al. 2018). In terms of governance, urban adaptation has been proposed to take place in four broad governance modes: self-governing (or mainstreaming); provisioning of new services or activities; regulation of private actors (whether firms, individuals or communities); and enabling of partner agencies (Bulkeley & Kern 2006). Research suggests successful climate health adaptation is likely to require a mix of these modes, and explicit collaborative arrangements across a variety of agencies (Hughes 2015; Austin et al. 2016; Austin et al. 2019).

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834 Wellcome Trust supports research to ensure health evidence plays a role in regulating urban
835 zoning, building codes and other regulation of private sector housing (Carmichael et al. 2020).
836 Further to determining the health-association of urban adaptation actions particularly in the
837 built environment, Chapter 4 on *Strengthening and Implementing the Global Response* of the
838 IPCC's *Special Report on Global Warming of 1.5°C* (SR15) examines the enabling conditions for
839 various mitigation and adaptation options, along with indicators of feasibility and constraints (de
840 Coninck et al. 2019). Many of these adaptation options are particularly relevant for urban areas.
841 Underlying SR15 Chapter 4, the Supplementary Material (4.SM) evaluates the peer-reviewed
842 literature to identify strengths for conducting feasibility assessments for a variety of adaptation
843 policy options, determining areas in which assessment could be undertaken with plentiful literature
844 in a variety of indicator areas. Particularly relevant to the present research are those adaptation
845 options undertaken in urban areas and the indicator of health benefits or co-benefits. Areas where
846 the indicator health benefits and co-benefits of urban adaptation activities would not pose a barrier
847 (i.e., would likely be favorable) to feasibility include: land-use and urban planning (Tables
848 4.SM.10 and 4.SM.19); public transport and non-motorized transport (4.SM.11); sustainable water
849 management (Table 4.SM.19); green infrastructure and ecosystem services (4.SM.20); disaster
850 risk management (4.SM.22); and population health and health system adaptation (4.SM.23).
851 Informed by the above literature – and building particularly on the WHO health systems
852 climate resilience framework, the urban health findings of ARC3.2 Chapter 10, and the
853 implementation recommendations of IPCC SR15 Chapter 4 – we propose a typology structured
854 around five groups of health-associated adaptation action categories: (i) organizing climate-related
855 health *governance*; (ii) developing and sharing climate-relevant health *information*; (iii) providing
856 climate-health *services*; (iv) developing infrastructure and policies in support of climate-relevant

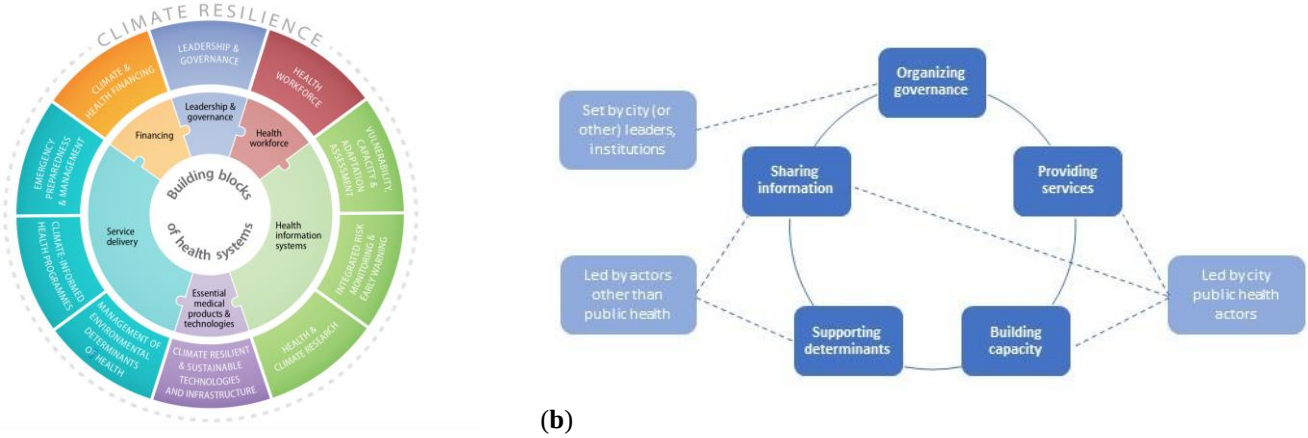
857 health *determinants*; and (v) building health adaptive *capacity* (Table 1 and Figure 1.b). Each of
858 these five groups is comprised of categories derived from those proposed by Lesnikowsi et al.
859 (2013) and Biagini et al. (2014), and further refined for the urban health context.
860
861
862
863

Typology group	**Typology categories**	**Public health role**
Organizing city climate health ***governance***	- Integrating health in climate-relevant planning, and supporting health adaptation with resources	Partner, collaborator
Developing and sharing city climate health ***information***	- Vulnerability and risk assessment - Monitoring and surveillance - Hazard and vulnerability mapping - Community outreach on climate and health - Early warning systems	Leader, partner or collaborator
Providing city ***services*** for climate-relevant health outcomes	- Vector control programs - Infectious disease control, prevention programs - Mental health programs - Other programs (nutrition, migration, conflict) - Preparedness, response activities	Leader, partner
City infrastructure and policies on health ***determinants*** linked to climate hazards	- Managing UHI risks - Managing flood and storm water risks - Managing water quality risks - Managing air quality risks	Partner or collaborator
Building city climate health adaptive ***capacity***	- Health workforce training, networking, research	Leader, partner

864

865 **Table 1.** City Climate Health Adaptation Typology: 5 groups and16 categories, with hypothesized
866 public health role
867

868 In addition, our typology proposes an indicative mapping of three broad possible public health
869 roles for each group (Figure 1.b), ranging from leader to co-equal partner to one of several
870 collaborators. As a working hypothesis, we suggest indicative public health roles for each
871 typology group, for example: public health is often *leader* in the services group (e.g., vector control
872 programs); it may be a *partner* in the determinants group (e.g., managing UHI risks jointly with
873 urban planning, by providing health outcome, vulnerability and other data); or public health may
874 be one (of many) *collaborator* in the information group (e.g., cooperating to develop hazard
875 vulnerability mapping, along with meteorology, environment, urban planning and other agencies).
876 In practice, these roles will differ not only by typology group and category but also by city, region,
877 population, decentralization regime, and a variety of other factors (Moulton & Schramm 2017;
878 Fox et al. 2019). Particularly for the typology groups where public health agencies may not be in
879 the lead, defining these roles may be among the most critical challenges (Austin et al. 2016; Austin
880 et al. 2019; Doubleday et al. 2020). Further developing monitoring, tracking and evaluating
881 governance modes of health adaptation activity, including the various roles for public health
882 agencies, is a desirable goal for a City Health Adaptation Typology, though is beyond the scope
883 of this study.
884



(**a**) (**b**)

885

886 **Figure 1.** Conceptual models for climate-related health adaptation activities: (**a**) Ten building blocks of the
887 Climate Resilience Framework, World Health Organization (WHO 2015) (WHO, 2015); (**b**) Five groups
888 of health adaptation actions and hypothesized institutional leadership roles, City Health Adaptation
889 Typology (authors).

890

Better understanding parameters that reflect the ambition of adaptation could also be valuable. For example, one examination of national climate action plans found adaptation in low-income countries tended toward reactivity, i.e., avoiding, retreating, accommodating, adjusting, spreading risk, securing income; whereas adaptation in high-income countries tended toward proactivity, i.e., planning, monitoring, increasing awareness, building partnerships, enhancing learning or research (Berrang-Ford et al. 2011). It was not part of our study goal to test this hypothesis. But we did find suggestive consistency in our results, since the bulk of governance, capacity building and information-related activities were reported by cities in high-income countries; while cities in low- and middle-income countries reported more actions taken as the result of specific extreme events. We suggest future research could build on this parameter (Reckien et al. 2015).

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Appendix B. CDP Database Main Variable Categories

Table 1. CDP city climate hazards, as consolidated for analysis[1]

1. **Extreme heat and drought**
   - Heat wave (Extreme temperature)
   - Extreme hot days (Extreme temperature)
   - Drought (Water scarcity)

2. **Flooding and sea-level rise**
   - Flash/surface flood (Flood and sea level rise)
   - River flood (Flood and sea level rise)
   - Coastal flood (Flood and sea level rise)
   - Groundwater flood (Flood and sea level rise)
   - Permanent inundation (Flood and sea level rise)
   - Salt water intrusion (Chemical change)
   - Ocean acidification (Chemical change)
   - Storm surge (Storm and wind)
   - Subsidence (Mass movement)

3. **Extreme storms**
   - Rain storm (Extreme precipitation)
   - Monsoon (Extreme precipitation)
   - Fog (Extreme precipitation)
   - Hail (Extreme precipitation)
   - Severe wind (Storm and wind)
   - Tornado (Storm and wind)
   - Cyclone/hurricane/typhoon (Storm and wind)

[1] Original ten CDP hazard options (in parenthesis) combined into seven categories.

- Extra tropical storm (Storm and wind)
- Tropical storm (Storm and wind)
- Lightning/thunderstorm (Storm and wind)

4. <u>Wildfire</u>

- Forest fire (Wild fire)
- Land fire (Wild fire)

5. <u>Changes in conditions for disease (vector- and airborne)</u>

- Water-borne disease (Biological hazards)
- Vector-borne disease (Biological hazards)
- Insect infestation (Biological hazards)
- Atmospheric CO2 concentrations (Chemical change)
- Air-borne disease (Biological hazards)

6. <u>Land movements</u>

- Landslide (Mass movements)
- Avalanche (Mass movement)
- Rock fall (Mass movement)

7. <u>Extreme cold</u>

- Extreme winter conditions (Extreme temperature)
- Cold wave (Extreme temperature)
- Extreme cold days (Extreme temperature)
- Heavy snow (Extreme precipitation)

<u>None reported</u>

Appendix B. CDP Database Main Variable Categories

Table 2. CDP city climate adaptation action categories, as consolidated for analysis[2]

I. PREPARATORY ACTIONS

1. Incorporating climate change into long-term planning documents
2. Community engagement/education
3. Flood mapping
4. Heat mapping and thermal imaging
5. Landslide risk mapping

6. Hazard monitoring

- Sea level rise modelling
- Biodiversity monitoring
- Real time risk monitoring

II. ADAPTIVE ACTIONS

Health and Health-Related Adaptive Actions

7. Projects and policies targeted at those most vulnerable
8. Testing/vaccination programs for vector-borne disease
9. Disease prevention measures
10. Air quality initiatives
11. Crisis management including warning and evacuation systems
12. Public preparedness (including practice exercises/drills)

Other Adaptive Actions

13. Infrastructure preparedness

- Resilience and resistance measures for buildings
- Hazard resistant infrastructure design and construction
- Cooling systems for critical infrastructure
- Retrofit of existing buildings

[2] Original 43 CDP adaptation action options reported by cities, consolidated into 20 categories (indented adaptation action options were combined as indicated, bold italics indicates a new consolidated category). Shown as I. Preparatory Actions; and II. Adaptive Actions (Health & Health-Related and Other), based on nature of action.

14. Flood defenses

- Soil retention strategies
- Flood defenses – development, operation
- Restrict development in at-risk areas

15. Water supply management

- Storm water capture systems
- Additional reservoirs and wells for water storage
- Water extraction protection
- Water butts/rainwater capture
- Maintenance/repair – leaking infrastructure
- Improve water supply distribution method
- Diversification of water supply

16. Water demand management

- Promoting low flow technologies
- Xeriscapes – low water landscaping design
- Promoting and incentivizing water efficiency
- Water use restrictions and standards
- Water efficient equipment and appliances
- Water smart metering
- Water use audits
- Awareness campaign/education to reduce water use

17. Green/white roofs/surfaces

- Green roofs/walls
- White roofs
- Cool pavement

18. Shading/tree-planting

Shading in public spaces, markets

Tree planting and/or creation of green space

19. Cooling centers, pools, water parks/plazas
20. Other

Appendix C. Reported City Adaptation Actions:
All Responsive Database Cities and Large Cities

Complete CDP database information for our analysis was available for 282 cities from 60 countries representing all world regions. These cities were concentrated (85%) in North America, Latin America and Europe; 42% were medium-sized (population > 500,000) or larger, and 58% were smaller cities. Seventy percent of cities were associated with two large city networks, ICLEI (48%) and C40 (22%). The majority (80%) of adaptation actions addressed three hazards: flooding, heat and/or drought, and extreme storms. One or more flooding hazard was reported by 66% of cities, one or more extreme heat or drought hazard by 60% of cities, and one or more extreme storm hazard by 54% of cities. In many cases, cities reported adaptive actions in response to multiple sub-categories of one hazard (e.g., coastal, river, flash, permanent and storm-surge flooding).

This group of cities reported 1,324 adaptation actions (mean 4.7 per city, range 1-20) (Table). Based on CDP category definitions, we evaluated 35% of actions as preparatory, and 65% as actual adaptive actions. The share of actions by region broadly mirrored the share of cities by region. Of the 282 cities, 34 were particularly active, reporting ten or more actions each. Of actions with implementation status available, 22% reported being in the initial stages of activity (scoping or feasibility study), while 78% were in some form of ongoing implementation or had been completed. Actions reported in the six health and health-related categories comprised 19% of total, or 253 actions, and were reported by 140 cities (1.8 per city). The preparedness and vulnerability-targeting categories accounted for 81% of these health actions, with the disease-prevention categories accounting for 19%.

Reported City Adaptation Actions: All Responsive and Large Cities

by reported CDP action category

	All responsive cities (n = 282)		**Large cities** (n = 106)	
Adaptation action category	Number	*% of total*	Number	*% of total*
I Preparatory actions	**468**	***35.3***	**180**	***30.6***
Climate in long-term planning	73	*5.5*	22	*3.7*
Community engagement	91	*6.9*	33	*5.6*
Flood mapping	141	*10.6*	56	*9.5*
Heat mapping	43	*3.2*	22	*3.7*
Landslide mapping	27	*2.0*	11	*1.9*
Hazard monitoring	93	*7.0*	36	*6.1*
II Adaptive actions	**856**	***64.7***	**409**	***69.4***
Health and health-related	**253**	***19.1***	**130**	***22.1***
Projects targeting vulnerable	47	*3.5*	31	*5.3*
Vector testing, vaccination	12	*0.9*	6	*1.0*
Disease prevention	23	*1.7*	12	*2.0*
Air quality initiatives	14	*1.1*	6	*1.0*
Crisis management & warning	115	*8.7*	61	*10.4*
Public preparedness	42	*3.2*	14	*2.4*
Other adaptive actions	**603**	***45.5***	**279**	***47.4***
Infrastructure preparedness	95	*7.2*	45	*7.6*
Flood defenses	83	*6.3*	48	*8.1*
Water demand management	69	*5.2*	34	*5.8*
Water supply management	112	*8.5*	46	*7.8*
Green/white roofs/surfaces	27	*2.0*	11	*1.9*
Shading/tree planting	95	*7.2*	43	*7.3*
Cooling centers	22	*1.7*	10	*1.7*
Other actions	100	*7.6*	42	*7.1.*
TOTAL	**1,324**	***100.0***	**589**	***100.0***

Of cities reporting to the CDP database, 106 had 2018 UN populations greater than one million and reported at least one adaptation action with a sufficient written description to evaluate. These cities reported 589 adaptation actions (5.6 per city, range 1-20). While the large cities group reported more actions per city than all responsive cities, the differences across CDP categories of action were small: large cities reported a lower share of preparatory actions (31% vs. 35%), a higher share of adaptive actions (69% vs. 65%), and a slightly higher share of health and health-related actions (22% vs. 19%) (Table). Large cities also had higher proportional representation from Asia, Africa and the Middle East.

Appendix D. Large Cities: Analysis of Written Adaptation Action Entries

by City Health Adaptation Typology group and category

Number of cities, number of actions, share of total, actions per city, actions by climate hazard

	Cities[a/]	Actions				Actions by Hazard (No.)				
	No.	No.	% Total	% Health	Action/ City	Heat	Flood	Storm	Disease	Others
Organizing governance	**14**	**18**	***3.3%***	***4.9%***	**1.3**	**7**	**6**	**0**	**0**	**5**
Sharing information	**78**	**181**	***33.0%***	***49.1%***	**2.3**	**58**	**56**	**30**	**3**	**34**
Risk assessments	4	4	*0.7%*	*1.1%*	1.0	1	1	1	1	0
Hazard mapping	50	83	*15.1%*	*22.5%*	1.7	19	35	14	0	15
Monitoring	18	26	*4.7%*	*7.0%*	1.4	0	11	3	2	10
Community outreach	21	26	*4.7%*	*7.0%*	1.2	13	3	3	0	7
Early warnings	42	25	*7.7*	*11.4%*	1.7	25	6	9	0	2
Providing services	**34**	**52**	***9.7%***	***14.4%***	**1.5**	**1**	**13**	**16**	**15**	**8**
Vector-borne disease	11	11	*2.5%*	*3.8%*	1.0	0	0	0	14	0
Infectious disease	3	3	*0.2%*	*0.3%*	1.0	0	0	0	1	0
Nutrition, migration, conflict	0	0	*0.0%*	*0.0%*	-	0	0	0	0	0
Mental health	0	0	*0.0%*	*0.0%*	-	0	0	0	0	0
Preparedness and response	28	38	*6.9%*	*10.3%*	1.4	1	13	16	0	8
Supporting determinants	**64**	**110**	***20.0%***	***29.8%***	**1.7**	**66**	**19**	**4**	**0**	**21**
UHI reduction	53	71	*12.9%*	*19.2%*	1.3	59	4	1	0	7
Flood management	17	21	*3.8%*	*5.7%*	1.2	1	13	3	0	4
Water & air quality	9	18	*0.9%*	*1.4%*	2.0	6	2	0	0	10
Building capacity	**6**	**8**	***1.3%***	***1.3%***	1.2	**3**	**2**	**1**	**0**	**1**
Total health-associated	**98**	**369**	***67.1%***	***100%***	**3.8**	**135**	**96**	**51**	**18**	**69**
Share						*36.6%*	*26.0%*	*13.8%*	*4.9%*	*18.7%*
Economic efficiency	25	35	*6.4%*	--	1.4	25	4	3	0	3
Infrastructure protection	60	104	*18.9%*	--	1.7	15	51	25	0	13
Biodiversity protection	18	26	*4.7%*	--	1.4	9	5	2	2	8
Routine maintenance	13	15	*2.7%*	--	1.2	0	1	5	2	7
Total non health-associated	**73**	**180**	***32.8%***	**--**	**2.5**	**49**	**61**	**35**	**4**	**31**
Share						*27.2%*	*33.9%*	*19.4%*	*2.2%*	*17.2%*
TOTAL ACTIONS	**106**	**549**	***100%***	**--**	**5.2**	**184**	**157**	**86**	**22**	**100**
Share						*33.5%*	*28.6%*	*15.7%*	*4.0%*	*18.2%*

[a/]City totals do not add since many cities reported multiple actions.

Appendix E. List of Cities in Large Cities Group

Country, region, population, number of reported total and health-associated actions

	City	Country	Region	UN 2018 Population	Total actions[a/]	Health-associated actions[b/]
LOW- AND MIDDLE-INCOME COUNTRIES						
1	Accra	Ghana	Africa	2,439,000	2	2
2	Addis Ababa	Ethiopia	Africa	4,400,000	1	1
3	Amman	Jordan	Middle East	2,065,000	2	0
4	Asunción	Paraguay	Latin America	3,222,000	3	3
5	Bangkok	Thailand	SE Asia and Oceania	10,156,000	1	1
6	Buenos Aires	Argentina	Latin America	14,967,000	6	6
7	Campinas	Brazil	Latin America	3,210,000	5	3
8	Cape Town	South Africa	Africa	4,430,000	10	8
9	Cartagena	Colombia	Latin America	1,047,000	1	0
10	Chennai	India	South and West Asia	10,456,000	1	1
11	Chihuahua	Mexico	Latin America	1,012,000	1	1
12	Córdoba	Argentina	Latin America	1,548,000	5	5
13	Curitiba	Brazil	Latin America	3,579,000	3	2
14	Dar es Salaam	Tanzania	Africa	6,048,000	2	2
15	Dhaka	Bangladesh	South and West Asia	19,578,000	3	2
16	Durban	South Africa	Africa	3,134,000	3	2
17	Fortaleza	Brazil	Latin America	3,977,000	3	2
18	Goiânia	Brazil	Latin America	2,565,000	4	2
19	Guadalajara	Mexico	Latin America	5,023,000	2	2
20	Guayaquil	Ecuador	Latin America	2,899,000	1	1
21	Ho Chi Minh	Viet Nam	SE Asia and Oceania	8,145,000	6	4
22	Hong Kong	China (HK SAR)	East Asia	7,429,000	5	4
23	Ibadan	Nigeria	Africa	3,383,000	1	1
24	Iskandar	Malaysia	SE Asia and Oceania	1,900,000	6	2
25	Jaipur	India	South and West Asia	3,717,000	1	1
26	Jakarta	Indonesia	SE Asia and Oceania	10,517,000	1	0
27	Johannesburg	South Africa	Africa	5,486,000	3	2
28	Juárez	Mexico	Latin America	1,480,000	1	0
29	Kaohsiung	Taiwan, Greater China	East Asia	2,776,912	2	0

	City	Country	Region	UN 2018 Population	Total actions*	Health-associated actions**
30	Karachi	Pakistan	South and West Asia	14,910,000	1	0
31	Kinshasa	DR Congo	Africa	13,171,000	6	4
32	Kolkata	India	South and West Asia	14,681,000	8	6
33	Lagos	Nigeria	Africa	13,463,000	3	1
34	Medellín	Colombia	Latin America	3,934,000	7	7
35	Mérida	Mexico	Latin America	1,122,000	4	4
36	Mexico City	Mexico	Latin America	21,581,000	2	1
37	Nairobi	Kenya	Africa	4,386,000	2	2
38	New Taipei	Taiwan, Greater China	East Asia	3,986,689	1	1
39	Porto Alegre	Brazil	Latin America	4,094,000	1	1
40	Quezon City	Philippines	SE Asia and Oceania	3,005,413	11	11
41	Quito	Ecuador	Latin America	1,822,000	5	5
42	Recife	Brazil	Latin America	4,028,000	2	2
43	Rio de Janeiro	Brazil	Latin America	13,293,000	18	12
44	Santiago	Chile	Latin America	6,680,000	3	2
45	São Paulo	Brazil	Latin America	21,650,000	3	1
46	Sofia	Bulgaria	Europe	1,272,000	4	4
47	Taichung	Taiwan, Greater China	East Asia	1,283,000	3	3
48	Taipei	Taiwan, Greater China	East Asia	2,706,000	4	3
49	Tegucigalpa	Honduras	Latin America	1,363,000	1	1
50	Vitória	Brazil	Latin America	2,003,000	1	0
Subtotal low- and middle-income countries				**305,023,014**	**175**	**131**
Share total low- and middle-income total					*100.0%*	*74.8%*
Share all large cities totals (last line of table)				*56.4%*	*31.9%*	*35.5%*
	City	**Country**	**Region**	**UN 2018 Population**	**Total actions***	**Health-associated actions****
HIGH-INCOME COUNTRIES						
1	Athens	Greece	Europe	3,156,000	9	7
2	Atlanta	USA	North America	5,572,000	6	4
3	Auckland	New Zealand	SE Asia and Oceania	1,557,000	8	7
4	Austin	USA	North America	1,915,000	9	7
5	Baltimore	USA	North America	2,315,000	10	8

	City	Country	Region	UN 2018 Population	Total actions*	Health-associated actions**
6	Barcelona	Spain	Europe	5,494,000	12	8
7	Boston	USA	North America	4,308,000	7	6
8	Calgary	Canada	North America	1,477,000	13	7
9	Changwon	Republic of Korea	East Asia	1,060,000	4	3
10	Chicago	USA	North America	8,864,000	4	3
11	Cincinnati	USA	North America	1,733,000	2	1
12	Cleveland	USA	North America	1,776,000	3	2
13	Columbus	USA	North America	1,598,000	4	2
14	Denver	USA	North America	2,753,000	3	2
15	Houston	USA	North America	6,115,000	9	6
16	Indianapolis	USA	North America	1,753,000	9	6
17	Las Vegas	USA	North America	2,541,000	20	10
18	Lisbon	Portugal	Europe	2,927,000	15	8
19	London	UK	Europe	9,046,000	9	5
20	Manchester	UK	Europe	2,690,000	3	1
21	Melbourne	Australia	SE Asia and Oceania	4,771,000	5	3
22	Memphis	USA	North America	1,139,000	7	3
23	Minneapolis	USA	North America	3,280,000	1	1
24	Montréal	Canada	North America	4,172,000	6	1
25	Nagoya	Japan	East Asia	9,507,000	1	1
26	Nanjing	China	East Asia	8,245,000	3	2
27	New York City	USA	North America	8,537,673	5	2
28	Oslo	Norway	Europe	1,012,000	7	5
29	Paris	France	Europe	10,901,000	11	5
30	Philadelphia	USA	North America	5,695,000	3	3
31	Phoenix	USA	North America	1,615,017	8	6
32	Portland, OR	USA	North America	2,104,000	6	4
33	Porto	Portugal	Europe	1,307,000	4	3
34	Providence	USA	North America	1,205,000	7	3
35	Richmond	USA	North America	1,081,000	5	3
36	Roma	Italy	Europe	4,210,000	7	4

37	Rotterdam	Netherlands	Europe	1,008,000	1	1
	City	**Country**	**Region**	**UN 2018 Population**	**Total actions***	**Health-associated actions****
38	Sacramento	USA	North America	2,054,000	2	1
39	Salt Lake City	USA	North America	1,147,000	10	7
40	San Antonio	USA	North America	2,217,000	5	5
41	San Francisco	USA	North America	4,729,000	9	6
42	San José	USA	North America	1,776,000	5	2
43	Seattle	USA	North America	3,379,000	9	6
44	Seoul	Republic of Korea	East Asia	9,963,000	2	1
45	Singapore	Singapore	SE Asia and Oceania	5,792,000	6	3
46	St Louis	USA	North America	2,213,000	1	1
47	Stockholm	Sweden	Europe	1,583,000	3	2
48	Suwon	Republic of Korea	East Asia	1,265,000	1	1
49	Sydney	Australia	SE Asia and Oceania	4,792,000	5	5
50	Tel Aviv-Yafo	Israel	Middle East	4,011,000	8	6
51	Tokyo	Japan	East Asia	37,468,000	10	5
52	Torino	Italy	Europe	1,786,000	15	12
53	Vancouver	Canada	North America	2,531,000	11	4
54	Warsaw	Poland	Europe	1,768,000	1	1
55	Washington DC	USA	North America	5,207,000	10	5
56	Yokohama	Japan	East Asia	3,731,096	15	12
Subtotal high-income				**235,851,786**	**374**	**238**
Share high income total					*100.0%*	*63.9%*
Share all large cities totals				*43.6%*	*68.1%*	*64.5%*
Total all large cities				**540,874,800**	**549**	**369**
Share all large cities total				*100.0%*	*100.0%*	*67.2%*

*All responsive actions, i.e., all actions with descriptions for which categories could be discerned

**All health-associated adaptation actions based on assignment to City Climate Health Action Typology categories