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Piloting a City Health Adaptation Typology in climate-engaged cities:

Toward identification of an urban health adaptation gap

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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

129   adaptation actions reported by 73 of 401 world cities (Araos et al. 2016a). A baseline review using

130   the same database found 42 cities, or 10% of total, reported health adaptation actions (Araos et al.

131   2016b). While governance arrangements for climate-relevant health initiatives vary across cities

132   and by region (Heidrich et al 2016; Austin et al. 2019), cities often have greater institutional and

133   political independence of climate planning and action than national governments (Barata et al.

134   2018; Rosenzweig et al. 2018). Large cities in particular, with their concentration of knowledge,

135   capacity to innovate and provide services, and practice of networked learning, may have an

136   advantage in delivering health-supportive climate policies and actions (Reckien et al. 2015; Ezzati

137   et al. 2018).

138   However, there is a dearth of evidence on climate-related health adaptive actions across world

139   cities, and the information available suggests health is often less well-integrated into urban climate

140   planning than other sectors. For example, an international survey of 350 city climate action plans

141   found only 35% had incorporated public health, which was among local government agencies

142   considered "on the margins of urban adaptation" (Aylett 2015). A qualitative review of six US

143   cities' adaptation plans found lack of information on climate-health impacts and exclusion of

144   public health from climate planning in adaptation planning (Shimamoto & McCormick 2017).

145   Analysis of ten world megacities found health accounted for just 2-4% of adaptation spending

146   (compared to 11-13% for transport, 11-15% for water, and over 30% for the built environment),

147   and priorities seemed "largely influenced by market-based responses to protecting physical capital

148   rather than at-risk populations" (Georgeson et al. 2016).

149   Research on adaptation tracking has found that reliable, meaningful adaptation monitoring

150   requires consistent definitions, comprehensive and comparable data and coherency (Ford &

151   Berrang-Ford 2016). In addition, particularly for cities, monitoring of health adaptation must

152   inevitably go beyond public health departments (Baum et al. 2014; Patz & Thomson 2018). That

153   population health is determined to a large extent outside the health sector is widely accepted, as

154   underlined by the upstream determinants focus of the recent WHO strategy, and holistic

155   assessment frameworks such as Health-in-All Policies integrating health into broader cross-

156   disciplinary planning (WHO 2019; Baum et al. 2014; de Leewu 2017). Water and sanitation have

157   been at the core of urban public health for centuries; reducing risk of microbial infection remains

158   a critical area of collaboration between health and water agencies (Hoornweg et al. 2011; World

159   Bank 2011). Greening initiatives carried out by urban planning departments can reduce hazardous

160   heat exposures as can other modifications to the built environment at building, city and peri-urban

161   scales (Barata et al. 2018), though it is rare to find they integrate health into decision-making.

162   Public preparedness (emergency response, hospital surge-capacity) is essential to protecting urban

163   dwellers from climate-related epidemics and disasters (McMichael & Lindgren 2011) and is

164   formally considered a 'health-related' field (Watts et al. 2019).

165   Thus, adaptive actions that contribute to protecting population health and building health

166   resilience in the urban space can be expected to cover a wider range than the climate-related

167   activities carried out by local health departments, or budgeted under their mandates. Some

168   researchers have addressed this by distinguishing between adaptation actions which have an

169   'explicit' health focus, and those which have an 'implicit' contribution to population health

170   (Lesnikowski et al. 2011). However, a unified and consistent typology of health-associated

171   adaptation actions in the urban space is lacking. Moreover, few efforts have looked

172   comprehensively at a large sample of cities in low-, middle- and high-income countries to identify

173   categories of planned or completed health adaptive action as well as determine deficits. This

174   makes it difficult to assess progress and needs in a consistent, comparable, comprehensive and

175   coherent way across cities.

176   **1.3 Study Goal: Characterizing Urban Health-Associated Adaptation**

177   The goal of this study is to characterize urban health-associated adaptation by proposing a

178   consistent City Health Adaptation Typology and testing its use with a major public global city

179   database of active adapters. We hypothesized that this close-up view of climate-engaged cities

180   would also enable us to begin to understand more comprehensively the scope and nature of city

181   adaptive actions aimed at safeguarding human health and wellbeing, as well as to move toward

182   mapping the elements of an 'urban health adaptation gap.' The ultimate motivation of this research

183   is to enhance the ability to consistently monitor, evaluate and learn from cities' ongoing and

184   planned health-associated activities as these become more fully integrated into adaptation

185   planning, and as urban climate health challenges become increasingly more complex.

186

187   **2. Materials and Methods**

188   **2.1 Materials**

189   **2.1.1 City Health Adaptation Typology**

190   We first developed a City Health Adaptation Typology based on a review and synthesis of

191   over 30 articles from the literature outlining climate adaptation typologies or frameworks that were

192   general, health-related or specific to urban areas. Our review findings are outlined here and we

193   provide the full literature review and describe the typology in Appendix A. Briefly, we found that

194   adaptation is commonly divided into three time-linked phases: (i) planning, (ii) preparation, and

195   (iii) adaptive actions (Lesnikowski et al. 2011); and into ten functional categories: capacity

196   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-

266   and middle-income, or high-income) (World Bank 2020).   We also identified active health

267   adapters, which we defined as those cities with health-associated actions at or over the 75th

268   percentile. The majority of adaptation action descriptions were in English; we translated those

269   reported in French, Spanish, Portuguese or Chinese.

3. Results

271   *When we reviewed* the 549 written adaptation actions of 106 large world cities in the CDP

272   database to allocate them to categories in our typology, we determined 369 actions (67% of total)

273   reported by 98 cities were health-associated (3.8 actions per city, range 1-12); we deemed 180

274   actions (33%) reported by 73 cities to be not health-associated (2.5 actions per city, range 1-8)

275   (Table 1 and Appendix C). Among health-associated actions, 33% (2.3 per city) were in the

276   sharing information group; 20% (1.7 per city) were in the supporting determinants group; 9.5%

277   (1.5 per city) were in the furnishing services group; 3.3% (1.3 per city) were in the organizing

278   governance group; and 1.3% (1.3 per city) were in the capacity building group (Table 1 and Figure

279   1.a). Hazard and vulnerability mapping (information group) was the largest single health-

280   associated adaptation action category (83 actions, 1.7 per city); a majority of these actions were

281   identified with flood, storm and landslide hazards (Figure 1.b). Managing the urban heat island

282   effect (determinants group) was the second-largest category (71 actions, 1.3 per city). Early

283   warning (information group) and preparedness and response (services group) were also frequently

284   reported (42 actions, 1.7 per city; and 38 actions, 1.4 per city, respectively).

285   There were few or no actions reported for several categories in the climate-health services

286   group (including climate-sensitive infectious disease, mental health, nutrition or rural-to-urban

287   migration related interventions; Appendix C). Few actions were reported in the climate-health

288 governance and capacity groups. The largest number of non-health-associated actions was in the

289 protecting physical infrastructure category (104 actions by 60 cities, 1.7 per city).

290

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**

291

292   **Table 1. Large Cities' Reported Adaptation Actions**, Health-associated and non health-associated actions

293   (number, share of total, number of cities, and actions per city), n = 106 cities with 2018 UN populations over

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

295   Of large cities reporting health-associated adaptation actions, 42 were in low- or middle-

296   income and 56 were in high-income countries (Table 1). Cities in high-income countries reported

297   more total actions than those in low- and middle-income countries (Figure 2.a); they also reported

298   more health actions per city (4.3 compared to 3.1). However, cities in low- and middle-income

299   countries reported a higher share of health-associated adaptation actions (75% compared to 64%)

300   (Figure 2.b and Appendix D). One-third of large cities (n=33) were active health adapters, i.e.,

301   reporting health-associated actions at or above the 75th percentile, accounting for 62% of total

302   health-associated actions. Three quarters of these active health adapters were in high-income

303   countries.

304
305

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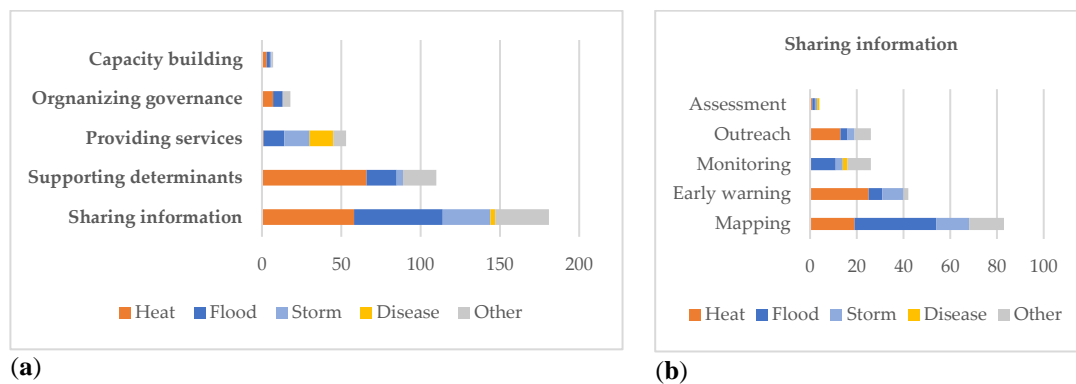
306   **Figure 1.** Health-associated adaptation actions for 98 large world cities by climate hazard: (**a**) Total health-
307   associated actions (n=369) according to the five typology groups; (**b**) Actions in the sharing information
308   group (n=181) according to typology category.

309

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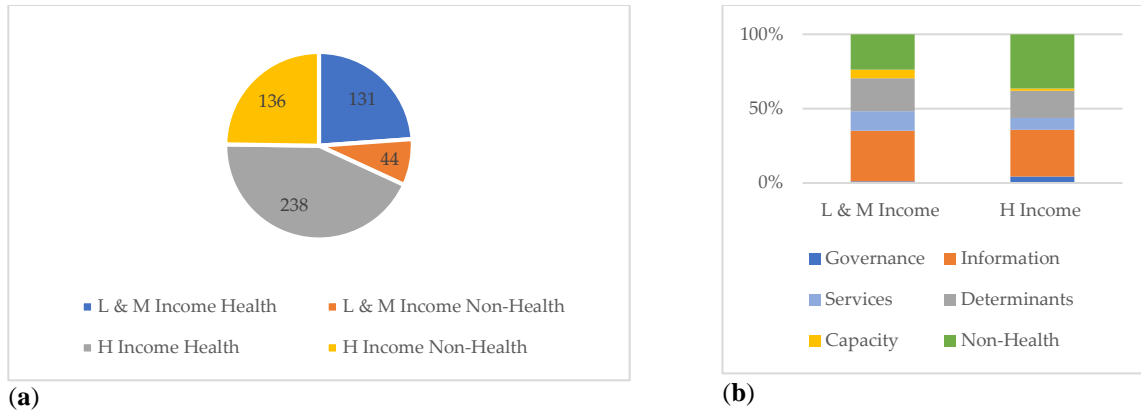
Figure 2. Total adaptation actions (n=549) for 42 large cities in low- and middle-income countries, and 56 large cities in high-income countries: (**a**) Number of health and non-health actions; (**b**) Share of health and non-health actions.

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-

15

327 related outcomes; moreover, we identified very few activities addressing climate-health

328 governance or workforce capacity building.

4. 1 Comparison With Recent Research

330   To our knowledge, no previous study has proposed an urban health-specific adaptation

331 typology, or examined the health-associated adaptive actions reported to the CDP Adaptation

332 Actions database. While it did not outline a specific typology of adaptation actions, one recent

333 study mapping adaptation to climate-linked hazards in five large Mediterranean-climate cities also

334 took a health-determinants approach; these authors found all cities had designed heat, flood and

335 water management interventions responding to identified risks in order to protect the health of

336 populations, though in multiple differing ways that did not always specify a role for public health

337 agencies (Paz et al. 2016).

338   Another study aimed to establish a global baseline of reported health adaptation actions for

339 401 large world cities using publicly-available climate planning documents and based on general

340 adaptation categories; these authors identified health adaptive actions in 42 cities responding to

341 extreme weather risks in the categories of management, planning and policy, and practice and

342 behavior, however noted few capacity building or information-related activities, or few cities in

343 low- or middle-income countries reporting actions (Araos et al. 2016b).

344   In contrast, we aimed to propose a tailored urban-health adaptation typology and test it with a

345 fairly sizable sample of highly climate-engaged cities. Using our proposed typology to examine

346 the CDP data we identified a large number of health-associated actions and determined with some

347 specificity the nature of the most frequently-reported health actions. Our findings are suggestive

348 of an increasing trend health-related adaptation, which may be due to the passage of time and

349 shared learning across cities. We noted in particular an intensive effort toward gathering, assessing

350 and communicating climate adaptive hazard and health risk information. One possible vehicle for

351 this is city networks such as ICLEI and C40 Cities which may have helped scale-up promising

352 information-intensive actions such flood mapping and heat early warning systems (Lee & Van de

353 Meene 2012; Fungfeld 2015; Watts 2017).

354 Our findings otherwise run largely in parallel with the relatively limited literature on city

355 health adaptation. Consistent with previous research, cities in our study were most concerned with

356 addressing heat/drought, storms and flooding (CDP 2013; Paz et al. 2016; Araos et al. 2016b;

357 Barata et al. 2018). As a result, their health-associated adaptation effort was predominantly

358 directed toward two clusters of adaptive interventions (many cities reported actions in both):

359 (1) *Reducing population risk due to flooding and storm-related damage* through flood and

360 landslide mapping, flood and storm preparedness and response activities, and flood relocation and

361 re-zoning. One or more of these actions was reported by 84% (n=89) of large cities. Flood

362 mapping was the single most frequently-reported health-associated activity.

363 (2) *Protecting populations from the health impacts of extreme heat* through structural efforts

364 to minimize the UHI, heat health plans and early warnings, and heat-related community outreach.

365 One or more of these actions was reported by 72% (n=76) of large cities. Managing the UHI effect

366 was the second most frequently-reported health-associated activity.

367 We were not able to evaluate the role of local public health agencies in these commonly-

368 reported activities. The CDP database did not include as a systematically-collected variable the

369 department responsible for implementing reported actions, and this information was available only

370 in a few of the written adaptation action descriptions (e.g., we identified 17 entries mentioning

371 public health agencies, mainly associated with vector and heat management activities). Based on

372 the literature, flood- and storm-related actions may be led by one or a range of local planning

373 agencies, regional and/or national engineering, environment, water resources or emergency

374 management agencies (Dhakal & Chevalier 2016; Francesch-Huidobro et al. 2017); the role, if

375 any, for local health departments is likely to be providing vulnerability data, and/or partnering in

376 preparedness or in community outreach. It is more common for local health departments to take a

377 leadership role in issuing heat early warnings and community heat risk messaging, or for these to

378 be carried out as a partnership between health and environment agencies (Lowe et al. 2011);

379 however, involvement of health agencies in bricks-and-mortar UHI management initiatives is rare

380 (Casanueva et al. 2019).

381 Notably, our large city sample included 42 cities (nearly 40%) from low- and middle-income

382 countries. These cities had a higher health-associated share of adaptation actions than cities in

383 high-income countries, particularly in the providing services group which includes many of the

384 core traditional public health functions. This pattern is consistent with an analysis of adaptation

385 spending in mega-cities in which the health share was larger in cities with lower per capita income

386 (Georgeson et al. 2016). The comparatively strong representation of low- and middle-income

387 countries in our sample represents a change from previous research, and may be due in part to the

388 role in CDP reporting of city networks, several of which have targeted increasing participation of

389 cities in the global South (Kernaghan & da Silva 2013; ACCCRN 2020; UN Habitat 2020).

390 **4.2 City Health Adaptation Gap**

391 The large cities in our sample appear to be undertaking substantial efforts toward two of the

392 three UNEP-identified health adaptation gap priority areas. First, a majority of cities reported one

393 or more health-associated adaptive activities, particularly hazard and vulnerability mapping, early

394 warning actions and alerts, and community outreach (Figure 1.b). Second, large cities are

395 strengthening their emergency preparedness and response efforts, and many also demonstrate

396 evidence of multi-sectoral actions addressing health determinants, in particular management of the

397 UHI effect and of flooding risks (Figure 1.a). In particular, both for the 42 cities in low- and

398 middle-income countries and for the group of 33 extensive health adapters, our study suggests

399 growing urban health adaptive performance.

400   However, our results also suggest important deficits, mainly in the third UNEP-identified gap

401 area of better integrating health into climate planning while enhancing the climate-resilience and

402 capacity of health systems (Figure 1.a). The share of the providing services group was less than

403 10% of total adaptation actions reported, and the bulk of these actions were for preparedness and

404 response. Other than HRI initiatives and a small number of arbovirus surveillance programs,

405 monitoring activities related to climate-sensitive diseases were generally not reported. Few

406 adaptation actions were reported for water- and food-borne disease management, and no health-

407 associated actions at all were reported for climate-relevant nutrition, or mental health outcomes.

408   Moreover, the share of actions in the governance and capacity building groups combined was

409 less than 5% of total. This may be indicative of wider challenges with integrating health systems

410 into health-protective adaptation under the typical competencies of local governments (Austin et

411 al. 2019). Taking urban planning and heat as an illustration, the potential of public health

412 interventions to influence urban form to minimize the health impacts of heat is often limited; not

413 only are these decisions typically outside health agency mandates, but inter-sectoral coordination

414 mechanisms for public health practitioners to feed health evidence into decision cycles frequently

415 do not exist (Rantala et al. 2014). Exploring the experimental efforts by extensive health adapters

416 may help indicate pathways forward. For example, the Barcelona Public Health Agency (ASPB)

417 has worked with the city planning department under the umbrella of the Barcelona Adaptation

418 Plan to recommend specific at-risk neighborhoods for expanded urban greening activities based

419   on results of sociodemographic and landscape characteristic heat vulnerability mapping (Villalbi

420   & Ventayol 2016; Xu et al. 2013).

421   This third gap area suggests that cities may not be anticipating and preparing the needed scale-

422   up in healthcare surge capacity, nor building the robust climate-adaptive health agency capacity

423   needed to address the complex, often indirect health challenges of urban climate hazards of the

424   21st century. Programs in the US and elsewhere have demonstrated that local health agencies can

425   build capacity and develop collaboration strategies by working through learning networks, often

426   with limited resources (Sheehan et al. 2017; Du et al. 2019; Rudolph et al 2020). The creation of

427   a dedicated network to strengthen urban health agency adaptive capacity, including to build on the

428   recent lessons of the COVID-19 pandemic through a city learning exchange may be a timely

429   initiative (Rudolph et al. 2020; Bai et al. 2020).

430   **4.3 Limitations and Future Challenges**

431   The CDP Cities Adaptation Actions database is a valuable resource for policy-makers and

432   researchers. However, we found several issues that affect its use for our research. First, the

433   selection of participants was based on an opportunistic convenience sample of world cities

434   surveyed through the CDP city network. However, CDP cities data is validated and the dataset is

435   the most important, largest repository of such information, collected in a comparable manner.

436   Second, the cities of Asia and Africa are under-represented which is of concern, as infectious

437   disease and nutrition-related morbidity are on the rise there. Our typology groups and categories

438   helped aggregate reported activities more consistently and comparably into classifications

439   structured to be systematic and relevant to urban health. However, given these limitations our

440   findings quantifying city adaptation actions should be seen as providing a snapshot of currently

441   available reporting from this source.

442   Typologies should evolve as adaptation advances (Biagini et al. 2014). Among future

443   challenges is defining governance aspects, including the role of public health agencies, and

444   whether adaptation actions are mainstreamed or new public policies, or result from social or private

445   partner activity (Bulkeley & Kern 2006). Successful climate health adaptation is likely to require

446   a mix of these modes, and explicit collaborative arrangements (Hughes 2015; Austin et al. 2016;

447   Austin et al. 2019). Tracking these modes of governance, when the information is available to do

448   so, will be useful. These and other refinements will help ensure increased utility of the proposed

449   typology as well as move toward greater consistency and comparability of data over time.

450

451 **5. Conclusions**

452   The City Health Adaptation Typology is proposed as a systematic, literature-grounded

453   approach to enhancing the specificity of urban health adaptation action categories in order to

454   contribute to enhanced consistency and comparability in monitoring. In testing the typology with

455   large active adapters in the CDP city database, we found two-thirds of the reported adaptive actions

456   of 98 world cities with populations over one million were aimed at protecting population health

457   and wellbeing from climate change hazards through actions known to have health benefits or co-

458   benefits. While most health adaptation effort was reported by cities in high-income countries,

459   cities in low- and middle-income countries represented 40% of total and reported a higher share

460   of health-associated adaptation than cities in wealthier countries. Health-associated adaptive effort

461   focused largely on reducing risk from and building resilience to extreme flooding, heat and storms.

462   Reported actions in this group of large cities suggest a strong response in two of three

463   UNEP-identified health adaptation gap areas: adaptive information activities such as hazard

464   mapping, community outreach and early warning; and infrastructure and policies that address

465 health determinants by reducing the climate-vulnerability of the urban built environment.

466 However, our analysis revealed a deficit among these cities in the third UNEP-identified

467 adaptation gap area of integrating public health into climate planning and building local health

468 adaptive capacity. To remedy this gap, greater attention should be focused on integrating public

469 health agencies into local climate action planning, enhancing and defining collaboration

470 arrangements for climate-relevant health outcomes between health and non-health agencies, and

471 targeted efforts to strengthen the adaptive capacity of city public health agencies including through

472 city networks.

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476 **Supplementary Materials.** Appendix A: City Health Adaptation Typology (including Appendix

477 A References); Appendix B: CDP Database Main Variable Categories; Appendix C: Large Cities:

478 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

789   Essential Public Health Services model as applied to climate change similarly identifies an

790   information-based assessment role (including disease surveillance and risk assessment), and a

791   service-oriented assurance role (including provisioning of health and safety services), as well as a

792   policy development role (Frumkin et al. 2008). Clearer governance arrangements among agencies

793   for health adaptation, more explicit attention to implementation, and integrative learning through

794   tracking and evaluation have been suggested as enhancements to this model (Fox et al. 2019).

795   The urban environment also presents unique challenges and vulnerabilities that must be

796   reflected in an urban health adaptation typology. Central among them are the UHI and its impacts,

797   which make certain adaptive activities (e.g., heat health action plans, urban forestry programs)

798   high priority for many cities (US EPA 2019). Networked urban infrastructure is another major

799   urban vulnerability; cascading impacts of service interruptions from storms, flooding and other

800   stresses in turn contribute to population health risks which require monitoring and mapping of

801   hazards, vulnerabilities and risks; outreach to the public; and preparedness and emergency

802   response efforts (USGCRP 2016; Clark et al. 2019). Reliance on risk management tools to build

803   resilience and flexibility was seen as key in one literature review of urban adaptation strategies

804   (Hunt & Watkiss 2011). While it does not recommend specific categories of urban health

805   adaptation, the health chapter (Chapter 10) of the *Second Assessment Report on Climate Change*

806   *and Cities* (ARC3.2) of the Urban Climate Change Research Network (UCCRN) recommends city

807   health adaptation plans, or health components of broader adaptation plans, include the following

808   components: early warning systems; citizen training in preparedness; vulnerability mapping; and

809   mainstreaming of health concerns into other sectors with relevance to health determinants,

810   including food distribution, water and waste management, energy and transport, land use

811   management and urban planning (Barata et al. 2018).

812   With the health advantages of urban living unevenly distributed over short distances, also vital

813   is vulnerability targeting and addressing inequalities (Ezzati et al. 2018). Ensuring health-related

814   adaptation is equitable, efficient, effective and legitimate will require enhancing involvement of

815   non-governmental stakeholders, as well as providing means for health and vulnerability data to

816   reach non-health actors. Cities are experimenting with such governance arrangements

817   (Anguelovski & Carmin 2010; Castan-Broto & Bulkeley 2013; Hughes 2015). Evidence indicates

818   most city adaptation effort to date is public sector-driven; and that limited private sector

819   engagement seems to be governed largely through partnerships, while rarer cases of citizen

820   engagement is via information provision (Klein et al. 2018). In terms of governance, urban

821   adaptation has been proposed to take place in four broad governance modes: self-governing (or

822   mainstreaming); provisioning of new services or activities; regulation of private actors (whether

823   firms, individuals or communities); and enabling of partner agencies (Bulkeley & Kern 2006).

824   Research suggests successful climate health adaptation is likely to require a mix of these modes,

825   and explicit collaborative arrangements across a variety of agencies (Hughes 2015; Austin et al.

826   2016; Austin et al. 2019).

827   Evidence indicates most city adaptation effort to date is public sector-driven; and that limited

828   private sector engagement seems to be governed largely through partnerships, while rarer cases of

829   citizen engagement is via information provision (Klein et al. 2018). Ensuring health-related

830   adaptation is equitable, efficient, effective and legitimate will require enhancing involvement of

831   non-governmental stakeholders, as well as providing means for health and vulnerability data to

832   reach non-health actors. Cities are experimenting with such governance arrangements

833   (Angeuelovski & Carmin 2010; Castan-Broto & Bulkeley 2013; Hughes 2015). For example, the

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.

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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
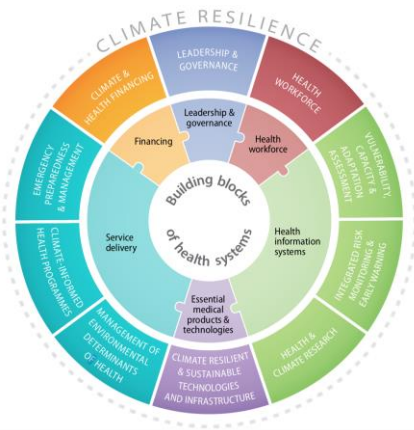
883   of this study.

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(**a**)　　(**b**)

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

890

891 Better understanding parameters that reflect the ambition of adaptation could also be valuable.

892 For example, one examination of national climate action plans found adaptation in low-income

893 countries tended toward reactivity, i.e., avoiding, retreating, accommodating, adjusting, spreading

894 risk, securing income; whereas adaptation in high-income countries tended toward proactivity, i.e.,

895 planning, monitoring, increasing awareness, building partnerships, enhancing learning or research

896 (Berrang-Ford et al. 2011). It was not part of our study goal to test this hypothesis. But we did

897 find suggestive consistency in our results, since the bulk of governance, capacity building and

898 information-related activities were reported by cities in high-income countries; while cities in low-

899 and middle-income countries reported more actions taken as the result of specific extreme events.

900 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)

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

1036	-	Extra tropical storm (Storm and wind)
1037	-	Tropical storm (Storm and wind)
1038	-	Lightning/thunderstorm (Storm and wind)
1039		

4. Wildfire

1040	**4.**	**Wildfire**
1041	-	Forest fire (Wild fire)
1042	-	Land fire (Wild fire)
1043		

1044	**5.**	**Changes in conditions for disease (vector- and airborne)**
1045	-	Water-borne disease (Biological hazards)
1046	-	Vector-borne disease (Biological hazards)
1047	-	Insect infestation (Biological hazards)
1048	-	Atmospheric CO_2 concentrations (Chemical change)
1049	-	Air-borne disease (Biological hazards)
1050		

1051	**6.**	**Land movements**
1052	-	Landslide (Mass movements)
1053	-	Avalanche (Mass movement)
1054	-	Rock fall (Mass movement)
1055		

1056	**7.**	**Extreme cold**
1057	-	Extreme winter conditions (Extreme temperature)
1058	-	Cold wave (Extreme temperature)
1059	-	Extreme cold days (Extreme temperature)
1060	-	Heavy snow (Extreme precipitation)
1061		

1062		**None reported**
1063		

1064　**Appendix B. CDP Database Main Variable Categories**

1065　Table 2. CDP city climate adaptation action categories, as consolidated for analysis[2]

1066　**I. PREPARATORY ACTIONS**

1067　1. Incorporating climate change into long-term planning documents

1068　2. Community engagement/education

1069　3. Flood mapping

1070　4. Heat mapping and thermal imaging

1071　5. Landslide risk mapping

1072　***6. Hazard monitoring***

1073　-　Sea level rise modelling

1074　-　Biodiversity monitoring

1075　-　Real time risk monitoring

1076　**II. ADAPTIVE ACTIONS**

1077　**Health and Health-Related Adaptive Actions**

1078　7. Projects and policies targeted at those most vulnerable

1079　8. Testing/vaccination programs for vector-borne disease

1080　9. Disease prevention measures

1081　10. Air quality initiatives

1082　11. Crisis management including warning and evacuation systems

1083　12. Public preparedness (including practice exercises/drills)

1084　**Other Adaptive Actions**

1085　***13. Infrastructure preparedness***

1086　-　Resilience and resistance measures for buildings

1087　-　Hazard resistant infrastructure design and construction

1088　-　Cooling systems for critical infrastructure

1089　-　Retrofit of existing buildings

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[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.

1090	***14. Flood defenses***
1091	- Soil retention strategies
1092	- Flood defenses – development, operation
1093	- Restrict development in at-risk areas
1094	***15. Water supply management***
1095	- Storm water capture systems
1096	- Additional reservoirs and wells for water storage
1097	- Water extraction protection
1098	- Water butts/rainwater capture
1099	- Maintenance/repair – leaking infrastructure
1100	- Improve water supply distribution method
1101	- Diversification of water supply
1102	***16. Water demand management***
1103	- Promoting low flow technologies
1104	- Xeriscapes – low water landscaping design
1105	- Promoting and incentivizing water efficiency
1106	- Water use restrictions and standards
1107	- Water efficient equipment and appliances
1108	- Water smart metering
1109	- Water use audits
1110	- Awareness campaign/education to reduce water use
1111	***17. Green/white roofs/surfaces***
1112	- Green roofs/walls
1113	- White roofs
1114	- Cool pavement
1115	***18. Shading/tree-planting***
1116	Shading in public spaces, markets
1117	Tree planting and/or creation of green space
1118	19. Cooling centers, pools, water parks/plazas
1119	20. Other
1120	

Appendix C. Reported City Adaptation Actions:

1122 **All Responsive Database Cities and Large Cities**

1123

1124   Complete CDP database information for our analysis was available for 282 cities from 60

1125 countries representing all world regions. These cities were concentrated (85%) in North America,

1126 Latin America and Europe; 42% were medium-sized (population > 500,000) or larger, and 58%

1127 were smaller cities. Seventy percent of cities were associated with two large city networks, ICLEI

1128 (48%) and C40 (22%). The majority (80%) of adaptation actions addressed three hazards:

1129 flooding, heat and/or drought, and extreme storms. One or more flooding hazard was reported by

1130 66% of cities, one or more extreme heat or drought hazard by 60% of cities, and one or more

1131 extreme storm hazard by 54% of cities. In many cases, cities reported adaptive actions in response

1132 to multiple sub-categories of one hazard (e.g., coastal, river, flash, permanent and storm-surge

1133 flooding).

1134   This group of cities reported 1,324 adaptation actions (mean 4.7 per city, range 1-20) (Table).

1135 Based on CDP category definitions, we evaluated 35% of actions as preparatory, and 65% as actual

1136 adaptive actions. The share of actions by region broadly mirrored the share of cities by region. Of

1137 the 282 cities, 34 were particularly active, reporting ten or more actions each. Of actions with

1138 implementation status available, 22% reported being in the initial stages of activity (scoping or

1139 feasibility study), while 78% were in some form of ongoing implementation or had been

1140 completed. Actions reported in the six health and health-related categories comprised 19% of

1141 total, or 253 actions, and were reported by 140 cities (1.8 per city). The preparedness and

1142 vulnerability-targeting categories accounted for 81% of these health actions, with the disease-

1143 prevention categories accounting for 19%.

1144

1145 **Reported City Adaptation Actions: All Responsive and Large Cities**

1146 by reported CDP action category

1147

Adaptation action category	All responsive cities (n = 282)		Large cities (n = 106)	
	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***

1148

1149   Of cities reporting to the CDP database, 106 had 2018 UN populations greater than one

1150 million and reported at least one adaptation action with a sufficient written description to evaluate.

1151 These cities reported 589 adaptation actions (5.6 per city, range 1-20). While the large cities group

1152 reported more actions per city than all responsive cities, the differences across CDP categories of

1153 action were small: large cities reported a lower share of preparatory actions (31% vs. 35%), a

1154 higher share of adaptive actions (69% vs. 65%), and a slightly higher share of health and health-

1155 related actions (22% vs. 19%) (Table). Large cities also had higher proportional representation

1156 from Asia, Africa and the Middle East.

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1159

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.

1166 **Appendix E. List of Cities in Large Cities Group**

1167 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

#	City	Country	Region	UN 2018 Population	Total actions*	Health-associated actions**
37	Rotterdam	Netherlands	Europe	1,008,000	1	1
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%*

1168

1169   *All responsive actions, i.e., all actions with descriptions for which categories could be discerned

1170   **All health-associated adaptation actions based on assignment to City Climate Health Action Typology categories

1171