Adaptation to climate change in urban areas: A global assessment and a case study of Dhaka, Bangladesh

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Preface and contribution of authors

This thesis contains three manuscripts that contribute to answering my research questions. The first manuscript (Chapter 3) has been published in the peer-reviewed journal *Environmental Science & Policy* on July 6, 2016. The second manuscript (Chapter 4) was peer-reviewed and published on January 11, 2016, in the *International Journal of Health Services*. The third manuscript (Chapter 5) is in the process of being prepared for submission to a journal.

I developed the study rationale, the methods, collected data, analyzed the data, and wrote a full draft of the first manuscript (Chapter 3). Dr. Lea Berrang-Ford and Dr. James Ford contributed to the conceptual development of the study, provided guidance on the methods, and edited and commented on the manuscript for content and style. Stephanie Austin, Dr. Robbert Biesbroek, and Alexandra Lesnikowski provided suggestions and comments, and edited the manuscripts for grammar and style. I am first author of the article and the co-authors are, in order: Dr. Lea Berrang-Ford, Dr. James Ford, Stephanie Austin, Dr. Robbert Biesbroek, and Alexandra Lesnikowski. The manuscript was submitted to a special edition of *Environmental Science & Policy* on January 31, 2016. The special edition focuses on urban adaptation to climate change.

For the second manuscript (Chapter 4) I conceived the project, designed the methods, retrieved data, conducted data analysis, and wrote a full draft of the article. I acknowledge Stephanie Austin's contribution to the second manuscript, as she provided many edits on early versions of the manuscript, expanded the discussion section, and contributed to the production of figures and tables. Dr. Lea Berrang-Ford and Dr. James Ford contributed to the conceptual development of the study, provided guidance on the methods, and commented and edited the manuscript for content and style. I am first author of the article and the co-authors are, in order: Stephanie Austin, Dr. Lea Berrang-Ford, and Dr. James Ford. As described above, the article was published in the *International Journal of Health Services* in January, 2016.

The third manuscript (Chapter 5) is currently in preparation for submission to an academic journal. I conceptualized the study, gathered data, analyzed the results, and wrote a full draft of the manuscript. Dr. Lea Berrang-Ford and Dr. James Ford aided the conceptual development, guided the methods, and gave feedback on the organization and analysis of the results. Both provided extensive comments on early drafts of the manuscript and their suggestions improved the paper. Dr. Robbert Biesbroek and Dr. Sarah Moser provided substantial comments on the conceptual framework and analysis section respectively, and both had minor comments for all sections of the manuscript.

I am thankful to all co-authors and contributors. The work presented in this thesis could not have been done without their input. All errors and omissions remain my own.

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Abstract

Cities globally are at serious risk from climate change. Over half the world's population live in cities and this proportion will grow to 80% by 2050. Urban areas face many risks from climate change including higher frequency and intensity of extreme heat, flooding, and higher demands on water and energy. Human health will be particularly affected as climate effects are compounded by fast urbanization, high population density, and climate-sensitive built environments. Cities in the Global South will be even more affected due high poverty rates, increasing number of informal settlements, and limited human and financial resources to plan for the impacts of climate change. Local governments are positioned to protect population from climate risks, as often they are equipped with local knowledge of impacts and authority to build infrastructure and manage utilities. However, it remains unclear how municipalities are dealing with the challenge of climate change impacts: what are cities doing to adapt? Is adaptation taking place, where, by whom, and in what ways? This thesis illuminates the adaptation practices of large cities worldwide. The first manuscript presents a global systematic assessment of adaptation activities. Specifically, we develop and test a framework to track urban climate change adaptation policy using municipal adaptation reporting. From 401 local governments globally in urban areas with >1m people, we find that only 61 cities (15%) report any adaptation initiatives, and 73 cities (18%) report on planning towards adaptation policy. The second manuscript samples the same 401 cities and provides an in-depth characterization of adaptation taking place in one specific sector: public health. We find that only 10% of the sampled urban areas report any public health adaptation initiatives. The initiatives identified most frequently address risks posed by extreme weather events and involve direct changes in management or behaviour rather than capacity building, research, or long-term investments in infrastructure. We identified several gaps in public health sector adaptation: limited evidence of reporting of institutional adaptation at the municipal level in urban areas in the Global South; lack of information-based adaptation initiatives; limited focus on initiatives addressing infectious disease risks; and absence of monitoring, reporting and evaluation (MRE). The third manuscript assesses how adaptation is taking place in Dhaka, Bangladesh, a Global South megacity. We use a multilevel governance framework to assess adaptation progress and readiness and find that national level plans drive adaptation progress in the city, while city-driven progress and readiness are comparatively absent. Overall, the findings from this thesis indicate that cities globally are in the early stages of adaptation planning and the activities taking place and some of the most vulnerable cities such as Dhaka do not exhibit adaptation planning commensurate to the climatic risk they face. Nonetheless, some cities with limited human resources and wealth are extensively planning for climate change impacts, and can act as focal points for policy-oriented learning across cities.

Résumé

Mondialement, les villes font face à de sérieux risques en rapport aux changements climatiques. Plus de la moitié de la population mondiale habite en ville et cette proportion va croître jusqu'à 80% en 2050. Les zones urbaines sont confrontées à de nombreux risques résultant des changements climatiques comprenant de plus fréquents et intenses épisodes de canicule, inondations et de plus grandes demandes en eau et énergie. La santé humaine sera particulièrement atteinte puisque les effets du climat sont aggravés par l'urbanisation rapide, une densité de population élevée et un environnement urbain sensible au climat. Les villes des Pays du Sud seront encore plus touchées étant donné leur taux de pauvreté élevé, le nombre de bidonvilles à la hausse et les ressources humaines et financières limitées pour planifier les impacts des changements climatiques. Les gouvernements locaux se positionnent pour protéger la population aux risques climatiques et bénéficient souvent du savoir local au sujet de ces impacts et de l'autorité pour construire l'infrastructure ainsi que gérer les services publics. Cependant, on ne sait toujours pas comment les municipalités font face au défi des impacts que l'on doit aux changements climatiques : que font les villes pour s'adapter? Est-ce que l'adaptation a lieu, où, par qui et comment? Ce mémoire illustre les pratiques en lien avec l'adaptation à travers le monde. Le premier manuscrit présente une revue systématique globale des activités d'adaptation. Spécifiquement, nous développons et testons un cadre théorique pour faire le suivi des politiques d'adaptation urbaines aux changements climatiques en utilisant les rapports d'adaptation municipaux. De 401 gouvernements locaux dans le monde en zone urbaine avec plus d'un million d'habitants, nous remarquons que seulement 61 villes (15%) signalent des initiatives reliées à l'adaptation et 73 villes (18%) signalent un plan vers des politiques d'adaptation. Le deuxième manuscrit reprend les même 401 villes et offre une caractérisation détaillée de l'adaptation prenant place dans un secteur spécifique : la santé publique. Nous observons que seulement 10% des villes échantillonnées rapportent des initiatives d'adaptation en santé publique. Les initiatives identifiées les plus fréquentes portent sur les risques posées par les phénomènes météorologiques extrêmes et impliquent des changements directs dans la gestion ou comportement plutôt que dans le renforcement des capacités, la recherche, ou les investissements à long-terme dans les infrastructures. Nous identifions plusieurs lacunes pour l'adaptation dans le secteur de santé publique : peu de preuves de rapports d'adaptation institutionnelle au niveau municipal dans les zones urbaines des Pays du Sud; manque d'initiatives d'adaptation basées sur la recherche d'information; peu de focus sur les initiatives en lien avec les risques de maladies infectieuses; et absence de suivi, contrôle et évaluation. Le troisième manuscrit évalue comment l'adaptation a lieu à Dhaka, au Bengladesh, une mégapole du Sud. Nous utilisons un cadre théorique sur la gouvernance pour évaluer le progrès et le degré de préparation et remarquons que les plans au niveau national guident le progrès en terme d'adaptation dans la ville, tandis que le progrès en rapport avec l'adaptation menée par la ville est comparativement absent. Somme toute, les résultats de ce mémoire indiquent que mondialement, les villes en sont à leurs débuts en termes de planification pour l'adaptation et parmi les villes les plus vulnérables telles que Dhaka, peu de planification existe en lien avec l'adaptation aux risques climatiques auxquels elles font face. Toutefois, certaines villes ayant des ressources humaines et financières limitées planifient largement pour les impacts des changements climatiques, et ainsi peuvent agir de points de mire pour l'apprentissage en rapport avec les politiques d'une ville à l'autre.

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CHAPTER 1: INTRODUCTION

This thesis examines the extent to which cities globally are managing the impacts of climate change. Urban areas face serious risks from climate change due to the increased frequency and intensity of extreme heat events, air pollution, drought, and flooding episodes (Revi et al. 2014). Cities will be home to two thirds of the world population by 2050 and at present concentrate economic activity and infrastructure vulnerable locations, with future flood losses in coastal cities estimated at $52b USD per year in 2050 (Hallegatte et al. 2013). The health of urban citizens will be particularly affected as changing infectious disease patterns, water and food insecurity, storms, declining air quality, and low-quality housing have been flagged as major threats to global health this century (Smith et al. 2014b). Cities in the Global South are among the most sensitive as low-income residents often lack adequate means to protect themselves, their assets, and their livelihoods. Poor urban households also have limited capacity to bounce back from damage to property and income (Sugar, Kennedy and Hoornweg 2013). The international climate agreement signed in Paris (2015) identifies cities as important actors for adaptation, but the question of to which extent cities are planning climate-adaptive policies remains.

1.1 Research aim and objectives

This thesis contributes to the work of the Tracking Adaptation to Climate Change Consortium (TRAC3), a collaborative research group based at McGill University in Montreal and Wageningen University in the Netherlands seeking to develop robust and large-scale metrics to track global progress on climate change adaptation. Previous TRAC3-affiliated research has tracked adaptation policies across nations, within regions, and within countries. The aim of this thesis is to track how cities are managing the risks of climate change. Particularly, I aim to answer: Is urban adaptation taking place, where, by whom, and in what ways? I seek to capture both breadth and depth by analyzing adaptation policy at a global extent, providing an in-depth analysis of adaptation in the health sector, and going in-depth into the adaptation experience of one city. Specific objectives are:

1. **To assess the extent to which urban municipalities globally are adapting to climate change.** In this objective I aim to develop and apply a framework to compare

climate change adaptation policy across cities using publically available climate change planning documents. I also seek to identify which cities are adapting and to what extent. Finally, I will reflect on the effect of reporting bias on the results, with particular attention to the question of whether low-income cities undertake initiatives framed as adaptation to climate change but fail to report them in planning documents.

2. **To provide an in-depth analysis of how cities are managing the risks from climate change in one sector: public health.** In this objective I aim to provide an in-depth characterization of public health adaptation activity taking place in cities globally, as risks from climate change have been noted as a particular threat to the health of urban dwellers. I also seek to identify which health risks generate the greatest levels of adaptation response.

3. **To characterize the adaptation status in one geographic location: Dhaka, Bangladesh.** In this objective I seek to develop and apply a framework to characterize adaptation progress and readiness in Global South cities. I also aim to validate the global assessment performed for Objective 1 with a case study of a highly vulnerable city with low incidence of reporting in the Global South.

1.2 Thesis overview

This thesis contains six chapters, starting with an introduction and followed by a review of relevant literature. Chapter 3 is the first manuscript and presents a global assessment of climate change adaptation activities taking place in cities larger than 1 million inhabitants. Chapter 4 is based on a subset of health-specific data from Chapter 3, and provides a characterization of urban adaptation in the health sector. Chapter 5 is a case study of the adaptation status of Dhaka, Bangladesh with the purpose of triangulating the results from the global assessments in Chapter 3 and 4, and characterizing how ready institutions are to plan for climate change impacts in this Global South megacity. Chapter 6 presents key findings, reflects on the contribution to the literature on urban adaptation, and identifies limitations and avenues for future research. Since the thesis contains three standalone manuscripts, the reader may encounter repetition of concepts across the introduction and literature review sections of each manuscript.

CHAPTER 2: LITERATURE REVIEW

This thesis is broadly informed by concepts from the climate change impacts, vulnerability, and urban adaptation scholarship. This chapter begins by reviewing different framings of "adaptation" and their implications for the operationalization of the term in this thesis. The chapter then outlines literature on climate change impacts and vulnerability in urban areas, with an emphasis on the health effects of climate change. The chapter ends by outlining trends in the existing scholarship on urban adaptation.

2.1. Definitions of adaptation

International climate policy, such as the United Nations Framework Convention on Climate Change agreement reached in Paris (2016), does not define "adaptation" with enough clarity to distinguish the concept from other vulnerability-reductive activities such as disaster management or other social policies (e.g. poverty alleviation that improves well-being generally) (Ford et al. 2015, UNFCCC 2015). This ambiguity leads to a number of interpretations of what "adaptation" means. Documented examples range from the construction of green infrastructure to mitigate the urban heat island effect, to development-oriented initiatives that do not address climatic factors directly, such as poverty reduction initiatives (Gill et al. 2007, Schipper 2007).

Studies of urban climate change have commonly used a definition of adaptation that directly addresses climatic risk (Carmin, Anguelovski and Roberts 2012a, Roberts 2008, Rosenzweig and Solecki 2014b, Carmin, Nadkarni and Rhie 2012b). Often this means that activities are only included for analysis if they are explicitly communicated as "adaptations" (Hughes 2015, Araos et al. 2015, Austin et al. 2015, Lesnikowski et al. 2015). This approach provides only a partial picture, however, because it excludes activities that significantly reduce vulnerability and enhance resilience but are not explicitly termed as "adaptation"*;* such actions are what Dupuis and Biesbroek (2013) refer to as being highly *substantial* but not *intentional*. For Dupuis and Biesbroek (2013), activities can be substantial in that they contribute to solving the problem of climate impacts, but can also be non-intentional in that they are not purposefully designed to manage the impacts from climate change. In this study we use explicit mention of "climate change" as a filter for activities, as adaptation

requires an understanding of current and (uncertain) future vulnerability. Using activities framed under the auspice of "climate change" ensures that attention is paid to current and future vulnerability.

Beyond debates over the definition of adaptation, scholars are often split between those who view adaptation as formal government policy and those who argue that adaptation namely takes place outside the realm of planning and is a process undertaken autonomously by individuals, households, and communities (Eriksen, Nightingale and Eakin 2015). The IPCC reaffirms this dichotomy by referring to both *planned adaptation* and *autonomous adaptation* in their Fourth Assessment Report. *Planned adaptation* refers to "deliberate policy decisions, based on awareness that conditions have changed or are about to change" (IPCC 2007c). The mention of "deliberate policy decisions" in this definition suggests that planned adaptation is considered to be decisions by government or private actors that are intentionally designed to deal with the impacts of climate change. *Autonomous adaptation,* on the other hand, refers to actions that "do not constitute a conscious response to climatic stimuli but are triggered by […] market or *welfare* changes in *human systems*" (IPCC 2007c). The suggestion here is that adaptation can also be conceptualized as a spontaneous reaction to change in human systems, without acknowledgement of a changing climate. In this study we use explicit mention of "climate change" as a filter for activities mentioned in climate change plans, but also use open-ended interview questions to capture broader and more critical viewpoints on what adaptation means for policy makers. Many scholars and government officials do not consider adaptation to be conceptually separable from development or infrastructure projects that reduce vulnerability, or projects that are not designed with climate change as the primary motivation.

2.2. Climate change impacts and vulnerability of cities

The United Nations Intergovernmental Panel on Climate Change (IPCC) has produced the most comprehensive documentation of scientific knowledge on climate change. The contribution of Working Group II to the IPCC's Fifth Assessment Report, released in 2014, contains a thorough synthesis and characterization of peer-reviewed literature regarding

climate change impacts, vulnerability, and adaptation. Chapter 8 of Working Group II's report focuses exclusively on the impacts, vulnerability and adaptation to climate change in cities (Revi et al. 2014).

An expected impact of climate change on cities is the rise in mean temperature and frequency of hot days per year (Revi et al. 2014). Higher temperatures are expected to worsen the effects of the urban heat island, increase air pollution, and place a stress on energy demands for warm season air conditioning (Lemonsu et al. 2013, Campbell-Lendrum and Corvalán 2007). Heightened frequency and severity of droughts may increase electricity shortages where hydropower is the main source, as well as increase the prevalence of water-related diseases and food insecurity among urban dwellers (Vairavamoorthy, Gorantiwar and Pathirana 2008). Predicted sea level rise, coastal flooding, and inland flooding from rainfall may have widespread impacts on people, infrastructure, property, and ecosystems near the coast. These effects will put a strain on livelihoods, commercial activity, and will damage biodiversity in coastal and riverbank cities (Hanson et al. 2011, Lwasa 2010, Chang et al. 2010).

Often, one specific climatic impact can affect many sectors at the same time (Ernstson et al. 2010). Energy supply, for example, is a sector that can be disrupted by either flooding or long periods of high heat, with wide-ranging consequences for urban businesses, infrastructure, and services such as healthcare (Jollands et al. 2007). Extreme weather can also affect transportation and telecommunications by physically damaging or obstructing roadways or toppling cell-phone towers, and loss of communication and connectivity can severely inhibit disaster response (Jacob and Winner 2009). Urban housing is another major component of the built environment, and scholars highlight the sensitivity of housing structures in the face of climate change (Jacob and Winner 2009). In terms of green areas of cities, climate change will alter ecosystems, decreasing the positive benefit of ecosystem services such as storm water draining and storm surge protection via wetlands (Kitha and Lyth 2011). Finally, the sensitivity and exposure of health and social services to climate change has been identified as a central component of vulnerability in cities (Barata et al. 2011).

Climate change impacts disproportionately affect the poorest and most marginalized urban citizens, even as they have contributed minimally to global emissions. Many low-income households live in informal settlements in hazardous or high-risk location and have few resources to cope with or bounce back from shocks to property, income, or livelihoods. Other individual characteristics such as gender or ethnicity can combine with poverty to make certain individuals particularly susceptible to the effects of climate change (Shi et al. 2016). For example, most deaths from disasters are concentrated in low- and middle-income nations, including 95% of deaths from natural disasters between 1970 and 2008 (Mitlin and Satterthwaite 2013).

2.2.1. Climate change impacts on health

The IPCC (2014b) determines that climate change affects health through three basic pathways: a) direct impacts from changes in frequency of extreme weather such as the urban heat island, flooding, and droughts; b) impacts mediated through natural systems such as water-borne diseases and urban air pollution; and c) effects mediated through human systems such as negative impacts on livelihoods and mental stress. Extreme heat has been shown to raise body temperature past 40 degrees Celsius, risking physical and cognitive impairment from heat exhaustion, and in acute cases risking organ damage and loss of consciousness from heat stroke. Flooding, the most frequent type of natural disaster is deleterious for health due to the possibility of drowning and hypothermia. The trauma of floods may have implications for mental health through distress, anxiety, and depression (Schnitzler et al., 2007; Neria, 2012).

In cities, the effects of climate change on health are exacerbated by the built environment. The urban heat island, for example, is caused by retention of heat by the dark surfaces of concrete buildings and paved roads, and can produce dangerous areas of hotter air in the city during extreme heat events (Oke 1982). The 2003 European heat wave, for example, was associated with 70,000 deaths from the stress of extreme heat. The government of France responded by re-training health professionals on issues of extreme heat, and changing spatial urban planning practices and building new physical infrastructure to reduce pockets of extreme heat in cities. These adaptation strategies were

agreed to have been effective as 4,400 fewer excess deaths were recorded in the 2006 heat wave (Fouillet et al. 2008). In the next section we present examples and studies of urban adaptation in more detail.

2.3. Urban adaptation

Over the last decade there have been an increasing number of studies examining cases where cities are planning for climate change impacts and proposing "best practices" for adaptation planning in urban areas (Revi et al., 2014). The experiences of a few leading cities have been well documented (e.g. New York, London, Rotterdam, Hamburg). In New York, for example, progress on adaptation has been attributed to characteristics of municipal government planning, including the city government's adoption of "flexible adaptation pathways", and leadership from the mayor and across different levels of government (Rosenzweig and Solecki 2014a). In the delta city of Rotterdam, as part of the "Rotterdam Climate initiative" to become "100% climate proof" by 2025, various innovative pilot projects are being implemented to strengthen experimental learning on adaptation, collect experiences and showcase best practices on urban adaptation, including floating houses, water plazas, multi-functional dykes, and others (RCI, 2013). In the Makoko neighbourhood of Lagos, Nigeria, a floating school was built by a Nigerian architect and international donors to avoid recurring flooding (NLÉ 2012).

2.3.1 Methodologies in urban adaptation scholarship

While many examples of adaptation are being documented, comparative policy assessments of urban adaptation are scarce. In this section we review methods for comparing the adaptation experience across cities and identify the strengths of each method. We begin by a review of small scale comparative studies, then outline regional-level studies, and end by looking at global scale surveys of adaptation taking place.

Most comparative policy studies on urban adaptation taking place have tended to focus on districts within one city, comparing cities within one country or on a particular continent (Austin et al. 2015, Heidrich et al. 2013, Reckien et al. 2014). City-specific studies have analyzed barriers and enablers of adaptation progress at district-level government (Burch 2010). Burch (2010) for example, found that path dependency and the

organizational culture of institutions have been a significant barrier for planning municipal adaptation in British Columbia, Canada. Adopting such a focused geographic scope affords in-depth analysis of adaptation in these studies, and interviews with local government officials have yielded information on how infrastructure, community attitudes, and the planning process can obstruct or enable adaptation across districts (Measham et al. 2011, Vogel and Henstra 2015).

At the regional level, an extensive report on European urban adaptation gives a detailed breakdown of how cities will be affected by climate change and how society, including government, must respond to the challenge but does not assess how adaptation is currently taking place (EEA, 2012). Other country-level and regional analyses have used publically available municipal planning documents to assess the state of adaptation in multiple cities, mostly in developed contexts (Austin et al., 2015; Reckien et al., 2014). Beyond noting the existence of a planning document, these studies aim to characterize the climate impacts addressed therein and the policy methods used for implementation (Austin et al., 2015; Heidrich et al., 2013; Reckien et al., 2014). These studies have selected documents motivated by climate change, thus capturing government-led and explicit adaptation efforts. While these in-depth case studies and small scale comparative analyses provide important baseline information on whether adaptation is being considered in specific urban contexts, inference to the global scale requires research with larger sample sizes and breadth to complement depth.

Surveys have also been used to produce large-scale assessments of adaptation taking place (Carmin et al. 2012b, CDP 2014). These surveys assess thematic content of adaptation policies and often assess the priorities of cities regarding different climate impacts (Carmin et al., 2012; CDP, 2014). In this work, an assessment of thematic content is complemented with an analysis of planning approaches to adaptation policy: Carmin et al. (2012), for instance, offer a snapshot of adaptation policy-making by quantifying reported progress on planning and challenges, such as the creation of vulnerability assessments and financing of adaptation projects. Surveys can be a powerful method to assess adaptation as researchers can ask focused questions to identify progress or pinpoint factors for adaptation success.

Chapter 3: Climate change adaptation planning in large cities: a systematic global assessment

Role of Chapter 3

This manuscript provides a global assessment of adaptation taking place in urban areas over 1 million people. The findings presented in the literature review will be synthesized to provide context for the manuscript rationale and objectives. The aim of this manuscript is to answer the question: to what extent are cities adapting to climate change? In response to this question, this manuscript develops and tests a framework to compare adaptation policy across cities. We apply this framework to 401 cities and analyze global gaps in urban adaptation: which cities are adapting more than others, what types of climate risks are generating response, and what types of policies, programmes, or actions are being implemented. The findings herein act as a starting point for the rest of the thesis. The following chapters provide depth to the breadth of results from this Chapter. Chapter 4 takes the findings from this manuscript and dives into an in-depth analysis of adaptation in one sector, public health. The following Chapter and assesses adaptation taking place in one geographic location, Dhaka.

This manuscript is published in the journal *Environmental Science & Policy*. I am first author and the co-authors are, in order, Dr. Lea Berrang-Ford, Dr. James Ford, Stephanie Austin, Dr. Robbert Biesbroek, and Alexandra Lesnikowski. The manuscript presented here is unchanged from the version on the journal, except for formatting and table and figure numbering.

Abstract

Cities globally face significant risks from climate change, and are taking an increasingly active role in formulating and implementing climate change adaptation policy. However, there are few, if any, global assessments of adaptation taking place across cities. This study develops and tests a framework to track urban climate change adaptation policy using municipal adaptation reporting. From 401 local governments globally in urban areas with >1m people, we find that only 61 cities (15%) report any adaptation initiatives, and 73

cities (18%) report on planning towards adaptation policy. We profile cities based on their adaptation reporting as *extensive adaptors, moderate adaptors, early stage adaptors,* and *non-reporting*. With few exceptions, *extensive adaptors* are large cities located in high-income countries in North America, Europe, and Oceania, and are adapting to a variety of expected impacts. *Moderate adaptors* usually address general disaster risk reduction rather than specific impacts, and are located in a mix of developed and developing countries. *Early stage adaptors* exhibit evidence of planning for adaptation, but do not report any initiatives. Our findings suggest that urban adaptation is in the early stages, but there are still substantive examples of governments taking leadership regardless of wealth levels and institutional barriers.

1. Introduction

Cities globally face significant risks from climate change (Revi et al. 2014). Urban areas are home to >50% of the world's population, are growing rapidly, and often concentrate economic activity, population, and infrastructure in high-risk locations. Many of the largest cities are located in coastal areas, for instance, and are thus exposed to projected increases in sea level, storm activity, and associated flooding (Hallegatte et al. 2013, Hanson et al. 2011). Given these threats, cities are taking an increasingly active role in climate policy action, with mitigation experiences well-documented (Castán Broto and Bulkeley 2013, Bulkeley 2010). There are also widely referenced examples of city leadership and action on adaptation (e.g. New York, London) (Rosenzweig and Solecki 2014, Wilbanks 2011). Yet there have been few, if any, global-scale analyses of what cities are doing to adapt: is adaptation taking place, where, by whom, and in what ways? (Berrang-Ford, Ford and Paterson 2011). The purpose of this article is to shed light on the emerging adaptation practices of cities globally.

Identifying, monitoring and evaluating adaptation at a large-scale presents significant conceptual and methodological challenges (Dupuis and Biesbroek 2013, Ford et al. 2013). Unlike mitigation, where greenhouse gas emissions can be measured to examine the effectiveness of policy initiatives, there are no similar 'off-the-shelf' metrics available for adaptation (Ford and Berrang-Ford 2015). In the follow-up from a new international

climate agreement in Paris, where cities are identified as important actors for mitigation and adaptation, it is thus of paramount importance to develop standards, methodologies, indicators and baselines for assessing progress towards adaptation goals (Ford et al. 2015, UNFCCC 2015). We refer to such work as 'adaptation tracking', a subcomponent of monitoring and evaluation that seeks to systematically identify, characterize and compare adaptation across nations or cities and over time.

Adaptation tracking research has highlighted the need for comparative, systematic analysis of adaptation action and reporting across nations and cities. The major obstacle to such efforts remains the absence of appropriate data sources that fulfill the 4C's of adaptation tracking: a *consistent* and operational conceptualization of adaptation, *comparable* units of analysis, *comprehensive* datasets on adaptation action, and *coherence* with our understanding of what constitutes adaptation (Ford and Berrang-Ford 2015). Data and knowledge on adaptation are difficult to find, and we have to date relied on the reporting of adaptation as the only option currently available for systematic analysis (Berrang-Ford et al. 2014, Gagnon-Lebrun and Agrawala 2007, Lesnikowski et al. 2015, Reckien et al. 2014). Though an imperfect proxy sample of adaptation on the ground, adaptation reporting is used to identify trends in adaptation action and planning (Berrang-Ford et al. 2014, Ford et al. 2013, Gagnon-Lebrun and Agrawala 2007, Lesnikowski et al. 2015, Reckien et al. 2014). Reporting of adaptation in itself is an important proxy providing insight into how governments recognize and prioritize adaptation options (Austin et al. 2015). Limited reporting of adaptation programmes and actions may hinder sharing of experiences and best practices, transparency, and effective monitoring and evaluation.

Despite the importance of cities as administrative units where adaptation will be implemented, adaptation tracking studies have been undertaken predominantly at the national level (Lesnikowski et al. 2015). There is negligible comparative and systematic research available on the extent to which global cities are responding to, and reporting on, climate change adaptation. In response to this gap in baseline characterization of global urban adaptation, we develop a framework to characterize reporting on adaptation planning in urban areas globally over 1 million people, creating a descriptive classification of the types, extent, and nature of adaptations in diverse urban contexts.

2. Tracking urban adaptation to climate change

A number of studies have examined adaptation progress, compared different government systems, and proposed "best practices" for adaptation planning in urban areas (Revi et al. 2014). International climate policy has set an adaptation financing goal of $100b per year and so a key challenge will be to track adaptation to ensure accountability and transparency in governance processes (Adger 2003, Ford et al. 2015, Preston, Westaway and Yuen 2011). Reporting on progress toward planning adaptation helps the public keep track of whether investments in adaptation are consistent with the outputs (Preston et al. 2011).

While many specific examples of adaptation are being documented, systematic global assessments of urban adaptation are scarce. Most comparative policy studies on urban adaptation have focused on districts within one city, comparing cities within one country or on a particular continent, but not globally (Austin et al. 2015, EEA 2012, Heidrich et al. 2013, Reckien et al. 2014, Reckien et al. 2015). City-specific and regional studies have analyzed barriers and enablers of adaptation progress Other country-level and regional analyses meanwhile have used publically available municipal planning documents to assess the state of adaptation in multiple cities, mostly in developed contexts (Austin et al. 2015, Reckien et al. 2014). While these in-depth case studies and small-n comparative analyses provide important baseline information on whether adaptation is being considered in specific urban contexts, inference to the global scale requires research with larger sample sizes and seeking breadth to complement depth (Araos et al. 2015, Ford and Berrang-Ford 2015).

Surveys have also been used to produce large scale assessments of adaptation (Aylett 2015, Carmin, Nadkarni and Rhie 2012b, CDP 2014). These surveys assess the content of adaptation policies and the priorities of cities regarding different climate impacts (Aylett 2015, Carmin et al. 2012b, CDP 2014). Carmin et al. (2012b), for instance, offer a snapshot of adaptation policy-making in ICLEI member cities by quantifying reported progress on

planning and challenges, such as the creation of vulnerability assessments and financing of adaptation projects. Aylett (2015) found that while a number of cities report integrating adaptation planning into their agendas, many sectoral agencies remain uninvolved in climate change planning (Aylett 2015). Surveys can be a powerful method to assess adaptation as researchers can ask focused questions to identify progress or pinpoint factors for adaptation success, and survey-based studies have so far been important contributions to the study of urban adaptation.

In this study we draw on publically available information on urban adaptation policy, with the presupposition that adaptation tracking initiatives and data sources should be guided by: 1) data sources that transparent and open-access datasets for open-source analysis; 2) consistent data collection strategies that facilitate longitudinal analysis of adaptation progress over time, and; 3) are consistent with the 4C's of adaptation tracking. The goal is to build on existing studies that use expert knowledge and opinion with systematically collected publically available data from climate change planning documents.

3. A framework for tracking urban adaptation across cities globally

We developed a conceptualisation of urban adaptation that allows for comparative analysis, building on previous efforts described in section 2 (see supplementary materials for detailed figures and further description of the framework components). We characterized urban adaptation along two axes, policy content and policy process, building on the literature evaluating urban adaptation and proposed frameworks for comparing local adaptation (Vogel and Henstra 2015). In doing so, we are guided by best-practice approaches for systematic review in adaptation research (Berrang-Ford, Pearce and Ford 2015) and the 4C's of adaptation tracking as proposed by Ford et al. (2015).

3.1. Defining adaptation for systematic review

One of the reported challenges to engage in comparative policy studies is to overcome the challenge of identifying what is being compared. Here we use the IPCC AR4 definition of planned adaptation as "Adaptation that is the result of a deliberate policy decision, based on awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state" (IPCC 2007). Thus we gathered

and analyzed government documents that reported on purposeful adaptation designed to reduce vulnerability to climate change, as per the literature on comparatives studies of adaptation (Dupuis and Biesbroek 2013, Heidrich et al. 2013, Reckien et al. 2014). In this study we focus on government-led adaptation, as municipalities have an important role in adaptation due to managing services and utilities, as well as having authority over important levers of adaptation such as land use regulation and building codes (Bulkeley et al. 2011). Nonetheless, we recognize that adaptation is frequently conceptualized as adjustments by individuals, communities, the private sector, and NGOs, among others. (Carmin, Anguelovski and Roberts 2012a, Romero-Lankao and Dodman 2011).

3.2. Policy content

Policy content refers to the thematic content of policy and the government's methods for implementing policy (Henstra 2015, Howlett and Rayner 2007). In this study we assessed policy content through a thematic and typological classification of adaptation initiatives in urban areas. An adaptation initiative is defined here as any individual adaptation program, action, or project reported by the municipality. We characterize these adaptation initiatives according to whether they are groundwork initiatives or adaptation actions, according to adaptation policy typology, climate impacts, and affected human systems, building on prior work in the adaptation tracking scholarship that has used adaptation reporting as a data source (Lesnikowski et al. 2015). We assess whether initiatives are groundwork or action. Groundwork initiatives are intended to enable the conditions necessary for adaptation, but do not reduce vulnerability directly. Groundwork initiatives aim to build a context conducive to adaptation, while adaptation actions directly reduce vulnerability to climate change (Dupuis and Biesbroek 2013). For example, a research project identifying the most cost-effective type of permeable road surface will be classified as groundwork, while the installation of the new road type will be classified as an adaptation actions.

We also classified initiatives according to their policy typology. Adaptation policy typology provides a way to identify how governments prioritize different types of policies. We adapted Biagini et al.'s (2014) typology categories and classified each adaptation

initiative (both groundwork and actions) into one of five categories: capacity building; management, planning, and policy; practice and behaviour; information; and financing. This classification system provides insight into what adaptation looks like in practical terms (Howlett and Rayner 2007).

To understand what motivates cities to adapt and to contextualise the type of adaptation initiatives identified, we characterize initiatives according IPCC-defined climate change impacts and affected sectors in urban areas. The five direct and indirect climate change impacts in urban areas identified in the IPCC's Fifth Assessment Report (AR5) were used for this classification: heat spells, drought, coastal exposure, inland flooding, and human health issues (Revi et al. 2014). The first four impacts are extreme weather events, expected to increase in frequency intensity and duration with climate change. The IPCC AR5 also outlines six urban sectors exposed to climate change impacts: water supply; energy supply; transportation and telecommunications; the built environment; green infrastructure and ecosystem services; and human and social services (Revi et al. 2014). We use these sectors to specify which impacts and systems are being addressed and prioritized by each city, identifying gaps in adaptation policy.

3.3. Policy process

The axis of policy process refers to the *steps taken* by governments to plan and implement adaptation policy. Although there are many components of a policy process, we base this axis on a review of existing components of the adaptation decision-making process (Hinkel et al. 2013, Mukheibir and Ziervogel 2006, Prutsch et al. 2014). The following indicators measure policy process: a) evidence of analysis of climate projections; b) evidence of preparation of vulnerability assessments; c) consideration of multiple sectors; d) re-assessment of development priorities in the face of climate change; e) the creation of a climate change planning documents; f) usage of consultative tools and stakeholder engagement; g) management of barriers and uncertainty; h) and monitoring and evaluation of adaptation activities**.** Although these steps resemble the stages in a policy process, they are not necessarily sequential in practice (Vogel and Henstra 2015). Nonetheless, a focus on components of the municipal planning process has been proposed

as heuristic to facilitate municipal adaptation planning and enable the characterisation of the state of urban adaptation (Mukheibir and Ziervogel 2006).

4. Methods

To assess the state of urban adaptation we used systematic data collection and analysis methods (Berrang-Ford et al. 2015). We used web-based climate change planning documents from cities as a proxy for identifying and characterizing adaptation taking place. Information was retrieved from urban municipalities selected on the basis of population and language of official documents (see Appendix A for inclusion criteria and reference list of reviewed documents). Adaptation information was retrieved from Municipal Adaptation Plans, Climate Action Plans, and government projects in partnership with NGOs. The documents were retrieved on a city-by-city basis using the search engine Google with a two-stepped process. First, we identified the city's municipal website, then scanned the site for adaptation planning documents, either on the website itself or linked from the website. For the second step, if no adaptation documents were found on the website, we performed another Google search using the search terms *climate change* and the city's name. We reviewed the first fifty results (5 pages) based on title and page description. From the retrieved documents we extracted discrete individual initiatives to form a database. We used this dataset to produce a set of descriptive statistics to outline global trends in urban adaptation. Our use of official government documents is consistent with adaptation tracking research in other sectors and scales (Carmin et al. 2012b, CDP 2014, Heidrich et al. 2013, Reckien et al. 2014), and underpins consistency in the data source as all documents were published by municipal government. Consistency in the source of data is a key consideration in studies tracking adaptation (Ford and Berrang-Ford 2015).

We focused on urban areas with over 1 million inhabitants, as per the United Nations definition of "urban agglomeration" (Heilig 2012). UN-reported urban agglomerations often encompass several municipalities (Heilig 2012). For the majority of agglomerations we collected and analyzed data for the central municipality. In some highly fragmented urban areas, however, we accessed the website of the urban region's (i.e. metropolitan area) government. Municipalities were included for analysis where a language was spoken

in at least five cities with over 1 million inhabitants. This included: English, French, and Spanish (spoken by the research team), and Chinese, Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Turkish, and Indonesian (using hired translators). Cities with languages spoken in <5 cities were excluded due to the logistical constraints of hiring translators for a small number of observations.

The final dataset contains 401 urban areas covering 1.3 billion people: 33 cities in Africa, 164 in Asia, 33 in Europe, 63 in South and Central America, 50 in North America, and 6 in Oceania. Chinese cities with over 1 million inhabitants comprise nearly a quarter of all cities in the study (n=92). Data were collected between early January and the end of March 2014. Any documents published online after this date were excluded. We accessed 2 metropolitan government websites (Santiago, Chile; London, UK), and the remainder are municipal government websites.

We developed a coding system based on the framework for tracking urban adaptation categories listed in Section 3 (for detailed description of coding categories and examples from city documents see Appendix B). The coding system classified each adaptation initiative according to the climate impact and affected sector motivating the initiative, as well as its policy type. Further, each city was assigned a *process score* based on how many elements of the process indicators are reported, from the list presented in Section 3. Once the coding was completed, cities were classified according to their reported adaptation status (see Table 1 for classification criteria). Cities were classified relative to each other, rather than to an objective standard of what constitutes extensive or moderate levels of adaptation due to a the lack of consensus in defining 'successful' adaptation.

4.1 Limitations

Our focus on government-led adaptation does not eliminate reporting bias. Even where adaptation is occurring, it may not be reported, and this bias may result in under-reporting of adaptation initiatives in low-income nations. Our focus on large urban centres — often the most technologically advanced hubs in even poorer nations — mediates some but not all of this bias. Evaluating the potential impact of reporting bias is a grand challenge in adaptation tracking research. The central challenge is that it is difficult to establish how

closely aligned adaptation *reporting* is with the on-the-ground implementation. We thus sought to evaluate the potential role of reporting bias in affecting our results. There are limited data available, however, at the city level for global urban centres that provide proxy measures of reporting capacity (e.g. technological capacity). Variables such as mobile phone coverage or electricity coverage, for example, are available for only 8-12% of global cities in our dataset. We thus tested and present the impact of wealth and urban population size on adaptation status, and discuss implications of reporting bias in adaptation tracking research. Beyond reporting bias, we also acknowledge that we do not capture urban-related adaptation led by governments other than municipalities. While local governments plan and implement concrete strategies, national governments in some cases dictate broad policy directions for urban-related climate change concerns. In Bangladesh, for instance, the National of Adaptation Programme of Action urges to raise capacity in local governments to enhance the resilience of urban infrastructure (Government of Bangladesh 2005). Local governments, in turn, will then have an increased capacity to integrate climate change concerns when upgrading or building new urban infrastructure. Lastly, each city's adaptation efforts will be affected by how urgent and widespread are the threats from climate change. Lack of available data on vulnerability for the 401 cities in our analysis precludes an analysis of the relationship between the adaptation planning and the risks a city faces.

5. Results

5.1. Global trends

We retrieved and analyzed 997 adaptation initiatives reported from 74 large cities in 80 countries. Only 18% of all cities analyzed report any adaptation activity, and for most of the 401 cities evaluated (81%, n=327) we found no evidence of adaptation policy (neither *policy content* nor *process*) taking place (Fig. 1). 72% of the initiatives documented are directly and intentionally targeted reductions of vulnerability or resilience building (i.e. adaptation actions), as opposed to 28% for groundwork responses (i.e. those building capacity to enable adaptation actions).

Most governments report undertaking direct forms of adaptation activities such as management, planning, policy, and behaviour changes (62% of total initiatives) rather than capacity building, financing, or research (38%). These findings, although descriptive, appear to support the argument by Adger, Arnell and Tompkins (2005) that local scales deliver direct adaptation (management, planning, policy, and practice and behaviour functions), while higher level jurisdictions deliver enabling policy to create supportive institutional environments (Adger et al. 2005, Austin et al. 2015).

Climate change impacts and sectors targeted vary across cities, but initiatives targeting coastal impacts, the built environment and green infrastructure are most frequent. Only 142 initiatives (14%) target health and social services, while the rest focus on protecting physical infrastructure. The study design allowed for classification of initiatives into more than one category, but the majority (97%) of initiatives do not target more than one impact at a time, and none of the initiatives address more than one sector at a time. Serrao-Neumann et al. (2014) argue that adaptation must be integrated across sectors to deal with sectoral trade offs, suggesting that the mono-sectoral initiatives identified here can be limited in their effectiveness. With regards to policy *process*, cities performed overall slightly better than on policy *content.* Over half (60%) of cities reporting on adaptation (reporting either any initiatives or any planning process score, n=74) scored over three in adaptation planning process (reporting undertaking over three of the eight components of adaptation planning process described in the methods), while 40% scored between one and three. Broken down by the adaptation planning process components, a majority of adapting cities show evidence of a climate projection (89%) and vulnerability assessments (87%). On the lower end, less than half of city governments report undertaking monitoring and evaluation of adaptation initiatives (49%), engaging with stakeholders (48%), and acknowledging barriers or uncertainties in the adaptation policy-making process (32%).

There was a positive correlation ($r=0.49$, $p<0.001$) between cities' policy process score and the number of adaptation initiatives reported, excluding New York. The U.S. city was excluded because it is a significant outlier with 243 reported initiatives, over a quarter of the total adaptation initiatives identified globally (Fig. 2). Notably, many cities showed evidence of progress on policy process yet did not report — or reported few — adaptation

initiatives, implying early phase engagement with adaptation. The inverse did not occur, however: with few exceptions, cities did not report adaptation initiatives in the absence of adaptation process.

The distribution of adaptation activity *within* continents is heavily skewed. New York City represents over half of North America's initiatives and South Africa is the only African country with cities reporting adaptation online. In Asia there are also outliers. Singapore reports 15 discrete initiatives. In contrast, adaptation in Latin American cities is more dispersed, with large capital cities usually reporting some adaptation. Many cities in low and middle income countries report adaptation initiatives above the global median (7 initiatives), such as Cape Town, Semarang, Quito, Santa Cruz, Surabaya, Wenzhou, and Yangzhou.

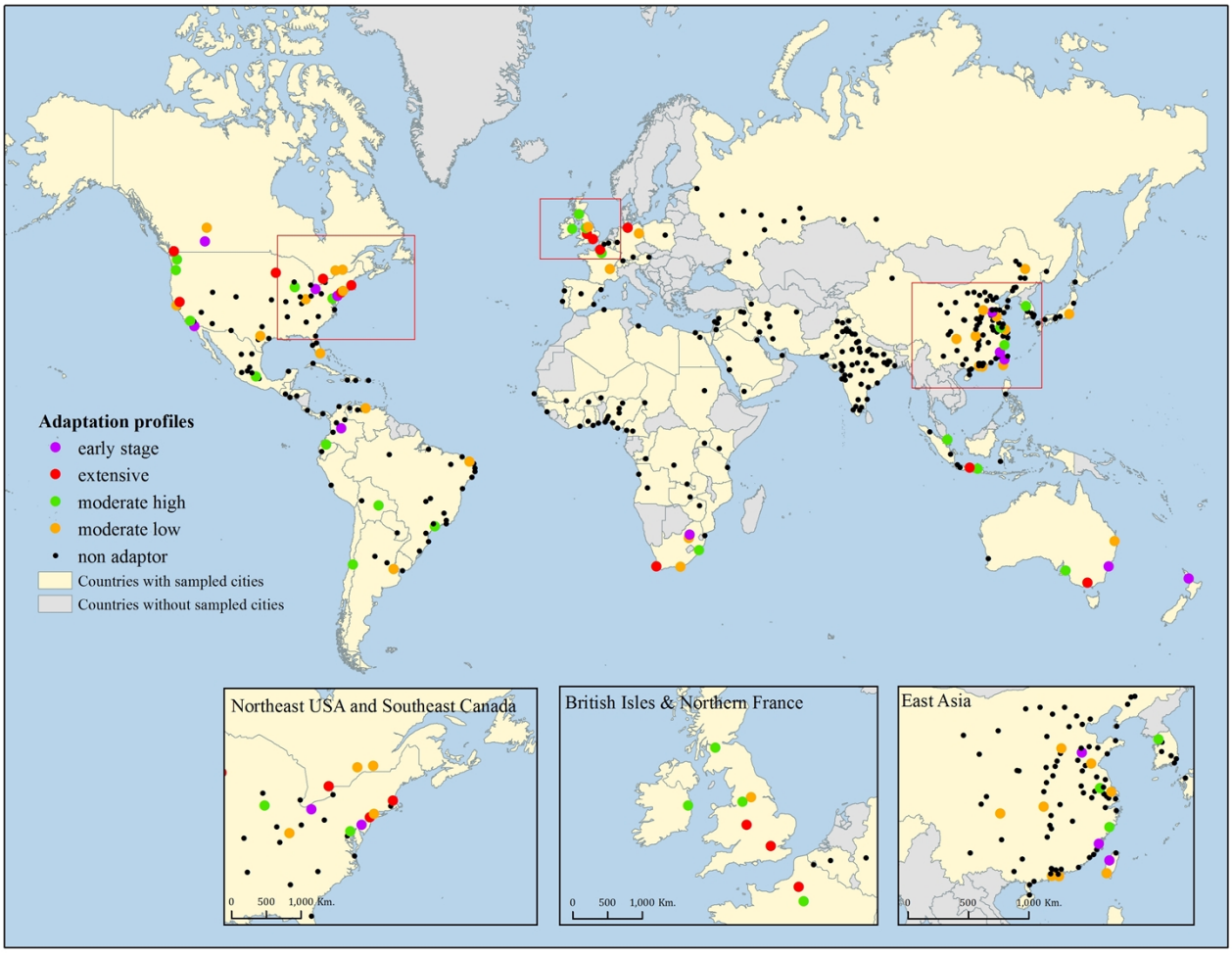

Figure 1: Map of global urban adaptation

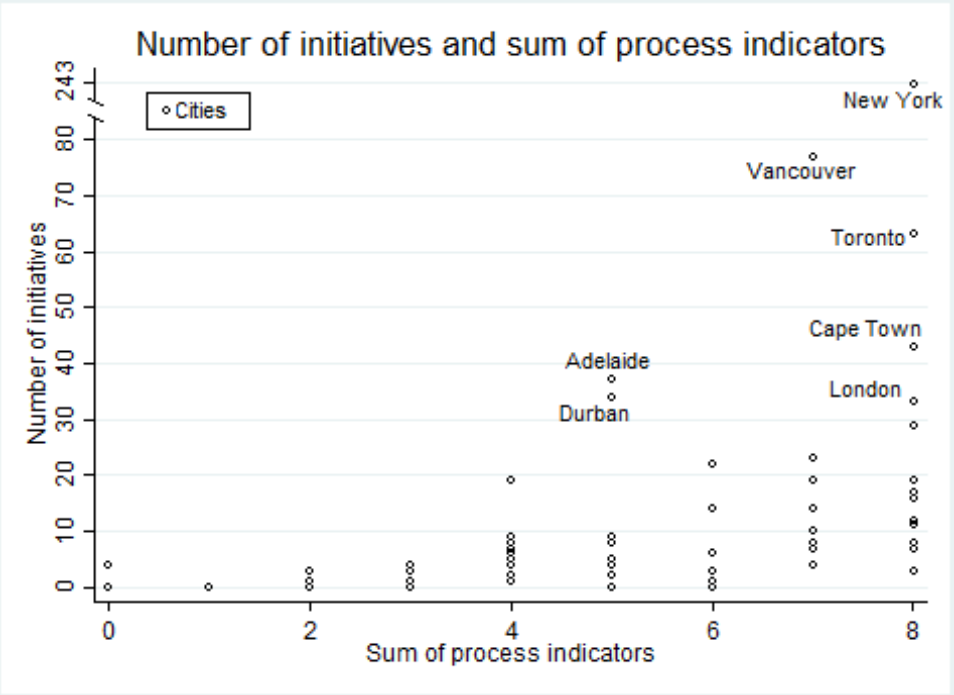

Figure 2: Relationship between number of initiatives and process indicators (cities with 30+ initiatives labelled to highlight highest performers).

5.2. City adaptation classification

We classified adapting cities into *extensive adaptors*, *moderate adaptors*, *early stage adaptors*, and *non-reporting* based on a classification of reported initiatives and policy process (Table 1).

Table 1: Cities and their adaptation classifications

Classification	Criteria and description	Cities (see sup. mat. for document references)
Extensive adaptors	• Top quartile of both adaptation initiatives and process score (>17 initiatives, >6 process score) • Adapting to all IPCC-identified impacts • Global leaders	Birmingham, Boston, Cape Town, Hamburg, London, Marseille, Melbourne, Minneapolis, New York, Sacramento, Semarang, Toronto, and Vancouver.
Moderate adaptors (high)	• Above median of adaptation initiatives and process score (>7 adaptation initiatives, >5 process score), excluding extensive adaptors • Substantial effort to produce adaptation policy, but not the *extensive adaptors*	Adelaide, Baltimore, Chicago, Dublin, Durban, Glasgow, Los Angeles, Manchester, Mexico City, Paris, Portland, Quito, Santa Cruz, Santiago, Seattle, Seoul, Singapore, Surabaya, Sao Paulo, Wenzhou, and Yangzhou.
Moderate adaptors (low)	• Either <7 adaptation initiatives (median) or <5 process score (median) based on web reporting • Reporting suggests limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning	Austin, Berlin, Bridgeport, Brisbane, Buenos Aires, Caracas, Chongqing, Cincinnati, Edmonton, Grande Vitoria, Haerbin, Handan, Hong Kong, Jingzhou, Johannesburg, Kaohsiung, Leeds, Linyi, Lyon, Miami, Montreal, Nantong, Ottawa, Port Elizabeth, San Francisco, Shanghai , Tokyo, Vereeniging, and Zhongshan.
Early stage adaptors	• Zero adaptation initiatives reported on-line, but >0 process score. • Exhibit evidence of planning for adaptation, but report no adaptation initiatives	Auckland, Bogota, Calgary, Cleveland, Fuzhou, Philadelphia, Pretoria, San Diego, Sydney, Tai'an, and Taichung.
Non reporting	• Zero reported initiatives and zero process score reported • No reported, web-based evidence of adaptation policy-making	See Appendix C for full list (n=328)

5.2.1. Extensive adaptors

Extensive adaptors (n=13) represent cities reporting in the top quartile of number of adaptation initiatives (>17 initiatives) and reported evidence of planning for adaptation, and include two global mega-cities (New York and London) (Table 1). *Extensive adaptors* frequently undertake concrete initiatives explicitly aimed at reducing climate change vulnerability. Often, *extensive adaptors* report adaptation in the form of dedicated policy documents such as adaptation plans or as distinct sections of climate change strategies. With the exception of Cape Town and Durban in South Africa and Semarang in Indonesia, all extensive adaptors were located in North America, Europe, or Oceania. Cities in this classification frequently took actions regarding expected coastal impacts, the urban environment, green infrastructure, and urban water supply. Management, planning, and policy, as well as practice and behaviour initiatives compose the bulk of adaptation activity among extensive adaptors.

5.2.2. Moderate adaptors

Moderate adaptors reflect cities reporting some adaptation initiatives and process indicators, but below the top quartile (Table 1). Given the global absence of evidence of adaptation action (83% of cities classified as non-reporting), *moderate adaptors* reflect a range of cities producing adaptation initiatives and engaging in the policy-making process. We identify 2 sub-categories of *moderate adaptors*: *high moderate adaptors* (44%, n=21) and *low moderate adaptors* (56%, n=30). *High moderate adaptors* typically engage in a small number of initiatives that may reflect emerging and recent efforts to build a foundation for more adaptation activity on a pathway towards increased adaptation (i.e. towards *extensive adaptors)*. *Low moderate adaptors* are cities with limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning. Miami in the United States, for example, reports air quality improvements and storm water management as adaptation initiatives, but present no evidence or suggestion that policy is being enhanced within the specific context of climate change impacts.

5.2.3. Early stage adaptors

Early stage adaptors (n=11) are cities showing evidence of adaptation policy-making (*policy process)* but not reporting any adaptation initiatives (*policy content*). We infer that some of these cities have taken first steps on their way to more substantial adaptation. Philadelphia and Cleveland in the United States, for example, report extensively on mitigation initiatives, but have not developed the adaptation portion of their climate change action document. Climate projection and vulnerability assessments are reported along with the need to develop adaptation strategies, but they report no initiatives thus far. The most common process reported by *early stage adaptors* is the assessment of future climate trends and vulnerability assessments, suggesting that city governments are aware of the impacts and vulnerabilities they face, but have not begun planning specific initiatives.

5.2.4. Non-reporting

Cities reporting no adaptation activity in government plans, either *policy content* or *process*, were categorized as *non-reporting*, and this category captured the majority of cities in the dataset (81%, n=328/401) (Table 1). *Non-reporting* cities are globally distributed, with cities in all regions and all income levels reporting no publically-available documentation of adaptation. Of 43 Indian cities in our dataset, for example, we found no examples of municipal government adaptation being reported. Ninety-two percent (185/202) of cities in Asia do not report adaptation initiatives, 89%% (42/47) in Africa (all in South Africa), and 87% (55/63) in Latin America. By contrast, in our dataset 71% (24/34) of cities in Europe report adaptation, as well as 62% (31/50) of cities in North America, and 50% in Oceania (3/6 of these in Australia).

5.2.5. Adaptation reporting vs. adaptation action

Cities reporting adaptation initiatives (adaptors) were significantly wealthier and larger than cities reporting no adaptations (non-reporting).[†] Population was largely associated with adaptation status due to its collinearity with wealth (larger cities are poorer on

[†] *GDP per capita: chi-squared for Kruskal-Wallis=13.00, p<0.01, n=187; log of total population: chi-squared for Kruskal-Wallis=9.23, p<0.01, n=401*

average, and poorer cities typically reported fewer or no adaption initiatives), indicating that wealth is the more important determinant of adaptation reporting. Indeed, other studies testing drivers of urban adaptation have found that larger cities were more likely to have an adaptation plan (Reckien et al. 2015). These associations were robust when using adaptor classification, number of initiatives, process score, and when removing outliers (e.g. New York). These results are consistent with research on the determinants of adaptation, highlighting wealth as a likely common driver of both adaptation action and adaptation reporting (Berrang-Ford et al. 2014). Despite inclusion of a range of languages and translators, English-speaking cities were more likely to be adaptors.[‡]

6. Discussion

To our knowledge, this paper provides the first systematic global assessment of adaptation reporting in large urban areas, using web-based reporting as our data source. The methods used in the study rely on publically available data on urban adaptation policies, rather than expert opinions and impressions or the normative selection of 'best practices'. Municipal reporting of adaptation indicates that most cities with >1 million people do not yet report planning for climate change, yet some cities exhibit significant progress. We classified adapting cities as *extensive adaptors, moderate adaptors, early stage adaptors,* and *non-reporting.* With few exceptions, *extensive* and *moderate adaptors* are cities located in countries in North America, Europe, and Oceania, and are adapting to a variety of expected impacts. *Moderate adaptors* are divided into two sub-classifications to distinguish between cities reporting above median levels of adaptation and those adapting but scoring below median levels of policy *content* and *process*. *Early stage adaptors* are those reporting components of adaptation planning (*policy process*) but at the time of data collection did not report any concrete adaptation initiatives. This classification reflects cities at the preparatory stages of adaptation planning, but do not show evidence of implementing adaptation initiatives. This study finds similar results to those from Carmin et al. (2012b) survey of 468 cities, where 18% reported implementing adaptation planning. Self-reported global surveys have shown much higher rates of engagement with adaptation

[‡] *Chi-squared 18.7, p<0.01*

previous to the implementation phase: the same Carmin et al. survey (Carmin et al. 2012b) found that 68% are engaged with adaptation planning of some type (e.g. plan development), and Aylett found that 75% of cities are integrating adaptation into long-range or sectoral plans (Aylett 2015).

It is difficult to disentangle lack of adaptation from lack of reporting, and the results likely bias against the capture of adaptation in lower income cities. This is supported by our finding of an association between wealth and adaptation reporting. This association does not, however, tell us whether wealthier cities have greater capacity to undertake adaptation, or simply greater capacity to report on their adaptation undertakings; the answer is most likely a combination of both, making quantitative assessment of reporting bias difficult. Significant enough regional variation exists in our findings, however, to suggest that country wealth is not a sufficient explanation of differences in urban adaptation progress. Good governance has also been suggested as a driver of adaptation activity in Berrang-Ford et al. (2014). At the national level, a measure of good governance (the Corruption Perception Index) was found to affect the relationship between population size and adaptation activity. Specifically, in countries with higher than average governance, population has a statistically significant relationship to adaptation activity. We could not test this relationship in this study due to lack of comprehensive indicators of good governance at the city-level. In this context, integrated case-studies and pilot methods to validate the extent to which web-based records differentially proxy on-the-ground adaptation is a priority for future research.

Beyond reporting bias, differences in municipal responsibilities across cities affect how and if climate planning is divulged. In many cases, city governments themselves are not the key agents of climate action within their jurisdiction and cannot be expected to report on the topic. Well-documented examples of adaptation action at the metropolitan level, such as in Bogota, Colombia, show that local governments are not always the locus of adaptation planning (Lampis 2013). In India, the state of Maharastra has been responsible for Mumbai's adaptation planning, highlighting the role of the state in Indian environmental planning (Boyd, Ghosh and Boykoff 2015). These examples show that state structures particular to each country may affect how urban adaptation planning is carried out, and

solely focusing on municipal action may omit other forms of adaptation by higher levels of government. The challenge of finding suitable data sources from which to identify, characterize, and monitor adaptation across underscores the need to utilize multiple data sources from which to examine adaptation (Ford et al. 2013). Differences in municipal autonomy may also account for high variation in adaptation reporting *within* regions with similar income levels and population. Especially notable are cases where cities in low income countries report adaptation initiatives and planning. Some cities classified here as *extensive* and *moderate* adaptors are in low and middle income countries (as defined by the World Bank), such as Quito, Ecuador, Santa Cruz, Bolivia, Cape Town and Durban, South Africa, and Semarang, Indonesia. This suggests that cities with limited financial resources are still able to plan and report adaptation activities. Similarly, the availability of financial resources is not a sufficient condition for cities to plan and report adaptation activity. Cities such as Calgary, Canada, and Auckland, New Zealand, which face significant climatic-risks, are not constrained by limited financial resources or institutional capacity — relative to other cities globally — yet they do not report adaptation initiatives. Another concern is the type of adaptation policy that makes its way into climate change plans. Shi et al. (2016) note that a minority of municipalities engage with communities or social advocacy groups in planning adaptation, and in cases where planners do involve citizens in adaptation planning, it tends to be for the development of vulnerability assessments and not for the design or framing of adaptation strategies. The absence of integration of citizen concerns suggests that the needs of marginalized and the most vulnerable groups may not be adequately included in plans.

Our findings suggest that while most cities do not report adaption planning, there are substantive examples of governments taking leadership regardless of wealth levels and institutional barriers. For cities wanting to engage in adaptation planning, cities with extensive adaptation activity can act as focal points for learning. Although vulnerabilities and government capacities are different across income levels, past successes and failures in other cities can provide valuable information on how to plan for future climate risk. The growth of international networks for city-level action on climate change, such as C40 Cities Climate Leadership Group, shows that cities are interested in sharing knowledge and

experiences with climate policy. However, a number of cities reporting extensive adaptation action, such as Hamburg, Sacramento, and Minneapolis among others, are not part of C40 Cities (2016). Thus there are still unexamined opportunities for cities to learn from each other about adaptation policy.

Cities with extensive adaptation experience generally exhibit a mix of policy types, undertaking direct and concrete activities such as legislation changes as well as soft policies such as capacity building and research activities. Our results support previous studies (Berrang-Ford et al. 2011, Bizikova et al. 2014, Ford et al. 2014, Sud et al. 2015), implying that government-led adaptation is predominantly occurring in wealthy countries, despite low-income countries being the most vulnerable. This study only considers government-led adaptation, but while doing so we acknowledge that adaptation can be unplanned, at the household level, community-based or originating from the private sector. Future research should seek to expand the systematic study of urban adaptation to these sectors and so enhance our understanding of global trends in urban adaptation, particularly in middle- and low-income countries. Efforts to systematically track non-government adaptation and understand the nature and contexts of adaptation in the global south should ideally be based on approaches that are comprehensive, comparable, consistent, and coherent (Ford and Berrang-Ford 2015). Potential avenues for future work in urban adaptation monitoring and evaluation include systematic ground-truthing, where the findings of global assessments such as this study could be validated by in-depth case research. The value of this complementary approach lies in its ability to capture vulnerability-reductive activities that are not explicitly defined as “adaptation” and as such improve our frameworks for tracking urban adaptation systematically.

Chapter 4: Public Health Adaptation to Climate Change in Large Cities: A Global Baseline

Role of Chapter 4

This manuscript builds on the findings from the global assessment presented in Chapter 3. The aim of this manuscript is to illuminate one important sector of urban adaptation to climate change: public health. Specifically, we quantify the number of public health adaptation policies taking place in cities, we assess which health risks generate the greatest levels of response, and identify gaps in geographic areas and types of policies undertaken in cities. This manuscript describes and compares climate-adaptive policies in 401 cities. The methods and data collection are paralleled from the previous manuscript (Chapter 3), diving into the public health sector in-depth by only retaining adaptation initiatives that address health risks. With this paper we hope to incentivize policy-oriented learning across cities, and to highlight cities where extensive action on climate change and health is already taking place.

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Abstract

Climate change will have significant impacts on human health, and urban populations are expected to be highly sensitive. The health risks from climate change in cities are compounded by rapid urbanization, high population density, and climate-sensitive built environments. Local governments are positioned to protect populations from climate health risks, but it is unclear whether municipalities are producing climate-adaptive policies. In this paper we develop and apply systematic methods to assess the state of public health adaptation in 401 urban areas globally with >1 million people, creating the first global baseline for urban public health adaptation. We find that only 10% of the sampled urban areas report any public health adaptation initiatives. The initiatives identified most frequently address risks posed by extreme weather events and involve

direct changes in management or behaviour rather than capacity building, research, or long-term investments in infrastructure. Based on our characterization of the current urban health adaptation landscape, we identify several gaps: limited evidence of reporting of institutional adaptation at the municipal level in urban areas in the Global South; lack of information-based adaptation initiatives; limited focus on initiatives addressing infectious disease risks; and absence of monitoring, reporting and evaluation (MRE).

4.1. Introduction

It is now widely accepted that the global climate is changing and that we are locked into some degree of future warming. The Intergovernmental Panel on Climate Change (IPCC) estimates a rise in average global temperatures between 1.8°C and 4°C by 2100, with significant consequences for human health (Hartmann et al. 2013, Smith et al. 2014b). Urban populations in particular are expected to be adversely affected, as many cities worldwide are growing rapidly and often concentrate population and economic activity in geographical areas of high-risk (Revi et al. 2014). Notwithstanding global efforts to limit the temperature increase to 2°C over the next century, temperature will rise around 0.6°C by 2050 even in the unlikely scenario that emissions were to reduce to zero immediately. This is compounded by a failure to date to meet even modest global emissions reductions targets, highlighting the need for adaptation measures to complement action on greenhouse gas emissions (Smith et al. 2014b). Adaptation refers to the process of adjustment to actual or expected climate change and its effects (Ipcc 2014). In the public health context adaptation is synonymous with prevention and may constitute policies, strategies, or interventions to avert the negative health impacts of climate change. (Ipcc 2014, Ford et al. 2014b) While a number of opportunities for urban health adaptation have been identified, the task of managing health risks from climate change remains a significant challenge for local governments. (Costello et al. 2009)

The health risks from climate change have been well-documented in the last decade (Revi et al. 2014, Smith et al. 2014b). Changing infectious disease patterns (Rweyemamu, Otim-Nape and Serwadda 2006), water and food insecurity (Schmidhuber and Tubiello 2007), extreme climatic events (Russo et al. 2014), declining air quality (Kinney 2008), and

low-quality housing (Smith et al. 2014b) have been identified as major threats to global health this century. Risk in cities is compounded where the number of people exposed is amplified due to high population density and rapid migration (Carballo 2007, Oke 1982). Every year, 67 million people migrate to cities, with around 90% of this growth occurring in developing countries (Habitat 2011). By 2030, 60% of the world's population is expected to live in urban centres and over 2 billion people are predicted to live in dense informal settlements (slums) often located in low lying coastal areas (Habitat 2011, Hallegatte et al. 2013).

Climate effects on health are also exacerbated by characteristics of the urban built environment. For example, the frequency, intensity, and duration of extreme heat events is worsened by the urban heat island effect: greater retention of heat by the dark surfaces of buildings and pavement relative to reflective vegetation produces localized pockets of warmer temperature (Oke 1982). There is increasing evidence that municipal authorities are aware of the risk from climate change. A recent survey of 110 city governments found 88 cities reported risks from temperature increase, and 43 cities reported risks from storms and floods (CDP 2013). Adaptation measures, however, have been shown to reduce the negative health effects of extreme heat in urban areas (Fouillet et al. 2008). The 2003 European heat wave was associated with 70,000 excess deaths, leading France to implement a heat wave warning system involving the retraining of healthcare professionals, changing spatial planning practices and development of new physical infrastructure (Pascal et al. 2006). The strategy was deemed effective when 4,400 fewer deaths than anticipated were recorded during the subsequent 2006 heat wave (Fouillet et al. 2008). Examples such as this demonstrate that adaptation strategies and actions can significantly reduce the health burden from climate variation on urban citizens.

Indeed, there is increasing pressure on health professionals and policy makers across scales to protect the public's health in the face of climate change (Watts et al. 2015). This pressure reflects a shift from a recognition of the problem into action. The Lancet's two Climate Change Commissions in 2009 and 2015, for example refer to climate change as both the greatest global health *threat* (Costello et al. 2009) and the greatest global health *opportunity* (Watts et al. 2015) of the 21st century. As part of this effort to tackle climate

change, the Lancet Commission and the World Health Organization have called for systematic monitoring of progress on adaptation to identify success and areas where progress is lagging (WHO 2015, Watts et al. 2015). In the case of mitigation, progress can be quantified using conceptually simple (if technologically complex) metrics by measuring the change of greenhouse gases over time; for adaptation there are no similar standard metrics (Ford et al. 2015, Ford et al. 2013). Tracking the planning and implementation of adaptation policy has therefore been used as a reasonable proxy to measure progress in the absence of direct indicators (Ford and Berrang-Ford 2015, Lesnikowski et al. 2011b, Lesnikowski et al. 2013b, Poutiainen et al. 2013).

Despite the magnitude of the risks and the importance of monitoring progress, however, we have little knowledge on whether cities are planning for adaptation in general and with regards the health risks of climate change in particular. This gap constrains our knowledge of how adaptation is taking place and whether the response is commensurate to the risks. In the context of this gap, this paper identifies and characterizes the state of public health adaptation planning in urban areas globally with over 1 million people. Specifically, we investigate five key questions for assessing health adaptation planning in cities: a) Which cities report the greatest levels of adaptation activity? b) Which health risks are generating the greatest levels of adaptation response? c) What types of adaptation are being reported? d) What stage of adaptation are urban municipalities at? e) Are reported adaptation initiatives new or mainstreamed? These questions allow us to characterize and compare the state of *reported* urban government health adaptation activity globally, and also establish a baseline against which future progress can be measured.

Identifying comparable datasets for comparing adaptation across countries or municipalities remains a significant challenge in tracking adaptation (Ford and Berrang-Ford 2015, Ford et al. 2013). Data and knowledge regarding adaptation measures are difficult to find, and thus systematic analyses of adaptation largely rely on adaptation *reporting* (Lesnikowski et al. 2013b, Austin et al. 2015, Ford et al. 2013). Though imperfect, using adaptation reporting as a proxy for adaptation measures at present remains the only option. Reporting of adaptation is in itself important as a proxy for prioritisation of adaptation and for adaptive capacity. A lack of adaptation reporting hinders sharing of

experiences and best practices, transparency, and effective monitoring and evaluation. Accordingly, in this paper we are not comparing actions themselves, but rather comparing reporting of actions.

4.2. Methods

4.2.1. Data Collection

To assess the state of public health adaptation in cities we used systematic data collection methods (Ford and Berrang-Ford 2015). We analyzed health adaptation planning in urban municipalities larger than 1 million people as per the United Nations definition of "urban agglomeration" (Heilig 2012). A total of 401 cities were included for analysis, where at least one of their country's official languages was spoken in five or more cities among urban areas larger than 1m. Languages included are: English, Spanish, and French (spoken by the researchers), and Chinese, Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Turkish, and Indonesian (using hired translators). Urban agglomerations often contain several municipalities. In the majority of cases, the namesake and most populous municipality was included for analysis. In the case of London, UK, and Santiago, Chile, the urban agglomerations are highly fragmented and the central municipality is small. In these two cases the metropolitan government was included instead – the Greater London Authority and the Region Metropolitana respectively. The final dataset contains 401 urban areas (90% of 449), with Chinese cities (n=92) notably constituting close to one fourth of all cities (see Appendix A of the supplementary materials for a list of all cities reviewed).

Climate change planning documents from municipalities were used as the data source for identifying and characterizing adaptation taking place. The documents were publically available and accessed via web. The documents were retrieved on a city-by-city basis using the search engine Google via a two-step process. The first step was to identify the city's municipal website through a Google search of the city's name and subsequently we scanned the site for climate change planning documents, either on the website itself or as standalone documents linked from the website. If no relevant documents were found on the website, an additional Google search was performed using the search terms *climate*

change and the city name. The first fifty results (5 pages) were reviewed based on title and page description from Google. Climate change planning documents were classified into four different categories: a) Municipal Adaptation Plans (MAPs), which focused exclusively on climate change adaptation and outlined the risks posed by climate change as well as the municipality's responses; b) Climate Action Plans (CAPs), which covered both mitigation and adaptation activity by the municipality; c) Adaptation web-pages of municipal government websites, which outlined the adaptation activities of local governments but did not consist of standalone documents; and d) Adaptation documents developed by consulting firms or other external research groups in partnership with the municipality. Documents falling under category 'd)' were only found for Minneapolis, U.S. and Cape Town, South Africa. For these two cities we categorized the initiatives as "recommendations" because the status or intent of implementation are unverifiable. Data were collected between January 2nd and March 29th, 2014, and any documents published after this date were excluded (see Appendix II for complete document inclusion). Data from the documents were used to produce a dataset of worldwide public health adaptation activity in cities. The use of publically available climate change plans is consistent with adaptation tracking methods and provides consistency in the source of the initiatives, a key consideration in adaptation tracking studies (Reckien et al. 2014, Ford and Berrang-Ford 2015).

A challenge in comparative policy research is to identify clearly what is being compared. A number of studies have sought to measure and compare adaptation progress, but they have often used conflicting frameworks and provide little agreement on what is understood as 'adaptation policy' (Dupuis and Biesbroek 2013). For example, some development-oriented initiatives have been considered 'adaptation' as they alleviate underlying drivers of vulnerability (e.g. improved income or education)(McGray et al. 2007), while other studies have required adaptation to have a clear climate change lens (Dupuis and Biesbroek 2013). In this study we use the IPCC AR4 definition of adaptation as the "result of deliberate policy decisions based on awareness that conditions have changed or are about to change" (IPCC 2007b). Documents were only included for analysis if they explicitly concerned climate change and the task of reducing vulnerability or increasing

resiliency to climate change, as determined by a review of the document's title and content. The database does not include information from non-governmental entities or cross-city international networks such as C40 Cities Climate Leadership Group. Documents focused exclusively on mitigation and sustainable development were also excluded from analysis. Sectoral plans were also excluded from analysis to facilitate comparison: while not every city has the same sectoral agencies, each city has a local government unit. This approach is consistent with previous adaptation tracking study designs (Berrang-Ford et al. 2014, Ford et al. 2013, Lesnikowski et al. 2011a). Policies and strategies that address current natural climate variability help reduce vulnerability to extremes, but adaptation policy must incorporate a consideration of changing future hazards and vulnerabilities. Our analysis excluded documents that address current or past climate risk without a consideration of how risk will change in the medium- and long-term future.

There are limitations in using publically available municipal planning documents. First, the documents analyzed are only relevant to the municipal level and the findings cannot be generalized to the national scale. Different jurisdictions are responsible for different aspects of public health: while national levels commonly dictate broad policy directions, local governments plan and implement concrete strategies more quickly (Austin et al. 2015). Second, there is a possibility that documents are already dated as there is a gap between document preparation and publishing and planning the initiatives themselves.

Finally, this study relies on adaptation reporting as a proxy for activity taking place. Thus we expect to capture the activities of governments with mechanisms for reporting and the capacity to produce planning documents. We do not argue, however, that adaptation is completely absent where governments are not reporting it. Case studies on low-income urban areas have found that adaptation activity is often community-based or informal and goes unreported (Lwasa 2010, Carmin et al. 2012a). Therefore this study will not capture every action that increases the health resilience of urban dwellers, and will only characterize government policy reported in publically available plans. Nonetheless, it can be argued that public health requires government accountability in how policy is taking place and reporting on activities is an important indicator in itself.

4.3.2. Data Analysis

A systematic classification method was designed to quantitatively retrieve data related to health adaptation initiatives in planning documents (see Appendix II for coding examples). The following variables were collected for classification of each discrete initiative: health risk targeted, adaptation type, level of groundwork or action, and the importance of climate change as a driver of change (whether the initiative is new or mainstreamed). We also collected general information such as city location (latitude, longitude, country, and continent) and the title and language of the planning document.

Any initiative responding to the health risks of climate change was recorded for inclusion as an observation in the database. Health risks were defined and categorized as per the IPCC Fifth Assessment Report chapter on human health (Smith et al. 2014b). These health risks include extreme temperatures, floods and storms, water and food insecurity, air quality, and infectious diseases (Smith et al. 2014b). Initiatives addressing general health without specifying a risk were classified into a newly created category for "general health". Similarly, initiatives alluding to extreme weather events without being specific about which risk they address (e.g. heat or flooding) were classified into a category for "general disaster preparedness." Initiatives reducing vulnerability in other sectors (e.g. water supply or the built environment) may have implications for health without emerging from the public health sector directly. Rather than excluding these initiatives, we included them contingent on explicit evidence of recognition of the health benefits or prevention of harm.

Adaptation typology refers to the type of initiative being undertaken. The adaptation initiatives identified were classified into one of seven categories: 1) management, planning, and policy; 2) practice and behaviour; 3) information and research; 4) capacity building; 5) physical infrastructure; 6) warning or observation systems; 7) recommendations (adapted from Biagini et al. 2014). Initiatives were also classified according to whether they are groundwork or action. Groundwork initiatives enable the conditions necessary to adapt, while actions directly reduce vulnerability (Lesnikowski et al. 2011a). Initiatives classified as groundwork can be understood as the initial steps toward building resilience, while

adaptation actions directly protect the public's health from climate risks. Examples of groundwork include: mapping vulnerable areas, assessing different options to cool the urban heat island, analyzing weather data, and creating relationships among stakeholders. Examples of actions include: increasing the number of trees in the city, instituting early heat warning systems, implementing pest management systems, and mandating green roofs on new construction. Finally, initiatives were categorized according to whether they are new or mainstreamed. New initiatives are standalone measures designed with the sole purpose of adjusting to the actual or expected impacts of climate change. Mainstreamed initiatives are meant to add an adaptive climate change lens to existing policies, programmes, or actions (Lesnikowski et al. 2011a).

Initiatives were recorded as observations and the variables as columns in a spreadsheet. Descriptive statistical analyses and figures were created using STATA (StataCorp version 13). QGIS (OSGeo) was used to create a cartographic map illustrating urban public health adaptation initiatives.

4.3. Results

Of 401 cities analyzed, only 42 municipalities (10%) report planning or implementing public health adaptation initiatives (Figure 3). From these 42 cities we extracted 226 individual initiatives. Eight cities report 10 or more initiatives: New York City, Toronto, Sacramento, Vancouver, Adelaide, London, Melbourne, and Durban. New York City is the highest reporting city with 34 individual public health adaptation initiatives. On the low end, 10 cities report only one initiative: San Francisco, Edmonton, Zhongshan, Lyon, Bridgeport, Buenos Aires, Brisbane, Quito, Cincinnati, and Chongqing. In this section we outline trends regarding geographic location of public health adaptation initiatives, health risks motivating change, adaptation typology, level of the initiative (groundwork vs. action), and whether initiatives are new or mainstreamed. Recommendations make up 9% (n=20) of total initiatives, and are exclusively from Minneapolis and Cape Town. Both cities' adaptation plans were commissioned to external bodies, and developed in partnership with the municipal government. All the initiatives described below are either in the planning process or have been implemented unless noted as recommendations.

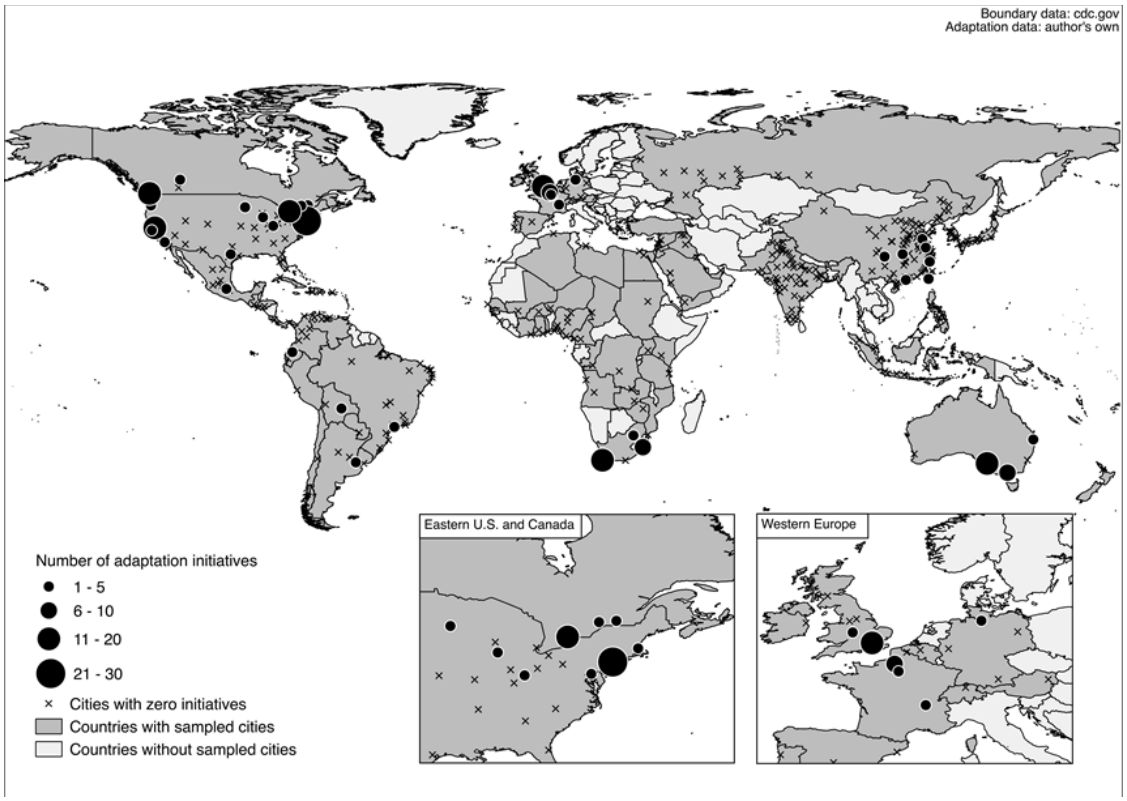

Figure 1: Geographic distribution of urban public health adaptation initiatives

4.4.1. Health adaptation is largely being reported in cities of high-income countries

The majority of cities (67%, n=28) reporting any public health adaptation initiatives are in high-income countries, as per the World Bank's categorization of country and lending groups (World Bank 2015a). Another 31% (n=13) of cities reporting any public health adaptation initiatives are in upper-middle-income countries. In contrast, Santa Cruz, Bolivia is the only city among the lower-middle-income countries or low-income countries to report adapting to the health risks of climate change. This trend suggests that public health adaptation reporting is patterned by national income and municipal governments in high-income nations are more likely to plan and implement — or at minimum report on — public health adaptation.

Nonetheless there are exceptions: Durban in South Africa reports high levels of adaptation initiatives relative to the median, despite being located in a middle-income nation. Notably, Durban is the only urban area among sampled countries in Africa to have

published a dedicated and extensive planning document on adaptation to climate change. Durban also exhibits a significant focus on public health within its adaptation documents. As such, Durban can be viewed as a focal point for learning and sharing experiences on responding to — or at minimum reporting response to— the health risks from climate change. It is possible that urban areas in low- and middle-income countries are adapting but not reporting it. This may be explained in part by a lack of reporting capacity, however the high variation in adaptation reporting within regions of similar capacity, such as within South Africa where 43% (n=3) of urban areas with >1 million people (n=7) report any public health adaptation initiatives.

4.4.2. Preparations for extreme temperatures and natural disasters are the most frequent initiatives

Initiatives addressing extreme heat and cold-related impacts are the most frequent (30%, n=67), followed by general disaster preparedness responses (17%, n=38) (Figure 4). Although the category for extreme temperatures includes cold-related effects, all of the temperature-related initiatives targeted heat. Common initiatives addressing heat risks include: mapping the urban heat island to identify the most vulnerable locations (Baltimore); identifying areas with deficits of green spaces (Los Angeles); providing dedicated cool public spaces during heat waves (Sacramento); providing information about how to stay safe while outdoors during heat waves (Melbourne); and regularly ensuring water drinking fountains function correctly (Vancouver). General disaster preparedness activities often involve building redundancy and safe failure in preparation for extreme weather. In New York, for example, there is emphasis placed on ensuring the operation of critical services through protection from physical damage (New York City 2013). Initiatives preventing damage from disasters include (from New York): retrofitting existing hospitals in the 500-year floodplain; installing backup generators for pharmacies; establishing temporary ambulatory clinics in vulnerable areas; and updating emergency response plans to account for increased potential of climatic-induced events (e.g. blackouts).

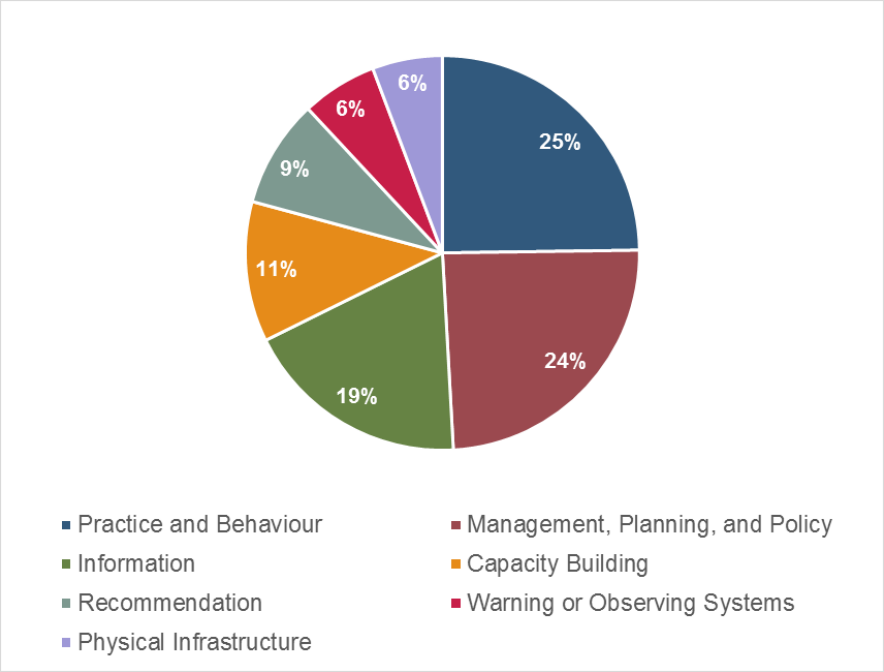

Figure 2: Health risks addressed as percentage of total number of adaptation initiatives

Floods and storms are the third most addressed health risks (16%, n=36), followed by "general health" initiatives (15%, n=33), and water and food security initiatives (9%, n=20). Activities addressing floods and storms take the shape of mapping flood-prone areas (Boston); evaluating soft infrastructure's potential for flood protection (New York); creating online data portals to allow flood risk management partners to share information (London); and planning and implementing integrated flood management systems in coastal communities (New York). General health initiatives target human health generally but do not specify individual health risks. Initiatives of this type include: expanding epidemiological analyses of health and environmental data (Sao Paolo); establishing systems to monitor the health impacts of climate change (Mexico City); vulnerability studies in the health sector (Paris); and enhancing awareness of climate health risks with leaflets (Hamburg).

Initiatives addressing air quality (8%, n=18) and infectious diseases (7%, n=16) are implemented less frequently. Air quality adaptation activities include: increase human resources allocated to air quality (recommendation for Cape Town, enforce pollution-related legislation (e.g. recommendation of black smoke legislation in Cape Town);(City of

Cape Town 2006) and increasing the tree canopy (Toronto). Initiatives to prevent the potential increase of infectious disease incidence include: monitoring development in infectious disease vectors/pathogens (Hamburg); public awareness campaigns on conditions favourable to rodent or mosquito breeding (Durban); increase support for public health facilities to deal with diarrhoea and dehydration (recommendation for Cape Town), and requiring drainage of untreated pools or other water features in homes and businesses that are not being maintained (Sacramento).

Mental health is not explicitly addressed by any initiatives, even though improved mental health has been identified as a significant co-benefit of green urban design (Watts et al. 2015). Mental health was originally left in data analysis as a type of health risk, but is absent from the figures and tables as none of the initiatives explicitly target mental health. UV radiation and land shifts were two other categories initially selected for classification due to their understood importance to morbidity, injury, and death, but were eliminated when none of the initiatives addressed these risks in the context of human health (Smith et al. 2014b).

4.4.3. Municipalities favour direct adaptation action rather than soft indirect activities

From 226 extracted initiatives, 34% (n=76) are groundwork activities and 66% (n=150) are adaptation actions. Practice and behaviour (PB) initiatives are the most frequent adaptation type (25%, n=56) (Figure 3), and can be characterized as changes of behaviour directly associated with building resilience on the ground.(Biagini et al. 2014) Initiatives of this type evident in adaptation of urban areas are: improving drainage in identified vulnerable locations (Melbourne); implementing permeable pavement surfaces (Toronto); improving sanitation in informal settlements (recommendation for Cape Town); and raising awareness among consumers regarding food hygiene practices during extreme heat events and power cuts (Adelaide). Management, planning and policy initiatives are the second most reported type (24%, n=55), and often constitute direct changes in how management of resources takes place, the thematic priorities in city plans, and changes in legislation. Example initiatives of this type include: establishing emergency response plans (Austin); allocating budget for vulnerability research (Bridgeport); enacting legislation to

limit air pollution (recommendation for Cape Town); and incorporating response to climate change impacts into health care provision and social services (London).

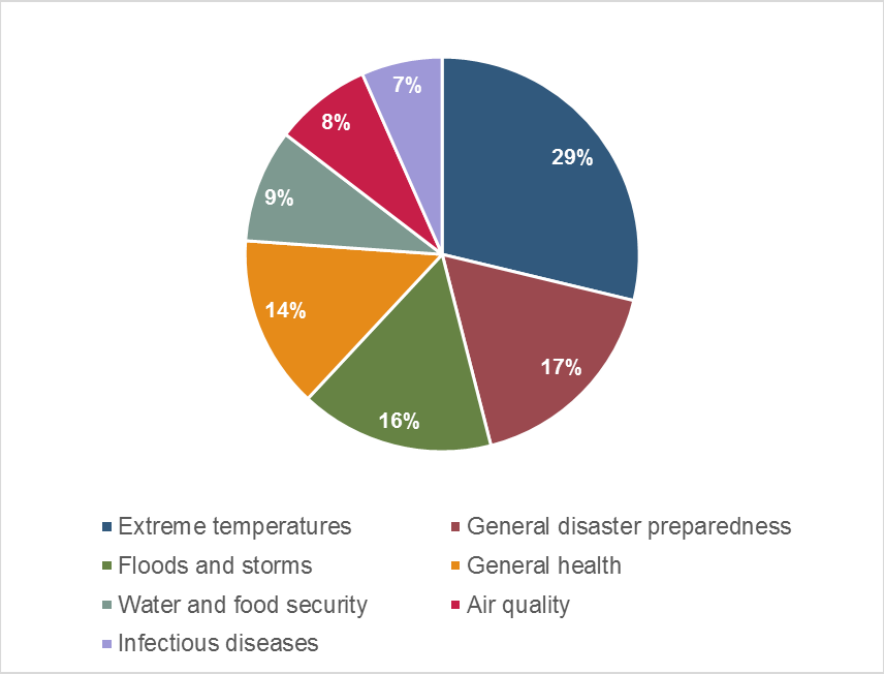

Figure 5: Adaptation types as percentages of total number of adaptation initiatives

Information and research are less frequently reported (n=42, 19%). This type of initiative is stressed by the Lancet's Commission on Climate Change as among the most important activity as it helps parse out potential risks and vulnerabilities. Initiatives of this type include: developing vulnerability assessments (Paris); exploring improved approaches for vulnerability mapping (Marseille); and undertaking research to understand the impacts of climate change. (Melbourne) Capacity building initiatives can be understood as softer more indirect activities and constitute an even smaller share of total initiatives (12%, n=26). These types of initiatives include: expanding public awareness (Durban); training workshops (London); creating information kits for health managers (Melbourne); and improving capacity to respond to emergencies through community education and outreach (Jingzhou).

The difference between direct and soft initiatives can be illustrated with a comparison of Los Angeles' (LA) and Toronto's approach toward green roofs. The city of LA encourages

homeowners to build green roofs and provides information on the benefits of impervious and reflective roof surfaces (City of Los Angeles 2007). It can be understood that LA is providing conditions enabling for change with encouragement and information. Meanwhile Toronto in 2010 instituted legislation (municipal bylaw) requiring all types of new construction to have green roofs, including residential, commercial, institutional, and industrial development (City of Toronto 2011). This legislation change directly reduces vulnerability to climate change impacts as green roofs mitigate the intensity of the urban heat island and provide permeable surfaces for improved rainfall drainage.

Warning or observation systems constitute only 6% (n=14) of total initiatives and often take the shape of early heat warning systems or flooding forecasting systems (Chongqing). Physical infrastructure initiatives are the least frequent (6%, n=13) and can be found exclusively in New York. These initiatives adjust the architectural design of nursing homes and adult care facilities to increase flooding resistance so that these institutions can continue functioning during storms (New York City 2013).

Most reported initiatives are new (74%, n=168) and not mainstreamed (36%, n=82). New initiatives involve the creation of new plans, strategies, or measures with climate change as the primary motivator for change. Mainstreamed initiatives, on the other hand, enhance, intensify, improve, or bolster the adaptive capacity of existing policies. The difference between new and mainstreamed initiatives can be can be illustrated with a comparison of Melbourne and Sacramento's extreme heat plans. Melbourne is developing a program to provide community members with information about staying safe in the heat (City of Melbourne 2014). This initiative is new and thus requires resources from the municipality: human resources to deliberate and select the appropriate policy instruments to implement the initiative, and financial resources to prepare and disseminate the heat awareness program. Sacramento's effort to update their heat response plan to include climate change effects is an example of a mainstreamed initiative (City of Sacramento 2012). The heat response already exists, so the paths for implementation are already in place. Sacramento therefore will require fewer resources, namely in the form of information, to add climate change as a consideration in their heat response plan.

4.4. Discussion

To our knowledge, this paper is the first global baseline of municipal reporting on urban public health adaptation initiatives. The key finding is that a large majority of municipalities sampled (90%) are not reporting implementation of any public health adaptation initiatives. This finding differs from results in previous self-reported survey-based literature, where it has been found that around 35% of global municipalities report planning for the health risks from climate change (Aylett 2015). Among the municipalities reporting adaptations, public health adaptation planning is still in its early stages.

Extreme heat, floods, storms and other unspecified disasters are the most addressed health risks of climate change in municipalities (23, 17, and 17 cities report planning for these risks. respectively). However, there remains a large adaptation gap since studies have found that a number of cities reported recognition of risk from extreme heat (88 cities) and more frequent storms (43 cities), suggesting a time lag between cities' self-reported recognition of risk and the formation of actual plans (CDP 2013). Notably, only 6% of heat-related initiatives are early warning systems, despite evidence that the use of these systems is growing in many large cities (Toloo et al. 2013). The majority of heat-related initiatives found in this study aim to reduce the long-term effects of the urban heat island through green infrastructure projects. Green infrastructure initiatives include expanding the urban tree canopy, converting rooftops into vegetable gardens. While heat early warning systems focus exclusively on protecting citizens from extreme heat, green infrastructure provides wider co-benefits. Green urban design can promote active lifestyles through the production of a more appealing urban environment, thus improving public health (Younger et al. 2008). The number of added benefits from green infrastructure beyond reduction of the urban heat island may explain why cities report a relatively low number of heat early warning systems compared to green infrastructure.

Direct actions, in the form of management, planning and policy, and practice and behaviour changes are the most frequently reported urban public health adaptation initiatives. These baseline results highlight a key gap in adaptation: a very small percentage of cities report any planning towards climate change health risks. Other gaps identified

include: limited adaptation in the Global South; lack of information-based adaptation initiatives; few initiatives addressing infectious disease risks; and absence of monitoring, reporting and evaluation (MRE).

While cities in high-income countries have begun reporting on adaptations that respond to the projected health impacts of climate change, and to a lesser degree upper-middle-income countries, there remains an important gap in our understanding of adaptation in the Global South, where populations will be most affected by the health impacts of climate change (Watts et al. 2015). The lack of evidence of reporting on urban health adaptation planning in India (100% of sampled cities non-adapting, n=43 cities sampled) or China (92%, n=86) is particularly notable, two countries where over a third of the world's population lives (World Bank 2015b). Populations in the Global South will be faced with disproportionately high health impacts of climate change. Moreover, the existing considerable inequalities within urban areas in the Global South will be exacerbated by climate change, where the health burden among the urban poor will grow, particularly among those living in slums and informal settlements (Kovats and Akhtar 2008). The absence of reporting on adaptation planning in urban areas of low- and middle-income countries may correspond to a lack of resources, knowledge and institutional capacity to adapt, or simply to lack of reporting of adaptation measures (Chu, Anguelovski and Carmin 2015, Satterthwaite 2014, Reid et al. 2010). In other contexts institutional capacity and good governance have been shown to be drivers of adaptation (Berrang-Ford et al. 2014). The complexity and uncertainty surrounding the pathways between climate change and health heighten the challenges faced by urban planners, public health officials and health professionals (Revi et al. 2014, Friel et al. 2011). To reduce vulnerability, urban adaptation in the Global South must sustainably manage rapid urbanization, and reduce poverty and disaster risks (Tanner et al. 2009). While adaptation may be occurring in the absence of reporting, lack of reporting in itself reflects lower prioritization and a proxy for reduced adaptation capacity, therein constrains oversight, sharing of experiences and best practices, and monitoring and evaluation mechanisms.

Although identifying problems and objectives, assessing risk, identifying options and appraising options have been identified as some of the first steps in adapting to climate

change (UKCIP 2013), half of the adapting cities (55%, n=23) do not report any information-based adaptation initiatives. These findings suggest a potential lack of climate change and health research or information for local governments. One of the Lancet Commission's primary recommendations is to "Invest in climate change and public health research, monitoring and surveillance to ensure a better understanding of the adaptation needs and the potential health co-benefits of climate mitigation at the local and national level," (Watts et al. 2015) emphasizing the importance of research and information for public health adaptation to climate change. It is possible upper-level governments are filling this gap and providing information to lower-level governments, as is the case in Canadian jurisdictions (Austin et al. 2015). Similarly, the Swiss national government plans to support adaptation in the cantons, municipalities and cities by supplying targeted information, ensuring the transfer of knowledge between levels.(Swiss Confederation 2014) Among academic sources, literature on best practices for urban adaptation tends to focus on the developed-country context (e.g. New York City (Rosenzweig and Solecki 2014b), European cities (Carter 2011) and Canadian municipalities (Burch 2010)), despite the significant adaptation barriers related to low capacity in developing countries (Mittal, Petrarulo and Perera 2015, Romero-Lankao et al. 2013). Adaptation science is needed specifically for cities in the Global South to investigate ways of planning and implementing adaptation in the context of low governance capacity (e.g. limited material and financial resources).

Climate change is expected to alter patterns of vector-borne infectious diseases and food- and water-borne infectious diseases and increase disease incidence and prevalence (Smith et al. 2014b, Altizer et al. 2013, Gould and Higgs 2009). For example, the incidence of Lyme disease has risen swiftly in Europe and North America, where the geographical range and upper temperature limits of ticks, the disease vector, are spreading northward (Greer, Ng and Fisman 2008, Semenza and Menne 2009). Likewise, climate change is projected to expand the geographic area suitable for dengue transmission globally (Åström et al. 2012). Infectious disease transmission will also be mediated by non-climatic factors, such as adaptation or socioeconomic development (Åström et al. 2012). Despite the many infectious disease risks associated with climate change, our findings suggest infectious

disease risks are not consistently being addressed by adaptation initiatives (Figure 2). Given the pervasive health risks posed by infectious diseases and climate change, the issue has received disproportionately low attention and focus at the local level. Though it is possible national governments are filling this gap due to the inter-jurisdictional nature of some infectious disease threats, Panic & Ford's (2013) review of national-level adaptation initiatives addressing infectious disease risks in OECD countries demonstrates that adaptation for infectious disease risks also remains a gap among many national-level governments. The need for community-based adaptation to the health risks posed by climate change and stakeholder engagement have been highlighted in the literature (Ebi and Semenza 2008).

Among the municipal adaptation plans reviewed, there is little evidence of monitoring, reporting or evaluation (MRE) of adaptation in reducing vulnerability or increasing resilience. Vancouver is one of the exceptions among the urban areas sampled and includes provisions for annual reviews in its municipal adaptation plans (City of Vancouver 2012). MRE is needed to track and assess outcomes of adaptation initiatives and interventions; ensure accountability and efficient allocation of resources; target, justify and monitor adaptation funding; and facilitate comparison of adaptation achievements (Brooks et al. 2011, Harley et al. 2008, Ford et al. 2013). Stakeholder engagement in adaptation planning and MRE is essential for ensuring the needs of vulnerable populations are addressed in public health adaptation, particularly among poor and marginalized groups in the Global South (Ebi and Semenza 2008). MRE of public health adaptation initiatives remains a gap that must be addressed in urban adaptation planning.

A lack of MRE evidence in adaptation plans, however, does not mean that MRE is not taking place since reporting bias is a limitation of this study. Governance capacity has been found to be a determinant of whether governments publish their climate change plans for the public, and low capacity government may be unfairly penalized in this study due to non-reporting of adaptation activity taking place (Berrang-Ford et al. 2014). Differences in public information disclosure norms across cities and countries may also have affected the availability of climate change documents. There is evidence that vertical coordination across different levels of government is crucial for planning effective public health policy

(Bowen et al. 2013) This study focused on the city-scale and evidence of interactions with other levels of government, especially the national government, may not appear in municipal climate planning documents. Additionally, cities may have sectoral agencies (e.g. water supply authorities) that produce climate planning documents, but these were excluded from analysis by the study design. Finally, search comprehensiveness is a limitation for any adaptation tracking study, and there may be publically available documents that are not accessible via web.

A second limitation is that this study tracks reported adaptation initiatives, but the methods presented here cannot verify whether the initiatives have been implemented in reality or whether they have successfully reduced vulnerability to climate risk, a common challenge in adaptation MRE (Dupuis and Biesbroek 2013). Lack of sufficient detail and unclear language often obfuscated whether reported initiatives are in the planning stage or have been implemented.

4.5. Conclusion

Adapting to the health risks of climate change is paramount to ensuring populations' well-being (Watts et al. 2015, Neira et al. 2014, Hess et al. 2014). The current and projected health impacts of climate change vary by region, but are expected to exacerbate existing inequalities and burdens of disease (Kovats and Akhtar 2008), and specific risks may include extreme weather events, changing patterns of infectious diseases, deteriorating air quality, declining food security, and mental health impacts (Smith et al. 2014b). In this paper we have used a systematic approach to empirically review and characterize reporting on public health adaptation in 401 urban areas globally. We find that most urban areas (n=359, 90%) are not reporting any public health adaptation initiatives. This finding suggests that there is a significant gap between the risks faced by cities and municipal responses to these risks.

The few urban areas reporting public health adaptation initiatives are primarily in high-income countries, indicating a significant gap in health adaptation reporting in low- and middle-income countries. The limited research and information based initiatives, the lack of initiatives addressing infectious disease risks, and the absence of MRE have also

been identified as important gaps in urban public health adaptation to climate change. The methodological framework employed in this study can be applied in the future to measure progress on global urban public health adaptation, yet is premised on addressing reporting bias across nations, particularly in the Global South. In light of mounting health risks, and growing financing for adaptation, this type of standardization in adaptation tracking is necessary to measure progress at a global level (Ford and Berrang-Ford 2015).

Chapter 5: Climate Change Adaptation in Global South Megacities: The Case of Dhaka, Bangladesh

Role of Chapter 5

The two previous chapters in this thesis provided global-level assessments of adaptation activity taking place in cities over 1 million people. This manuscript adds depth to the thesis in a different manner than the previous manuscript: rather than focus on one sector here we characterize adaptation in one specific geographic location: Dhaka, Bangladesh. The South Asian capital is a rapidly growing megacity with acute vulnerability to climate change impacts. Extreme heat and flooding episodes put pressure on the health of citizens and the integrity of infrastructure, and these impacts are expected to worsen over the 21st century. Dhaka's vulnerability is exacerbated by high levels of urban poverty, a massive proliferation of unplanned informal settlements, and limited governance capacity to plan for infrastructure and utility upgrades. Our global assessments used publicly available planning documents from city municipalities. The studies found that the wealth of cities is highly related to their reporting of adaptation initiatives. This case study, then, uses a more thorough approach to characterize adaptation status of cities, which is not possible in global assessments. The aim is to reflect on the extent to which methods for the global assessment accurately portray the extent of adaptation activities taking place on the ground. In the Conclusion to the thesis I reflect on the implications of this study for the global assessments, and propose ways to perform more in-depth large scale urban adaptation tracking studies.

This manuscript was developed for publication in a journal, but the authors have not determined which journal or when the paper will be submitted. I am first author, but the final list of co-authors has not been finalized.

Abstract

Megacities in low- and middle- income countries face impacts from climate change as they concentrate population and infrastructure in high-risk areas. It is unclear, however, if these cities are responding to the risks and how they are adapting. Studies tracking

adaptation progress have analyzed municipal adaptation planning, but lack of reporting on activities taking place limits the information available on adaptation. Informed by literature on multilevel approaches to characterize urban adaptation, we develop and apply a framework to characterize adaptation progress and readiness in urban areas with limited resources and governing capacity, applying it to a case study. We used Dhaka, Bangladesh as a case study due to its acute exposure to flooding and extreme heat, rapid growth, and dense population. We review planning documents from the national, city, and ward-level (n=23), peer-reviewed literature (n=20), and interview climate change planning officials and researchers (n=15) to assess the status of adaptation in Dhaka. We find that national level plans and international organizations, or *exogenous* forces, drive adaptation progress in the city. On the other hand, city-level internal factors such as leadership and municipal support, or *endogenous* forces, are comparatively absent. We suggest that Dhaka's *endogenous* factors have not been sufficient to create innovative adaptation policy, and that *exogenous* factors such as national and international drive adaptation progress where governments have limited human and financial resources. Nonetheless, lack of political will, widespread corruption, and implementation capacity are frequently reported in the interviews as barriers to translate national directives into local level planning.

5.1. Introduction

Planning for climate change impacts is a complex and urgent task facing cities globally. It is widely accepted that shifting temperatures and precipitation will put urban areas at risk through increased incidence of heat waves, flooding, water scarcity, infectious diseases, and damage to infrastructure (Revi et al. 2014). Rapidly growing cities in the Global South are particularly sensitive, as climate change amplifies existing social vulnerabilities in cities with high proportions of urban poor. Often, low-income households are concentrated in high-risk areas and lack adequate means to protect themselves, their homes, and their livelihoods (Alam and Rabbani 2007). Further, poorly resourced households have low levels of capacity to bounce back from damage to property and income. The complexity of adapting urban areas remains a challenge for decision-makers, and the question still remains: are Global South cities planning for the impacts of climate change?

Dhaka is a Global South megacity at the forefront of impacts from climate change (Hanson et al. 2011, Hallegatte et al. 2013, Alam and Rabbani 2007, UN Habitat 2008). Megacities are defined as urban areas over 10 million people and the Bangladeshi capital ranks among the world's largest at nearly 15 million and an annual growth rate of 3.6% (Alam and Rabbani 2007). Climatic pressures drive much of Dhaka's growth as migrants come to the city after facing extreme events such as cyclones or rapid land erosion in coastal and rural areas (Black et al. 2011). The capital, however, is not immune to the impacts of extreme climate: most of Dhaka is less than three metres above sea level and many of the city's vast residential developments are located in areas assigned for flood drainage, exposing whole neighbourhoods to chronic water logging. The health of Dhakans is impacted by flooded neighbourhoods as the prevalence of infectious diseases such as diarrhoea and dysentery increase during flooding episodes. While Dhaka's vulnerability is well-documented, less attention has been paid to how governments, private actors, and international agencies plan to adapt to climate change and enhance the resilience of the local population (Alam and Rabbani 2007). A growing number of case studies seek to examine successful examples of local government planning adaptation in cities of the Global South (Anguelovski, Chu and Carmin 2014, Pasquini et al. 2015, Carmin et al. 2012a, Roberts 2008).

Case-studies taking stock of adaptation progress have become increasingly important as adaptation becomes central to international climate policy and the goal for climate financing through the United Nations Convention on Climate Change reaches $100b per year by 2020 (GCF 2016). Research examining the adaptation experience of cities typically assumes that local governments are the appropriate scale for planned adaptation: since the impacts of climate change are highly localized, local authorities are viewed to be equipped with the knowledge and the policy tools to implement adaptation plans (Carmin et al. 2012a, Sugar et al. 2013). Increasingly, however, research on urban adaptation governance has called for a multilevel approach (Revi et al. 2014, Amundsen, Berglund and Westskog 2010, CCFLA 2015, Shi et al. 2016). The multilevel approach considers that adaptation planning is fraught with tensions between local and national governments with regards to regulatory authority and funding (Shi et al. 2016). Therefore a multilevel approach is

particularly useful in low-income countries where limited financial and human resources in local governments lead to greater dependency on regional or national governments and other (donor) organisations to design and implement policy.

This paper reviews and examines the current status of climate change adaptation planning in Dhaka based on an analysis of gray and scientific literature as well as in-person interviews with government, academic, and civil society experts. The aim is to characterize what adaptation activities are currently occurring in Dhaka and to assess how ready governments are to plan for adaptation. The article also investigates how tensions between different levels of government affects if and how adaptation planning takes place in Dhaka. Finally, this paper examines how aspects of governance such as political transparency and corruption affect how adaptation planning takes place in Dhaka. The goal is to identify gaps in government institutions and sectors across scales, and to suggest ways to incentivize progress in these areas. We use a multilevel approach and assess how national and regional governments are enabling or constraining Dhaka's progress on adaptation

5.2. Theoretical framing

5.2.1. What is adaptation?

A key challenge in the adaptation literature has been to identify what "adaptation" means (Dupuis and Biesbroek 2013). International climate agreements do not define adaptation with enough clarity to distinguish the concept from other vulnerability-reductive activities such as disaster risk reduction or social policies that improve well-being generally (Ford et al. 2015, UNFCCC 2015). Documented examples in cities range from the mandate of green roofs to avert the urban heat island effect to poverty reduction schemes that decrease social vulnerability, but do not address climatic factors directly (Gill et al. 2007, Schipper 2007). This ambiguity emerges from two contrasting framings of vulnerability. O'Brien contends that 'end-point' vulnerability is conceptualized as a product of climate change impacts that are additional to those from natural climatic extremes (2007). 'Starting-point' vulnerability, on the other hand, refers to the socioeconomic and environmental factors determining how humans are affected by extreme weather and the ability to cope and bounce back (O'Brien et al. 2007).

The United Nations Framework Convention on Climate Change and studies of urban climate change have commonly used a definition of adaptation that directly addresses climatic risk, derived from an 'end-point' framing of vulnerability (Carmin et al. 2012a, Roberts 2008, Rosenzweig and Solecki 2014b, Carmin et al. 2012b). Often this means that activities are only considered adaptation to climate change if they are explicitly communicated as such (Hughes 2015, Araos et al. 2015, Austin et al. 2015, Lesnikowski et al. 2015). Dupuis and Biesbroek call these "highly intentional" initiatives, as they are purposefully designed to deal with risks of climate change (Biesbroek et al. 2011). In this study we use explicit mention of "climate change" as a filter for activities, as adaptation requires an understanding of current and (uncertain) future vulnerability. While some actions by government plausibly reduce current vulnerability to extreme weather, a lack of attention to projected climate trends risks maladaptation (Adger et al. 2003): for example if a city builds an embankment to eliminate current flood exposure without considering climate projections, then rising flood levels in the future may overcome the embankment and cause damage.

Consistent with the conceptualization of adaptation described above, this study draws from Dupuis and Biesbroek (2013) to define adaptation policy as: "The process leading to the production of outputs in forms of activities and decisions taken by purposeful public and private actors at different administrative levels and in different sectors, which deal intentionally with climate change impacts, and whose outcomes attempt to substantially impact actor groups, sectors, or geographical areas that are vulnerable to climate change." This definition allows us to capture activities undertaken by both public and private actors, across governmental levels, and across sectors.

5.2.2. Assessing adaptation progress

Adaptation progress here refers to intentional policy change toward dealing with climate change impacts (Table 1). Progress is characterized against a baseline of no evidence of climate change adaptation policies. In this sense, any evidence of policy framed as 'adaptation to climate change' signifies progress. While this approach does not directly quantify adaptation policy, it qualitatively characterizes adaptation progress in Dhaka by

discussing all the adaptation policies gathered through the literature search and from interviews, and comparing them to previous plans to discern how discussions of adaptation planning have changed across documents.

This framework characterizes adaptation activity across administrative levels. This multilevel approach is consistent with the notion that adapting to climate change involves a range of decisions across a number of people and governments at local, regional, and national scales (Adger et al. 2005). Different actors have different responsibilities and interdependencies across administrative levels. National governments, for example, have been associated with building adaptive capacity through building awareness of climate impacts, encouraging economic growth, establishing legislative frameworks conducive to adaptation, and communicating climate change information (Austin et al. 2015, Berrang-Ford et al. 2014). Local governments, on the other hand, are responsible for delivering basic services and utilities, and protecting their integrity from the impacts of extreme weather (Adger et al. 2005, Austin et al. 2015).

The multilevel approach seeks to determine whether adaptation progress is driven by national, international or city level factors, and to identify tensions across government levels. National or international factors refer to governments or organizations from *outside* the city-level planning and implementing adaptation projects, policies, or programmes, such as national-level directives or projects by international donors taking place in a city. City level factors, on the other hand, refer to the forces from *within* the city that spur progress on adaptation. Individual political leadership by a city government, for example, has been cited as city level factor driving adaptation policy in early adopters in Quito, Ecuador, and Durban, South Africa (Carmin et al. 2012a).

5.2.3 Assessing adaptation readiness

Adaptation readiness is defined as "the extent to which human systems are prepared to adapt, providing an indication or measure of the likelihood of adaptation taking place" (Ford and King 2015). This concept is complementary to assessing progress as it characterizes if the human system, e.g. a city, exhibits the necessary conditions to make intentional policy change for adaptation. The adaptation readiness framework helps

identify the factors that allow government and other decision makers to act on adaptation, build support, identify relevant policy strategies, and remove barriers to adapt (Ford and King 2015). The concept of readiness for adaptation has partly emerged in response to new international climate funds such as the Green Climate Fund (GCF): International policy commentators have noted that low-income countries will encounter difficulties, since evidence of financial transparency and institutional capacity to implement adaptation projects are necessary to access funds such as the GCF (Tollin 2015). Assessing the preparedness of low-income countries and cities to plan for adaptation is thus necessary to prove eligibility for funding and to ensure progress in creating adaptation policies.

The framework consists of two sets of factors essential for readiness adapted from Ford and King (2015): a) government factors, composed of presence or absence of political leadership, institutional organization, and funding for adaptation; and b) civil society factors, composed of stakeholder participation, the availability of usable science for adaptation, and public support for adaptation. Government institutions have an influence on adaptation readiness as political leadership, for example, is critical for initiating the process of adaptation. Leaders provide strategic direction and convince others of the need to act (Moser and Ekstrom 2010, Eisenack et al. 2014). Clear institutional structures and demarcated mandates have also been noted as important enablers for adaptation planning (Eisenack et al. 2014, Burch 2010). Burch et al. (2010), for example, explain how centralizing climate adaptation planning in the Mayor's office and close collaboration among sectoral agencies is a strategy to overcome barriers in municipal adaptation. Further, Eisenack et al. (2014) cite the fragmentation of Santiago, Chile into 52 municipalities as a hindrance to adaptation planning. Finally, the availability of funding for adaptation has been identified as an essential institutional factor that can enable or restrict adaptation. A lack of sustained multi-year funding has been cited has a significant barrier for adaptation planning in local governments (Eisenack et al. 2014, Opitz-Stapleton 2009).

Civil society factors refer to any support for adaptation provided by civil society: the general public, non-governmental organizations, and scientists. Public opinion has a strong influence on the conception and development of adaptation programs, since public perception of policy issues can influence how these issues are prioritized by government.

The slow and uncertain onset of climate change has traditionally acted as a barrier for climate policy because the public does not perceive the problem to be urgent (Boykoff, Ghoshi and Venkateswaran 2013, Ford and King 2015). Further, political context plays a role since the variable degrees of democracy and government transparency across nations affects the influence of the public on decision-making. Additionally, the engagement of civil society stakeholders has been noted as part of good governance, and a key factor for policy development based on knowledge of local conditions and decision-making processes (Gupta et al. 2010, Shi et al. 2016). Finally, the interaction between scientists and policy makers is key for producing effecting adaptation policy. Mechanisms for translating traditional science into tailored information for policymakers, such as boundary organizations, must be present to ensure scientific knowledge feeds into adaptation planning. The issue here is less about the amount of science available for decision makers and more about the usability of science for policy, taking into account the attitudes, capabilities, and world views of decision makers (Lemos, Kirchhoff and Ramprasad 2012).

Government and civil society factors described above are not a complete list of barriers to plan climate adaptation, but they are pillars of a framework to design open-ended interview questions about a city's adaptation readiness. Specifically, the effect of public opinion and stakeholder participation on adaptation is expected to be lower in cities where justice and participation are not integrated into or valued in adaptation planning (Shi et al. 2016). Other factors related to "good governance" such as corruption have been noted to hinder adaptation, or at least reporting of adaptation, in low-income countries (Berrang-Ford et al. 2014). In the results and discussion, then, we will reflect on the ability of the framework to characterize adaptation barriers related to corruption, lack of transparency, and injustice in the adaptation planning process.

Table 1: Framework for characterizing the adaptation status of Global South megacities

Framework component	**Key considerations**
Operational definition of adaptation	• Adaptation projects, programmes, or policies must explicitly integrate considerations of future climate change • Adaptation projects, programmes, or policies can be undertaken by public or private actors • Adaptation projects, programmes, or policies must attempt to substantially impact groups, sectors, or geographical areas that are vulnerable to climate change
Adaptation progress	• Adaptation progress refers to intentional policy change toward dealing with climate change impacts • Progress on adaptation is measured across time and across documents • Adaptation progress must be approached through a multilevel governance lens to unpack the role of each level of government and organization (international, national, local), as well as identifying tensions across levels

Adaptation readiness	• Adaptation readiness refers to the extent to which governments or international organizations are prepared to plan adaptation
	• Adaptation readiness consists of two sets of factors:
	  ○ Government factors, composed of presence or absence of political leadership, institutional organization, and funding for adaptation
	  ○ Civil society factors, composed of stakeholder participation, the availability of usable science for adaptation, and public support for adaptation.

5.3. Dhaka case study

Dhaka is the capital and largest city of Bangladesh with a population of almost 15 million people. The city produces around a fifth of the country's total GDP and as the main economic engine has attracted a significant migrant population from rural areas of the country, contributing to its rapid expansion (Kabir and Parolin 2012). Fast growth and poor urban management have created huge deficits in infrastructure provision such as housing, transportation, as well as basic services such as water and electricity (Hafiz, Jahan and Khan 1997). The problem is compounded as 37% of the population lives in poverty and around 3.4 million people live in the city's 5,000+ informal settlements (World Bank 2007).

Extreme weather amplifies social vulnerabilities in Dhaka through increased water logging from flooding and more intense heat stress (Alam and Rabbani 2007). The rivers of the Bengal Delta surround the city and while they make the area's soil fertile they also constitute a destructive hazard as yearly floods affect the city. The Buriganga River and nearby rivers frequently spill over and Dhaka has experienced damaging floods in 2009, 2004, 1998, and 1988 (World Bank 2007, Alam and Rabbani 2007). The expected acceleration of snow melt from the Himalayas is projected to aggravate river flooding (Rabbani, Rahman and Islam 2011). The main reason for the 1988 flood was intense rainfall, when flooding depths reached an average of 2.4 metres and around 60% of the city was affected.

The unprecedented flooding in 1988 affected city life and air travel, disrupting communication and transport between Dhaka and the rest of the country (and world) for almost two weeks (Alam and Rabbani 2007). During floods, industries of all kinds (e.g. garment, textile, and food-based) shut down due to disruptions from waterlogging. During the 2004 flood, the Dhaka Water Supply and Sewerage Authority estimates that around 250 schools and 681 garment factories were inundated. Utility and service systems such as water supply, waste management, electricity, and communications infrastructure are damaged regularly during floods (Alam and Rabbani 2007). Human health is significantly impacted by flooding as the prevalence of infectious diseases such as diarrhoea and dysentery increase during flooding episodes. Floodwater frequently mixes with sewage

and seeps from the drainage system into waterlogged streets, exposing Dhakans to contaminated and potentially infected water (Gain and Hoque 2013a, Rabbani et al. 2011). In terms of heat stress, Dhaka's large size, high population, and dense built environment with few green spaces make the city susceptible to the urban heat island effect (Rabbani et al. 2011).

Dhaka's current acute vulnerability and projections of future trends make adjustment to climate change an imperative. The IPCC asserts that warming between 3C and 6C in the 21th century is very likely in South Asia. Similarly, 95% of climate models predict an increase of heavy precipitation events across Asia, including South Asia (GFW 2016). However, it remains unclear whether government at the local and national level have made progress planning for climatic impacts, and it is unknown how ready they are to face uncertain future climate change, underpinning the aim of this study.

5.4. Methods

The use of multiple and diverse data sources has been identified as an important component in research identifying and examining adaptation (referred to as 'adaptation tracking') (Ford et al. 2014). Different types of sources are biased in different ways. National-level documents, such as the National Adaptation Programmes of Action (NAPAs), tend to report national-level adaptation activities and under-report or not report initiatives at lower levels of government (Berrang-Ford et al. 2014, Lesnikowski et al. 2013a). Peer-reviewed literature, on the other hand, has been shown to report a higher share of individual, household, and community adaptation initiatives while under-reporting national and multi-national efforts on adaptation (Ford et al. 2014). Reflecting the need to use different type of sources, we used planning documents, peer-reviewed literature, and semi-structured interviews. Below is a summary of the data sources:

1) National-level plans (*n=6*), metropolitan area plans (*n=1*), and ward-level plans (*n=16*).

2) Systematic search of peer-reviewed articles (*n=20* meeting inclusion criteria).

3) Interviews with government officials, academic experts, and non-governmental organization professionals (*n=15*).

Key planning documents from three levels of government were gathered and reviewed: the national government, the metropolitan government, and the city ward level. Climate change planning documents from national and subnational governments have been used as a reasonable proxy to track adaptation in countries and cities. (Araos et al. 2015, Austin et al. 2015, Lesnikowski et al. 2013a, Reckien et al. 2015). At the national government level we gathered urban-related, environmental, and disaster management plans for analysis. At the metropolitan level, we gathered land use plans and spatial plans to identify current and planned adaptation initiatives. The metropolitan-level plans outline the strategy for Dhaka's development across a large time span (40 years from 1995-2035) and set the frameworks for local level planning. Local level plans, or "Detailed Area Plans", provide specific guidelines on how the Structure Plan will be implemented at the ward level. Planning documents were gathered in consultation with researchers at the International Centre for Climate Change and Development hosted at the Independent University of Bangladesh in Dhaka. Also included were documents and materials presented at key events and profiling relevant plans and policy documents for climate change planning in Dhaka: the workshop, "Mainstreaming Climate Change Concerns into National Urban Related Policies" organized by UN Habitat in Dhaka (August 2nd, 2015) and the 3rd Urban Dialogue conference hosted in Dhaka (5th and 26th of August, 2015).

This study also used peer-reviewed literature to validate and expand the information gathered from documents and capture adaptation activity occurring outside the formal institutional realm. Because autonomous adaptation often occurs spontaneously and does not take the shape of formal policy, it will often go unreported or be reported in diverse media types. Peer-reviewed literature was gathered using a systematic search methodology. The GEOBASE, Web of Knowledge, and Scopus databases were searched using a search string composed of climate change-related and geographic-specific search terms (see Table 1 in Appendix III for search terms and document inclusion criteria). This search methodology is consistent with previous studies seeking to gather and analyze case-studies of specific adaptation activities currently being undertaken, as well as consistent

with meta-synthesis approach seeking to identify broad trends in urban adaptation (Berrang-Ford et al. 2015). Title and abstract of the articles were reviewed to determine inclusion in the study, and articles were only retained for analysis if they explicitly discussed climate change adaptation measures taking place in the Dhaka area (Table 1 in Appendix III).

In-depth interviews with government officials, academic experts, and non-governmental organization professionals were conducted in Dhaka during July and August, 2015. Interviewees were predominantly individuals in leadership positions within their organization (n=9). Individuals in leadership positions were sought to ensure adequate knowledge about the activities of their organization and the decision-making processes related to climate change and adaptation. The remaining interviewees were professionals with specific specialized skills (e.g. GIS specialists or environmental engineers) working in the field of climate change (n=6). A semi-structured interview guide included open-ended questions aimed at characterizing adaptation readiness in Dhaka's institutions. Each question was associated with a category of the adaptation readiness framework, and each category contained three or four questions (Table 2 in Appendix III). Individuals representing national, metropolitan, and municipal levels of government, as well as academic experts and employees at NGOs, were selected based on their job description and professional expertise, invited (via email or phone) for a private and confidential interview, and interviewed at their workplace (Table 1 below):

Table 2: Characteristics of interviewees

Professional characteristics	**Number of interviewees (n)**
Institution	
Government	11
NGO	3
Research	1
Sector	
Urban planning	7
Environmental policy	2

Development	1
Disaster management	2
Water management	3
Position	
Leadership position (e.g. CEO, director)	9
Other professional (e.g. GIS specialist)	6

Interviews and documents were coded using qualitative techniques. The information extracted was coded twice: once to determine what adaptation initiatives are taking place in Dhaka, and a second time to assess readiness in institutions as per the adaptation readiness framework. For adaptation activities taking place, the information was categorized by level of government. This approach aims to identify gaps and opportunities for intervention at different scales, as well as linkages across different levels of government by identifying when documents at one level (e.g. national) referred to other levels (e.g. city) in the documents. For the coding of adaptation readiness, the coding scheme identifies relevant concepts in the data and classifies them into the categories of the adaptation readiness framework. Guided by trends emerging from interviews and documents, a qualitative interpretation of the data was performed. The interpretation allows for a narrative abstraction of the adaptation readiness conditions in Dhaka.

5.5. Adaptation progress in Dhaka

Government planning for urban adaptation is led by national-level policies and plans, but explicit focus on Dhaka is infrequent and favours discussions of the urban sector in Bangladesh more generally. Metropolitan and ward-level plans comparatively demonstrate little progress on adaptation planning. A number of national-level plans, namely the National Adaptation Programme of Action (NAPA) and the Bangladesh Climate Change Strategy and Action Plan provide detailed outlines of adaptation activities planned and taking place in urban areas, including Dhaka (see Table 3 in Appendix III for full list of reviewed government documents). Key characteristics of adaptation taking place in Dhaka are: First, limited examples of leadership and a handful small-scale adaptation initiatives

are evident. Second, national-level plans deal with adaptation in depth, but about adaptation across all geographic areas and sectors in Bangladesh. This means that important context-specific issues and circumstances in Dhaka are not considered. Flooding issues are often discussed, for example, but specific concerns on infrastructure or governance around flooding are not examined for Dhaka's context. Third, the capital is seeing large scale infrastructure projects that will plausibly reduce vulnerability to climate change impacts, such as the replacement of groundwater supply with large scale surface water treatment. However, these projects are not being framed explicitly as adaptation measures and are not developed using projections of what the climate will be like in the future. This is a practical problem because infrastructure is being planned without consideration of how climatic conditions will change in the medium- and long-term.

5.5.1. National-level policies

A number of national level plans have directly integrated climate change, namely the National Adaptation Programme of Action and the Bangladesh Climate Change Strategy and Action Plan. The National Adaptation Programme of Action (2005) is the first adaptation plan for the country of Bangladesh and as such contains detailed directives on how the country aims to deal with the impacts of climate change. According to interviewees, an updated version of the NAPA is under preparation as of 2015. The document lays out 15 adaptation strategies, mostly dealing with coastal impacts from extreme weather and modifications to agriculture in light of salinized water due to sea level rise. The eighth strategy, however, calls for "enhancing resilience of urban infrastructure and industries to impacts of climate change". There are three activities framed as adaptation associated with this directive: the development of better building codes, the development of better waste management for industries, and the development of better warning systems. In terms of impacts, the NAPA recognizes that urban areas in Bangladesh will be affected by sea level rise, floods, and drainage congestion. Discussions of urban adaptation in the NAPA are applicable to any urban area in the country, including Dhaka. This lack of context-specificity indicates that planning for enhanced resilience of urban infrastructure is in the early stages. There is no evidence in the plan or from interviews that the NAPA directive is reaching Dhaka at this time.

The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) (2009) is another important and more recent plan containing directives on both adaptation and mitigation. With regards to adaptation, food security, disaster management, infrastructure protection, knowledge management, and capacity building are central themes in the document. The BCCSAP, as for the NAPA, similarly focuses on protecting agricultural productivity and coastal assets. In the urban sector, the document discusses how the Government of Bangladesh and development partners have developed flood protection and drainage schemes in urban areas since the 1970s. The plan is taking these previously existing flood protection policies and re-labelling them as climate change adaptation. Dupuis and Biesbroek (2013) critique that if a policy was designed with an objective other than adaptation, then that policy runs the risk of not meeting its objectives under a climate change scenario. For example, Bangladeshi flood protection measures were designed for flooding conditions of the 1970s; evidence on whether these measures will be effective in a context of more intense monsoon rainfall is lacking.

The National Plan for Disaster Management 2010-2015 discusses climate change primarily in the context of the NAPA and Climate Change Strategy and Action Plan mentioned above. The climate change discussions in this plan focus on mainstreaming climate change concerns into disaster management planning. There is no focus on urban adaptation in Dhaka specifically. However, Dhaka is mentioned in the context of climate impacts and flooding, specifically the 333mm rainfall in 2009 which produced significant drainage congestion. A number of country-wide adaptation priorities that have relevance to Dhaka are also profiled. The document promotes the construction of flood shelter, and information and assistance centres to deal with recurring floods in flood-prone regions, including urban centres. The Plan also reiterates the NAPA call for enhancing resilience of urban infrastructure and industries to the impacts of climate change. Finally, the plan states that disaster risk reduction and climate change adaptation issues will be integrated into the training curriculum for local government representatives and officials. The goal of this activity is to raise national capacity and knowledge about disaster risk reduction and climate change adaptation.

There are a number of documents that can act as entry points for urban adaptation planning, but do not yet tackle climate change concerns. Such plans and policies include the National Urban Sector Policy (2014), the Urban and Regional Planning Act 2014, the National Water Management Plan (2000), the National Housing Policy (2008), the National Land Use Policy (2001), and the Delta Plan 2100.

5.5.2. City-level policies

Dhaka's Structure Plan 2016-2035 provides a detailed overview of climate change impacts and vulnerabilities in Dhaka, including some adaptation strategies. This indicates a degree of progress on adaptation planning since the previous master plan, the Dhaka Metropolitan Development Plan 1995-2015 did not contain any reference to global climate change or its impacts on Dhaka. The plan identifies the two main impacts relevant for Dhaka: increased flooding and heat waves (page 198). Flooding is associated in the document with damage to households in informal settlement areas, damage to infrastructure, damage to utilities, and the spread of water borne diseases. Extreme heat is associated with changes in energy demand (e.g. air conditioning) and health stress due to extra heat. The plan also identifies migration as a climate-driven stressor for Dhaka's urban environment (page 62). River erosion from cyclones such as Aila and Sidr have forced people to leave coastal areas and move to Dhaka in the last ten years, boosting the capital's population. The plan estimates that 63% of the city's inhabitants are migrants, while 37% of growth is from natural increase.

The Structure Plan recognizes that Dhaka will face serious challenges from climate change (page 277) and several strategic actions are outlined. Among them is a study on improving urban climate through greening of the built environment and promoting urban agriculture (page 118). Another is the development of a comprehensive Water Resources Management Action Plan accounting for climate change impacts and conform to urban development plans (page 209). These actions are presented as planned, but the document provides little evidence of activities already completed or detail on how the proposed actions will be carried out. The Structure Plan, however, does describe a working paper

written to analyze the status of solid waste management in relation to climate change (Annex-1.2 in the plan).

The area served by the Master Plan contains two municipalities: Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). The DNCC has a Climate Change, Environment and Disaster Management department established in 2011. The department is composed of three staff and reports a number of small-scale adaptation initiatives funded by international organizations such as the Asian Development Bank. Examples of these initiatives include pilot rooftop garden projects and the production of educational videos on extreme weather disasters for the use in elementary school classrooms. Dhaka South City Corporation has not significantly engaged with climate change planning.

The Detailed Area Plans (DAPs) for 2016-2035 are currently undergoing public consultation at the time of writing. The DAPs are ward-level documents containing specific instructions to carry out the Structure Plan. There are potential entry points for adaptation planning in the DAPs. There are, however, currently no specific directives on policy or planning frameworks in place to guide ward-level adaptation initiatives.

An example of an infrastructure project from the water supply agency shows how some initiatives can contribute to reducing vulnerability even if the initiatives are not explicitly framed as "adaptation". While the definition of "adaptation" used in this study does not consider such initiatives, their examination can improve our understanding of how specific framings of adaptation can exclude projects that indeed reduce vulnerability to climate change impacts. Government official interviewee explained how the Dhaka Water Supply and Sewerage Authority (DWASA) is planning to switch the water supply from groundwater to surface water in response to rapid urbanization. Currently Dhaka uses mostly groundwater supply (70%) and a smaller portion of surface water supply (30%). As larger portions of land become covered by urban development, groundwater below the city's surface is depleting. Groundwater depletion occurs due growing water supply demands combined with a growing area of impermeable surfaces (e.g. concrete streets and buildings). Impermeable surfaces mean that rainfall cannot seep into the water table, and

groundwater increasingly depletes. Climate change is not an explicit motivation, but the project has the potential of significantly reducing vulnerability. According to Dupuis and Biesbroek (2013) this can be called a *contributive* project. The switch to surface water is designed to deal with changing environmental circumstances (less availability of groundwater). While climate change is not an explicitly stated motivation in the switch to surface water, rapid urbanization itself is driven by climate pressure on coastal communities (e.g. cyclones) and rural areas (e.g. salinization of water for rice farming). Therefore climate change may be indirectly affecting the policy change even if not recognized as a motivating factor.

5.5.3. Autonomous initiatives framed as "adaptation" in peer-reviewed literature

We identified a number of spontaneous activities in Dhaka that are framed in peer-reviewed literature as adaptation initiatives. The two main themes of research in this area are case studies of household adaptation in informal settlements in Dhaka and the role of gender in climate change adaptation (Rashid, Hunt and Haider 2007, Rashid 2000, Jabeen 2014b, Jabeen 2014a, Jabeen and Guy 2015, Jabeen and Johnson 2013, Jabeen, Johnson and Allen 2010).

The main finding on the adaptive capacity of households in Dhakan informal settlements is that even in contexts of high vulnerability and severe resource constraints, inhabitants show resilience when dealing with climate-related disasters. Jabeen et al. (2010) note that households in exposed locations often prepare for flooding by putting flood-barriers across doors, increasing the height of furniture, and arranging higher storage facilities. During disasters the role of community relationships is heightened as homeowners cooperate to clean drainage systems and help affected families move to safe areas in the neighbourhood (Jabeen et al. 2010). Indeed, Braun and Assheuer (2011) confirm that mutual help and social support during flood events are the dominant features of coping in informal settlements. In another study, Jabeen and Johnson (2013) suggest that frequent and repeated exposure to natural disasters in informal settlements nurtures sensitivity to climate variability and risk from flooding. However, while frequent exposure

normalizes the experience of dealing with floods, the question remains of whether frequent exposure encourages learning or improves adaptive capacity for future flooding events.

The role of gender in resilience to climate change is also well-documented (Jabeen 2014a, Jabeen et al. 2010). In informal settlements, women are typically underrepresented when it comes to decision-making about home construction and planning. Home-design and building decisions have significant impact on how flooding and extreme heat are experienced. The use of corrugated metal roofs and partitions, for example, has been known to exacerbate extreme heat in Korail, Dhaka's largest informal settlement (Jabeen and Guy 2015). In the face of a challenging environment, however, the role of women in coping has become increasingly important. Thus Dhaka's informal settlement are seeing a gradual shift in the power balance between men and women (Jabeen 2014a).

5.6. Adaptation readiness in Dhaka

Several gaps in readiness to adapt are evident based on the interviews conducted: First, city-level institutions lack clarity on who is responsible for leading on adaptation planning. A number of fragmented agencies and departments with overlapping mandates recognize climate change concerns to various degrees. Second, lack of governance capacity to enforce plans as well as high corruption levels is a frequently reported barrier to action. Third, while there is evidence of public support for climate change action is high and universities in Dhaka produce policy-relevant research for adaptation, a lack of linkages among the public, scientists, and policy-makers precludes action at the city-level.

5.6.1. Institutional factors

Political leadership has been identified as an important factor driving urban adaptation in the global south (Anguelovski et al. 2014, Romero-Lankao 2011). Specifically, well-connected "champions" have been noted to sway local government agendas and promote progress on adaptation (Roberts and O'Donoghue 2013). Political leadership on adaptation in Dhaka is commonly described to be low. While a number of officials are aware of potential climate change impacts in Dhaka, there is variation in how committed different institutions are to plan for the impacts of climate change. An official from the Bangladeshi national government, for example noted: "Climate change doesn't fall within the top ten

priorities for the government. Right now Bangladesh is trying to come out of the Least Developed Country group and trying to become a middle-income country by 2020". This quote illustrates the adaptation is seen as another item in a list of priorities for action, and that other issues such as poverty-reduction are perceived as more important.

Dhaka's institutional organization acts as a barrier to adapting. Responsibilities for the city's administration are divided among multiple organizations, often with overlapping mandates. For example, Dhaka North City Corporations and the Dhaka Water Supply and Sewerage Authority (DWASA) are both tasked with planning and building the city's drainage system. DWASA is responsible for the major drainage pipes in the city, while the City Corporation is responsible for surface street drainage. A lack of organization or linkages between both organizations was reported to produce disconnects between drainage system plans, worsening water congestion problems in the city. Generally, administrative institutions for the city do not seem to cooperate or plan together: as one city agency official offered: "RAJUK [development agency] and DNCC [municipality] only interact for planning the flyovers such as Mohakali". The implication here is that the two agencies do not interact regularly, even though both institutions are significantly involved in the management of the city.

In other cases, interviewees explained how the same organization is assigned conflicting mandates. RAJUK, the city's development and planning agency, is responsible for both land development *planning* and *control*. This means that the same organization is responsible for creating the plans and the accountability for enforcing the plans. RAJUK's land development plans are often not enforced and private development frequently occurs in areas assigned for natural water drainage. This has implications for flooding in Dhaka and contributes to the depletion of the water table, and important source of water supply for the city.

A recurrent theme emerging from interviews is that other "good governance" factors not included in the adaptation readiness framework affect the implementation of adaptation policy. These factors can be broadly described as corruption, lack of transparency, lack of ability to implement national-level directives, and local re-

interpretation of policy. These factors can significantly impact how adaptation planning translates (or does not translate) into action on the ground. Interviewees also noted that local re-interpretation of policies is a barrier to their implementation. An official from the Bangladesh government notes that, for example, ward authorities in Dhaka interpreted a permit for a ten-metre footbridge to mean "ten metres total of footbridge". The result was the construction of three different footbridges: two three-metre bridges and one four-metre bridge.

Beyond a lack of political willingness to act, resource constraints were reported in interviews to act as a barrier to action, since financial resources are necessary to fund research and staff for planning adaptation. The Ministry of Environment and Forests is the focal ministry for all climate change-related activities at the national level. The Climate Change Cell within the ministry is funded through the United Kingdom Department for International Development. However, the Climate Change Cell is tasked with compiling adaptation research and producing adaptation strategies for the whole country and all sectors. Competing priorities – both geographically and sectorally – mean that adaptation progress in Dhaka receives few resources. The Dhaka North City Corporation department of Climate Change, Environment, and Disaster Management receives funds directly from international organizations (e.g. the Asian Development Bank), but these funds are small and for individual pilot projects. Larger infrastructure projects, such as overhauling the drainage system while integrating future climate projections would require new funding streams that do not currently exist.

5.6.2. Civil society factors

Civil society's readiness to aid the government to adapt was characterized to be high by interviewees from research organizations and NGOs. A variety of stakeholders in research and NGOs in Bangladesh are reportedly engaged with climate change issues, and there is some evidence that public support for climate change concerns is high, as public media in Dhaka frequently covers climate change issues and often discusses extreme weather events in the context of a changing climate. The *Dhaka Tribune*, for example, is an English language

print newspaper that publishes a weekly section on climate change where local and international scientists and commentators are invited to write short pieces.

NGOs in Bangladesh often feature climate change concerns as a central aspect of their mandate. WaterAid, for example, has integrated climate change as a key challenge and opportunity in their work in the country. Indeed, WaterAid operations in the country are organized under three domains: a rural program, and urban program, and a climate change program. Some of the projects gleaned from interviews include infrastructure, such as latrines, made more robust in the face of uncertain trends in extreme weather. DSK, an NGO providing health services to informal settlement dwellers, has also integrated climate change into their mandate, and advocate the protection of vulnerable citizens in the face of a changing climate.

While there is evidence of public support and engagement with climate change issues by NGOs and universities, interviewees still noted a lack of scientific advancement to support planning efforts. One researcher interviewed deemed scientific knowledge to be "not adequate in the cities". Another city official said: "having no city data affects mitigation and adaptation. We need to know how much greenhouse gases Dhaka emits and we need to know who is in the low-lying areas." This implies that there is an unmet need for city-specific data to plan for adaptation, and a characterization of people living in flood-prone low-lying areas is needed to facilitate adaptation.

Research organizations, such as the International Centre for Climate Change and Development (ICCCAD) also offer courses and seminar sessions to build capacity and knowledge about climate change impacts and adaptation in Bangladesh. These activities are offered to policy-makers and professionals from the environment, social policy, and disaster management fields. Example topics include workshops on climate change education in primary schools and the synergies between disaster management and adaptation. However, interview participants noted that the existence of these courses is not sufficient to mainstream climate change into planning. One researcher, for example, noted that "political leaders rarely use research findings and only attend the workshops". The lack of linkages between scientists and policy-makers was also reported to be a barrier for

their consideration of issues of climate change in urban-related plans. From the officials and professionals interviewed for this study, only one person was aware and had attended a short course on climate change issues.

Therefore an analysis of adaptation readiness in Dhaka reveals that the current institutional configuration is not conducive for adaptation planning. Limited staff, resources, information, corruption and lack of transparency, and competing priorities at the local government level combine with high levels of institutional fragmentation to diffuse responsibility on climate change planning. Nonetheless, widely reported high levels of public, stakeholder, and scientific engagement with flooding and heat issues in the city provide meaningful opportunities for mainstreaming adaptation concerns into city plans. Additionally, high levels of public and scientific engagement with issues of climate change is an opportunity for national policymakers and international donor organizations to cooperate and plan adaptation projects in Dhaka.

5.6. Discussion

In this study we proposed a framework to characterize the status of climate change adaptation in Global South cities and tested Dhaka, Bangladesh as a case study. We found that the Bangladeshi national government leads urban adaptation planning with policy directives in a few key documents, namely the NAPA and the BCCSAP. There are no organizations or governments at levels between the national and city level (e.g. district) planning for adaptation in Dhaka. The city-level government, conversely, is in the early stages of adaptation planning through small initiatives undertaken at the municipality (Dhaka North City Corporation) level. Sectorally, we found that climatic and demographic pressures reportedly drive an upcoming infrastructural change in water supply from groundwater to surface water, although climate change threats are not an explicit motivation for this infrastructural project. Autonomous adaptation activities at the household and community level have also been well-documented in peer-reviewed literature. These include physical modifications to homes such as flood barriers and moving assets to higher elevations within the home. Scholars have also paid attention to shifting gender roles as extreme weather events give women in Dhaka an opportunity to

make decisions about home building and household organizations. Governmental conditions for adaptation are reportedly poor due to absence of political will, corruption, and disorganization among institutions managing the city. However, academic institutions, NGOs, and public media in Dhaka are well-engaged with adaptation and climate change issues. More explicit linkages among scientists and policy-makers are needed to produce policy-relevant research, such as collecting information about the people in Dhaka living in low-lying areas.

The general lack of available information on adaptation taking place in low- and middle- income cities is a challenge for assessing whether Dhaka is doing well compared to other cities. Where case studies of urban adaptation in the Global South exist, they have tended to focus on successful cases of local action on adaptation (Anguelovski et al. 2014, Carmin et al. 2012a, Castán Broto and Bulkeley 2013). Durban, South Africa, for example, has been characterized an early adaptation leader due to its Headline Adaptation Strategy document from 2006, followed by the development of Municipal Adaptation Plans (MAPs) to be adopted by each city agency and department (Emfuleni Local Municipality 2013, Roberts and O'Donoghue 2013, Carmin et al. 2012a). Quito, Ecuador, has also developed its own Strategy for Climate Change, acting as the official environmental policy for the city (Carmin et al. 2012a). The City of Cape Town has also instituted a Municipal Adaptation Plan and the framework for its development has been widely used a guide for the development of local adaptation plans globally (Mukheibir and Ziervogel 2006, Satterthwaite 2007). Mexico City has integrated air pollution concerns into the city's climate change plan, which focuses mostly on mitigation. However, the plan has also been criticized for not including attention to flood, heat stress, and water scarcity, other major issues exacerbated by climate change (Mexico City 2009, Satterthwaite 2007). In Dhaka we see evidence that adaptation planning is being incorporated at the city-level Structure Plan, with a few initiatives being planned around water management and green infrastructure. However Dhaka has lack of a dedicated climate change plan that can be integrated into sectoral departments and agencies.

Literature has characterized urban adaptation in the Global South as an emerging policy domain where adaptation is driven namely by *endogenous* forces (Carmin et al.

2012a, Anguelovski and Carmin 2011). *Endogenous* forces refer to factors emerging from *within* the municipality, such as local political entrepreneurs and civil society groups such as environmental organizations (Carmin et al. 2012a). Quito and Durban, for example, are documented to have local political leaders championing the issue of climate change adaptation at the municipal level (Carmin et al. 2012a). Endogenous factors in Dhaka are present in different forms, such as a presence of engaged scientists proposing adaptation options (Table 5) and supportive public media, but these factors have not been integrated into the city's long-term development plans. Thus, in spite of the presence of some endogenous factors, Dhaka has not been an early innovator of adaptation policy. *Exogenous* forces exist in Dhaka, such as pressures from the national government or international organizations. The directives coming from the NAPA and the BCCSAP come from the national level, and feed into the UNFCCC process.

Dedicated adaptation plans at the national level outline a number of resilient infrastructure and flood protection projects to take place in Dhaka. The question remains, however, whether the policies at the national level will translate to action on the ground. Several interviewees reported how serious levels of corruption in Bangladesh and lack of organization among institutions that administer services and utilities put doubts into whether national directives will translate into local action. For example, an official at a utility company noted how influential private interests in groundwater supply are impeding the switch of Dhaka's supply to surface water. In cases where national policy makes it to the city level, the policy is often reinterpreted away from its original purpose. For instance, a national government official cited the case of a single bridge permit being re-interpreted to build three separate bridges. Corruption and lack of capacity to implement policies or projects will have increasing impact on the vulnerability of Dhakans, as acute exposure to extreme climate events is predicted to become worse in the 21st century. This is a weakness of the framework developed and used here: corruption and "messiness" of policy implementation are no considered in the framework. In this context, future research should look directly at the political tensions between local and national government levels that impede adaptation, and devise strategies to enable adaptation planning in face of limited organization capacity and corruption.

Chapter 6: Conclusion

6.1. Key findings and contributions

Put together, the three manuscripts answer the question: is adaptation taking place, where, by whom, and in what ways? Globally, only 18% of cities report any adaptation activity. Large cities of North America, Europe, and Australia are undertaking extensive and comprehensive adaptation planning. In low income cities, with exceptions, poor governance capacity and absence of financial resources constrains adaptation at the local government level, but adaptation projects are still undertaken by the national government, international organizations, and individuals and households. While some of these projects reduce current vulnerability to extreme weather, they do not purposefully integrate future projections of climate change impacts, which introduces doubt regarding their long-term effectiveness. Most reported adaptation initiatives deal with the physical built environment such as flood resilient infrastructure and green building to reduce the effect of the urban heat island. A minority of reported initiatives deal with protecting vulnerable populations or strengthening healthcare or social systems.

The thesis uses two distinct approaches: a global assessment, and an in-depth case study to validate the global assessment. The case study uses diverse data sources to characterize the state of adaptation, and this methodology illuminates weaknesses in the global assessments. Indeed, Dhaka, as a low-income city with limited governance capacity, does not report adaptation initiatives in Climate Change Plans or Adaptation Plans at the municipal level, so the global assessments would not have captured any adaptation initiatives. This finding suggests that the global assessments are suitable as a rapid proxy to capture broad trends in urban adaptation at a large scale, but do not capture the nuance of adaptation planning in each city (see Limitations section below). Even in cities classified as *extensive adaptors* in the global assessments, other levels of government (e.g. regional or national) and private organizations may be planning adaptation projects, programmes, or policies that are not capture in these studies.

To our knowledge, this thesis presents the first global assessment of adaptation taking place in large urban areas. In Chapter 3 we used publically available climate change

planning documents from 401 cities over 1 million people. We found that most (82%) of cities do not yet report planning for climate change impacts. This manuscript found similar results to previous self-reported surveys on urban adaptation: Carmin et al. (2012), for example, found that 18% of cities reported adaptation to climate change impacts. The findings suggest that while global urban adaptation is still in the early stages, there are significant examples of extensive adaptation planning regardless of wealth levels or institutional barriers.

In Chapter 4, we provide the first global baseline of municipal reporting on urban public health initiatives. A large majority of cities (90%) do not report any public health adaptation initiatives. Different than Chapter 3, this result differs from previous self-reported surveys, which have found that 35% of cities are planning for the health threats from climate change (Aylett 2015). Extreme heat, floods, storms, and other unspecified disasters are the most addressed health risks from climate change. Only 6% of reported heat-related adaptation initiatives are early warning systems, despite evidence that these systems are increasingly popular (Toloo et al. 2013). Finally, the few cities reporting any public health initiatives are almost exclusively in developed countries. This indicates that health adaptation in the urban Global South is significantly lagging behind.

Chapter 5 presents a framework to characterize the status of climate change adaptation in Global South cities and tested Dhaka, Bangladesh as a case study. The manuscript examines the status of climate change adaptation planning in Dhaka based on an analysis of gray and scientific literature as well as in-person interviews with government, academic, and civil society experts. In this study we found that the national government of Bangladesh leads urban adaptation in the country and adaptation activities are outlined mostly in two documents: the National Adaptation Programme of Action (NAPA) and the Bangladesh Climate Change Strategy Action Plan (BCSSAP). At the city-government level, we found that a handful of initiatives are being undertaken by the Environment, Disaster Management, and Climate Change Circle department at one of Dhaka's municipalities (the Dhaka North City Corporation). In sectoral agencies of the city we also found vulnerability-reductive activities taking place that were not framed as adaptation: Dhaka is switching its water supply from groundwater to surface water in response to rapid urbanization, which

in itself is driven by climate-induced migration from the coastal and rural areas. From interviewees we learnt that government in Dhaka are not ready to plan for adaptation due to limited political will, widespread corruption, and disorganization among institutions managing the city. Nonetheless, academic institutions, the NGO sector and public media are reportedly well-engaged with adaptation and climate change issues.

6.2. Limitations

The methods in this thesis have three main limitations. First, reporting bias is a limitation for the global assessments of Chapters 3 and 4. In some places where adaptation is occurring, it may not be reported, and this bias will inflate the number of adaptation initiatives reported in high income cities. The focus on large cities mediates some but not all of the bias, as these are often the more technologically advanced centres even in poorer nations. Second, all three manuscripts use some definition of what a city is, but this concept is contested in urban geography generally. The U.N. (2013) defines urban agglomerations to be the area of built up human settlement. However in most if not all cases this area encompasses multiple local governments. The size of municipalities differs from city to city and across countries because each city's unique history of development and local politics will define how the municipal boundaries are defined. Some cities are so different in size that comparisons have limited value. For instance, comparing the City of London Corporation (pop. 7,375) to New York City (pop. 8,491,079) serves no meaningful purpose. We attempted to minimize this disparity by comparing central and most populous municipalities to each other and making a small number of exceptions to include the metropolitan government where the central municipality was very small (e.g. London). However, significant population variations across cities remain. Third, arriving at a universally agreed operational definition of adaptation is close to impossible. The ambiguity of the adaptation concept has been discussed at length in the literature review and in each manuscript, but the problem remains a significant limitation throughout. This thesis assesses the state of urban adaptation using a particular definition of adaptation: actions that are intentionally and explicitly designed to deal with the impacts of climate change. This definition excludes actions that reduce vulnerability generally without paying attention to projected climate trends, as well as individual or community actions that

respond to the impacts of extreme weather but do not consider future climate projections. In the next section I outline how possible options for mediating the limitations in this thesis.

6.3. Future research

This thesis is about tracking adaptation taking place in cities. The manuscripts presented here proposed concepts and methods to measure how much cities are currently adapting. In light of the limitations outlined in the previous section, here I propose how future urban adaptation tracking research can be enhanced to advance our understanding of global urban adaptation. First, urban adaptation tracking efforts should use multiple and diverse data sources. In the global assessments of Chapter 3 and 4 I used exclusively publically available climate change plans from the municipal government. While these documents constitute a comparable data source on adaptation planning across cities, they may leave out important sources of information from sectoral agencies (e.g. water supply), non-governmental organizations, or the private sector. Future adaptation tracking research should try to identify all plausible agents of adaptation planning in a given city to capture the breadth of possible adaptation activities. In Chapter 5, the case study, we pursued this approach and indeed found adaptation activities undertaken, for example, by the water supply agency of Dhaka.

Second, urban adaptation tracking should adopt a multilevel governance approach. In the global assessments I focused on one level of government: the municipality. This approach worked because the municipality provides a consistent unit of analysis to compare policy across cities. Focusing on a single level of government also reduces the workload and logistical strain of analyzing multiple jurisdictions for 401 cities. However, as discovered in the case study of Dhaka, national and international actors have been shown to plan policies in cities with limited governance capacity, but lack of linkages across government levels preclude implementation of these policies “on the ground”.

Finally, future urban adaptation tracking research should continue to develop an operational definition of adaptation. While here we used a definition of adaptation that includes initiatives explicitly communicated as climate change adaptation, many scholars

do not consider adaptation to be conceptually separable from development practices. In the case study of Dhaka, interviewees reported projects that plausibly reduced vulnerability to climate change, but were not designed to purposefully deal with future (uncertain) climate impacts. Further, autonomous actions undertaken by households to reduce the damage from flooding, for example, are framed as "adaptation" in peer-reviewed literature, even if they do not use future climate projections to guide the actions (e.g. raising assets off the ground). These findings indicate that using a narrow, "high intentionality" definition of adaptation may constrict our understand of adaptation, especially in cities of the Global South where limited science about future impacts are available, but citizens continuously deal with and bounce back from instances of extreme heat and flooding.

Overall, this thesis proposes that urban adaptation is not and should not be confined to plans by municipal governments, but rather is a practice and a process undertaken across geographic scales and across a range of actors. At the national level, governments have a role to build an encouraging legislative framework to plan for adaptation, and to propose broad policy directives and provide support for local governments to adapt. Local governments such as municipalities can use financial resources and authority to directly protect utilities from extreme weather and build resilient infrastructure. At the city level, sectoral agencies have a role to plan for adaptation independently from the municipality, as they hold knowledge about the functioning of specific systems in cities such as the water and energy supply, telecommunications, transportation, and human health and social services. Future global assessments of urban adaptation, therefore, should improve upon the studies presented here by taking a multilevel governance and a multisectoral approach for characterizing urban adaptation.

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Appendix I – Supplementary materials for Chapter 3, Climate change adaptation planning in large cities: a systematic global assessment

1. Cities selected for analysis

Table 1: List of 401 cities included in this analysis:

City name	Country name	Government Type	Document language
El Djazaïr	Algeria	Municipal	Arabic
Luanda	Angola	Municipal	Portuguese
Huambo	Angola	Municipal	Portuguese
Córdoba	Argentina	Municipal	Spanish
Rosario	Argentina	Municipal	Spanish
Buenos Aires	Argentina	Municipal	Spanish
Brisbane	Australia	Municipal	English
Melbourne	Australia	Municipal	English
Sydney	Australia	Municipal	English
Perth	Australia	Municipal	English
Adelaide	Australia	Municipal	English
Vienna	Austria	Municipal	German
Bruxelles	Belgium	Municipal	French
Santa Cruz	Bolivia	Municipal	Spanish
La Paz	Bolivia	Municipal	Spanish
Belo Horizonte	Brazil	Municipal	Portuguese

São Paulo	Brazil	Municipal	Portuguese
Recife	Brazil	Municipal	Portuguese
Pôrto Alegre	Brazil	Municipal	Portuguese
Salvador	Brazil	Municipal	Portuguese
Belém	Brazil	Municipal	Portuguese
Fortaleza	Brazil	Municipal	Portuguese
Curitiba	Brazil	Municipal	Portuguese
Manaus	Brazil	Municipal	Portuguese
Natal	Brazil	Municipal	Portuguese
Santos	Brazil	Municipal	Portuguese
Florianópolis	Brazil	Municipal	Portuguese
Brasília	Brazil	Municipal	Portuguese
Goiânia	Brazil	Municipal	Portuguese
Grande São Luís	Brazil	Municipal	Portuguese
Grande Vitória	Brazil	Municipal	Portuguese
João Pessoa	Brazil	Municipal	Portuguese
Nordeste Catarinense	Brazil	Municipal	Portuguese
Maceió	Brazil	Municipal	Portuguese
Campinas	Brazil	Municipal	Portuguese
Rio de Janeiro	Brazil	Municipal	Portuguese
Ouagadougou	Burkina Faso	Municipal	French
Douala	Cameroon	Municipal	French
Yaoundé	Cameroon	Municipal	French
Toronto	Canada	Municipal	English
Montréal	Canada	Municipal	English/French
Vancouver	Canada	Municipal	English
Edmonton	Canada	Municipal	English
Ottawa	Canada	Municipal	English/French
Calgary	Canada	Municipal	English
N'Djaména	Chad	Municipal	French

Santiago	Chile	Metropolitan	Spanish
Haerbin	China	Municipal	Chinese
Shijiazhuang	China	Municipal	Chinese
Wuhu, Anhui	China	Municipal	Chinese
Zhangjiakou	China	Municipal	Chinese
Jingzhou	China	Municipal	Chinese
Xi'an, Shaanxi	China	Municipal	Chinese
Ningbo	China	Municipal	Chinese
Beijing	China	Municipal	Chinese
Jilin	China	Municipal	Chinese
Luoyang	China	Municipal	Chinese
Dalian	China	Municipal	Chinese
Baoding	China	Municipal	Chinese
Huai'an	China	Municipal	Chinese
Jining, Shandong	China	Municipal	Chinese
Liuzhou	China	Municipal	Chinese
Qiqihaer	China	Municipal	Chinese
Wenzhou	China	Municipal	Chinese
Yinchuan	China	Municipal	Chinese
Guangzhou	China	Municipal	Chinese
Huainan	China	Municipal	Chinese
Hohhot	China	Municipal	Chinese
Xuzhou	China	Municipal	Chinese
Dongguan	China	Municipal	Chinese
Wuhan	China	Municipal	Chinese
Mianyang, Sichuan	China	Municipal	Chinese
Yancheng, Jiangsu	China	Municipal	Chinese
Hefei	China	Municipal	Chinese
Datong, Shanxi	China	Municipal	Chinese
Nanchang	China	Municipal	Chinese

Taizhou, Jiangsu	China	Municipal	Chinese
Nanning	China	Municipal	Chinese
Nantong	China	Municipal	Chinese
Jinan, Shandong	China	Municipal	Chinese
Changchun	China	Municipal	Chinese
Jiangmen	China	Municipal	Chinese
Weifang	China	Municipal	Chinese
Yangzhou	China	Municipal	Chinese
Putian	China	Municipal	Chinese
Wuxi, Jiangsu	China	Municipal	Chinese
Quanzhou	China	Municipal	Chinese
Zhanjiang	China	Municipal	Chinese
Hengyang	China	Municipal	Chinese
Qingdao	China	Municipal	Chinese
Zhenjiang, Jiangsu	China	Municipal	Chinese
Taian, Shandong	China	Municipal	Chinese
Zhuzhou	China	Municipal	Chinese
Kaohsiung	China	Municipal	Chinese
Anyang	China	Municipal	Chinese
Shenyang	China	Municipal	Chinese
Maoming	China	Municipal	Chinese
Zaozhuang	China	Municipal	Chinese
Xiamen	China	Municipal	Chinese
Suzhou, Jiangsu	China	Municipal	Chinese
Zibo	China	Municipal	Chinese
Huizhou	China	Municipal	Chinese
Tangshan, Hebei	China	Municipal	Chinese
Foshan	China	Municipal	Chinese
Shenzhen	China	Municipal	Chinese
Chongqing	China	Municipal	Chinese

Tianjin	China	Municipal	Chinese
Haikou	China	Municipal	Chinese
Zhuhai	China	Municipal	Chinese
Yueyang	China	Municipal	Chinese
Fushun, Liaoning	China	Municipal	Chinese
Nanjing, Jiangsu	China	Municipal	Chinese
Zhengzhou	China	Municipal	Chinese
Shantou	China	Municipal	Chinese
Hangzhou	China	Municipal	Chinese
Ürümqi (Wulumqi)	China	Municipal	Chinese
Jixi, Heilongjiang	China	Municipal	Chinese
Kunming	China	Municipal	Chinese
Changzhou, Jiangsu	China	Municipal	Chinese
Changsha, Hunan	China	Municipal	Chinese
Daqing	China	Municipal	Chinese
Yantai	China	Municipal	Chinese
Xiangyang	China	Municipal	Chinese
Linyi, Shandong	China	Municipal	Chinese
Xianyang, Shaanxi	China	Municipal	Chinese
Lanzhou	China	Municipal	Chinese
Zhongshan	China	Municipal	Chinese
Pingdingshan, Henan	China	Municipal	Chinese
Taiyuan, Shanxi	China	Municipal	Chinese
Xining	China	Municipal	Chinese
Baotou	China	Municipal	Chinese
Shanghai	China	Municipal	Chinese
Anshan, Liaoning	China	Municipal	Chinese
Fuzhou, Fujian	China	Municipal	Chinese
Nanyang, Henan	China	Municipal	Chinese
Guiyang	China	Municipal	Chinese

Handan	China	Municipal	Chinese
Chengdu	China	Municipal	Chinese
Xinxiang	China	Municipal	Chinese
Hong Kong	China	Municipal	Chinese
Bogotá	Colombia	Municipal	Spanish
Medellín	Colombia	Municipal	Spanish
Cali	Colombia	Municipal	Spanish
Barranquilla	Colombia	Municipal	Spanish
Bucaramanga	Colombia	Municipal	Spanish
Brazzaville	Congo	Municipal	French
San José	Costa Rica	Municipal	Spanish
Havana	Cuba	Municipal	Spanish
Abidjan	Côte d'Ivoire	Municipal	French
Kinshasa	Democratic Republic of the Congo	Municipal	French
Lubumbashi	Democratic Republic of the Congo	Municipal	French
Mbuji-Mayi	Democratic Republic of the Congo	Municipal	French
Santo Domingo	Dominican Republic	Municipal	Spanish
Quito	Ecuador	Municipal	Spanish
Guayaquil	Ecuador	Municipal	Spanish
Cairo	Egypt	Municipal	Arabic
Alexandria	Egypt	Municipal	Arabic
San Salvador	El Salvador	Municipal	Spanish
Paris	France	Municipal	French
Lyon	France	Municipal	French
Lille	France	Municipal	French
Marseille	France	Municipal	French
München (Munich)	Germany	Municipal	German
Köln (Cologne)	Germany	Municipal	German

Berlin	Germany	Municipal	German
Hamburg	Germany	Municipal	German
Accra	Ghana	Municipal	English
Kumasi	Ghana	Municipal	English
Guatemala City	Guatemala	Municipal	Spanish
Conakry	Guinea	Municipal	French
Port-au-Prince	Haiti	Municipal	French
Tegucigalpa	Honduras	Municipal	Spanish
Asansol	India	Municipal	English
Madurai	India	Municipal	English
Kanpur	India	Municipal	English
Chennai	India	Municipal	English
Pune (Poona)	India	Municipal	English
Delhi	India	Municipal	English
Hyderabad, India	India	Municipal	English
Amritsar	India	Municipal	English
Allahabad	India	Municipal	English
Mumbai (Bombay)	India	Municipal	English
Nashik	India	Municipal	English
Nagpur	India	Municipal	English
Jodhpur	India	Municipal	English
Ludhiana	India	Municipal	English
Aurangabad	India	Municipal	English
Meerut	India	Municipal	English
Jaipur	India	Municipal	English
Jamshedpur	India	Municipal	English
Dhanbad	India	Municipal	English
Patna	India	Municipal	English
Coimbatore	India	Municipal	English
Lucknow	India	Municipal	English

Surat	India	Municipal	English
Visakhapatnam	India	Municipal	English
Bangalore	India	Municipal	English
Ranchi	India	Municipal	English
Gwalior	India	Municipal	English
Indore	India	Municipal	English
Varanasi (Benares)	India	Municipal	English
Kolkata	India	Municipal	English
Chandigarh	India	Municipal	English
Jabalpur	India	Municipal	English
Raipur	India	Municipal	English
Ahmadabad	India	Municipal	English
Vijayawada	India	Municipal	English
Tiruchirappalli	India	Municipal	English
Durg-Bhilainagar	India	Municipal	English
Rajkot	India	Municipal	English
Vadodara	India	Municipal	English
Srinagar	India	Municipal	English
Kochi	India	Municipal	Malayalam
Bhopal	India	Municipal	English
Agra	India	Municipal	English
Bandung	Indonesia	Municipal	Indonesian
Semarang	Indonesia	Municipal	Indonesian
Ujung Pandang	Indonesia	Municipal	Indonesian
Medan	Indonesia	Municipal	Indonesian
Palembang	Indonesia	Municipal	Indonesian
Jakarta	Indonesia	Municipal	Indonesian
Surabaya	Indonesia	Municipal	Indonesian
Ahvaz	Iran	Municipal	Farsi
Esfahan	Iran	Municipal	Farsi

Karaj	Iran	Municipal	Farsi
Mashhad	Iran	Municipal	Farsi
Qom	Iran	Municipal	Farsi
Shiraz	Iran	Municipal	Farsi
Tabriz	Iran	Municipal	Farsi
Tehran	Iran	Municipal	Farsi
Baghdad	Iraq	Municipal	Arabic
Mosul	Iraq	Municipal	Arabic
Erbil	Iraq	Municipal	Arabic
Dublin	Ireland	Municipal	English
Osaka-Kobe	Japan	Municipal	Japanese
Sapporo	Japan	Municipal	Japanese
Kyoto	Japan	Municipal	Japanese
Fukuoka-Kitakyushu	Japan	Municipal	Japanese
Hiroshima	Japan	Municipal	Japanese
Nagoya	Japan	Municipal	Japanese
Sendai	Japan	Municipal	Japanese
Tokyo	Japan	Municipal	Japanese
Amman	Jordan	Municipal	Arabic
Nairobi	Kenya	Municipal	English
Seoul	Korea	Municipal	Korean
Kuwait	Kuwait	Municipal	Arabic
Beirut	Lebanon	Municipal	Arabic
Tripoli	Libya	Municipal	Arabic
Bamako	Mali	Municipal	French
Tijuana	Mexico	Municipal	Spanish
Toluca de Lerdo	Mexico	Municipal	Spanish
León de los Aldamas	Mexico	Municipal	Spanish
Puebla	Mexico	Municipal	Spanish
Querétaro	Mexico	Municipal	Spanish

Ciudad Juárez	Mexico	Municipal	Spanish
Mérida	Mexico	Municipal	Spanish
Mexico City	Mexico	Municipal	Spanish
Guadalajara	Mexico	Municipal	Spanish
San Luis Potosí	Mexico	Municipal	Spanish
Monterrey	Mexico	Municipal	Spanish
Torreón	Mexico	Municipal	Spanish
Fes	Morocco	Municipal	Arabic
Casablanca	Morocco	Municipal	Arabic
Rabat	Morocco	Municipal	Arabic
Maputo	Mozambique	Municipal	Portuguese
Auckland	New Zealand	Municipal	English
Niamey	Niger	Municipal	French
Port Harcourt	Nigeria	Municipal	English
Kaduna	Nigeria	Municipal	English
Ibadan	Nigeria	Municipal	English
Benin City	Nigeria	Municipal	English
Kano	Nigeria	Municipal	English
Abuja	Nigeria	Municipal	English
Lagos	Nigeria	Municipal	English
Ogbomosho	Nigeria	Municipal	English
Peshawar	Pakistan	Municipal	English
Multan	Pakistan	Municipal	English
Gujranwala	Pakistan	Municipal	English
Rawalpindi	Pakistan	Municipal	English
Lahore	Pakistan	Municipal	English
Faisalabad	Pakistan	Municipal	English
Hyderabad	Pakistan	Municipal	English
Karachi	Pakistan	Municipal	English
Panama City	Panama	Municipal	Spanish

Asunción	Paraguay	Municipal	Spanish
Lima	Peru	Municipal	Spanish
Manila	Philippines	Municipal	English
Davao	Philippines	Municipal	English
Lisbon	Portugal	Municipal	Portuguese
Porto	Portugal	Municipal	Portuguese
San Juan	Puerto Rico	Municipal	English
Volgograd	Russia	Municipal	Russian
Yekaterinburg	Russia	Municipal	Russian
Ufa	Russia	Municipal	Russian
Sankt Peterburg	Russia	Municipal	Russian
Moskva	Russia	Municipal	Russian
Samara	Russia	Municipal	Russian
Kazan’	Russia	Municipal	Russian
Nizhniy Novgorod	Russia	Municipal	Russian
Chelyabinsk	Russia	Municipal	Russian
Rostov-na-Donu	Russia	Municipal	Russian
Omsk	Russia	Municipal	Russian
Novosibirsk	Russia	Municipal	Russian
Riyadh	Saudi Arabia	Municipal	Arabic
Mecca	Saudi Arabia	Municipal	Arabic
Medina	Saudi Arabia	Municipal	Arabic
Jiddah	Saudi Arabia	Municipal	Arabic
Dakar	Senegal	Municipal	French
Singapore	Singapore	Municipal/National	English
Vereeniging	South Africa	Municipal	English
Cape Town	South Africa	Municipal	English
Durban	South Africa	Municipal	English
Ekurhuleni	South Africa	Municipal	English
Pretoria	South Africa	Municipal	English

Port Elizabeth	South Africa	Municipal	English
Johannesburg	South Africa	Municipal	English
Daegu	South Korea	Municipal	Korean
Incheon	South Korea	Municipal	Korean
Gwangju	South Korea	Municipal	Korean
Suwon	South Korea	Municipal	Korean
Daejon	South Korea	Municipal	Korean
Busan	South Korea	Municipal	Korean
Ulsan	South Korea	Municipal	Korean
Barcelona	Spain	Municipal	Spanish
Madrid	Spain	Municipal	Spanish
Khartoum	Sudan	Municipal	Arabic
Zurich	Switzerland	Municipal	German
Homs	Syria	Municipal	Arabic
Damascus	Syria	Municipal	Arabic
Aleppo	Syria	Municipal	Arabic
Taipei	Taiwan	Municipal	Chinese
Taichung	Taiwan	Municipal	Chinese
Dar es Salaam	Tanzania	Municipal	English
Lomé	Togo	Municipal	French
Bursa	Turkey	Municipal	Turkish
Konya	Turkey	Municipal	Turkish
Istanbul	Turkey	Municipal	Turkish
Gaziantep	Turkey	Municipal	Turkish
Adana	Turkey	Municipal	Turkish
Ankara	Turkey	Municipal	Turkish
Izmir	Turkey	Municipal	Turkish
Kampala	Uganda	Municipal	English
Dubai	United Arab Emirates	Municipal	Arabic
Glasgow	United Kingdom	Municipal	English

Leeds	United Kingdom	Municipal	English
London	United Kingdom	Metropolitan	English
Birmingham	United Kingdom	Municipal	English
Manchester	United Kingdom	Municipal	English
Seattle	United States of America	Municipal	English
Salt Lake City	United States of America	Municipal	English
Miami	United States of America	Municipal	English
Virginia Beach	United States of America	Municipal	English
Indianapolis	United States of America	Municipal	English
Baltimore	United States of America	Municipal	English
Phoenix	United States of America	Municipal	English
Detroit	United States of America	Municipal	English
Orlando	United States of America	Municipal	English
Boston	United States of America	Municipal	English
Houston	United States of America	Municipal	English
Milwaukee	United States of America	Municipal	English
Cleveland	United States of America	Municipal	English
Austin	United States of America	Municipal	English
Kansas City	United States of America	Municipal	English
Atlanta	United States of America	Municipal	English
Tampa	United States of America	Municipal	English
San Antonio	United States of America	Municipal	English
Denver	United States of America	Municipal	English
Jacksonville, Florida	United States of America	Municipal	English
Portland	United States of America	Municipal	English
Buffalo	United States of America	Municipal	English
Riverside	United States of America	Municipal	English
Los Angeles	United States of America	Municipal	English
Providence	United States of America	Municipal	English
Pittsburgh	United States of America	Municipal	English

San Diego	United States of America	Municipal	English
Columbus, Ohio	United States of America	Municipal	English
Charlotte	United States of America	Municipal	English
Bridgeport	United States of America	Municipal	English
Las Vegas	United States of America	Municipal	English
Cincinnati	United States of America	Municipal	English
Minneapolis	United States of America	Municipal	English
Dallas	United States of America	Municipal	English
Philadelphia	United States of America	Municipal	English
New York	United States of America	Municipal	English
San Francisco	United States of America	Municipal	English
Sacramento	United States of America	Municipal	English
Memphis	United States of America	Municipal	English
San Jose	United States of America	Municipal	English
Washington, D.C.	United States of America	Municipal	English
Louisville	United States of America	Municipal	English
Chicago	United States of America	Municipal	English
St. Louis	United States of America	Municipal	English
Montevideo	Uruguay	Municipal	Spanish
Maracay	Venezuela	Municipal	Spanish
Caracas	Venezuela	Municipal	Spanish
Valencia	Venezuela	Municipal	Spanish
Maracaibo	Venezuela	Municipal	Spanish
Barquisimeto	Venezuela	Municipal	Spanish
Sana'a'	Yemen	Municipal	Arabic
Lusaka	Zambia	Municipal	English
Harare	Zimbabwe	Municipal	English

2. City selection and document inclusion/exclusion

City selection

We sampled cities based on two criteria:

1) *City size*: We retrieved adaptation data only for cities over one million inhabitants. To determine city size on a consistent basis we used the U.N. database of urban agglomerations. The U.N. defines urban agglomerations as "population contained within the contours of a contiguous territory inhabited at urban density levels without regard to administrative boundaries. It usually incorporates the population in a city or town plus that in the suburban areas lying outside of, but being adjacent to, the city boundaries"(Heilig 2012). There are 449 urban agglomerations larger than 1m. Urban agglomerations smaller than 1m were excluded from the study.

2) *Language*: We gathered adaptation initiatives from cities in which the language was spoken by at least five cities total. We excluded cities on the basis of language due to the logistical constraints of hiring translators for a small number of observations. We retrieved adaptation data for cities with official languages of English, French, and Spanish (spoken by the research team), and Chinese, Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Turkish, and Indonesian (using hired translators). Some cities where English is not an official language (e.g. Helsinki, Finland) publish documents in English, but we did not analyze these to avoid bias toward cities publishing in English.

In total, 401 urban agglomerations fulfill both size and language criteria. 33 in Africa, 164 in Asia, 33 in Europe, 63 in Latin America, 50 in North America, and 6 in Oceania. We searched for adaptations in all 401 urban agglomerations.

Jurisdictions

We collected and analyzed adaptation initiatives undertaken by municipalities. We excluded adaptations at the national level and subnational levels such as provinces, regions, wards, districts, or neighbourhood councils.

Many urban agglomerations encompass several municipalities. In these cases we collected and analyzed data for the *central* municipality, defined as the most populous and namesake administrative unit of the urban agglomeration. There were two cases where municipalities were not the most appropriate authority to analyze:

- In the two instances of highly fragmented urban agglomerations with small namesake municipalities (population < 10,000) (City of London, England and Municipalidad de Santiago, Chile) we analyzed adaptation initiatives undertaken by the metropolitan government (Greater London Authority and Region Metropolitana respectively).

- Singapore does not have subnational urban jurisdictions due to its small physical size and dense population. In effect the national and urban government are the same authority. In this case we analyzed all adaptation initiatives output by the unitary Singaporean government.

Data sources

For documents to be included in the analysis they had to be municipal government documents or websites in English, Spanish, French, Chinese (Mandarin and Cantonese), Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Korean, Japanese, Turkish, or Indonesian. The documents had to address health risks posed by climate change; include initiatives relevant to the urban municipality and be a Municipal Adaptation Plan (MAP), Climate Action Plan (CAP), or the adaptation web-page of the municipal government websites. Criteria for inclusion and exclusion are summarized below, adapted from Austin et al. (Austin et al. 2015) and Lesnikowski et al. (Lesnikowski et al. 2011a):

Table 2: Inclusion and exclusion criteria for reviewed documents

Inclusion Criteria	**Exclusion Criteria**
English, Spanish, French, Chinese (Mandarin and Cantonese), Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Korean, Japanese, Turkish, and Indonesian language	Any other language
Human dimensions of climate change	Non-human dimensions of climate change (e.g. natural systems focus)
Documents published by municipal governments	Documents published by non-governmental organizations, private companies, communities, households, or individuals
Documents explicitly mentioned adaptation or reducing vulnerability to climate change	Documents focused on mitigation, sustainable development,

Municipal Adaptation Plans (MAPs), Climate Action Plans (CAPs), or adaptation web-pages of government websites	Opinion pieces, public speeches, conferences, meetings, or presentations

Data organization

We collected general information such as city location (continent, country, latitude and longitude), and the publication year, name, and language(s) of their adaptation documents. From adaptation documents we recorded individual adaptation initiatives and planning process indicators onto a spreadsheet. STATA (Statacorp version 13) was used to create figures and perform a statistical correlation analysis between number of adaptation initiatives and adaptation planning process score. ArcMap 10 (ESRI) was used to create a map of cities reporting adaptation initiatives.

Adapting cities, profiles, and reviewed document references

Table 3: Cities, adaptation profiles, and adaptation document citations

Profile	**Criteria and description**	**Cities (adaptation document year, see references for full citation)**
Extensive adaptors	• Top quartile of both adaptation initiatives and process score (>17 initiatives, >6 process score) • Adapting to all IPCC-identified impacts • Global leaders	Birmingham (2011), Boston (2013), Cape Town (2006), Hamburg (2014), London (2011), Marseille (2012), Melbourne (2014), Minneapolis (2013), New York (2013), Sacramento (2012), Semarang (2013), Toronto (2011), and Vancouver (2012b).
Moderate adaptors (high)	• Above median of adaptation initiatives and process score (>7 adaptation initiatives, >5 process score), excluding extensive adaptors • Substantial effort to produce adaptation policy, but not the *extensive adaptors*	Adelaide (2011), Baltimore (2013), Chicago (2012), Dublin (2009), Durban (2011), Glasgow (2010), Los Angeles (2007), Manchester (2014), Mexico City (2009), Paris (2013), Portland (2009), Quito (2012), Santa Cruz (2013), Santiago (2012), Seattle (2014), Seoul (2013), Singapore (2013), Surabaya (2008), Sao Paulo (2011), Wenzhou (2011), and Yangzhou (2011).
Moderate adaptors (low)	• Either <7 adaptation initiatives (median) or <5 process score (median) based on web reporting • Reporting suggests limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning	Austin (2013), Berlin (2009), Bridgeport (2013), Brisbane (2007), Buenos Aires (2010), Caracas (2012), Chongqing (2009), Cincinnati (2013), Edmonton (2011), Grande Vitoria (2012), Haerbin (2013), Handan (2008), Hong Kong (2013), Jingzhou (2014), Johannesburg (2011), Kaohsiung (2013), Leeds (2012), Linyi (2013), Lyon (2009), Miami (2008), Montreal (2014), Nantong (2014), Ottawa (2005), Port Elizabeth (2009), San Francisco (2013), Tokyo (2013), Vereeniging (2013), and Zhongshan (2011).

3. Coding of adaptation initiatives

We classified initiatives based on whether the initiatives are groundwork or action, which impacts and sectors are targeted, and adaptation policy type. These coding systems are described in detail in this section.

Groundwork versus action

We distinguished between groundwork initiatives and adaptation action itself. Groundwork initiatives are meant to enable the conditions necessary for adaptation, but do not reduce vulnerability directly. Groundwork initiatives aim to build a context conducive to adaptation, such as addressing adaptation capacity and gathering information, rather than substantially protecting natural and human systems to the impacts of climate. Adaptation actions directly reduce vulnerability or build resilience to climate change. The following table details the types of initiatives falling into groundwork of adaptation categories:

Table 4: Description of groundwork vs. adaptation actions (adapted from Lesnikowski, 2011) .

Groundwork vs. Action	**Types of Initiatives**
Groundwork	Climate impacts assessment / vulnerability assessment / adaptation research / networking / co-operation with other governments
Action	Legislative change / awareness programs / adoption of practices / creation of plans and strategies / monitoring systems

Impacts and sectors

We coded adaptation initiatives according to IPCC-defined impacts and sectors. The IPCC Fifth Assessment Report (AR5) identified five direct and indirect climate change impacts on urban areas. These are increased frequency, intensity, and duration of extreme weather events such as heat spells; drought; coastal exposure; inland flooding; and human health issues (Revi et al. 2014). Additionally, the IPCC AR5 outlines six systems or sectors in urban areas that face exposure to climate change impacts. These are water supply, energy supply, transportation and telecommunications, the built environment, green infrastructure and ecosystem services, and human and social services (Revi et al. 2014). We coded adaptation initiatives according to the impact they target as well as the system or function they intend to strengthen. The *Human Health* category overlaps as both an impact and a sector, so we collapsed it into one category. An initiative that tackles human health as an impact logically also aims to strengthen the human health sector. We also added an

Emergency Preparedness category as a sector for initiatives that generally address Disaster Risk Reduction in the context of climate change without naming a specific impact or sector.

All the categories of impacts and sectors are non-mutually exclusive. It is important to allow flexibility in classification and to understand that one initiative may have multiple motivations and purposes. Some initiatives, for example, aim to reduce vulnerability to one specific impact (e.g. flooding) with implications to many sectors (e.g. human health or transportation). Other initiatives, however, aim to build resilience in a sector (e.g. energy supply) threatened by many different impacts (e.g. heat stresses on electricity usage or saltwater intrusion into substations). Table 3 shows a description of the impacts and sectors, as well as examples:

Table 5: Urban climate change impacts and sectors, adapted from Revi et al. (2014)

Adaptation impact/sector	Description	Examples
Impact: Urban Temperature Variation	More frequent hot days will exacerbate urban heat island effects and cause heat-related health problems, increased air pollution, and energy demand.	"Research to create a better understanding of heat related morbidity and mortality which could help with disaster management." (Durban, South Africa) "Focus researching new crop breed in order to adapt potential rising temperature" (Chongqing, China)
Impact: Drought and Water Scarcity	Drought in urban areas will produce water and electricity shortages, water-related diseases, and food insecurity.	"Singapore government is desalinating water to supplement water from local reservoirs during extended dry spells. Eventually, 70% of Singapore's water will come from desalinated water." (Singapore) "City of Melbourne has a strategy to develop as a water-aware city in the face of drought and reduced rainfall." (Melbourne, Australia)
Impact: Coastal Flooding, Sea Level Rise, and Storm Surge	Coastal cities are at risk of sea level rise and associated coastal and riverbank erosion, or flooding in conjunction with storm surge.	"Collaborate with regional partners in addressing the impacts of sea level rise: Evaluate the full range of impacts based on best available science. Prepare a worst case scenario response strategy." (Seattle, United States) "Implementation of a monitoring program for coastal waters." (Buenos Aires, Argentina)
Impact: Inland Flooding, Hydrological and Geo-Hydrological Hazards at Urban Scale	Increases in rainfall intensity and associated flooding risk damaging property and public infrastructure and contamination of water. Additionally, increased rainfall risks putting stress on urban drainage systems.	"Development of flood risk and hazard maps for the City." (Glasgow, Scotland) "Urban Green Network: among other benefits, this system of green connectors increase the surface of water absorption surfaces, reducing risk of flooding, landslides, and matter movements originating from paving of large tracts of land." (Quito, Ecuador)
Sector: General Emergency Preparedness and Disaster Risk	Increased frequency of potentially hazardous weather events motivates disaster response system planning.	"Create maps of meteorological risk of the Caracas metropolitan area." (Caracas, Venezuela)

Planning		"Disaster Management: Improve capacity to respond to an emergency through education and outreach." (Jingzhou, China)
Sector: Human Health, Disease, Epidemiology Issues, and Social Services	Impacts on social and environmental determinants of health such as clean air, safe drinking water, and food and shelter security will put stress on health and social care provision systems.	"Enable the resilience of Health/Fire/Police and Civil Contingency services and develop extreme event scenarios." (Manchester, England) "Enhance awareness of climate change related health risks with leaflets" (Hamburg, Germany)
Sector: Water Supply, Wastewater and Sanitation	Water supply systems are at risk due to saline intrusion and constraints in water availability and quality. Wastewater and sanitation systems will sustain increased stress due to more frequent extreme rainfall events.	"Urban water supplies - pressure management: Reduce off-peak water pressure in the pipes to reduce leakage" (Cape Town, South Africa)
Sector: Energy Supply	Electricity systems are threatened by changing patterns of energy consumption and reduced production due to more frequent hot days and drought when hydropower is the source.	"Understand the energy use patterns and needs of homeowners in order to implement comprehensive smart grid technology on a localized scale." (Minneapolis, United States) "Improve resilience of energy infrastructure by investing in renewable

		energy sources such as wind and solar." (Wenzhou, China)
Sector: Transportation and Telecommunications	Transport and communication infrastructure will be affected by degradation of transit routes and loss of communication during extreme weather events.	"Arrangement of flooding ditches away from avenues to diminish impact of large precipitation events." (Madrid, Spain) "Telecommunications - Create redundancy to reduce risk of outages: Study options to increase conduit infrastructure redundancy and resiliency." (New York, United States)
Sector: Built Environment, and Recreation and Heritage Sites	Urban housing is heavily affected by extreme weather, and informal structures are particularly affected due to poor structural integrity and materials quality. Recreational, heritage, and tourist sites are also at risk due to more frequent extreme weather.	"Participate actively in state of Oregon code-development processes to ensure that building codes support buildings that can adapt to higher temperatures, stronger storms, and other physical impacts of climate change." (Portland, United States) "Issue a bulleting on construction safety with changes in storms and wind increases. Include a sentence in building bylaw for construction on considering climate change in construction safety plan." (Vancouver, Canada)
Sector: Green infrastructure and Ecosystem Services	Ecosystems will be affected by changing temperature and precipitation trends, while the value of green urban construction will increase as these buildings offer climate-regulating benefits.	"Implement erosion control and rehabilitation works on River Torrens and creek lines and seek external funding partnerships." (Adelaide, Australia) "City of Lyon has partnered with company Canevaflor to instal green walls around the city. Green walls have heat insulating properties, improve the quality of urban air, and reduce the effects of urban heat island." (Lyon, France)

Policy typology

We coded adaptation initiatives based on policy form. We adapted Biagini et al.'s (2014) categories of adaptation typologies and classified adaptation initiatives into five distinct groups. The five categories are Capacity Building; Management, Planning, and Policy; Practice and Behaviour; Information; and Financing. Table 4 describes the categories and provides examples:

Table 6: Policy typology of adaptation initiatives

Adaptation category	Description	Examples
Capacity Building	Developing human resources, institutions, and communities, equipping them with the capability to adapt to climate change	"Enable 'Summer Sense' program to provide members of the community with information about staying safe in the heat" (Adelaide, Australia) "Disaster Management: Improve capacity to respond to an emergency through education and outreach." (Jingzhou, China)
Management, Planning, and Policy	Incorporating understanding of climate science, impacts, vulnerability and risk into government and institutional planning and management. Creation of new policies or revisions of policies or regulations to allow flexibility to adapt to changing climate	"Establish flooding and storm surge response plans." (Brisbane, Australia) "Establishment, implementation, and maintenance of an emergency response plan." (Edmonton, Canada)
Practice and Behaviour	Revisions or expansion of practices and on the ground behaviour that are directly related to building resilience	"Reduce the concentration of livestock in some areas to reduce the pressure on the water supply" (Santa Cruz, Bolivia) "Control West Nile Disease with measures such as spraying at larval state" (Ottawa, Canada)
Research & Information	Systems for communicating climate information to help build resilience towards climate impacts	"Monitoring and warning of impending disaster risks, with the help of the provincial weather and hydrological monitoring stations." (Cape Town, South Africa) "Flooding vulnerability mapping for schools, city hall, electricity generation, police stations, fire stations, EMS services, public housing, infrastructure, etc." (Boston,

		United States)
Financing	New financing or insurance strategies to prepare for future climate disturbances	“To develop a resilience plan, GBRC was awarded a FEMA Community Resilience Innovation Program rant for $35,000. Bridgeport will spend this money to sponsor a fellow to develop a resiliency plan for the city.” (Bridgeport, United States) “East and South Shores Staten Island: Secure available Federal funding to implement the Community Wildfire Protection Plan for fire-prone areas on the East Shore.” (New York, United States)

Policy process

To measure a city's engagement with adaptation policy making we coded municipalities based on evidence of planning for adaptation. We classified cities based on the seven indicators of adaptation policy-making (*policy process*). Each variable shows whether governments are undertaking these activities or not, therefore they are coded as binaries (0 = no evidence, 1 = evidence). Municipalities were given a numerical score out of seven according to how many components of the policy process they reported. This score is a broad measure designed to capture large variations in engagement with the adaptation policymaking process.

Table 7: Policy process indicators

Protocol component	**Indicators (coding: 1 = applies, 0 = does not apply)**
Policy process	• Evidence of a climate assessment • Evidence of a vulnerability assessment • Review current and future development plans with climate change lens • Consultation process and inclusion of multiple stakeholders • Existence of a climate change planning document • Management of barriers and uncertainties • Monitoring and evaluation

Table 8: Cities and their adaptation profiles

Profile	Criteria and description	Example cities
Extensive adaptors	• Top quartile of both adaptation initiatives and process score (>17 initiatives, >6 process score) • Adapting to all IPCC-identified impacts • Global leaders	Birmingham, Boston, Cape Town, Hamburg, London, Marseille, Melbourne, Minneapolis, New York, Sacramento, Semarang, Toronto, and Vancouver.
Moderate adaptors (high)	• Above median of adaptation initiatives and process score (>7 adaptation initiatives, >5 process score), excluding extensive adaptors • Substantial effort to produce adaptation policy, but not the *extensive adaptors*	Adelaide, Baltimore, Chicago, Dublin, Durban, Glasgow, Los Angeles, Manchester, Mexico City, Paris, Portland, Quito, Santa Cruz, Santiago, Seattle, Seoul, Singapore, Surabaya, Sao Paulo, Wenzhou, and Yangzhou.
Moderate adaptors (low)	• Either <7 adaptation initiatives (median) or <5 process score (median) based on web reporting • Reporting suggests limited, ad-hoc, and often tokenistic efforts to integrate climate change into city planning	Austin, Berlin, Bridgeport, Brisbane, Buenos Aires, Caracas, Chongqing, Cincinnati, Edmonton, Grande Vitoria, Haerbin, Handan, Hong Kong, Jingzhou, Johannesburg, Kaohsiung, Leeds, Linyi, Lyon, Miami, Montreal, Nantong, Ottawa, Port Elizabeth, San Francisco, Shanghai , Tokyo, Vereeniging, and Zhongshan.
Beginning stage adaptors	• Zero adaptation initiatives reported on-line, but >0 process score. • Exhibit evidence of planning for adaptation, but report no adaptation initiatives	Auckland, Bogota, Calgary, Cleveland, Fuzhou, Philadelphia, Pretoria, San Diego, Sydney, Tai'an, and Taichung.
No reporting	• Zero reported initiatives and zero process score reported • No reported, web-based evidence of adaptation policy-making	See Appendix C for full list (n=328)

Appendix II – Supplementary materials for Chapter 4, "Public Health Adaptation to Climate Change in Large Cities"

1. Inclusion and Exclusion Criteria for Reviewed Documents

For documents to be included in the analysis they had to be municipal government documents or websites in English, Spanish, French, Chinese (Mandarin and Cantonese), Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Korean, Japanese, Turkish, or Indonesian. The documents had to address health risks posed by climate change; include initiatives relevant to the urban municipality and be a Municipal Adaptation Plan (MAP), Climate Action Plan (CAP), or the adaptation web-page of the municipal government websites. Criteria for inclusion and exclusion are summarized below, adapted from Austin et al. (Austin et al. 2015) and Lesnikowski et al. (Lesnikowski et al. 2011a):

Inclusion Criteria	Exclusion Criteria
English, Spanish, French, Chinese (Mandarin and Cantonese), Arabic, Russian, German, Portuguese, Farsi, Korean, Japanese, Korean, Japanese, Turkish, and Indonesian language	Any other language
Human dimensions of climate change	Non-human dimensions of climate change (e.g. natural systems focus)
Documents published by municipal governments	Documents published by non-governmental organizations, private companies, communities, households, or individuals
Documents explicitly mentioned adaptation or reducing vulnerability to climate change	Documents focused on mitigation, sustainable development,
Municipal Adaptation Plans (MAPs), Climate Action Plans (CAPs), or adaptation web-pages of government websites	Opinion pieces, public speeches, conferences, meetings, or presentations
Addresses health risks posed by climate change	Addresses climate change risks unrelated to health (e.g. tourism)
Documents published before March 2014	Documents published after March 2014

2. Documents Reviewed

Below is a table of cities reporting public health adaptation initiatives, as well as the document name and citation:

City name	Country name	Continent	Year	Document name
Africa	South Africa	Cape Town	2006	*Framework for Adaptation to Climate Change in the City of Cape Town (City of Cape Town 2006)*
Africa	South Africa	Durban	2011	*Climate Change Adaptation Planning for a Resilient City (Ethekwini Municipality 2011)*
Africa	South Africa	Johannesburg	2011	*Climate Change Adaptation Plan (City of Johannesburg 2011)*
Asia	China	Chongqing	2009	*Chongqing Climate Change Action Plan (City of Chongqing 2009)*
Asia	China	Jingzhou	2014	*Disclosure of Environmental Information (Jingzhou People's Municipal Government 2014)*
Asia	China	Kaohsiung	2013	*Summary of Policy Plan (Kaohsiung City Government 2013)*
Asia	China	Linyi, Shandong	2013	*Linyi Environmental Emergency Management (City of Linyi 2013)*
Asia	China	Wenzhou	2011	*City of Wenzhou's meteorological development Twelfth Fiver-Year Plan (City of Wenzhou 2011)*
Asia	China	Yangzhou	2011	*City of Yangzhou's Twelfth Five-Year Plan (City of Yangzhou 2011)*
Asia	China	Zhongshan	2011	*City of Zhongshan's meteorological department Twelfth Five-Year Plan (Zhongshan 2011)*
Europe	France	Lyon	2009	*Climate Plan (Grand Lyon 2009)*
Europe	France	Marseille	2012	*Territorial Climate Energy Plan (City of Marseille 2012)*
Europe	France	Paris	2013	*Climate Blueprint (City of Paris 2013)*
Europe	Germany	Hamburg	2014	*Action Plan Climate Change Adaptation (City of Hamburg 2014)*
Europe	United Kingdom	Birmingham	2011	*Climate Change Adaptation Action Plan 2012+ (Birmingham*

				City Council 2011)
Europe	United Kingdom	London	2011	*Managing Risks and Increasing Resilience (Greater London Authority 2011)*
Latin America	Argentina	Buenos Aires	2010	*Action Plan against Climate Change. Chapter 6: Adaptation Measures (City of Buenos Aires 2010)*
Latin America	Bolivia	Santa Cruz	2013	*Adaptation Measures in the Framework of the Pilot Program for Adaptation to Climate Change (Autonomous Departmental Government of Santa Cruz 2013)*
Latin America	Brazil	Sao Paulo	2011	*Guidelines for the Action Plan of the City of São Paulo for Mitigation and Adaptation to Climate Change (City of Sao Paulo 2011)*
Latin America	Ecuador	Quito	2012	*10 Actions by Quito in the Face of Climate Change (Municipality of the Metropolitan District of Quito 2012)*
Latin America	Mexico	Mexico City	2009	*Vulnerability Analysis and Development of Adaptation Measures for Mexico City's Climate Action Plan (Mexico City 2009)*
North America	Canada	Edmonton	2011	*The Way We Green (City of Edmonton 2011)*
North America	Canada	Montreal	2014	*Adaptation to Climate Change (City of Montreal 2014)*
North America	Canada	Ottawa	2005	*Air Quality and Climate Change Management Plan (City of Ottawa 2005)*
North America	Canada	Toronto	2011	*Toronto's Adaptation Actions (City of Toronto 2011)*
North America	Canada	Vancouver	2012	*Climate Change Adaptation Strategy (City of Vancouver 2012b)*
North America	United States	Austin	2013	*Resolution 20131121-060 (City of Austin 2013)*
North America	United States	Baltimore	2013	*Baltimore Climate Action Plan (City of Baltimore 2013)*
North America	United States	Boston	2013	*Climate Ready Boston. Municipal Vulnerability to Climate Change*

				(City of Boston 2013)
North America	United States	Bridgeport	2013	*BGreen 2020 A Sustainability Plan for Bridgeport, Connecticut (City of Bridgeport 2013)*
North America	United States	Chicago	2012	*Chicago Climate Action Plan (City of Chicago 2012)*
North America	United States	Cincinnati	2013	*Green Cincinnati Plan (City of Cincinnati 2013)*
North America	United States	Los Angeles	2007	*Green LA. An Action Plan to Lead the Nation In Fighting Global Warming (City of Los Angeles 2007)*
North America	United States	Minneapolis	2013	*Climate Change Impacts & Adaptation Strategies (City of Minneapolis 2013)*
North America	United States	New York	2013	*A Strong, More Resilient New York (New York City 2013)*
North America	United States	Portland	2009	*Climate Action Plan 2009 (City of Portland 2009)*
North America	United States	Sacramento	2012	*Sacramento Climate Action Plan (City of Sacramento 2012)*
North America	United States	San Francisco	2013	*San Francisco's Climate Change Adaptation Working Group (City of San Francisco 2013)*
North America	United States	Seattle	2014	*Adaptation Planning (City of Seattle 2014)*
Oceania	Australia	Adelaide	2014	*Climate Change Adaptation Action Plan 2011-2013 (Adelaide City Council 2011)*
Oceania	Australia	Brisbane	2007	*Brisbane's Plan for Action on Climate Change and Energy 2007 (Brisbane City 2007)*
Oceania	Australia	Melbourne	2014	*Adapting to Climate Change (City of Melbourne 2014)*

3. Coding Examples

Groundwork and action

We distinguished between groundwork and action initiatives. Groundwork initiatives aim to build a context enabling for adaptation, such as gathering information or research on the impacts of climate change, rather than substantially protecting human from the risks of climate change. Adaptation actions directly reduce vulnerability to climate change impacts. Examples of groundwork and action initiatives are described below, adapted from Lesnikowski et al. (Lesnikowski et al. 2011a) and Ford et al. (Ford et al. 2013):

Groundwork vs. Action	Examples of Initiative
Groundwork	• Climate impacts assessment • Vulnerability assessment • Adaptation research • Networking • Co-operation with other governments
Action	• Legislative action • Awareness programs • Adoption of practices • Creation of plans and strategies • Monitoring systems • Delivering services

Health risks

Initiatives responding to health risks of climate change were recorded for inclusion in the study. Health risks are defined as per the Intergovernmental Panel on Climate Change's Fifth Assessment Report chapter on human health (Smith et al. 2014a). Some initiatives did not provide enough detail to be classified into any of the established categories. Initiatives of this type were usually classified into a category name "general health." However, if initiatives alluded to extreme weather events without specifying a health risk, then they were classified into a category for "general disaster preparedness." A summary of health risks as well as the expected health impacts associated for the risks can be found below, adapted from Smith et al. (Smith et al. 2014a) and Austin et al. (Austin et al. 2015):

Health Risk	Expected Health Impacts
Heat and cold-related	• Heat-related morbidity and mortality • Respiratory and cardiovascular disorders
Floods and storms	• Death, injury and illness • Psychological health effects, including mental health and stress-related illnesses • Health impacts due to food or water shortages • Illnesses related to drinking water contamination • Effects of the displacement of populations and crowding in emergency shelters • Indirect health impacts from ecological changes, infrastructure damages and interruptions in health services • Effects of the displacement of populations and crowding in emergency shelters • Indirect health impacts from ecological changes, infrastructure damages and interruptions in health services
Water and food insecurity	• Impacts on water availability and quality from drought or contamination from floods and storms • Impacts on nutrition due to availability of local and traditional foods from poorly designed built environments
Air quality	• Eye, nose and throat irritation, and shortness of breath • Acute and chronic damage to the respiratory system • Chronic obstructive pulmonary disease and asthma • Exacerbation of allergies and asthma • Increased risk of cardiovascular diseases (e.g. heart attacks and ischemic heart disease) • Respiratory and cardiovascular mortality
Infectious diseases	• Increased incidence of vector-borne infectious diseases native to the city • Introduction of infectious diseases new to the local area • Possible emergence of new diseases, and re-emergence of those previously eradicated in cities

Adaptation type

Adaptation type refers to the category of instrument being used by the municipal government to undertake the initiative. Adaptation types were adapted from Biagini et al. (Biagini et al. 2014) and are summarized with examples below:

Adaptation type	Description	Example
Management, planning, and policy	Incorporating understanding of climate science, impacts, vulnerability and risk into government and institutional planning and management. Creation of new policies or revisions of policies or regulations to allow flexibility to adapt to climate change.	"Air pollution: enforce the industrial black smoke legislation" – Cape Town, South Africa (City of Cape Town 2006)
Practice and behaviour	Revisions or expansion of practices and on the ground behaviour that are directly related to building resilience	"Provide indoor cooling centres and outdoor cooling stations during summer heat for tourists and city dwellers" – Toronto, Canada (City of Toronto 2011)
Information and research	Systems for communicating climate information to help build resilience toward climate impacts.	"Expand the epidemiological analysis of health and environmental data for the adaptation to climate changes" – Sao Paulo, Brazil (City of Sao Paulo 2011)
Capacity building	Developing human resources, institutions, and communities, equipping them with the capability to adapt to climate change.	"The Mayor will work with the shadow London Health Improvement Board to facilitate the provision of climate risk information to borough Health and Well-Being Boards" – London, United Kingdom (Greater London Authority 2011)

Physical infrastructure	New or enhanced physical infrastructure providing direct or indirect protection form climate impacts.	"Adapt parks and expand green infrastructure to shield adjacent communities from the impacts of extreme weather events: Harden or otherwise modify shoreline parks and adjacent roadways to protect adjacent community." – New York, United States (New York City 2013)
Warning or observation systems	New or enhanced tools for communicating climate hazards and monitoring potential risks from weather	"Improve disaster relief and prevention measures: complete and maintain a disaster notification information web" – Yangzhou, China (City of Yangzhou 2011)

New and mainstreamed

Initiatives were classified as either new or mainstreamed depending on whether they were new standalone activities or whether they enhanced or intensified existing policies, strategies, or measures. The categories are adapted from Lesnikowski et al. (Lesnikowski et al. 2011a)and are summarized with examples below:

Category	**Description**	**Example**
New	Climate change impacts are the primary motivator and the initiative is a new and discrete activity.	"Extreme heat events and health: Implement an effective climatic modelling and warning system" – Johannesburg, South Africa (City of Johannesburg 2011)
Mainstreamed	The initiative is planned or implemented within a context of existing policies, strategies or measures. The initiative's aim is to enhance, intensify, improve or bolster the adaptive potential of existing activities.	"Health: Continue development and implementation of the City's Integrate Pest Management program for City facilities." – Sacramento, United States (City of Sacramento 2012)

4. Results: classification of health adaptation initatives

Table 1: Level of adaptation activity and health risks

	Level	
Health risk	Groundwork	Action
Air quality	4	14
Heat and cold-related	21	44
Floods and storms	9	27
General disaster preparedness	3	36
General health	9	23
Infectious diseases	4	11
Water and food security	8	13
Total	58	168

Table 2: Cities by adaptation types and health risks

	Adaptation type						
Health risk	Capacity building	Information and research	Management, planning, and policy	Physical infrastructure	Practice and behaviour	Recommendation	Warning or observing systems
Air quality	*Sacramento*	*N/A*	*Sacramento*	*N/A*	*Austin, Baltimore, Chicago, Marseille*	*Cape Town*	*Ottawa, Toronto*
Heat and cold-related	*Durban, Melbourne*	*Adelaide, Baltimore, Durban, London, Melbourne, San Francisco, Toronto, Vancouver*	*Chicago, Hamburg, Marseille, Montreal, Paris, Sacramento, Toronto, Vancouver*	*N/A*	*Adelaide, Birmingham, Chicago, Cincinnati, London, Los Angeles, Lyon, Marseille, Melbourne, New York, Ottawa, Paris, Sacramento, Toronto, Vancouver*	*Cape Town, Minneapolis*	*Johannesburg, Ottawa, Toronto*

Floods and storms	*Chicago, London, Melbourne, Vancouver,*	*Boston, London, Melbourne, New York, Portland*	*Adelaide, Birmingham, Boston, Brisbane, Edmonton, Jingzhou, Marseille, Montreal, New York, Sacramento, Vancouver*	*New York*	*Melbourne*	*Minneapolis*	*Toronto*
General disaster preparedness	*Durban, Jingzhou, New York, Sacramento,*	*New York, Wenzhou, Yangzhou*	*Adelaide, Austin, Bridgeport, Kaohsiung, Linyi, New York, Ottawa, Sacramento, Seattle, Sao Paulo, Vancouver*	*New York*	*Mexico City, New York*	*N/A*	*Yangzhou, Zhonshan*

General health	*Adelaide, Birmingham, London, Toronto, Wenzhou,*	*Baltimore, Birmingham, Buenos Aires, Durban, Marseille, Paris, Seattle, Sao Paulo, Toronto, Vancouver*	*Adelaide, Austin, Birmingham, Hamburg, Jingzhou, London, Melbourne, New York*	*New York*	*Adelaide, Linyi, Toronto, Vancouver*	*N/A*	*Marseille*
Infectious diseases	*Durban, Sacramento,*	*Baltimore*	*Marseille, Montreal*	*N/A*	*Adelaide, Durban, Kaohsiung, Ottawa, Sacramento*	*Cape Town*	*Chongqing, Hamburg, Mexico City*
Water and food security	*Durban*	*Durban, New York, Toronto*	*Adelaide, Durban, Quito, Santa Cruz, Seattle*	*N/A*	*Adelaide, New York, Sacramento, Santa Cruz, Vancouver*	*N/A*	*N/A*

Table 3: Category of adaptation activity and health risks

	Category	
Health risk	Mainstreamed	New
Air quality	10	8
Heat and cold-related	13	52
Floods and storms	15	21
General disaster preparedness	17	22
General health	13	19
Infectious diseases	6	9
Water and food security	8	13
Total	82	144

Appendix III – Supplementary materials for Chapter 5, "Climate Change Adaptation in Global South Megacities: The Case of Dhaka, Bangladesh"

Tables and figures

Table 1: Peer-reviewed article inclusion criteria and search terms

Inclusion	Exclusion
Published after January 1st, 2000 and before October 1st, 2015	Article published before January 1st 2000 or after October 1st, 2015
Focuses explicitly on climate change	Does not mention climate change
Discusses adaptation and resilience in relation to humans	Discussions of adaptation, vulnerability or resilience that are unrelated to humans
Focuses on post-industrial revolution climate change	Focuses on prehistoric climate change
Focuses on adaptation and resilience	Focuses exclusively on mitigation
Publication is in English	Publication is in any other language
Search terms:	
Place names	Dhaka; Dhaka District; Dhaka North City Corporation; Dhaka wards: Uttara Model Town; Kuril; Khilkhat; Nikunjo; Mirpur; Byshteki; Bawneabad; Pollabi; Rupnagar; Box nagar; Vasantek; Maticata; Manikdey; Barentek; Baridhara; Shahjadpur; Gulshan; Banani; Mohakhali; Niketan; Badda; Ulon; West Haji Para; Khilgaon B Zone; Purbo Haji Para; Chowdhury Para; Tajgaon; Kunipara; Azrat Para; Rasul bag; Boro Moghbazar; Eskaton; Neyatola; Golartek; Bagbari; Darus Salam; Gabtoli; Paikpara; Ahmed Nagar; Monipur; Parer Bagh; Kazipara; Sawrapara; Senpara-parbata; Ibrahinpur; Kafrul; Kawranbazar; Tegturipara; Tejkunipara; Razabazar; Monipuripara; Agargaon; Mohammadpur; Adabor; Shakertek; Lalmatia; Basila; Basbari; Jafrabad; Sultanganj;

	Buriganga River
Generic climate change terms	Climate; Climate change; Climate risks; Climate hazards; Resilience; Vulnerability; Adaptation; Adaptive capacity; Coping; Global warming
Climate change impacts	Extreme heat; Urban heat island; Warm spells; Drought; Water scarcity; Sea level rise; Flooding; Coastal flooding; Storms; Winds; Coastal erosion; Riverbank erosion; Waterlogging; Extreme rainfall; Landslides; Land shifts; Air quality
Sectors affected by climate change	Disaster risk reduction; Disaster response; Emergency preparedness; Water; Water supply; Wastewater; Sanitation; Water quality; Drainage; Sewers; Energy; Power supply; Fuel; Power outage; Blackout; Energy consumption; Electricity; Air conditioning; Power lines; Transportation and Telecommunication; Bridges; Tunnels; Railways; Pipelines; Ports; Wireless networks; Cell phone towers; Telecommunications towers; Built environment, recreation, and heritage; Housing; Informal buildings; Stone structures; Metal structures; Playgrounds; Tourism; Heritage sites; Green infrastructure; Parks; Forests; Wetlands; Green belts; Pervious surfaces; Green roofs; Blue roofs; White roofs; Health and social services; Health care; Social care; Education; Police; Emergency services; Public service provision; Infectious diseases; Injury; Morbidity; Death

Table 2: Interview theme and question examples

Factor	Adaptation readiness framework component	Example interview questions
Institutional	Political leadership	Are there any people who are particularly important in ensuring adaptation is incorporated in the work of your organization?
	Institutional organization	Are there any linking mechanisms (such as partnerships) between your institution and other institutions involved in climate change and adaptation?
	Availability of funding	Can you explain to me how adaptation is funded in your organization?
Civil society	Public support for adaptation	Where do you see as the role of public support for adaptation and climate change?
	Engagement of stakeholders	What role does stakeholder engagement play in adaptation planning, development, implementation, and evaluation?
	Interaction between science & policy	What information or research informs adaptation policies, plans, programs, or actions?

Table 3: Government document sources included in the analysis

Document	Publisher	Year	Government level	Description
National Plan for Disaster Management 2010-2015	Ministry of Food and Disaster Management	2010	National	Plan for addressing natural, environmental, and human induced hazards
National Adaptation Programme of Action (NAPA)	Ministry of Environment and Forests	2005	National	Plan to reduce adverse effects of climate change on Bangladesh
Bangladesh Climate Change Strategy and Action Plan	Ministry of Environment and Forests	2009	National	Document outlining implication of climate change for Bangladesh; both mitigation and adaptation
National Urban Sector Policy [draft]	Ministry of Local Government, Rural Development and Cooperatives	2006	National	Draft policy document to strengthen beneficial aspects of urbanization
National Water Management Plan	Ministry of Water Resources, Government of the People's Republic of Bangladesh	2001	National	Guidelines for public and private sector to ensure the optimal management of water resources
National Land Use Policy	Ministry of Land, Government of the People's Republic of Bangladesh	2001	National	Directives for land use planning and development in Bangladesh
Dhaka Structure Plan 2016-2035	RAJUK development agency, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh	2015	City	Long-term urban development plan for the Dhaka urban area between 2016-2035

Detailed Area Plans (DAPs) Locations 1 – 16	RAJUK development agency, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh	1997	Neighbourhood	Development and service-provision planning for neighbourhoods within Dhaka

Table 4: Peer-reviewed articles included in the analysis

Author and year	Title	Scale of focus	Description
Alam and Rabbani (2007)	Vulnerabilities and responses to climate change for Dhaka	City government	Review of vulnerabilities and adaptation responses
Alam and Mullick (2014)	Climate change effects upon massive land and housing development Case of Dhaka, Bangladesh	City government	Analysis of flooding impacts on new housing developments and adaptation responses
Barua and van Ast (2011)	Towards interactive flood management in Dhaka, Bangladesh	City government	Analysis of current institutional setting and recommendations for adaptive water management
Braun and Assheuer (2011)	Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh	Households in informal settlement	Survey to identify vulnerability and adaptive responses to flooding in informal settlements
Cash et al. (2013)	Reducing the health effect of natural hazards in Bangladesh	National government	Analysis of how disaster management and public health activities have reduced vulnerability to climate change
Gain and Hoque (2013b)	Flood risk assessment and its application in the eastern part of Dhaka City, Bangladesh	National & city government	Testing a method to map flood hazard and vulnerability
Goudet et al. (2011)	Impact of flooding on feeding practices of infants and young children in Dhaka, Bangladesh Slums: what are the coping strategies?	Individuals in informal settlements	Analysis of flooding impact on children feeding practices and associated coping strategies
Haque, Grafakos and Huijsman (2012)	Participatory integrated assessment of flood protection measures for climate adaptation in Dhaka	National government	Assessment of adaptation options from the NAPA
Jabeen et al. (2010)	Built-in resilience: learning from grassroots coping strategies for climate variability	Household & community	Examination of adaptation strategies employed in Korail, Dhaka's largest informal settlement

Jabeen and Johnson (2013)	Perceptions of climate variability and coping strategies in informal settlements in Dhaka, Bangladesh	Household	Household survey of two informal settlements in Dhaka about hazard perception and individual adaptation
Jabeen (2014b)	Private sector investments and associated risk implications for post-disaster housing development in Dhaka	Private sector	Assessment of private sector housing development practices and opportunities to reduce disaster risk
Jabeen (2014a)	Adapting the built environment: the role of gender in shaping vulnerability and resilience to climate extremes in Dhaka	Household	Analysis of gender and its importance to adaptive capacity
Jabeen and Guy (2015)	Fluid engagements: Responding to the co-evolution of poverty and climate change in Dhaka, Bangladesh	Household	Analysis of locally designed adaptation activities in informal settlements
Mourshed (2011)	The impact of the projected changes in temperature on heating and cooling requirements in buildings in Dhaka, Bangladesh	City government	Analysis of building temperature impacts from climate change and opportunities for resilience enhancement
Mynett and Vojinovic (2009)	Hydroinformatics in multi-colours-part red: urban flood and disaster management	City government	Application of hydroinformatics to flood disaster management
Rashid (2000)	The urban poor in Dhaka City: Their struggles and coping strategies during the floods of 1998	Individuals in informal settlements	Review of impacts from the 1998 flood and associated coping strategies
Rashid et al. (2007)	Urban flood problems in Dhaka, Bangladesh: slum residents' choices for relocation to flood-free areas	Individuals in informal settlements	Survey of reasons for relocation after displacement from flooding