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Social and economic impacts of climate change on the urban environment

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Urban areas have unique characteristics that render their residents and assets particularly vulnerable to climate change. Many large urban centers are located along coasts or in low-lying areas around the mouths of major rivers, placing economic capital and human populations at risk of climate-related hazards including sea level rise and flooding from severe precipitation. Recent literature illustrates the economic and social challenges facing cities around the world as a result of climate change including energy shortages, damaged infrastructure, increasing losses to industry, heat-related mortality and illness, and scarcity of food and water. These challenges are interrelated. Economic losses make it difficult for residents to maintain their livelihoods and can therefore exacerbate social issues including poverty and hunger. At the same time, some demographic and socioeconomic characteristics of cities can make them especially vulnerable to climate change impacts. This paper reviews current literature on these issues and identifies future research needed to more fully understand climate change in the urban context.

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Introduction

Although climate change has been a prominent topic of research for the past several decades, the special significance of climate impacts on urban areas has only recently been recognized [1]. The scope of research is moving beyond categorization of the changing physical conditions facing urban areas as a result of climate change, including rising sea level, more variable and intense precipitation, more frequent flooding and landslides. Current work tends to take a broad view of how the risk of these hazards affects the economic and social fabric of communities. A critical facet of this discussion is the distinction between risk and vulnerability. Whereas risk expresses the likelihood of hazards occurring in particular areas, vulnerability captures those aspects of cities, groups or individuals that render them particularly susceptible to harm as a result of climate change [2]. There is a rich literature base providing a variety of nuanced frameworks that point to at least two common sources of climate change vulnerability (e.g. [3,4••]): first, exposure to physical hazards and second, ability to prepare for and respond to the risks of these hazards.

Urban areas are often situated in hazardous locations (e.g. along coasts) where economic assets and residents increasingly find themselves at elevated risk of climate-related events. To understand the implications of these risks for cities, one must assess how they affect social and economic conditions, the vital underpinnings of urban function. Social impacts of climate change are those that directly affect the physical and emotional well-being of residents including health effects, food and water scarcity, livelihood impacts and displacement. A critical aspect of the social nature of climate change is its differential impacts on residents, a phenomenon that has only relatively recently entered the climate change discourse. Literature increasingly demonstrates that climate change disproportionately impacts individuals and groups that have scarce resources or are socially isolated. Economic impacts disrupt the flow of goods and services within an urban area, for example through destruction of industrial infrastructure and loss of commercial activity. Increasing frequency of physical hazards and changing environmental conditions interfere with the provision of a wide range of services and, in some cases, may restrict activities that comprise significant portions of the urban economy. Because of the globalization of commerce and trade, climate impacts in one region can affect economies of cities around the world, particularly when transportation is impeded.

Although case studies sometimes focus on economic or on social impacts individually, research increasingly emphasizes their interrelated nature. Economic losses from climate events reduce resources available to address social issues [4••,5]. By affecting these resources, climate change-related events can pose a serious threat to urban livelihoods.

At the same time, some socioeconomic and demographic characteristics, particularly poverty, can increase a city's vulnerability to the same events. Climate change also has the potential to exacerbate existing social and economic

issues facing urban areas (e.g. rapid urbanization, poverty). This article reviews recent research on the economic and social impacts of climate change, emphasizing their interactions and compounding effects on cities.

Economic impacts

Industry

Climate change both directly and indirectly affects industrial assets. Extreme events and slow-onset changes damage infrastructure and interfere with services necessary to industrial operation including provision of electricity, water and sewerage. Sea level rise and associated erosion threaten coastal ports and industrial areas [6,7] and can raise salinity levels, changing the volume, timing and quality of surface water available for industrial purposes [8]. For instance in Philadelphia (US) increasing salinity levels of the Delaware River could negatively impact power stations, water treatment plants, food and beverage manufacturers and oil refineries [9].

Empirical studies in cities around the world reveal industrial interferences from climate impacts on the provision of electricity. Brazil, which is highly dependent upon hydroelectricity, is particularly vulnerable to changes in precipitation patterns that could result in water scarcity and energy shortages [10,11]. Ningbo (China), the fourth largest port in the world, could experience energy shortages as more frequent and intense extreme heat events strain the electricity network [11,12]. Energy shortages can impair industrial activity and limit economic growth.

Recent analyses suggest that significant costs can arise as a result of extreme climate events disrupting industrial activities. Although precise estimates of these costs are uncertain, current trends indicate that changes in climate will negatively impact urban economies. Many industries cease operations during flooding, resulting in missed deadlines both domestic and international. In Dhaka (Bangladesh), estimates of losses to large-scale industry from the 1998 floods total US$ 30 million, while losses to small and medium size industry total US$ 36 million. Flooding in 2004 impacted more than 681 garment factories causing an estimated US$ 9.1 billion in damages [13••].

Tourism

Climate influences the length of tourism seasons, destination choices and spending, and the quality of local environmental resources (e.g. reefs, biodiversity), which in turn impacts the flow of tourists [14]. Sea level rise in conjunction with an increased intensity and frequency of extreme coastal storms may affect coastal cities dependent on beach tourism, for instance Rio de Janeiro (Brazil) [15]. Extreme climate events and the redistribution of climate-based resources can impact physical infrastructure as well as operating costs and business costs of tourism activities. Changes in climate could significantly impact traditional tourist destinations. Evidence suggests that preferred destinations are likely to shift to higher latitudes and elevations in mountainous areas with tourists in temperate nations, who currently comprise the majority of travelers, likely to spend more holidays within their home country or nearby [15]. Changes in environmental conditions — including reduced water availability, loss in biodiversity, and increases in vector borne disease — can impact critical local resources for the tourism industry. Evidence suggests societal changes, such as perceived safety or political stability of a region, may be indirectly affected by climate change [16,17]. Recent research focuses on particular at-risk environments and climate related attractions. There remains a need for specific attention to impacts on urban tourism.

Retail and commercial services

'Climate change holds the potential to impact every link in the supply chain, including the efficiency of the distribution network, the health and comfort of the workforce, and patterns of consumption ([14,18], p. 368)'.

Case studies show that transportation infrastructure in coastal areas is vulnerable to sea level rise and extreme climate events. By 2100 portions of the transportation network along the eastern seaboard of the United States could be under water as a result of sea level rise or at risk of inundation due to storm surge events. Significant portions of the road and rail network are at risk in the Washington, DC area, as well as port property in Maryland, Virginia, and North Carolina [19••] (Table 1). The impacts of disruptions to even small portions of the transportation infrastructure can be large due to network effects.

By 2050 in Boston (US), the elevation of the 2005 100 year storm surge event may occur every 15 years or less. Flooding is likely to impact highly developed areas including Boston Logan International Airport with the associated economic costs being severe [20].

Much of the freight traffic in the US comes through major coastal cities that are vulnerable to sea level rise and changes to precipitation patterns [21] (Table 2). Six of the top 10 freight gateways are considered vulnerable to sea level rise and seven of the 10 largest ports are located in the Gulf of Mexico [22].

Insurance

The insurance industry is vulnerable to climate change as a result of two factors: first, increasing intensity and frequency of extreme climate events and second, population growth and rising real estate values in hazard-prone areas. To remain financially viable, insurers must reliably

Table 1

Percentage of transportation at-risk and impacted by regular inundation through storm surge in four US states, assuming a sea level rise of 59 cm in 2100.[a]

	Washington, DC		Maryland		Virginia		North Carolina	
	RI[b] (%)	AR[c] (%)	RI (%)	AR (%)	RI (%)	AR (%)	RI (%)	AR (%)
Length								
Interstates	0	5	0	0	0	1	0	0
Principal arterials	0	4	0	1	0	1	1	1
NHS minor arterials	0	0	1	4	0	0	2	2
National highway system	0	5	0	1	0	1	2	2
Rails	0	5	0	1	0	1	0	1
Area								
Ports	0	0	20	12	11	24	12	35
Airport property	0	0	1	1	2	3	1	2
Airport runways	0	0	0	0	2	3	0	2

Source: Ref. [62].

[a] In the table 0% does not mean there is no effect but instead is a product of rounding. Regularly inundated areas and areas at-risk are mutually exclusive.
[b] Regular inundation.
[c] At risk.

Table 2

Top 10 US foreign trade freight gateways by value of shipments, 2005.

Rank	Port	Mode	Shipment value ($ billions)
1	John F. Kennedy Airport, New York	Air	134.9
2	Los Angeles, California	Vessel	134.3
3	Detroit, Michigan	Land	130.5
4	New York, New York, and New Jersey	Vessel	130.4
5	Long Beach, California	Vessel	124.6
6	Laredo, Texas	Land	93.7
7	Houston, Texas	Vessel	86.1
8	Chicago, Illinois	Air	73.4
9	Los Angeles International Airport, California	Air	72.9
10	Buffalo-Niagara Falls, New York	Land	70.5

Source: BTS [22], p. 39.

predict the frequency and severity of insured losses to properly price and spread weather-related risk [23] and must be able to set insurance premiums on the basis of expected, rather than historical risk.

Independent of climate change, insurers' exposure to extreme climate events has been increasing as more individuals and businesses move to hazard-prone areas. The exposure of the National Flood Insurance Program (NFIP), a US federal insurance program, has quadrupled to almost $1 trillion between 1980 and 2005 because of increasing development of coastal areas and rising real estate values [24].

Hurricanes are the most damaging event faced by the insurance industry, accounting for 45% of all insured weather-related losses between 1980 and 2005. Because of increased risk exposure, expected insured loss from a one-in-one-hundred year hurricane has increased from $60 billion in 1995 to $110 billion in 2005 and is expected to increase to $200 billion in the next 10 years [25]. If the great Miami (US) hurricane of 1926 occurred around the 2020s, damages would total around $500 billion [26].

Social impacts of climate change

Health effects

Research indicates that some environmental stressors related to climate change have both immediate and lasting impact on the physical and psychological health of urban residents (Table 3). Chief among these stressors are severe weather events, extreme heat and disease transmission. The structures of cities have the potential to exacerbate these climate-related health risks. For example, urban form results in increased air temperature due to the urban heat island effect, more intense precipitation and thunderstorms, and in some cases reduced natural drainage [27–29].

Severe storms and bouts of heavy precipitation claim lives, cause injury and can leave significant proportions

Table 3

Recent research on climate change impacts on urban health.

Urban health impacts	Climate-related contributors	City-level studies
Water contamination/ water scarcity	Sea level rise	Mombasa (Kenya) [36]
	Drought	Alexandria (Egypt), Tunis (Tunisia), Casablanca, Bouregreg (Morocco) [43] Kampala City (Uganda) [28] Delhi, Mumbai, Kolcutta (India) [42] Chennai, Cochin (India); Chittagong (Bangladesh); Ningbo (China) [54]
Food scarcity	Drought Variable precipitation	Kampala City (Uganda) [28] Mombasa (Kenya) [36] Accra (Ghana) [39]
Severe flooding	Sea level rise Intense precipitation	Alexandria (Egypt); Tunis (Tunisia); Casablanca, Bouregreg (Morocco) [43] Rio de Janeiro (Brazil) [4••] Accra, Kumasi (Ghana); Maputo, Matola (Mozambique) [39] Buenos Aires, Pergamino (Argentina); Viacha (Bolivia) [49] Kampala City (Uganda) [28] New York City, Los Angeles (US) [48] Durban (South Africa) [35] Bangkok (Thailand); Chennai (India); Chittagong (Bangladesh); Ho Chi Minh (Vietnam); Ningbo (China) [54] Lagos (Nigeria); Nairobi (Kenya) [39]
Weather-related disasters (cyclones, landslides)	Intense precipitation Intense tropical storms	Caracas (Venezuela); Quito (Ecuador); central district of Honduras [49]
Spread of disease	Temperature change Variable precipitation Intense precipitation	Maputo, Matola (Mozambique) [39] Kampala City (Uganda) [28] Mumbai (India) [42] Durban (South Africa) [35] Bangkok (Thailand); Chennai, Surat (India); Chittagong (Bangladesh); Da Nang (Vietnam) [54] Santa Cruz (Bolivia) [37]
Heat-related illness and mortality	Temperature change	New York City (US); Montreal, Ottawa, Toronto, Windsor (Canada) [48] Detroit, Philadelphia, New York City, St Louis, Washington (US) [33] Boston (US) [32] Durban (South Africa) [35] Hangzhou (China) [54]

of affected populations homeless. During the past two years, these effects were illustrated by floods across cities in the Philippines, Pakistan and north-eastern Brazil. In addition to physical injury, psychological harm including post-traumatic stress disorder, anxiety, grief and depression have been observed to increase following storms and other disasters [30]. As the intensity and frequency of storms and severe precipitation increase, ever more urban residents will be at risk of injuries and illnesses that affect their lives and livelihoods.

Extreme heat is one of the deadliest weather phenomena, affecting residents of cities around the world. As temperature variability increases with climate change, more cases of heat-related illness and mortality may occur [31–33]. There is also evidence that changing temperature and precipitation patterns will alter the distribution of disease vectors (e.g. mosquitoes carrying malaria), potentially increasing the incidence of diarrheal and infectious diseases [34••].

Food and water scarcity

Increasingly, empirical and modeling analyses indicate the potential for climate change to create new food and water shortages and to exacerbate them where they currently exist. Persistent and seasonal water shortages exist across many large cities (e.g. Delhi (India), Durban (South Africa), Mombasa (Kenya)) [35,36]. As precipitation becomes more variable and demand for water rises, water scarcity will become an ever more salient issue. Likewise, floods, droughts and severe precipitation have caused damage to urban food sources, increasing the already prevalent issue of food scarcity [36]. Across Latin American cities, which generally have the most pronounced income inequality in the world, climate change is expected to increase the number of people at risk of hunger and to exacerbate existing water scarcity issues [37].

Livelihood impacts

Extreme climate events and slow-onset change can interfere with the ability of individuals and households in

urban areas to sustain livelihoods. Severe weather events can destroy a wide range of assets that residents rely upon to maintain their livelihoods including natural resources, health, infrastructure and financial capital [38]. Impacts from a single storm or heavy precipitation event can limit economic activity for weeks or months (e.g. [39]). As previously discussed, slow-onset climate change can shrink industries that communities have traditionally relied upon for employment. This is especially relevant for tourist communities, for instance Mombasa (Kenya), Rio de Janeiro (Brazil), Tallinn (Estonia) and Venice (Italy) [36,15,40].

Livelihood impacts are particularly severe for the urban poor, directly affecting their ability to buy food, pay bills and interact with their community. When their sources of income are disrupted, poor families often are forced to sacrifice nutrition, children's education or any remaining assets to meet their basic needs [2,41].

Displacement

Analyzing current urbanization trends and anticipating future migration patterns is a prominent body of research focused on limiting social problems (e.g. conflict, resource scarcity) that occur if climate change induces environmental migration. Studies have implicated environmental and climate-related issues in migratory events worldwide. Migration to Indian megacities occurs in part because of an economic transition from agriculture toward industry [42]. In coastal North African cities, a declining rural water supply is expected to be a push factor for urbanization over the next several decades [43].

Still, migration is a complex phenomenon that cannot often be ascribed to a single factor. And growth patterns among cities including drivers and settlement locations can vary widely across cities. For example, rural to urban migration has been a major component of urbanization across Africa and in Asia, whereas migration from one city to another is more common throughout the Latin American and Caribbean region [44]. Care should therefore be taken when making generalizations from studies of specific regions.

Distributional impacts within and among cities

Empirical studies show that particular groups within cities sometimes bear disproportionately large burdens of climate change based on gender, age and race. Because of different social roles and tendencies to take risks, men and women tend to have different rates of death and injury during climate-related disasters. In the developing world in particular, women are often more vulnerable because of restricted access to land, information or aid following a disaster [45,46]. Physiological, behavioral and social characteristics of the young and elderly predispose them to risk of injury and death during severe weather events, particularly when they or their families are poor [31,47].

The urban poor are particularly vulnerable because of limited assets, low income and restricted access to both public and private insurance. Within any urban area, poorer groups typically face disproportionate risk of climate events because they reside in particularly exposed areas, occupy low-quality housing, or have limited legal and financial protection in the case of a disaster [48]. Unlike their wealthy counterparts, low-income households often lack the resources to mitigate damages after they occur, for instance through health care, structural repair, communication, food and water [45]. Because of these interactions between socioeconomic status and physical hazards, climate change may widen existing inequality and interfere with the eradication of hunger and poverty, thus leaving marginalized groups continuously vulnerable to further change.

There are generally profound vulnerability differences between cities in developed countries and those in developing countries, where climate change impacts tend to exacerbate poverty, food scarcity and disease [48,49••]. Rapid urbanization coupled with urban planning failures has forced large populations of the poor to live in slums and informal settlements, often cited in areas prone to flooding and landslides [41,50]. Overcrowded conditions, lack of air conditioning and insulation, and poor-quality housing often contribute to the disproportionately high levels of injuries and deaths that occur in these communities during severe weather events. Because residents often lack legal tenure, they sometimes choose not to evacuate even when aware of dangerous conditions, fearing they may not be allowed to return (e.g. [51]).

Regional studies reveal this is an issue for cities throughout Latin America [51], Africa [40,52], and Asia [2,53,54]. Mumbai's burgeoning low-income population and poor building quality make it difficult to prepare for and cope with sea level rise. In many Latin American cities (e.g. Mexico City, Quito, Caracas), lack of drainage systems and trash removal in informal settlements exacerbates flooding by blocking water flow [55]. As floods occur more frequently and associated damages accrue, the local economy suffers, trapping cities in a reinforcing cycle of poverty and climate-related damages.

While the proliferation of informal settlements primarily affects urban areas in the developing world, the interactions between climate change and income do not affect these regions alone. In affluent countries as well, the urban poor tend to live in the least protected areas [48]. Access to insurance is generally more inclusive in cities in developed countries, but low-income individuals can be excluded by prohibitively high costs. Relatively few studies have focused on income effects of climate change in wealthy cities. Recent reviews also highlight the need for studies that evaluate the variation of vulnerability within low-income groups [56,57] and

that quantify the spatial aspects of urban vulnerability [58].

Discussion

A significant discussion exists within the literature on appropriate methods to quantify the economic costs of climate change. Reports from organizations such as the UNFCCC, World Bank, and others are criticized as significantly underestimating the costs of adaptation, resulting from several factors, such as first, non-inclusion of sectors, second, partial coverage of sectors included, and third, the use of 'climate mark-ups', an idea first put forth by the World Bank that estimates future adaptation costs by approximating the cost of 'climate proofing' current climate sensitive investments [59]. However, in much of the developing world investment levels are well below optimal levels today and by anchoring future estimates on current investments, studies stand to significantly underestimate the costs of adaptation. To circumvent issues such as these, future research should utilize bottom-up, detailed case studies across many places and sectors, in conjunction with a top-down, overarching framework. To allow for aggregation across sectors, regions and time, these case studies will need to be based on a common theoretical and methodological approach.

The unique nature of interrelated social and economic climate change impacts within urban areas is becoming increasingly clear through empirical research. Two main themes regarding these impacts emerge from this review. First, climate change has the potential to act as a 'threat multiplier' on the varied social and economic challenges currently facing cities [60]. Cities around the world are confronting poverty and hunger, increased demand for resources and economic recession irrespective of climate change. Evidence suggests that climate change will in many cases make it more difficult for cities to meet these challenges, namely by perpetuating poverty, further straining already limited resources, all while making the delivery of services more difficult. Second, climate change risks often appear to compound with these existing challenges, and with one another, in their impacts on cities. For example, the distributional effects of climate change in cities around the world can magnify socio-economic inequalities, making it more difficult to enact policies that encourage equitable, sustainable societies. Rapid urban population growth places demand on resources, including drinking water, which may be declining in abundance or quality as a result of climate change. The combination of social impacts (e.g. loss of livelihood, displacement) and economic impacts (e.g. damage to industry) could have cumulative or multiplicative effects that eventually interfere with the function and activity of communities within urban areas.

The ability of urban areas to cope with these challenges depends on governance at a variety of levels (e.g. [61••]) and on adequate understanding of local underlying vulnerabilities. Future research should focus on quantifying climate change impacts on specific cities with attention to the most vulnerable groups and the variation within these groups. Increased understanding of the drivers and destinations of migration will become ever more important for future planning in cities. Finally, continued integration of social and economic aspects of climate change with physical risks will create a more complete picture of urban vulnerability.

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