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# Climate Change and Health in the Urban Environment: Adaptation Opportunities in Australian Cities

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## Abstract

Urban populations are growing rapidly throughout the Asia-Pacific region. Cities are vulnerable to the health impacts of climate change because of their concentration of people and infrastructure, the physical (geographical, material, and structural) attributes of the built environment, and the ecological interdependence with the urban ecosystem. Australia is one of the most highly urbanized countries in the region and its already variable climate is set to become hotter and drier with climate change. Climate change in Australia is expected to increase morbidity and mortality from thermal stress, bacterial gastroenteritis, vector-borne disease, air pollution, flooding, and bushfires. The cost and availability of fresh water, food, and energy will also likely be affected. The more vulnerable urban populations, including the elderly, socioeconomically disadvantaged groups, and those with underlying chronic disease, will be most affected. Adaptation strategies need to address this underlying burden of disease and inequity as well as implement broad structural changes to building codes and urban design, and infrastructure capacity. In doing so, cities provide opportunities to realize "co-benefits" for health (eg, from increased levels of physical activity and improved air quality). With evidence that climate change is underway, the need for cities to be a focus in the development of climate adaptation strategies is becoming more urgent.

## Keywords

adaptation, Australia, climate change, co-benefits, health impacts, urban environment

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## Introduction

In the past 30 years, the urban population in the Asia-Pacific region has increased by about 560 million people (or 260%), and in the next 30 years it is expected to increase by a further 1450 million people (or 250%).[1]

With the notable exceptions of Singapore and Nauru (both primarily "urban"), Australia is the most highly urbanized country within the rapidly urbanizing Asia-Pacific region, with 89% of its population (19 million people) living in towns and cities. Australia's population is projected to grow from 22 million currently to 35 million by mid-century. Sydney and Melbourne will each have 7 million inhabitants by this time, whereas the populations of Perth and Brisbane will double to 3.4 million and 4 million, respectively.[2] Migration to coastal towns and cities along the eastern seaboard is expected to continue, as the population ages. In Australia, cities are where climate change will have the greatest impact on population health. While climate change is expected to exacerbate existing urban health problems, cities also provide adaptation opportunities to improve on today's public health and not simply reduce negative health consequences.

The consumption patterns of growing urban populations are a driver of climate change, yet the density of cities also provides economies of scale and opportunities to reduce energy use for transport, housing, commerce, services, and infrastructure.[3] In Australia, most of this energy comes from the burning of fossil fuels. In all, 40% of domestic energy consumption is from coal and 34% is from petroleum. Only 5% of energy consumed is produced from renewable sources.[4] Consumption continues to grow, although the rate of growth has declined in recent years. Goods transport between Australian cities—sometimes thousands of kilometers apart—is largely by road.

Urban environments are especially vulnerable to particular climate change impacts for reasons both structural (their location, design, materials) and social (concentrations of people, poverty, inequalities).[5] Several Australian cities, for example, experience extreme temperatures, tropical cyclones, or bushfires. Cities provide unique opportunities to rethink our approach to urban planning, development, and management in order to respond to the challenges of climate change. As a wealthy, highly urbanized country subject to extreme weather, Australia can provide a useful analogue for the potential consequences and opportunities elsewhere in the region.

## Health Impacts in Cities

Australia's climate is characterized by variability. Over the past 50 years, mean annual temperatures have increased by 0.7°C, and rainfall patterns (spatial, seasonal) have changed.[6] Future weather in Australia will not only be hotter but there will be more "hot days"—an increase in the number of days over a certain temperature threshold. It is expected that parts of Australia will experience more intense, prolonged, and frequent heat waves, as well as more intense storm events and rainfall interspersed with extreme dry season. The risk of flooding and bushfires will increase.[6] These changed weather patterns have health implications relevant to cities.

### *Thermal Stress*

Previously, models of temperature effects have focused on counting the projected number of days with temperatures >35°C. More recently, however, modeling in Australia and elsewhere shows that health effects become apparent at much lower maximum temperatures, depending on location,[7,8] and that nighttime minimum temperatures are at least as important as daily maximum.[9] Reduced nighttime cooling with global warming will enhance existing "urban heat island" effects, whereby daytime heat is trapped by densely built areas, which are slow to lose their heat in the relative cool of night. This leads to little overnight relief and a higher starting temperature the following day. Not only does excessive ambient heat increase mortality and hospital admissions for diagnoses related to chronic disease but increased admissions for mental health diagnoses and injuries resulting from assault have also been observed.[10]

Thermal stress impacts will be felt beyond that which is measured by hospital visits or mortality. The economic impact of lost workdays from heat events will be further augmented by reduced workplace productivity because of increased worker fatigue.[11] Industries most affected would be those that conduct their activities largely outdoors, such as the building sector, agriculture, and tourism. Increased temperatures may also reduce recreational physical activity,[12] contributing to Australia's already growing burden of chronic disease.[13]

## Air Quality

Motor car use is both a driver of global climate change and a significant cause of local pollution. Emissions are concentrated in urban areas, reducing air quality. Mortality and morbidity due to air pollution are expected to increase as global warming effects amplify concentrations of particulate matter, volatile organic compounds, and ozone.[14,15] There is also potential for increased aeroallergens from plants[16] and smoke particulates from more frequent or intense bushfires and a prolonged bushfire season[17] (see Beggs and Bennett, this issue).

## Urban Vectors

Climate change is expected to increase the transmissibility of a number of vector-borne diseases. Of particular concern in the urban environment is the dengue virus, which is transmitted by the urban-dwelling mosquito, *Aedes aegypti*.[18] Climate change has the potential to increase mosquito-borne disease as warmer temperatures shorten mosquito developmental time, improve survival (especially if humidity is also increased), increase feeding frequency, and reduce the external incubation period of the pathogen. A recent large and prolonged epidemic of dengue fever in two urban areas in Australia illustrates the capacity for climate impacts on vector-borne disease to impinge on urban public health.[19] The current distribution of dengue in Australia is restricted to the far north of Queensland, but scenario-based modeling of dengue in Australia suggests that transmission risk zones will expand to include large population centers to the south and west of the country in coming decades.[19]

## Enteric Pathogens

Warmer ambient temperatures are likely to increase the incidence of bacterial gastroenteritis. There is strong evidence of a relationship between ambient temperature and *Salmonella* infection in Australia[20] and elsewhere.[21,22] *Salmonella* notifications peak in summer and the rate of notifications has been shown to be positively, and largely linearly, associated with the mean temperature of the previous month[20] or week.[21,22] Although some of the excess summer cases may be because of changed eating behaviors (more "eating out" and attending outdoor functions), *Salmonella* appears to be highly sensitive to small changes in temperature, and ambient temperatures contribute directly to pathogen multiplication in foods and thus to likelihood of infection.[22,23]

Modeling for Australia suggests that annual cases of *Salmonella* infection could increase by approximately 3% by 2020 and 14% by 2050.[7] When other bacterial pathogens are included, the annual health and economic costs rise to 335 000 new cases, 1.6 million lost workdays, and $92 million in health and surveillance.[7] Summer peaks in incidence may be more prolonged, as well as higher, and seasonal patterns of peak infections may change.

### Other Health Impacts

Prolonged drought affecting major food producing regions could reduce the availability of fresh produce and drive up costs, with implications for food security.[24] In wealthier countries such as Australia, these impacts would be felt most strongly among more disadvantaged groups living in expanding urban areas with little access to local produce or opportunities to grow food themselves[25] (see Dixon et al, this issue), who already have high rates of chronic disease. The increased intensity and frequency of bushfires may not only have health consequences because of their impact on air quality but also endanger lives and property, especially on the urban fringe.[17] Urban mental health[26] and well-being may be affected by climate change through reduced social opportunities and limited connection to the natural environment (eg, if “escaping” from excessive heat means not venturing outside). Trauma from violence[10] associated with excessive heat (perhaps via an intermediary of excessive alcohol consumption) may also increase. The burden on health services and emergency transport[10] may increase as demand for secondary and tertiary care rises in response to acute events such as heat waves, heavy air pollution days, and epidemics, especially through emergency admissions. Demand could increase in the primary health care sector also (ie, general practice and community health centers) in response to greater need for management of chronic conditions such as asthma.

## Inequalities and Vulnerability

The health impacts of climate change will not be evenly distributed. Urban vulnerabilities are highly variable and depend on specific geographic, demographic, health, and social contexts.[7,27,28] Existing disease burden and social characteristics of the population are especially important in driving health outcomes. For example, existing chronic disease increases mortality risk during hot weather. McMichael et al[8] found in their multicity study a consistent U-shaped relationship between temperature and cardiorespiratory mortality (increased deaths at both colder and warmer temperatures). Obesity and its related diseases, such as type 2 diabetes and heart disease, are already highly prevalent and increasing in Australian urban populations because of low levels of physical activity and overconsumption of energy-dense food. More than half the population in Australia is now overweight or obese,[29] with obesity prevalence having tripled to 21% within the space of 3 decades.[30] Older people are more likely to have existing chronic disease and often multiple comorbidities. The proportion of people in Australia aged older than 65 years is expected to double by 2050 to more than one in four,[31] and this population ageing will act as a multiplier making the future population especially vulnerable to heat effects. Air pollution also affects those with an existing condition, whereas aging and illness not only increase exposure to enteric infection (such as through institutional living) but also reduce physical resilience for recovery. Cases of gastroenteritis among the elderly in Australia will probably become more frequent as the population ages and the climate warms.

The social isolation and relative disadvantage of some urban subpopulations increase their vulnerability to climate change health impacts, such as heat waves. Risk of death during heat waves is reduced with access to transport, having friends or activities nearby, and air-conditioning.[32] Lack of mobility and independence among the elderly have been highlighted as risk factors,[33-35] as has poor housing quality (multiple stories, high uninsulated thermal mass, inadequate insulation).[33] Heat wave deaths have also been linked to features of the urban landscape that affect its microclimate (asphalt, high density, buildings that reduce airflow, and little “greenspace”) that contribute to the “heat island” effect.[32,36] Vulnerability is further linked to perceptions of the surrounding neighborhood as unsafe,[37] and poorer neighborhoods may have more unfavorable microclimates.[38] Those who are homeless may be especially vulnerable and inadequately accounted for in cities as they tend to have poorer underlying health and are less protected from the environment,[39] and often have limited access to mainstream health services. The increasing costs of fresh food and domestic energy will have a disproportionately greater impact on more disadvantaged groups, reducing food security and potentially enhancing exposure to the elements through inadequate access to heating and cooling.

## Adaptation Opportunities

Given the uncertainties that prevail in determining the precise impacts of climate change, a further desirable characteristic of adaptation strategies is that they provide additional and substantive co-benefits to population health and well-being. In other words, adaptation actions serve to improve population health and quality of life *no matter what climate impacts eventuate*. If the approach to adaptation planning considers the complexities of a city as a system it could incorporate complementary strategies to reduce greenhouse gas emissions (mitigation) and to minimize and respond to the health impacts of inevitable warming already set in train by past emissions (adaptation).

### *Addressing Chronic Disease Burden*

Reducing overweight and obesity in the urban population is a leading example of such "no regrets" action that will make a fundamental difference to the health burden from climate change. Currently, high body mass index (a measure of body weight relative to height) is the third largest contributor to morbidity and mortality in Australia (behind tobacco and hypertension) contributing to 7.5% of the total burden of disease.[40] Reducing the prevalence of overweight and obesity in the Australian population has clear public health benefits even in the absence of climate change, including reducing the burden of chronic disease associated with population ageing. Lifestyles that promote or prevent obesity are in part shaped by the environment and contexts in which people live.[41] This highlights the need to develop policy that promotes social capital and cohesion in our cities and for public health messages to reach those most in need of behavioral change. The most effective strategies to reduce chronic disease would therefore apply an integrated approach to urban design and infrastructure, building social capital, and delivering effective health promotion.

### *Urban Design and Transport*

Improving urban transport systems and connectivity toward more active transport is another "no regrets" strategy. Public transport needs to be efficient (timely, reliable, and accessible) and affordable. The resulting increased physical activity would not only reduce overweight and obesity but also decrease urban air pollution and, importantly, mitigate global warming through lower emissions.

The overall design of the urban environment shapes its use. High-density communities with mixed land use and good connectivity promote higher rates of active transport such as walking and cycling for everyday purposes than low-density, poorly connected, and single land use neighborhoods.[42,43] Minimal urban sprawl and greater concentrations of people and services means that "active transport" such as cycling and walking become more attractive and viable alternatives to motorized transport.[44] While pedestrians and cyclists are exposed to serious injury in traffic accidents with motor vehicles, the risk of accident decreases per kilometer with an increase in active transport, as long as safety is considered in urban planning.[45] Incorporating activity into daily routines (incidental exercise), rather than quarantining targeted episodes of activity, may be the best way to meet recommended activity guidelines.

## Buildings

Several cities in Australia already swelter under heat wave conditions each summer. Ensuring building orientation, design, and materials appropriate for the climatic conditions would mitigate the effects of rising energy costs by reducing an otherwise increasing demand for energy and decrease greenhouse gas emissions from cheaper, dirtier energy sources. New houses and suburbs should be built to protect their inhabitants from extreme events (eg, heat, heavy rainfall and flooding, wind, bushfire) and should have the means to capture renewable energy (solar) and recycle water. If such features were to be more comprehensively mandated, the demand would drive technological improvement, efficiencies, and affordability. Significantly though, there remains the legacy effect of existing poor-performing buildings. Such buildings could be retrofitted to some degree (eg, improved insulation, solar panels) to improve their protective qualities and reduce emissions from energy use.

## Energy

In addition to building codes that promote building performance to reduce reliance on external energy to protect against extreme heat (eg, air-conditioning), switching to low-carbon electricity sources would bring significant and immediate health benefits to urban populations by reducing concentrations of small particles ($PM_{2.5}$). Markandya et al.[46] modeled a reduction in years of life lost (YLL) in India of 1492 per million by 2030, 8% less than today, if low-carbon electricity were adopted to meet global emissions reduction targets of 50% by 2050. This compares to an increase of 10 000 YLL (46% increase from today) under "business as usual."[46]

## Water

The impacts of climate change on urban water resources will be most strongly felt in southern and eastern Australia,[47] where lower rainfall and increased evaporation will reduce runoff and the supply of water in urban catchments. At the same time, increasing temperature and more frequent and severe heat events, combined with population growth, will increase urban water demand. A number of Australian cities are currently assessing the features of their urban system that are most vulnerable, thus facilitating investment in appropriate interventions. Determining patterns of water movement through cities and developing opportunities to limit loss and provide sufficient water for human and environmental needs would benefit already water-stressed Australian cities. This approach is referred to as creating "water-sensitive cities"[48] and involves innovative water capture, treatment, and reuse technologies as part of an integrated strategy. There remains concern, however, about the possible health and environmental effects of water reuse, which need further investigation.

## Early Warning Systems and Local Responses

A simple, city-specific, heat wave warning system based on forecast temperatures has been recommended by Nicholls et al.[9] Such early warning systems could provide notice to individuals and carers to be on alert during expected hot periods. Averting deaths from heat impacts is a good example of where local knowledge and local strategies can be very effective. For example, some local councils may advertise readily accessible "coolspots," or organize monitoring of known vulnerable people in the area (such as older people living alone).

### Public Health Surveillance and Response Capabilities

Surveillance of the health impacts of climate change relies on sound public health surveillance and monitoring. The likelihood that additional resources will be required for surveillance of infectious diseases with enhanced transmissibility under climate change conditions, for example, needs consideration, as does developing increased flexibility within the public health system to more readily respond to extreme events. In the case of dengue, for example, outbreaks will probably become more difficult to control as the climate changes. This is because warmer temperatures (to a threshold of about 40°C[49]) speed up vector development, increase feeding frequency and survival, causing denser vector populations, and reduce the extrinsic incubation period of the virus. The combined temperature effects on vector and virus increase the transmission potential, that is, opportunities for infection. Geographic regions under surveillance may need to expand to include other urban areas and control measures must be implemented swiftly. Regulatory action to reduce potential breeding habitats should be considered well in advance, such as adequate screening of domestic water tanks to inhibit oviposition by mosquitoes, even if global warming is kept to a minimum by strong emission reductions. Such changes would bring benefits beyond those linked to climate change, particularly as more cases would occur in the future simply because of population growth. Importantly, the example of dengue illustrates how attempts to adapt to climate change could potentially be maladaptive, with the widespread installation of domestic water tanks in urban areas (to mitigate drought effects) providing potential vector breeding habitat.[50]

Transmission of enteric pathogens can be reduced with proper food handling and storage and good hygiene. Regulation and enforcement of appropriate standards alongside public education campaigns to promote good practice could reduce the impact of warmer ambient temperatures. Practices at institutions such as hospitals and aged care facilities may require regular monitoring. An integrated system of food tracking from origin, throughout manufacture and transport, and rapid response to outbreaks, would facilitate recall of contaminated food. Such measures would increase the costs of surveillance and control.

### Social Capital and Disadvantage

Perhaps as important as the structural characteristics of the built environment is the social nature of the city. A relevant health outcome of social cohesion, community functioning and active social networks is reduced vulnerability among older people during heat waves. Such opportunities are likely to be more informal in their emergence but require a good structural base; urban design affects access to public space and opportunities to meet others while out walking, for example. Future urban planning could thus consider the downstream effects of safer neighborhoods (eg, build so people can see and access the streets) for promoting social interaction. Adger et al[51] have proposed a vulnerability "hotspot" approach to inform effective adaptation strategies which involves identifying vulnerable populations (eg, the urban poor) and their current coping strategies, so that integrative, multifactor approaches to adaptation can be developed. Federal, state, and local stakeholders could work together to develop methods and management approaches appropriate for different social and economic trajectories.[51]

**Table 1.** Examples of Urban Policy Responses to Selected Health Impacts of Climate Change

| Health Impacts of Climate Change | Urban Policy Responses | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water | Housing, Buildings, and Surrounds | Land Use | Transport | Energy | Health Systems | Other |
| Thermal stress | Sufficient supply available for direct physical cooling (swimming pools, cool showers) | Building codes, including orientation, thermal properties<br>Retrofitting, including insulation | Greening the city: public shade and "coolspots" | Active travel policies (reduced chronic disease burden and vulnerability) | Affordable, reliable energy for artificial cooling | Heat wave early warning systems<br>Heat wave respite centers<br>Service planning (seasonal/ in response to a forecast event) | Reduce social disadvantage<br>Neighborliness and neighborhood safety<br>Social capital |
| Air quality | | | Antisprawl policies and mixed use urban design | Active travel policy (reduced local pollution, reduced chronic disease burden and vulnerability) | Renewable "clean" energy generation | Air pollution warning systems<br>Service planning (seasonal/ in response to a forecast event) | |
| Urban vectors | Screen household water tanks<br>Capture urban runoff | Flyscreens<br>Improve drainage | | | | Arboviral surveillance and control | |
| Enteric pathogens | Monitor supply quality | Design of food preparation areas in institutions | Produce food locally (shorter, simpler route to the table) | | | Improved traceability and recall | Food safety regulations, audits, education |
| Food security | Appropriate irrigation | Growing food on buildings | Provision for urban agriculture | Fewer "food miles" | | | |

## *Other Opportunities*

Suitable investment in emergent technologies is an additional strategy to mitigate and adapt to climate change in the urban environment. For example, advancing communications and information technologies promote more telecommuting, whereas hybrid and alternative energy sources for cars would enable personal mobility while reducing emissions.

There is also an urgent need to identify the ways climate change and land use change (eg, rapid urbanization) is affecting urban biodiversity and ecosystem services at local to city-wide scales and to develop strategies for the long-term management of green assets.

Community engagement to determine most appropriate strategies from the local level should become a focus of adaptation. For example, bushfire preparedness and management should incorporate knowledge of community, government, and industry groups to identify impacts on community safety, especially at the urban interface.

Examples of possible policy responses to climate change health impacts in cities are shown in Table 1.

### *New Directions for Modeling and Monitoring Impacts and Adaptation*

Future modeling of heat impacts would no doubt benefit from incorporating specific population responses (eg, by age group, suburb, socioeconomic status, existing disease) to more detailed climate data (changes in nighttime minimums as well as maximum temperatures and numbers defined "hot" days) rather than just modeled averages over large geographic areas. The developing field of geographic information science has much to offer in providing spatial analytical perspectives, data, and technologies to understand options for climate change adaptation. It facilitates the multidisciplinary decision making for complex and interrelated exposures and outcomes related to climate change, and it promotes collaboration among researchers and practitioners. Geographic approaches can assist adaptive management approaches and interventions in the urban environment by combining social and ecological datasets. For example, land cover data sets (such as greenspace) or thermal imaging can be overlayed with sociodemographic or health data (such as age distributions or hospitalization data) to highlight especially vulnerable areas and generate hypotheses about health outcomes and to monitor and evaluate interventions.

## Conclusions

The rapid growth of cities in Australia and elsewhere in the Asia Pacific provides both challenges and provides opportunities for climate adaptation. At the current state of the science of climate change modeling, future changes in climate variability (most likely) are more difficult to model than are changes in average conditions. Our knowledge of climate change vulnerability and, therefore, adaptation options, is not well developed. Understanding vulnerabilities and adaptation strategies involves interdisciplinary approaches linking physical, ecological, and social science. A further challenge to planning for climate change in cities is limited availability and scope of city-scale modeling of potential impacts, and these do not deal with impacts and vulnerabilities in an integrated way.[52] New, unexpected vulnerabilities may continue to emerge that have not been considered.[53] Socioeconomic development will influence both climate change scenarios and adaptive capacity, whereas different adaptation options will affect socioeconomic trajectories. Decision making should thus be based on adaptive management strategies and risk-based approaches that allow for action in the face of best available, and constantly evolving, knowledge while working to manage complex trade-offs.[54]

A number of governance issues can be addressed in adaptation planning, including decision-making processes that integrate current climate change science and consider the implications and potential impacts of decisions about long-term strategies.[54] Participatory approaches to help stakeholders (such as land use planners and infrastructure developers) identify areas where early adaptation is one possibility,[55] as is supporting institutional arrangements for linking federal, state and territory, and local responses to climate change, vulnerability, and adaptation. All these goals could be pursued as "no regrets" adaptive management strategies that are flexible enough to incorporate new developments in climate change science and social and economic trends.

Another key challenge is the need to communicate effectively with specific stakeholders and the public at large. There needs to be a robust understanding of why the climate is changing, how cities are affected, and the health implications of these changes. Beyond understanding climate change and its impacts, there is a strong need to work with community and other stakeholders to identify mitigation and adaptation strategies that the community can support and in which they can participate.[56]

Reducing underlying disease burden will likely have the greatest impact on reducing the negative health consequences of climate change and is the quintessential “no regrets” approach. Although more appropriate building regulations to improve the thermal properties of residences, in combination with passive solar retrofitting, could reduce heat-related deaths, in the longer term, appropriate action would be to improve urban design (such as provision of cool, green spaces and easy access to services) and service provision (including transport) to improve mobility and perceptions of safety. Growing cities are where more structural changes such as these could most readily be implemented. As governments around the Asia-Pacific region begin responding to the challenges of climate change, there is an opportunity to integrate into these responses new understandings of relationships between ways of living in cities and health outcomes, striving concurrently for healthy and sustainable cities.

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