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REVIEW

Impact of climate change on human health: adaptation challenges in Queensland, Australia

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ABSTRACT: The purpose of this article was to explore the impacts of climate change on human health in Australia in general, and the state of Queensland in particular. We evaluated health-related services and adaptation challenges in the health sector and indicate possible remedies. The scientific consensus on the evidence for anthropogenic climate change is convincing. Climate change will have potentially devastating human health effects including increased morbidity, mortality and injury in the near future. Its impacts will be unevenly distributed among geographical regions and population groups. The elderly, children and people who are chronically ill and economically disadvantaged will be more vulnerable than others. Adaptation is a valuable tool for minimizing the effects of climate change on human health, but the mechanisms involve various societal, cultural, economic, political, environmental, information and technological challenges that need to be addressed rigorously and cautiously. Developing and designing appropriate healthcare systems to meet the challenges involved with adaptation is equally important in reducing the health effects of climate variability. There is an increased need for information about climatic impacts on human health and a need to increase institutional capacity, social and human capital, leadership, communication and partnerships as well as promoting stakeholders' engagement in the adaptation processes in order to ensure success.

KEY WORDS: Climate change · Health · Adaptation · Impact · Australia · Queensland

1. INTRODUCTION

With increased frequency and heightened intensity of natural disasters, climate change has been branded as 'the biggest global health threat of the 21st century' (Watts et al. 2018, p. 2482). Its impact is experienced the world over, mainly because of greenhouse gas (GHG) emissions in the atmosphere originating from the combustion of fossil fuels. During the last 100 yr, the global average temperature has risen by about 0.74°C. More alarming is that over the previous 40 yr, it increased by only about 0.2–0.3°C (IPCC 2007, CSIRO & BOM 2007). It is predicted that between 2030 and 2052, the global temperature increase is likely to reach 1.5°C if the current rate continues (Masson-Delmotte et al. 2018, Garnaut 2008). The number of 'hot days' (mean temperature >30°C) in Australian state capitals are predicted to significantly increase in the years to come (Table 1). Global warming, causing climatic variability, is also associated with significant changes in rainfall patterns, sea level rises, ice melts and natural disasters.

Australia is not immune to the effects of 'high-impact' climate extremes that endanger life and pose

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Table 1. Present and projected hot days (mean temperature >30°C) in Australian state capitals. Source: CSIRO (2008, p. 117)

Cities	Present	2030	2070	2100
Melbourne	9	12	22	27
Sydney	3.3	4.4	9	14
Brisbane	0.9	1.7	8	21
Adelaide	17	22	34	44
Perth	27	35	56	72
Canberra	5	8	21	32
Darwin	9	36	221	312
Hobart	1.4	1.7	2.5	3.4

threats to the environment and the economy (Metcalfe & Bui 2017). Climatic projections indicate more frequent heat waves per year, increased bushfires risks, more regular and intense droughts, increases in the severity and frequency of storms and coastal flooding, water shortages, loss of biodiversity, a decline in productivity of agriculture and forestry and damage to infrastructure (CSIRO & BOM 2007, Hennessy et al. 2007, Steffen 2009). According to Hennessy et al. (2007), the average temperature and the number of days over 35°C is increasing at a rate of 0.10 d yr^{-1}, threatening most areas with extreme heat and drought. In addition, rainfall patterns have been changing, with northern and western parts of Australia experiencing increased rainfall, and the sea level has been rising by 1.2 mm yr^{-1}.

The current climate in Southeast Queensland (SEQ) is mild and sub-tropical and typically features hot, rainy summers and mild, dry winters. While evidence of climate change is rapidly evolving, the present scientific estimates for 2030 indicate an increase in annual average temperature in SEQ of 0.2–1.6°C (Cai et al. 2005). The Fourth Assessment Report of the IPCC in 2007 identified SEQ as one of 6 'hotspots' in Australia because of potentially significant losses to the built environment as a result of rising sea levels, storm surges and flooding. The IPCC projects a sea-level rise of 0.18–0.79 m by 2100. Climate change could lead to an increase in the number of days above 35°C from 1 to 21 d yr^{-1} by 2070 (Hennessy et al. 2007) and reduce water availability in cities, industries, agriculture and natural ecosystems in this region (Queensland Government 2008, 2009).

In this article, we explored the impact of climate change on human health. We aimed to explain the various climatic phenomena and their effects, and highlighted the various diseases to which people are exposed. We also evaluated health-related services, adaptation challenges in the health sector and indicate possible remedies. While our focus was on the state of Queensland, we also made general observations pertaining to Australia as a whole. Recent climatic events with devastating consequences have highlighted the significance of understanding and reviewing the need to address the ramifications and implications of climate change in Australia.

2. MANIFESTATIONS OF CLIMATE CHANGE AND IMPACTS ON HEALTH

That climate change has been occurring is indicated by the frequency, magnitude and expanse of natural calamities. These events, known to humankind since the dawn of history, have become more ferocious, widespread and devastating in the last several decades. Climatic impacts are multidimensional, and are socially, economically and environmentally complex (Carey 2007, Tong et al. 2008, Baum et al. 2009, WHO 2017). In physiological, behavioral and cultural terms, the human population is acclimatized to their local climatic conditions. Every society and individual has a different level of tolerance that depends on their demographic and socioeconomic characteristics, living conditions and lifestyle, physical fitness and physiological state (Kovats & Akhter 2008, Kovats & Hajat 2008).

2.1. Climate change, climatic exposure and impacts

Socioeconomic, environmental and demographic factors strongly influence the consequences of climate change on human health (Preston & Jones 2006, Tong et al. 2008, Baum et al. 2009). Moreover, institutional and economic development, technological advancements, population density and movements, deforestation and land-use patterns, loss of biodiversity, surface water fluctuations, behavioral adaptations and health system capacity are linked to climate change. Some of the natural disasters that impact human health include heatwaves, floods, high winds and thunderstorms, tornadoes, cyclones, storm surges and bushfires. Climate change can affect human health directly, through thermal stress or injury as a result of floods and storms, and indirectly, through changes in the distribution of disease vectors (via mosquitoes, food and water-borne disease) and the availability and quality of food, water and air (McMichael et al. 2006, Carey 2007).

2.1.1. Heatwaves

Temperature levels can have different impacts on human health depending on the duration and timing of heatwaves and the state of climatic acclimatization of the population. Heatwaves that occur in early summer usually tend to have a more significant effect than comparable temperatures later in the season (Carey 2007). The IPCC has projected that the increasing number of extreme heat events associated with climate change will lead to increases in heat-related morbidity and mortality (Woodruff et al. 2005, Confalonieri et al. 2007) (Table 2). In 2019, extremely high temperatures — nearly 50°C in some places — were recorded in Australia, compelling authorities to issue health warnings, air quality alerts and authorizing total fire bans (Hannam 2019).

The elderly, children, people who are overweight or who have chronic diseases such as diabetics, those with pre-existing cardiovascular, cerebrovascular and respiratory illness and people dependent on drugs or alcohol are particularly vulnerable to heatwaves, food and water-borne disease and air pollution (AIHW 2018). By 2051, 25% of Australians will be 65 yr of age or older, and there will be 7–9 million people in this group (ABS 2005).

Extreme temperature, increasing humidity and urban air pollution can aggravate pre-existing respiratory and cardio-vascular conditions (Haines et al. 2006, Markandya & Chiabai 2009, AIHW 2018). There may also be incidences of dehydration and hyperthermia. Heat exhaustion, resulting from a severe depletion of blood plasma, causes peripheral blood pooling and impaired thermoregulation when a person's body temperature increases beyond 40°C. Its characteristics include mild disorientation, generalized malaise, weakness, vomiting, headache, tachycardia and hypertension (English et al. 2007). High body temperature and disseminated intravascular coagulation cause cell damage in vital organs, such as the brain, liver and kidneys, leading to severe illness or even death (Yoganathan & Rom 2001). Even before such effects occur, lower level heat exposure can reduce work capacity, which can adversely impact the economy.

Table 2. Projected human death due to heatwaves. Source: Woodruff et al. (2005)

Cities	1997–1999 (baseline)		2100 Rate per 100 000	
	Temp. attributable deaths	Rate per 100 000	Lower range	Higher range
Adelaide	200	135	179	281
Brisbane	89	56	130	267
Canberra	14	64	106	234
Darwin	2	69	446	1407
Hobart	5	20	24	41
Melbourne	289	77	112	169
Perth	294	220	287	495
Sydney	176	40	79	239
All cities	1069	82	131	246

2.1.2. Floods

Heavy rainfall, causing flooding from overflows or the breaking of levees, can submerge land areas (Baum et al. 2009). The IPCC projects that severe floods will occur in Australia due to a 30% increase in average rainfall in flood-prone SEQ by 2040 (Hennessy et al. 2007). The Gold Coast and Broadwater regions are at risk during extreme rainfall events (Abbs et al. 2007). Drowning and injuries can happen when vehicles are swept away by floodwater. Baum et al. (2009) reported that flood fatalities comprise half of all deaths in Australia.

Flooding also has the potential to increase outbreaks of vector-borne diseases such as malaria, lymphatic filariasis and arbovirus, and contribute to mental health conditions such as anxiety, depression, irritability and sleeplessness (Ahern et al. 2005). Ingestion of contaminated water or contact with flood waters can result in the spread of communicable diseases caused by microbial and toxic agents, which can permeate the human body, causing sepsis (Patz & Koats 2002).

2.1.3. Thunderstorms, tornadoes and cyclones

Disruptions in the atmosphere can impact the earth's surface and lead to severe weather conditions like strong winds, lightning and thunder, heavy rain and hail. A severe hailstorm is a weather event that produces hail with a diameter of 20 mm or more (BOM 2019). Wind gusts of 90+ km h^{-1}, flash floods, tornadoes or any combination of these can accompany thunderstorms (BOM 2019) and can damage buildings and disrupt electrical and water supplies, as well as road and rail networks. Lightning can ignite fires that cause injury and death. Australia experiences several hundred tornadoes each year, with up to 10% of these being severe; most occur in

midwinter and early summer, especially in SEQ where large hail storms have had a catastrophic impact (Kaiser 2010, BOM 2019).

Tropical cyclones, some producing sustained gale-force winds at more than 120 km h^{-1}, are probably one of the most feared extreme weather events in Australia. Cyclonic activities appear to be associated with variation in the Southern Oscillation index, being more frequent in EI Niño periods and less frequent in La Niña years (Baum et al. 2009). On average, at least 10 cyclones develop over Australian waters each year and around 6 of these make landfall and have a devastating impact on agriculture, farmer income and infrastructure, affecting health due to injury and mental illness (AIHW 2018). Often, a combination of storm systems and high tides create a storm surge. Mean water levels can rise 15 feet (~4.6 m) or more, leading to extreme coastal flooding during storms when high tide is a normal occurrence (Fang et al. 2016). Such surges damage property (houses and businesses), disrupt the provision of drinking water and the distribution of food supplies and can cause drowning, bodily injuries and water contamination (Baum et al. 2009).

2.1.4. Bushfires

The Australian summer is generally hot, dry and prone to droughts that can endanger vast areas with bushfires. This was particularly severe in late 2019 and early 2020. In general, weather conditions at the location of the fire dictate its pattern. High winds contribute to the impact of the fire by increasing its spread by carrying burning embers further downwind. Changes in wind direction associated with cold fronts and local topography can also influence fire intensity (Middelmann 2007).

Bushfires severely pollute the air, causing respiratory problems, chronic obstructive pulmonary disease, pneumonia and acute bronchitis mainly in the elderly, as well as contaminating water and damaging the environment (Coghlan 2004, Johnston 2009, Morgan et al. 2010). These can result in increased psychological morbidity amongst fire-fighters and in communities experiencing loss of property and belongings (Fitzgerald 2015, Shepherd & Birch 2020).

2.2. Climate change, disease exposure and impacts

Changes in temperature, humidity, rainfall, soil moisture, and increasing sea levels can accelerate the spread of disease, and societal conditions and demographic factors can contribute to the spread of disease. Climate change may also lengthen the transmission season in many areas (Haines et al. 2006).

2.2.1. Vector-borne diseases

Vector-borne viruses will likely increase in Australia due to climate change (McMichael et al. 2006, Trewin et al. 2013). It was projected long ago that a 1.5°C rise in temperature and 10% increase in rainfall would lead to an increase in the extent of malaria into coastal Queensland (Bryan et al. 1996). Though malaria is not endemic to Australia, on average 750 cases were recorded each year between 1991 and 2001 (CDNANZ 2002). Currently, several hundred imported cases, especially among migrants returning from their country of origin, are reported annually. Cases of dengue are common (Queensland Health 2019). Most vector-borne pathogens are sensitive to changes in temperature. Each year in Australia, Ross River and Barmah Forest viruses cause several thousand and several hundred cases, respectively (Russell & Dwyer 2000). Projections of climate change indicate a substantial rise in the incidence and distribution of these viruses associated with increasing temperature and rainfall, especially in Queensland (Russell et al. 2009).

2.2.2. Food-borne diseases

A link between climate change and microbial food-borne disease is evident (Smith & Fazil 2019). There is also a positive correlation between seasonal and latitudinal temperature variability and the amount of food-borne and diarrheal illnesses (Craig et al. 2007). Climate change, together with changes in food production and distribution and consumer behavior, have the potential to affect food-borne diseases. In Australia, about 4 million cases of food-borne infectious diseases occur annually, and the rate is increasing. North Queensland is exposed to very high rates of *Salmonella* causing diarrhea and gastroenteritis infection (Hall 2002, Queensland Health 2019).

2.2.3. Water-borne disease

There is also a link between climate change and water-borne disease (Hunter 2003, McMichael et

al. 2003). Climate change may affect water supplies in terms of quality, quantity and availability, with SEQ facing water shortage in the future (Hennessy et al. 2007). Evaporation is likely to reduce freshwater resources, and saltwater incursion will likely increase due to higher mean sea levels. Harmful algal blooms may develop, and may become more frequent and longer lasting with the relatively hot conditions resulting from climate change. These blooms produce powerful biotoxins, which could be a threat to human health from contaminated drinking water and recreational water use (Carey 2007).

2.2.4. Ultra-violet light exposure

Evidence suggests global warming is likely to result in increased stratosphere ozone depletion, which creates an opening for ultraviolet (UV) light penetration. Exposure to UV rays is the leading cause of skin cancer (melanoma) and cataracts in humans. Australia's solar UV radiation level is one of the highest in the world (Olsen et al. 2015), causing one of the highest rates of skin cancer. Every day, over 1000 Australians are treated for skin cancer and every year over 1700 Australians die from skin cancer (AIHW 2016). There is a strategy in place for managing ozone depletion, but it has had a minimal effect, as Australians continue to develop various forms of skin cancer (ANU 2020).

2.2.5. Air pollution

Climate change and air pollution are interlinked through fossil fuel combustion, which is the basis for their detrimental effects (Hansen et al. 2009). Major pollutants in urban areas generally include particulate matter and gases such as ozone, oxides of nitrogen, carbon monoxide and sulphur dioxide. In Australian cities, the health effects of air pollution range from minor respiratory symptoms to increased hospital admissions and mortality (Kjellstrom et al. 2002). Hansen et al. (2009) reported that ambient air pollution was linked to congenital disabilities in Queensland. The interrelation of weather conditions and air pollution and their impact on human health is severe when linked to heatwaves, bushfires and windblown dust, all of which can worsen symptoms of severe asthma and cardiovascular disease (Nitschke et al. 2007, Hansen et al. 2009).

2.3. Mental health

Climate change and mental health are correlated (Few 2007, Berry et al. 2008, Frumkin et al. 2008). Extreme weather events cause severe mental health issues in vulnerable communities as they experience disruptions in healthcare along with emotional distress and anxiety about future environmental changes (McMichael et al. 2008). The severity of these effects depends on individual or community circumstances, such as emergency support mechanisms, availability of resources, and rebuild capacity (Fritze et al. 2008). Common mental health problems are acute traumatic stress, post-traumatic stress disorder, lingering grief, depression, anxiety, somatoform disorders and drug and alcohol abuse (Silove et al. 2006). In Australia, about 18% of the population suffers from some form of mental or neurological disorder (AIHW 2003, 2007).

The uncertainty of climate change can cause further distress among humans, and responses to threats are often complex. Information is unsettling, and solutions seem to be problematic. Understanding climate change and its future effects on human society and the economy can make people feel anxious, depressed, numb, scared, helpless, hopeless, frustrated and angry. However, over time people can gain knowledge and build their awareness about its social, emotional and spiritual effects of climate change (Fritze et al. 2008).

2.4. Queensland healthcare structure

The healthcare system must be able to perform well in all the desired functions related to climate-change situations. The system needs to be able to plan, prepare, organize and manage to meet challenges. Essential elements of health services preparedness include emergency medical services, provision of treatment, staff training, well-equipped health facilities, appropriate size and location of hospitals that are equipped with suitable materials, thermal insulation, heating and cooling systems and electric power (WHO 2008). To meet the growing healthcare demands, availability of an appropriately skilled workforce, and the ability to be linked and integrated with other relevant services would be required. This is a challenge for the mental health workforce, as mental health services are under-resourced to meet existing and future demands (Spickett et al. 2008).

Queensland's public health system (including state, local council health departments, community

departments in conjunction with the state's emergency response network) needs to assume responsibility for the development and implementation of health-related policies and guidelines designed to protect the public from the medical consequences of climate change. The government's Smart State Health 2020 plan provides a vision for a future health system for all citizens. The vision emphasizes the development and provision of the best health and health-related services in the nation (Queensland Health 2002). The state is faced with a growing population because of interstate and international migration. Half of the international migrants come directly to this state to settle and hundreds come from other states. This influx of people will also have an impact on the public health system.

There is also an aging population facing a growing prevalence of chronic and complex diseases such as heart ailments, stroke, cancer, diabetes, respiratory disease, musculoskeletal issues and mental conditions (AIHW 2011); and consumers' knowledge and expectations for quality healthcare are increasing (Queensland Health 2005, 2007). These problems will put additional pressures on the healthcare system.

2.5. Climate change and community groups

Climate change has different effects on different communities and geographic regions. The segments of the population whose health is at higher risk and who will be most affected by climate change include the elderly, young, disabled, homeless and people with chronic diseases mentioned before (AIHW 2011). Biophysical characteristics (such as the location of residence, exposure to extreme events, housing conditions, land use and land cover) and socioeconomic parameters (economic, health and nutrition status, power structure, access to information and technology, land tenure and access to rights) will also contribute to the effects of climate change (FAO 2011).

The indigenous population is more prone to climatic effects on health. The people of these communities do not typically have water and power supplies or sewage removal services, and there is a lack of employment and generally inadequate health services (AIHW 2016, 2018). Healthcare personnel are in short supply, and this has the potential to cause problems for indigenous communities and the general public. Indigenous males are more likely to die earlier from preventable diseases than non-indigenous males and indigenous females. Aboriginal and Torres Islander men die 22.5 yr and women 24.6 yr earlier, and the infant mortality rate is twice that of the general population (Queensland Health 2007). About 25% of Indigenous Australians living in regional and remote areas are more susceptible to effects of climate change, which can affect their mental state and physical well-being and disrupt their cultural practices (Smith 2004, Tylor 2006, Hennessy et al. 2007). Green (2006, p. 3) argued that 'when considering the likely health impacts from climate change on Indigenous Australians living in remote communities it is crucial to explicitly address the interconnections between the health of "country", culture and mental and physical well-being'.

Climate change will affect urban–rural settlements in different ways. Urban centers are often affected by urban 'heat islands', resulting in temperatures that are somewhat higher than the surrounding peri-urban and rural precincts. During heat waves, air pollution concentrations rise and contribute to increasing deaths (Haines et al. 2006). In urban areas, economically deprived people live in more unhealthy and hazardous conditions than their rural counterparts. It is typical of developing countries where people live with extreme levels of polluted air and water and in unhygienic conditions. They are subject to water shortages and loss of property and jobs as a result of disasters (Goodman & Iltus 2008). On the other hand, regional and remote communities can lack services, have limited infrastructure and access to fewer resources. Compared to urban areas, these conditions make them more vulnerable to climate change.

3. ADAPTATION CHALLENGES IN THE HEALTH SECTOR

The vulnerability of the population becomes severe with lack of resources, poor governance, weak civil institutions and poor public health infrastructure. Moreover, limited or inadequate access to relevant local information on extreme events and weak or non-existent disease monitoring and surveillance results in more acute vulnerability (Institute of Medicine 2001). In addition, population vulnerability tends to be unevenly distributed due to bio-geophysical, socioeconomic, cultural, environmental and political factors (Haines et al. 2006, Confalonieri et al. 2007).

Adaptation is critical to protect human health and maximize the wellbeing of the population. Adaptation actions help to enhance the resilience of the vulnerable system. The Third Assessment Report of the

IPCC emphasizes the necessity to anticipate impacts and take appropriate adaptive measures (IPCC 2001). Adaptation is defined as a conglomeration of the natural responses of affected individuals or communities along with the intended responses by governments and institutions (Ebi & Semenza 2008). Designing and implementing systematic, comprehensive, practical and efficient adaptation strategies, policies and approaches can reduce the effects of climate change and lessen the vulnerability of the population (Ebi et al. 2005, Ebi 2009).

3.1. Political will and stewardship

Political will plays a significant role in strengthening the state's capacity to develop appropriate adaptation strategies and policies. The WHO's World Health Report 2000 emphasized the part of the government by stating 'the ultimate responsibility for the overall performance of a country's health system must always lie with the government… the government must ensure that Stewardship percolates through all levels of the health system in order to maximize that attainment' (WHO 2000, p. 119). Stewardship refers to actions that must be taken to achieve a desired result, and implies a sense of responsibility and leadership necessary to achieve these goals in the health sector (WHO 2000). Saltman (2002, p. 1677) made a similar observation, maintaining that 'A fundamental characteristic of contemporary health policy is the centrality of the state to the design and management of an effective health care system.' Political will and stewardship actions of national leaders will result in reducing GHG emissions as well as implementing further policy decisions to minimize the negative impacts of climate change on the population. Political leaders in Australia have so far failed to arrive at a consensus concerning the government's action on climate change, such as reducing GHG emissions. Policymakers and leaders need to support public health approaches as a prerequisite to reducing health risks and instability arising from climate change.

In 2009, the Health and Hospital Reform Commission failed to include climate change and its impacts and the need to design adaptation mechanisms for the health sector (Department of Health and Ageing 2009). Similarly, in 2005 the report on the health workforce by the Productivity Commission did not analyze the ability of the health workforce to meet future challenges of climate change (Productivity Commission 2005).

3.2. Uncertainty and lack of essential health data

There are uncertainties about the severity and intensity of future climate change, what impacts climate change will have on public health, as well as the rate, intensity, limiting forces and key drivers of adaptation (McMichael et al. 2004). In uncertain scenario situations, future adaptation mechanisms can be developed by 'applying projections from a range of climate models and/or their probability distributions, relating climate and disease data from wider range of climatic and socioeconomic environments, more careful validation against patterns in the present or recent past, and more detailed longitudinal studies of the interaction of climatic and non-climatic influences on health' (Haines et al. 2006, p. 592). Improved health surveillance data, detailed analysis of epidemiological data and collaboration with non-health related disciplines may help reduce these uncertainties (Campbell-Lendrum & Woodruff 2006). However, there may be a lack of a comprehensive longitudinal and historical data. The climatic effects of health burdens, disease distributions and their magnitude are not yet apparent. Thus, it can be inferred that planned adaptation under uncertain conditions is complex and challenging task.

3.3. Infrastructure preparation for hospital and health facilities

Australia's hospitals are mostly energy-intensive facilities. These buildings use double the energy per square meter compared to commercial office buildings, and almost 6 times as much water (Langdon 2009). Queensland Health consumes 30% of total state-occupied facilities (Queensland Health 2009). Hospital authorities need to prioritize the use of energy and ensure the maintenance of efficiency in building infrastructure. The healthcare industry needs to move to cleaner energy sources (Jackson & Shields 2008). Queensland Health prepared a strategic plan in 2009 to implement energy and water conservation measures into built infrastructure and business practices, targeted at reducing energy consumption by 5% in 2010 and 20% by 2050 (Queensland Health 2009). However, little success has so far been made to reduce consumption. Though Queensland Health has made commitments to minimize carbon emissions, there are considerable challenges to bring those commitments into practice.

3.4. Monitoring and surveillance

Reliable, relevant, and up-to-date information about the public health effects of climate change is essential in order to effectively monitor disease morbidity and mortality. Policymakers and decision-makers need comprehensive and credible information on the potential health impacts of climate change and also the capacity and capability of the current socioeconomic, political and healthcare system to deal with those impacts (Chiotti et al. 2002, Costello et al. 2009). Public health surveillance systems determine disease burden, identify vulnerable populations, areas or regions and facilitate action in the planning, implementation and evaluation of public health interventions. The design of effective interventions depends on how data is collected, analyzed, interpreted and disseminated (Frumkin et al. 2008). However, there is a lack of comprehensive monitoring and surveillance of climate variables (Chiotti et al. 2002). In responding to climate change, data on environmental risks, vulnerability and disease are essential. Data on risks, vulnerabilities, and illness are generally collected at different spatial scales using different methods. It is necessary to integrate and harmonize these data (Frumkin et al. 2008). The public health department collects infectious disease data, the Australian Bureau of Meteorology collects weather data and the Bureau of Statistics gathers socioeconomic data. Such data needs to be compiled and analyzed in order to build appropriate adaptation options.

3.5. Health community/workforce

Climate change is a global problem for public health, and it has produced new challenges for health professionals. Thus, it is particularly crucial for the medical and health community to have access to knowledge on the effects of climate change. This is essential for the success of any healthcare system. Health professionals also need information related to economics, ecology, vulnerability and health impact assessments, which will encourage them to expand their knowledge base and abilities in a wide range of areas (Gebbie et al. 2003, Frumkin et al. 2008, Costello et al. 2009). Along with scientists, they will require competencies in multiple disciplines in order to comprehend the impacts of climatic change as well as other health issues. The capacity of doctors must also be augmented to recognize and control local emerging health problems, in addition to their traditional training (Frumkin & McMichael 2008). Further challenges for physicians involve providing leadership and advocacy on the issue of adaptation (Blashki et al. 2009, Green et al. 2009). 'Doctors for the Environment' in Australia is an organization that distributes posters and pamphlets to educate patients about environmental impacts on health (McMichael et al. 2008). The Australian Psychological Society has also published a booklet aimed at helping people cope with environmental threats they face (Australian Psychological Society 2010). The Australian Medical Association (AMA) issued a position statement on climate change in 2004 (Woodruff et al. 2005). However, this organization needs to demonstrate substantive leadership and bring a clear understanding among its members about the climatic effects on human health. They need to develop flexible and interactive action plans to address climate change at the individual, local, regional and state levels and influence the government to implement those plans in the respective levels.

In 2016, 27.3% of the population in Australia were from a non-English speaking background. This was an increase of 4.1% in 5 yr (ABS 2017). Therefore, it is important for health professionals to develop better communicative strategies, especially people from a non-English speaking background. This will facilitate meaningful interactions among community members and further enhance community behavior in complying with medical advice (e.g. effective medication practice during heatwaves; Saniotis & Bi 2009).

3.6. Health system capacity

Health systems comprise 'all the organizations, institutions and resources that are devoted to producing actions principally aimed at improving, maintaining or restoring health' (Meene et al. 2008, p. 32). Public health systems have a responsibility to identify, investigate and explain health problems. Climate and other environmental changes will expose the presence of new diseases and will also change the incidence, range, and seasonality of many existing health disorders (Frumkin et al. 2008, McMichael et al. 2008). Therefore, the public health system needs necessary information to enhance their institutional capacity and requires enhanced diagnostic and investigative abilities to investigate existing as well as new and emerging diseases (Costello et al. 2009). The diagnosis process also tells us attribution to climate change.

Developing the most cost-effective strategies for the health system needs a clear understanding of the diagnosis process. Public health laboratories also need to build and enhance their capacity for rapid diagnosis and dissemination of alerts (Frumkin et al. 2008).

3.7. Persuasion through communication and empowerment of people

There is a growing level of understanding in the general public about climate change, but this knowledge is inexact and incomplete; in addition, the public lacks confidence in it. Information on health risks regarding climate change is also either inadequate or non-existent. Berry et al. (2009) noted that the most important factors in adaptation challenges in the health sector are to inform, educate and empower people about climatic risks related to health. Effective communication on climate change allows the public and policymakers to gain knowledge about the health effects of climate change and prepare appropriate policies for climate change adaptation. Communication should be targeted to specific groups emphasizing various levels of understanding, ethnic and cultural differences about vulnerability to climate change to better adapt communities to adaptation practices (Berry et al. 2008, Frumkin et al. 2008). Communication also should prioritize the impacts of climate change that cause health risks, such as risks related to heat stroke, extreme weather events and injuries (Berry et al. 2009). The Commonwealth Department of Climate Change, Australian Psychological Society and other non-governmental organizations share information on health effects arising from climate change. There is a need to build similar effective communication regarding smoking, HIV prevention and health promotion (physical activity, walking to school, etc.). The health sector requires the development and implementation of effective strategies and policies to educate people about climate change and empower them to make their own decisions at individual and community levels. Any communication strategy that is produced needs to be convincing rather than confronting.

3.8. Partnership building

Developing integrated, interdisciplinary, and multilevel adaptation mechanisms to meet the challenges posed by climate change is intricate. There is a necessity to establish partnerships among Commonwealth, state and local government agencies, universities, research organizations, non-governmental organizations, community organizations and the private sector in Australia (Frumkin et al. 2008). The health impacts of climate change involve not only the health sector but also other sectors, including emergency management, agriculture, planning, settlement, industries, etc. (McMichael et al. 2008).

Climate-sensitive health problems can be exchanging information relating to meteorological services, urban and spatial planning, and housing. In addition to sectoral strategies, cross-sectoral and inter-sectoral plans are also required (Füssel 2008). It is vital to further develop and strengthen current partnership mechanisms and build new alliances with other agencies, such as the water catchment authority, housing agencies, farmer associations, planners and architects to reduce vulnerability associated with heatwaves and floods (Frumkin et al. 2008, McMichael et al. 2008).

Active cooperation between members of the public, private, community and non-governmental organizations, primary care facilities, disability, ambulance and acute care services, local authorities, meteorological offices, social services and communities and emergency departments is necessary to detect and identify early signs of climate-induced changes. Thus, the preparation of an adaptation plan for the health sector needs to involve other sectors. However, strengthening collaboration, promoting common goals and sharing good practices across sectors and building teamwork between health and other professionals and community groups is a challenge in adaptation. Creating a multidisciplinary leadership team to lead state adaptation, developing a partnership with other government, private and non-governmental organizations and universities to address health aspects of climate change is also challenging (Jackson & Shields 2008).

3.9. Adaptation challenges and coordination at various levels

Developing and implementing adaptation plans for heatwaves, cyclones and floods by the local health department is challenging. They have limited resources to monitor and to collect information and have difficulty communicating and disseminating information in a timely and organized fashion.

Though some cities in Australia (such as Adelaide, Brisbane, Melbourne, Perth and Sydney) have developed heatwave adaptation plans, other cities are yet to show signs of decisive action to mitigate the effects of excessive heat, floods and cyclones. During heat waves, the local health department needs to work with other agencies, such as community and housing services, to ensure access to air conditioning for isolated populations. The department also needs to increase public education and communication methods related to climate change in general.

3.10. Stakeholder engagement

Public health intervention happens at 3 different levels: primary, secondary and tertiary. Primary intervention is at the disease exposure level, secondary intervention is at the disease surveillance level and tertiary intervention is treatment (Spickett et al. 2008). Local, state and national public health agencies also stimulate top-down intervention. Stakeholder engagement in designing, implementing and monitoring climate change adaptation in the health sector allows the reduction of health impacts and minimizes the vulnerability of the affected population (Ebi & Semenza 2008). Community engagement allows secure exchange of information, motivation and acceptance of any public health prevention or adaptation initiatives among community members (O'Neill et al. 2003, Lim et al. 2005). Community engagement will further enhance not only their resilience to climate stress but also the capacity to adapt to other social issues. Community adaptation allows stakeholders to be proactive in solving problems, thus enhancing social capital (Ebi & Semenza 2008, Ebi 2009). This social capital further helps to build social relationships among community members, and such relationships enable the community to achieve shared goals. However, there are some groups who are more vulnerable, including low-income communities and the elderly, pregnant women, children and those that are chronically ill or disabled (Ebi 2009). In addition, public health interventions, including the design and implementation of adaptation plan(s) to help these groups and facilitate climatic justice (i.e. an equitable share of environmental hazards and promotion of environmental rights), is complicated. Building a neighborhood support system to protect the most vulnerable segments of the population is also a challenge.

3.11. Possible and suggested adaptation measures

Despite the many challenges involved in developing an adaptation response plan, there are opportunities to integrate such plans into existing efforts and to develop a coordinated response to reduce the effects of climate change on human health (Chiotti et al. 2002). Adaptation is required to minimize current and projected risks (Confalonieri et al. 2007). The health systems need to make appropriate adaptation plans, which will ultimately reduce the effects of climate change on health (Haines et al. 2006). However, these plans must be prioritized depending on the severity and complexity of climatic events, disease patterns and vulnerability of population groups as well as socioeconomic, political and cultural complexity. This priority could be organized as short-, medium- or long-term, and risk assessed as extreme, extreme-high, high, high-medium, medium, medium-low, and low (Spickett et al. 2008). For example, climatic events such as heatwaves are classified as extreme events that require both short- and long-term adaptation responses. UV exposure and flooding are extreme to high-risk effects, which need a similar adaptation response plan, especially in Queensland. Bushfires have a high-risk effect that needs medium-term actions, while increased pesticide or chemical exposure is a low risk requiring short-term adaptation measures. Scheraga et al. (2003) suggested that decision-makers need to decide which adaptation measures are required based on assessments of the balance between competing priorities, along with where, when, and how these measures should be implemented. In such a context, optimal decision making involves increasing awareness of the health impacts of climate change as well as the exchange of knowledge about adaptation choices (Confalonieri et al. 2007). Adaptation measures can also be taken through informing, educating, convincing and motivating the population, by monitoring epidemiological, morbidity and mortality data, as well as infrastructural technological and engineering development, legislative and regulatory measures, medical and ecosystem intervention, and application of technology.

Adaptation measures could be primary, secondary or tertiary (Spickett et al. 2008). Primary adaptation measures for climatic events such as flooding can adopt land-use planning and build flood-safe infrastructure that involves engaging other sectors. Secondary adaptation could be surveillance of any vector or waterborne disease outbreak and epi-

demiological data collection, while at the tertiary level adaptation involves medical intervention, i.e. treating patients.

4. CONCLUSIONS

The scientific consensus on climate change is evident. The potential health effects of climate change are enormous. In Australia in general, and Queensland in particular, climate change has impacted human health through increases in the frequency and intensity of extreme weather events such as heatwaves, floods, cyclones, tornadoes and bushfires. Climate change has increased the distribution, incidence and magnitude of diseases. There are increased risks of vector-borne, waterborne, and food-borne illnesses. UV radiation and air pollution further exacerbate the severity of climate change impacts on human health. Climate-sensitive regions are more prone to disasters, which will eventually contribute negatively to the health and wellbeing of the population. There will be increased incidences of morbidity, mortality and injury. The elderly, children, people who are chronically ill and economically disadvantageous segments of the population are more vulnerable than others. Adaptation is necessary to reduce the effects of climate change on human health and to maximize population wellbeing. Adaptation enhances the resilience of a vulnerable system through natural responses of the affected population and intended response by the government. However, mechanisms of adaptation are limited by various societal, cultural, economic, political, informational and technological challenges that need to be rigorously addressed. Developing and designing an appropriate healthcare system to meet these challenges is also equally crucial in adapting to climate change. Policy- and decision-makers need comprehensive and credible information about potential health impacts of climate change, as well as the capacity and capability of the current socioeconomic, political and healthcare system to deal with those impacts. Therefore, there are increased demands for information and monitoring of the impacts of climate change on human health. It is necessary to build and accelerate institutional capacities, social and human capital, leadership, communication and partnerships as well as stakeholders' engagement in the adaptation process to ensure success. Possible adaptation measures and policy directions are suggested to curtail the adverse effects of climate change.

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