# Developing Health-Related Climate Indicators – A Case Study of South Australia

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| | |
|---|---|
| ABS | Australian Bureau of Statistics |
| BFV | Barmah Forest Virus |
| BOM | Bureau of Meteorology |
| CI | Confidence Interval |
| CSIRO | The Commonwealth Scientific and Industrial Research Organisation |
| $CO_2$ | Carbon dioxide |
| DPSEEA | Driving force-Pressure-State-Exposure-Effect-Action |
| EEA | European Environmental Agency |
| EPA | Environmental Protection Agency |
| GHG | Greenhouse Gas |
| GP | General practitioner |
| HHWS | Heat-health warning system |
| ICD | International Classification of Diseases |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Incidence Rate Ratio |
| IRSD | Index of Relative Socioeconomic Disadvantage |
| LGA | Local Government Area |
| NNDSS | Australian National Notifiable Diseases Surveillance System |
| NSW | New South Wales |
| $O_3$ | Ozone |
| PHA | Population Health Areas |
| PHIDU | Public Health Information Development Unit |
| $PM_{2.5}$ | Particulate matter with a mass median aerodynamic diameter of 2.5 micrometres |
| $PM_{10}$ | Particulate matter with a mass median aerodynamic diameter of 10 micrometres |
| POA | Postal area |
| RRV | Ross River Virus |
| SA Health | South Australia Department for Health and Ageing |

| | |
|---|---|
| SA | South Australia |
| SA2 | Statistical Areas Level 2 |
| SLA | Statistical Local Area |
| SEIFA | Socioeconomic Indexes for Areas index |
| SES | Socioeconomic status |
| UN | United Nations |
| US | The United States of America |
| WHO | World Health Organization |

# THESIS ABSTRACT

## Problem statement

Australia has experienced, and is projected to experience, a range of direct and indirect climate change-related health impacts. Extreme weather events have been associated with substantial increases in morbidity and mortality, as exemplified by the Victorian bushfires in 2009 and the Queensland floods in 2011. Moreover, significant epidemiological evidence of increases in morbidity and mortality during heatwaves has emerged in Australia.

Although the primary public health problem is extreme weather-related morbidity and mortality, a secondary public health problem is that there are limited tools to track the health impacts of climate change and to develop public health interventions in a timely manner. In particular, climate-sensitive health indicators are needed by public health planners and policymakers in order to mitigate the effects for vulnerable subpopulations. This issue has recently been raised at a global level by the Lancet Countdown, an international collaboration aiming to develop and report on a series of health indicators of climate change.

## Gap analysis

A scoping review of the literature in the area of climate-sensitive health indicators, together with preliminary consultations with stakeholders in public health agencies, identified three major gaps. Firstly, although climate-related impacts put significant pressure on the health sector, climate-related health indicators are generally not used as part of routine Australian health evaluation. In contrast, some such indicators have been developed in other countries and are currently used by the European Environmental Agency. Secondly, due to differences in climate characteristics and demographics, there is a need to identify a set of evidence-

based climate-sensitive health indicators specifically for use in Australia. Finally, the feasibility and usability of such indicators in an Australian context should be investigated.

## Purpose statement

The aim of this research was to develop and assess climate-sensitive public health indicators, using South Australia as a case study. For the purpose of this research, indicators are categorised in terms of health outcome, exposure and vulnerability; and climate-sensitive, or climate-related indicators, are simply referred to as climate health indicators.
Because South Australia has a hot dry climate there is a focus on heat-related indicators.

## Central research question

Using South Australia as a case example, the central research question is: What climate health indicators are most useful for public health planning, monitoring and intervention?

The central research question was divided into sub-questions as follows:

RQ1: What are the impacts of climate change on the health of Australians?
RQ2: What do stakeholders need as climate health indicators and what are the criteria that make a good indicator?
RQ3: What places are more at risk of health impacts during heatwaves?
RQ4: What are the characteristics of people that make them more vulnerable to heat impacts?

## Methodology

Due to the multidisciplinary aspects of climate-related health outcomes, a parallel mixed methods approach was adopted. The methodology entailed four elements:

- Systematized literature review for RQ1 -  Addressing health effects of climate change and a relevant framework for indicators development,
- Qualitative case study for RQ2 - Exploring stakeholder perspectives on indicator development,
- Quantitative case study for RQ3 and RQ4 - Environmental epidemiology focusing on spatio-temporal aspects of climate and health,
- The integration of qualitative and quantitative analyses to form a comprehensive and pragmatic view of climate health indicators.

### Systematized literature review: Addressing the health effects of climate change in Australia and a relevant framework for indicator development

Scopus, PubMed, Web of Science and Google Scholar were searched. This was supplemented with forwards and backwards searching and other extension approaches. The yield was summarised and critically appraised.

### Qualitative case study: Addressing stakeholder perspectives on climate-health indicators development

Interviews were conducted with key informants and service providers from state and local government, and non-government organizations in South Australia.  Thematic analysis was undertaken to explore their perspectives and requirements regarding indicators and their applicability and utility using Nvivo software for transcription and data management.

### Quantitative case study: Environmental epidemiology focusing on spatio-temporal aspects of climate and health

The analysis utilised health data including ambulance callouts, hospital admissions, and emergency department visits from the South Australian Department for Health and Ageing, temperature data from the Australian Bureau of Meteorology, and vulnerability data from the Australian Bureau of Statistics analyses. There were three aspects to the analysis.

- Incidence Rate Ratio (IRR) of ambulance callouts, hospital admissions and emergency department visits were calculated using case series analysis, comparing health outcomes during heatwaves compared to non-heatwaves periods by postcode, using Stata software. The IRR of each postcode was then mapped using GIS software (ArcMap).
- The IRR of ambulance callouts, hospital admissions and emergency department visits for heatwaves in 2009 and 2014 were calculated and presented spatially in maps at postcode level.
- The association between vulnerability risk factors such as age, living alone, socioeconomic status and IRR of ambulance callouts, hospital admissions and emergency department visits were statistically and spatially analysed.

Integration of qualitative and quantitative analyses to form a comprehensive view of climate health indicators.

Finally, the research findings from the literature review, together with the qualitative and quantitative studies were synthesised to provide a comprehensive and pragmatic picture of climate health indicators.

### Main findings

Systematized literature review: Addressing health effects of climate change in Australia and a relevant framework for indicators development

Findings from the literature review showed that there was adequate scientific evidence on the climate-sensitive health effects and vulnerability for Australia. A framework of 'Driving force-Pressure-State-Exposure-Effect-Action' (DPSEEA) for environmental health indicators was considered appropriate but could be improved by the addition of vulnerability. Findings of the literature review were structured in a modified framework to show links between the environment and health; and the actions that can be taken in a range of situations to mitigate effects were highlighted.

Climate-sensitive health outcomes such as heat-related morbidity and mortality were suggested as potential health indicators of climate change. Factors such as age, income and existing chronic diseases were identified risk factors that could increase vulnerability to climate change and heatwaves. Most of the reviewed studies focused on heatwaves largely because of the increases in the number and intensity of heatwaves in Australia and that data on heat-related morbidity and mortality are consistent and available.

Qualitative case study: Addressing stakeholder perspectives on climate-health indicator development

There was a high level of stakeholder awareness of the health impacts of climate change, and the need for indicators that can inform policymakers regarding interventions. Stakeholders' perceptions were consistent with the literature review findings that heat-related morbidity and mortality can be useful indicators of climate change. They were aware of risk factors such as older age, low income and lack of social connectedness. They also raised several issues including lack of resources and access to data. They found difficulty in measuring resilience to climate change and extreme weather events. Participants commented on criteria for robust indicators including that they should be accessible, credible, specific and could be represented spatially.

Quantitative case study: Environmental epidemiology focusing on spatio-temporal aspects of climate and health

Findings are presented in three parts as follows:

- Analysis of the relationship between heatwaves and ambulance callouts showed that Adelaide's western, inner and northern suburbs had a higher incidence rate ratio (IRR) during heatwaves 1994 - 2014 compared to non-heatwaves, with the highest IRR of 1.26 (95% CI: 0.64-2.47). Suburbs where residents had a higher risk of visiting an emergency department during heatwaves, with highest IRR of 1.72 (95% CI: 1.03-2.84), were mainly clustered in central Adelaide excluding outer eastern suburbs, which had too few observations for analysis. Hospital admission analysis during 2004 - 2014 showed a similar pattern to emergency department visits with highest IRR of 1.41 (95% CI: 0.89-2.22).

- The comparison of health effects during two extreme heatwaves showed decreases in IRR from 2009 to 2014 for ambulance callouts, hospital admissions and emergency department presentations in many suburbs across metropolitan Adelaide. The comparison was of interest because the heatwave warning system was introduced after the 2009 heatwave, indicating the success of the public health intervention.

- Analysis of the above-mentioned health outcomes and a range of vulnerability risk factors found four main risk factors positively correlated with higher IRR of heat-health outcomes; that is, suburbs with a higher percentage of people:
  - who live alone
  - who need assistance with core activities
  - who are aged 65 and above
  - who are socioeconomically disadvantaged

Integration of qualitative and quantitative analyses formed a comprehensive view of climate health indicators.

Using South Australia as a case study the three health indicators of ambulance callouts, hospital admissions and emergency department presentations were evaluated against the four main criteria mentioned by stakeholders - namely data availability, spatial representation of indicators, credibility, and specificity.

In terms of data availability, there are barriers to accessing health outcome data. Nevertheless, data quality and consistency of the health outcome data are good. Secondly, all three health indicators can be represented spatially as postcode is routinely recorded along with other patient information. The three indicators met the third criterion, credibility, as increases in ambulance callouts, hospital admissions and emergency department visits have been reported in the Australian and overseas scientific literature to be associated with increases in temperatures, and heatwaves. Finally, in regards to the specificity of indicators, data pertaining to hospital admission and emergency department visit data are categorised based on the International Classification of Diseases (ICD). Heat-related health morbidity may be linked to, for example, chronic diseases such as cardiovascular, renal and respiratory diseases that can be exacerbated during heatwaves. Ambulance callouts data also include similar categories, and increases in these have been also associated with heatwaves. Therefore, these indicators are considered specific for monitoring the health effects of climate change.

## Novelty and implications

This research, to the best of the author’s knowledge, is the first to use an integrated qualitative and quantitative approach to provide evidence for health-related climate change indicators. The DPSEEA framework modified by the addition of a vulnerability component in this research, in conjunction with evidence-based indicators, can enhance understanding of the linkages between exposure to the range of environmental hazards due to climate change and health effects. This may serve as an important tool for monitoring and decision-making and provide direction for collaborating efforts on reducing the climate change health impacts.

The spatio-temporal analysis yielded an insight on areas vulnerable to heat-health effects in metropolitan Adelaide. The evidence has important implications for stakeholders to consider population vulnerability to climate change and use this information for policy, planning and intervention.

## Conclusions

The research findings support the use of exposure, vulnerability and health data as climate health indicators. Relatedly, the research showed indicators can be used to evaluate the success of climate-related public health interventions. The modified DPSEEA framework is suitable for presenting relationships among factors that affect health in the context of climate change and for working collaboratively to maximise the utility of indicators for monitoring and decision making.

Heat–morbidity analysis showed that health outcomes were not evenly distributed in metropolitan Adelaide suburbs. It is concluded that vulnerability exacerbates the health outcomes and thus is an important consideration in understanding climate health effects particularly relevant for local governments.

Finally, the engagement of relevant government and non-government organisations which contribute in different ways to exposure, vulnerability and health aspects of climate change are required in the process of indicator development to ensure that the indicators are robust.

## Recommendations

On the basis of this research the following recommendations can be made for researchers and agencies.

### For researchers

***Using a similar methodology, research should be conducted in other jurisdictions and countries.*** The vulnerability risk factors for South Australia may not be necessarily applicable for other places. Further research might provide insight on new indicators due to different data availability or climate variability, address different issues and the nuances of population vulnerability.

***Future research should examine a wider range of climate-related health impacts*** of, e.g. bushfires which are projected to increase. However, data pertaining to these events are not systematically recorded and stored in an inclusive database, and the health effects of such events are not well documented in the literature in Australia.

For agencies

***Organisations concerned with the impact of climate change should collaborate to form an interdisciplinary surveillance group to regularly report on a series of indicators***. Given that public health is a principal consideration in the development of indicators, health departments could consider taking a leading role.

***A central repository for data that may be used as indicators is recommended***. This could be accessible to stakeholders required to report on the impact of climate change in their area. Currently stakeholders and data analysts who need to investigate the relationship between climate change-related extreme weather events and the health effects, have issues in gathering such data. If suitable data were collected these would be useful to examine potential climate change trends over time and would indicate the effectiveness of interventions.

# DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

I give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Signature: Date: __17/03/2018____________

# PUBLICATIONS CONTRIBUTING TO THIS THESIS

### *Published*

**Navi M**, Alana Hansen, Monika Nitschke, Scott Hanson-Easey and Dino Pisaniello, 2017, Developing Health-related indicators of climate change: Australian Stakeholder Perspectives, International Journal of Environmental Research and Public Health.

**Navi M**, Dino Pisaniello, Alana Hansen, Monika Nitschke, 2016, Potential health outcome and vulnerability indicators of climate change for Australia: Evidence for policy development, Australian Journal of Public Administration.

# PRESENTATIONS ARISING FROM THE THESIS

***Statistical and spatial analysis of ambulance callouts during heatwaves: A health indicator of climate change?,*** *The International Society for Environmental Epidemiology (ISEE) conference, Rome, Italy, September 1-4, 2016.* https://ehp.niehs.nih.gov/isee/2016-p3-050-3159/

***Developing health-related indicators of climate change incorporating vulnerability****, The International Society for Environmental Epidemiology (ISEE) conference, Rome, Italy, September 1-4, 2016.* https://ehp.niehs.nih.gov/isee/2016-p3-026-3253/

***Using environmental health indicators to identify populations vulnerable to climate change****, AMOS/ARCCSS National Conference, Melbourne, Australia, 8–11 February 2016.*

***Potential health outcome and vulnerability indicators of climate change for Australia,*** *Presentation for* Local Government Public Health Evaluation Group, Burnside council, 30 June 2015.

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# THESIS OVERVIEW

Changes in climate can cause impacts on human health. The prediction of future health impacts of climate change is a challenge because it relies on environmental conditions, socioeconomic status, and the preparedness, resilience and level of adaptation of communities and health systems to climate change. To monitor the impacts of climate change on human health and to develop public health adaptation plans and strategies, indicators of health and vulnerability, and climate data are needed. A set of robust indicators is the key to ensure preparedness and adaptation plans are measurable and accountable.

This thesis seeks to identify evidence-based indicators that can be used to measure the impact of climate change on human health and uses South Australia as a case study. It consists of six chapters, as illustrated below.

| Chapter number | Problem statement | Outcome |
|---|---|---|
| 1 | Introduction | An overview of the development of climate health indicators is provided together with an outline of how the problem is addressed in this thesis. |
| 2 | What is currently known about environmental indicators of climate change, both internationally and in Australia? | Literature reviews of the international and Australian literature were conducted to identify gaps in knowledge, a suitable framework and a list of potential climate health indicators’ |
| 3 | What are stakeholders’ perspectives on the establishment of climate health indicators of climate change? | Interviews were conducted with a range of stakeholders. Qualitative analysis was conducted to identify themes. Stakeholder requirements and issues were identified and addressed. |

| | | |
|---|---|---|
| 4 | To assist public health interventions and adaptation planning for vulnerable populations in Adelaide, areas at higher risk to heatwave health impacts need to be identified. | Areas at higher risk to heatwave health impacts and vulnerability characteristics in Adelaide are identified using quantitative methods. |
| 5 | Discussion of the findings of this mixed method study | Findings of literature review, qualitative and quantitative analyses were synthesised and discussed in the context of the whole thesis. Climate health indicators are suggested and the limitations and strengths of the study discussed. |
| 6 | Conclusion | Policy implications and recommendations are provided. |

Chapter 1 provides the Introduction to the thesis and outlines the background, the overall research question, scope and study setting. Chapters 2 to 4 address specific research questions as outlined in the research framework in section 1.2. Chapter 2 (*Literature Review)* comprises two parts: The first, a review of the international literature, explores indicators that are currently being used around the world to monitor and measure the impacts of climate change on human health with a focus on vulnerability. Findings of this review revealed research gaps in the current Australian literature about climate health indicators. Therefore, a second literature review was conducted to investigate the impact of climate change on Australian health and characteristics that influence vulnerability to climate change. This provided the scientific evidence upon which to base potential indicators of health-related climate indicators. This review has been published in the Australian Journal of Public Administration, 2016 (Navi et al., 2016) (Appendix A).

Chapter 3 *Climate-health indicators development: A qualitative study of stakeholders' views,* explores stakeholders' needs and requirements for measuring and tracking the adverse health effects of climate change and the factors perceived to increase people's vulnerability to the changing climate. This chapter has been published in the International Journal of Environmental Research and Public Health 2017, 14, 552 (Navi et al., 2017) (Appendix B).

Chapter 4 *Spatial aspects of heatwaves and health in metropolitan Adelaide*, investigates the effects of heatwaves on ambulance callouts, hospital admissions and emergency department presentations across metropolitan Adelaide. The second section of this chapter provides insights on disparities in the geographical distribution of the risk of health outcomes during heatwaves in Adelaide.

Chapter 5 *Integrations of findings and discussion,* synthesises results from both the qualitative and quantitative studies, together with findings from the literature, to address the research questions. The limitations and strengths of the study are discussed as well as implications for health policymakers.

Finally, Chapter 6 *Conclusions and recommendations* provides a summary of the previous chapters, concludes the thesis and provides recommendations for future research.

# CHAPTER 1

# Introduction

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## Overview

This chapter begins by providing a background about climate change around the globe and in Australia. It then defines research questions that this PhD research is aimed to address. The scope of the study is outlined together with the limits of the study. In the study setting a brief description of the location, population and weather of the study area are provided. Finally, the thesis layout specifies how the thesis is organised in each chapter.

## 1.1 Background

Climate is often described in terms of the mean state of the atmosphere and the variability in meteorological factors such as temperature, precipitation and wind, over relatively long periods of time (Sirocko et al., 2006). Weather on the other hand, is the daily condition of the atmosphere and differs from climate in that it is a short-term variation.

There is clear evidence that the earth's climate has been changing due to the increased concentrations of greenhouse gases (*water vapour, carbon dioxide, methane, nitrous oxide, and ozone*) in the atmosphere which trap heat in the atmosphere leading to changes in long-term climatic conditions. Scientists have analysed thousands of years of climate measures such as ocean sediments, ice cores and tree rings, to provide information on the responses of the earth's system to natural and anthropogenic drivers of climate change (IPCC, 2013). Natural causes of climate change such as volcanic eruptions are a small fraction compared to anthropogenic causes; since the industrial revolution anthropogenic emissions of greenhouse gases have been 100 times more than emissions of carbon dioxide ($CO_2$) from volcanic eruptions (IPCC, 2013).

Since 1990, global greenhouse gas (GHG) emissions have increased by 45 per cent and reportedly to approximately 54 Gigatonne $CO_{2e}$[1] in 2012 (UNEP, 2014). Scientists have projected that GHG emission levels, in the absence of climate policies, would rise to about 59 Gigatonne $CO_{2e}$ in 2020 and 87 Gigatonne $CO_{2e}$ in 2050 (UNEP, 2014).

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[1] $CO_{2e}$, or carbon dioxide equivalent, is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential. For example, the global warming potential for methane over 100 years is 21. This means that emissions of one million metric tons of methane is equivalent to emissions of 21 million metric tons of carbon dioxide. Source: OECD 2001. Environmental indicators for agriculture– Vol. 3: Methods and Results. Organisation for Economic Cooperation and Development. The OECD Observer.

The impacts of climate change on human and natural systems have been widespread and include rising temperatures and temperature extremes, sea level rise, and changes in precipitation patterns in many regions (Pachauri et al., 2014). Future risks of climate hazards are potentially severe for natural systems and vulnerable communities. Amongst key risks are the breakdown of infrastructure networks and services including electricity, and health and emergency services due to extreme weather events. Impacts on health can include death and injury due to storm surges, flooding (inland and coastal) and sea level rise; and mortality and morbidity during periods of extreme heat, especially for vulnerable urban populations and outdoor workers (IPCC, 2014b).

Under the Kyoto protocol, industrialized nations agreed to reduce their greenhouse gas emissions by at least 5 per cent below 1990 levels. 1990 was selected as a reference point since the United Nations (UN) first negotiations on climate change were launched that year. While the list of nations committed to GHG emission reduction has changed over the years, Australia has remained committed to reduce emissions and adapt to the impacts of climate change (UNEP, 2014).

Climate change affects Australia in different ways such as rising temperatures and more extreme weather events. Australia has experienced extreme heat with record temperatures in its major cities (Hughes and McMichael, 2012). Examples are provided in Table 1.1.

**Table 1.1 Selected examples of extreme heat in Australia**

| Heatwave event | Location | Temperature | Reference |
|---|---|---|---|
| 31 October 1923 to 7 April 1924 (period of 160 days) | Marble Bar, WA | above 37.8 °C | (CSIRO and BOM, 2014) |
| 13 January 1939 | Melbourne | 45.6°C | (NCC, 2009) |
| January 1939 | Adelaide | above 45 °C | (NCC, 2009) |
| March 2008 (12 consecutive days) | Adelaide, SA | above 38 °C | (BOM, 2008) |
| Early 2009 (6 days) | Adelaide, SA | Above 40 °C | (BOM, 2009) |
| 28th January 2009 | Edinburgh, SA | Above 45°C | (BOM, 2009) |
| 28-30 January 2009 (3 consecutive days) | Melbourne, Victoria | Above 43 °C | (Department of Health, 2009) |
| January 2010 (5 consecutive days) | Adelaide, SA | 4 days above 40°C | (BOM, 2010) |
| Summer of 2012-2013 (over a 90-day period) | Whole Australia | The hottest summer average on record | (BOM, 2013) |
| Two weeks in January 2013 | many parts of the country | above 48°C | (BOM, 2013) |
| Summer of 2012-2013 | Moomba, SA | highest recorded maximum of 49.6°C | (BOM, 2013) |
| 8 January 2013 | Sydney | 41°C | (Guardian, 2013) |
| March 2013 (9 nights) | Mount Gambier, SA | Broke temperature records, above 15°C for 9 nights | (ABC, 2013) |
| January 2014 | Victoria | Above 45°C for three consecutive days | (Department of Health, 2014) |

Observations and climate modelling for Australia have shown increases in the frequency or intensity of heat events (Figure 1.1), fire weather, drought and sea-level rise (BOM and CSIRO, 2016).

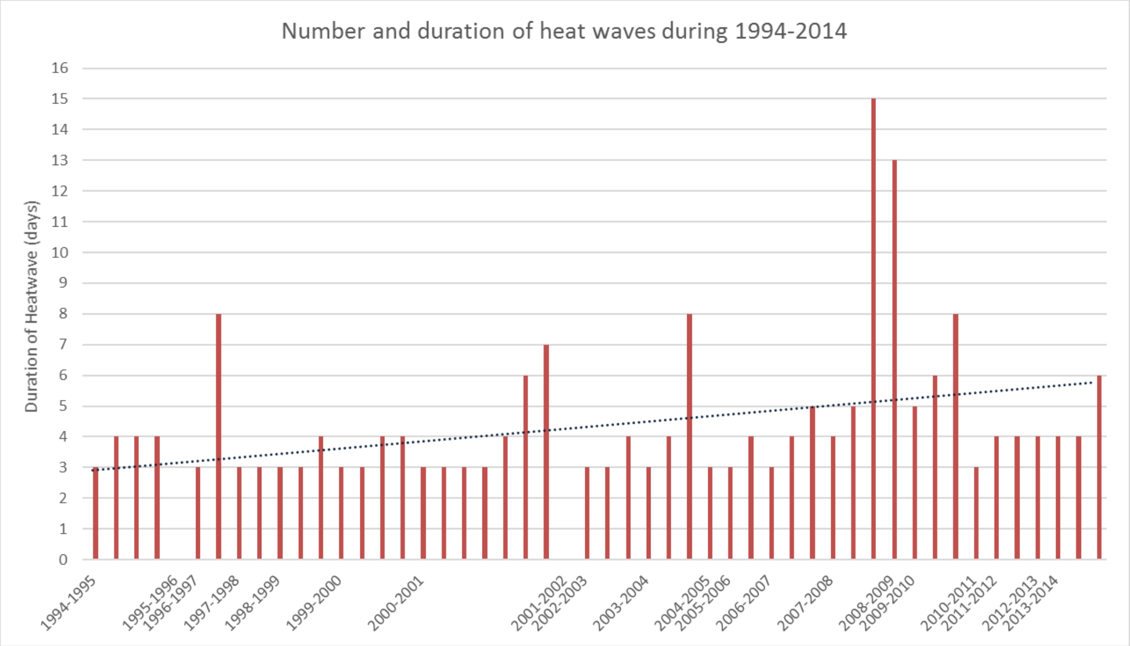

**Figure 1.1 Number and duration of heatwaves in Adelaide during 1994-2014, the dotted black line shows the upward trend of heatwave duration (data source: (BOM, 2017a))**

The impacts on human health of extreme weather events (which are predicted to increase due to climate change), are notable and varied in Australia. These impacts can be difficult to measure and are often quantified using recorded morbidity and mortality statistics coinciding with environmental (e.g. meteorological) data for extreme weather events. For example, in February 2004 a heatwave in Brisbane, Queensland, led to a 53% increase in ambulance call-outs, the largest recorded for ambulance call-outs in southeast Queensland (Steffen et al., 2006). In Adelaide, South Australia, during an extreme heat event in 2009, direct heat-related hospital admissions increased 14 times compared to previous heatwaves (Nitschke et al., 2011b). During a week-long heatwave over the same period in 2009, 374 excess deaths were reported in Melbourne, Victoria, representing a 62% increase in total all-cause mortality (Department of Health, 2009). These and many other relevant incidents have put considerable pressure on health services. There is a need to track these impacts on population health as climate change ensues. However, indicators based on associations between environmental and health data to monitor trends of climate change-related health outcomes on a regular basis have not been yet reported in Australia.

## 1.2 Research questions

The main research question proposed in this thesis is: *What are the most appropriate indicators to monitor health impacts of climate change in South Australia*? To develop a clear understanding of this issue, a set of sub-research questions were addressed. The following research framework (Table 1.2) summarises the questions, the study objectives and methods that will be used to address the research questions.

**Table 1.2 Research framework**

| **Research Questions** | **Objectives** | **Methods** | **Chapter** |
|---|---|---|---|
| What are the impacts of climate change on Australian's health? | To establish health outcomes likely attributable to climate change and relevant data that could be readily used as indicators | Literature review | Chapter 2 |
| What do stakeholders need as health-related climate change indicators and what are criteria that make a good indicator? | To explore stakeholders' requirements and their views on the usefulness of indicators | Qualitative (stakeholder interviews) | Chapter 3 |
| What are the areas more at risk of health impacts during heatwaves? | To investigate patterns of health impacts during heatwaves | Quantitative (case series approach) and spatial analysis | Chapter 4 |
| What are the characteristics that make people more vulnerable to heat impacts? | To identify risk factors of areas at higher risk to heatwave health impacts | Statistical and spatial analysis | Chapter 4 |

## 1.3 Scope

As well as direct effects on human health, climate change has wide-ranging effects that include impacts on ecosystem health, agriculture and food and water security, and these can have indirect effects on human health. However, these are outside the scope of the present research in this thesis. The focus of this research is the development of indicators that can be used to monitor and measure the direct impacts of climate change on the health of Australians.

This research is based in South Australia (SA) and uses South Australian data from a number of different organisations, and explores stakeholders' perspectives on indicators development within the state. However, the key findings could be useful to policymakers and stakeholders across Australia. Furthermore, given that climate change issues and the related adverse health outcomes have no borders, this study may have even wider relevance.

## 1.4 Study setting

Adelaide, the capital of the state of South Australia, is located near the coast in central southern Australia, extending 90 km from Gawler in the north to Sellicks Beach in the south and 20 km from the coast in the west to the hills in the east. Latitude and longitude coordinates for Adelaide are: 34°55'43.18"S, 138°35'55.07"E (Figure 1.2).

The population of metropolitan Adelaide was 1.32 million people in June 2015, accounting for 78% of the state's total population (ABS, 2016a). The population aged 65 years and above increased from 15% to 16% in metropolitan Adelaide and 18% to 21% in the rest of South Australia between 2010 and 2015 (ABS, 2016a). Population projections by The Australian Bureau of Statistics (ABS) show that the population is ageing and in the non-capital city areas of South Australia by 2056, it is expected that for every person above 65 years of age there will be less than two people from the working age group (ABS, 2016b).

Adelaide has a temperate climate with long hot summers and mild to cool winters with 400 mm average annual rainfall and mean maximum summer (January) temperature between 30°C to 33°C, according to the modified Köppen climate classification (Stern et al., 2000). The classification is based on native vegetation as an expression of climate and has been widely used around the world over decades (Stern et al., 2000).

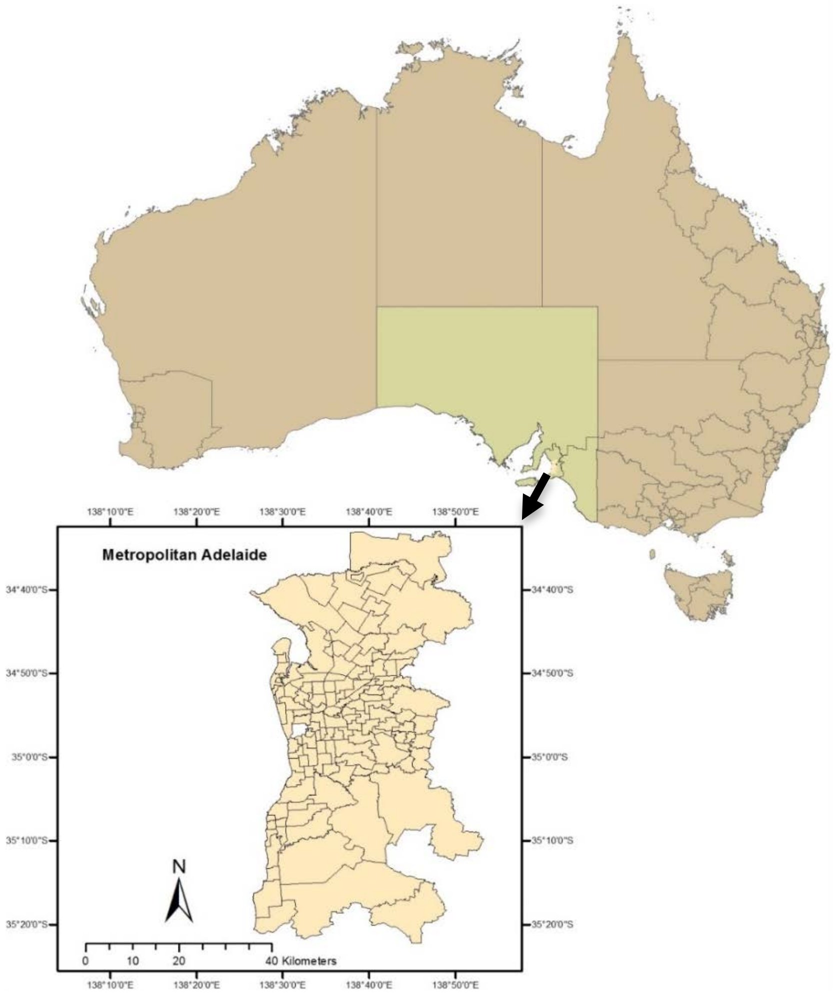

**Figure 1.2** **Location of the study area**

Climate change is evident in Adelaide. Data from the Bureau of Meteorology (BOM) show that the annual mean maximum temperature for Adelaide has increased by more than 1° C (Figure 1.3) and annual rainfall has decreased by approximately 50 millimetres, since 1975 (Figure 1.4)(BOM, 2017b). Climate change projections by the BOM and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) show more extremely hot days and fewer extremely cool days for South Australia (BOM and CSIRO, 2016).

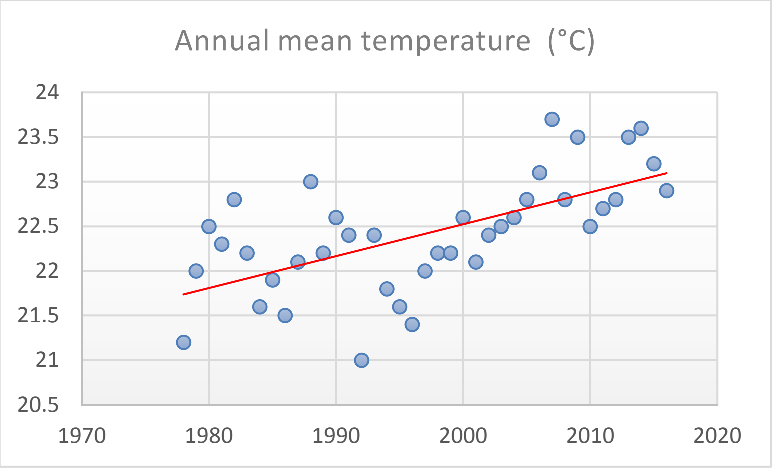

**Figure 1.3 Annual mean temperature for Adelaide, Kent Town station, the red line shows an upward trend of annual mean temperature by more than 1° centigrade (BOM, 2017b).**

Furthermore, fire weather monitoring data from 1974 to 2015 showed larger trends in fire weather in South Australia compared to other states, and the number of days with weather conducive to bushfire is predicted to increase (BOM and CSIRO, 2016). South Australia has experienced many bushfires, several serious, including the 1983 Ash Wednesday bushfires. This was one of the deadliest bushfires in Australian history with 28 deaths in SA and 47 in Victoria. Others include the 2005 Wangary bushfire with 9 fatalities, the 2007 Kangaroo Island bushfire with one fatality and the 2015 Sampson

Flat bushfires. The damages from the Sampson Flat fire were estimated to be $13 million (CFS, 2017b).

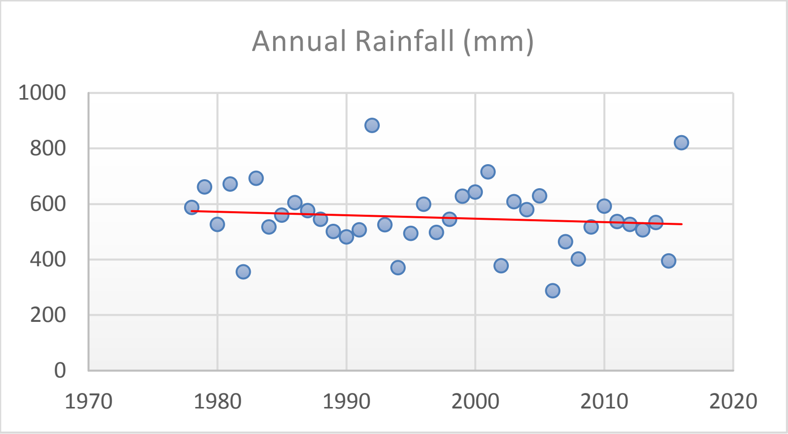

**Figure 1.4** **Annual rainfall for Adelaide, Kent Town station, the red line indicates a downward trend of annual rainfall (BOM, 2017b).**

It should be noted that the phrase “direct heat-related morbidity”, as mentioned in pp. 31, 60, 61, 71 in this thesis, refers to a category comprising “dehydration”, “heat and sunstroke” and “exposure to excessive heat” (ICD-9: 2765, 992, E900; ICD-10: E86, T67, X30), whereas heat-related morbidity or/and heat-related mortality refer to a broader meaning of health outcomes associated with heatwaves and extreme temperatures.

# CHAPTER 2

# Literature review

## Overview

This chapter of the thesis comprises two parts, the first of which is a scoping review of the literature in the area of climate health indicators, leading to the identification of gaps in current knowledge at a global level. The findings of the first part reveal indicators that have been suggested or used in other countries, and a need to develop a set of evidence-based climate health indicators specifically for use in Australia.

Part two is a systematized literature review to gather scientific evidence as a basis for potential indicators based on links between climate change and associated health effects in Australia. It addresses a relevant framework for the development of indicators and suggests potential indicators of health outcomes and vulnerability in the context of climate change.

## 2.1 International studies: a scoping review of climate health indicators

This scoping review aims to investigate whether indicators have been developed to measure the impact of climate change on human health and addresses gaps in the current knowledge in the field of climate health indicators.

### 2.1.1 Introduction

The climate is changing and the most telling indicators of this are surface air temperature and sea surface temperature (IPCC, 2013). A changing climate influences human life in several ways such as increasing extreme weather events that can be measured and monitored by, for example, the numbers of heatwaves (IPCC, 2014b).

In recent years, studies on the connection between climate change and human health and wellbeing have improved our understanding about multiple ways that a changing climate can increase the risk to human health (Hosking and Campbell-Lendrum, 2012). Diseases, injuries and death due to climate-related extreme weather events such as intense heatwaves, bushfires and floods are the main direct health impacts of climate change (Patz et al., 2005). The selection of indicators, however, that measure the impacts on human health is an evolving area of research to meet the need of health communities and policymakers with the best available data (Watts et al., 2016). Emphasis has also been made on the identification of populations and areas which are particularly vulnerable to the adverse health effects of climate change (IPCC, 2014b).

The purpose of this review is to investigate if, and what, climate health indicators have been developed internationally, the process of the development of indicators, and similarities and differences between climate health indicators used in different regions or countries.

### 2.1.2 Method

A search of literature using the keywords ‘indicator’, ‘health’, ‘environmental health’, and ‘climate change’ was conducted. Databases such as Google Scholar, Scopus, PubMed, and Web of Science were searched.  Using this approach very few published studies were found in the scientific literature and as a result grey literature including websites of organizations and reports relating to climate health indicators were also reviewed. Findings were collated and summarised into four main parts: climate health indicators studies; framework selection for the development of indicators; selection process and criteria for the development of indicators; and vulnerability to climate change. Finally, identified gaps in current knowledge are presented in section 2.1.4.

### 2.1.3 Results

#### 2.1.3.1 Climate health indicators studies

The adverse health impacts of climate change are significant in many countries around the world. Exposure to heatwaves has been associated with increased rates of heat stress, heatstroke, excess morbidity and mortality due to cardiovascular or respiratory causes (Kovats and Kristie, 2006, Bi et al., 2011, Sun et al., 2014, Bobb et al., 2014). Consequently, morbidity and mortality can be useful indicators of the health impacts of climate change (US-CSTE, 2014). In Canada, a study reviewed health outcome indicators and public health frameworks to develop indicators relevant to climate change (Cheng and Berry, 2013). The authors used eight indicators including: excess daily all-cause mortality due to heat; premature deaths due to air pollution (ozone ($O_3$) and particulate matter of 2.5 microns or less ($PM_{2.5}$)); preventable deaths from climate change; disability-adjusted life years lost from climate change; daily all-cause mortality; daily non-accidental mortality; and the incidence of West Nile Virus and Lyme borreliosis. Of these, excess daily all-cause mortality due to heat was seen to be the most appropriate indicator for quantifying climate change health effects (Cheng and Berry, 2013).

In the United States, English et al (2009) expanded indicators of climate change and human health and classified them into six groups – environmental, morbidity and mortality, vulnerability-related, mitigation, adaptation, and policy. The list includes environmental indicators (including $O_3$, pollen counts and maximum temperature), health-related indicators (which include excess mortality and morbidity due to extreme heat) and indicators of vulnerability (e.g. older people living alone and poverty status) (English et al., 2009). Heat-related morbidity and mortality indicators are predominantly used to track the impact of climate change. Heat-related deaths and illness are generally preventable and informed interventions assist in this regard (USEPA, 2014b). Public warnings that increase awareness of the risk connected to exposure to high temperatures and provide specific advice on how people can adapt their behaviour and protect themselves, can reduce heat-related impacts (Koppe et al., 2004). For example, an extreme heat preparedness plan developed in the city of Milwaukee after a 1995 heatwave, showed about 50% decrease in heat-related deaths during the 1999 heatwave (Weisskopf et al., 2002). There are also indirect health issues of climate change which are more difficult to quantify (Myers and Bernstein, 2011) and are out of the scope of this study.

To mitigate the impact of climate change and to develop adaptation strategies, the European Environmental Agency (EEA) has developed 52 indicators for climate change (EEA, 2016). Five out of the 52 are relevant to health. These are:  flooding, extreme temperatures, heat-related air pollution and infectious diseases (EEA, 2014). River and coastal flooding have affected the health of millions of people in Europe in the last decade through drowning, heart attacks, injuries, infections, exposure to chemical hazards and psychosocial consequences (EEA, 2014). Heatwaves and excessive exposure to ground-level $O_3$ have increased mortality, especially in vulnerable population groups in Europe (EEA, 2014). Furthermore, it has been predicted that climate change will affect the transmission of vector-borne diseases and has been regarded already as the main factor behind the observed northward and upward shifts in the distribution of certain tick species in parts of Europe (EEA, 2014).

Indicators such as the number of heatwave warning systems in countries and the number of health surveillance systems related to climate change can be used to evaluate how well we are adapting to the health impacts of climate change (English et al., 2009). A study by the University of Freiburg and the WHO in Germany identified eight core elements of heat-health action plans in European countries (Bittner et al., 2013). The elements identified through meetings with representatives from the WHO were: 1) agreement on a lead body and clear definition of actors' responsibilities; 2) accurate and timely alert systems; 3) a health information plan; 4) reduction in indoor heat exposure, 5) particular care for vulnerable groups; 6) preparedness of the health/social care system; 7) long-term urban planning, and 8) real-time surveillance. The results showed that some, but not all, European countries are prepared for the next major heatwave. Eighteen of 51 countries have developed heat-health action plans; while 33 countries have not. Only the United Kingdom and the Former Yugoslav Republic of Macedonia have described in detail all eight core elements and included measures for evaluation. One of the important findings of this work was that evaluation of heat-health actions plans is necessary for them to be functional and effective (Bittner et al., 2013).

In Europe heat-related indicators have been used in several countries. In Germany, heat-related excess mortality and morbidity have been used in Berlin as prevalence indicators to explore the spatial variability of mortality patterns at the neighbourhood level (Schuster et al., 2014). In England, a near real-time daily mortality surveillance system was developed to detect excess mortality during heatwaves using daily mortality registrations (Green et al., 2012). These indicators have implications for targeting vulnerable populations and timely heatwave public health interventions.

#### 2.1.3.2 Framework selection for the development of indicators

Climate change can have negative impacts on the physiological wellbeing of humans. The health impacts of climate change can be modified by a range of non-climate factors such as human behaviour and socioeconomic status (McMichael et al., 2003). This adds complexity to measuring the health effects. Understanding the interaction among climatic, environmental, economic, and social factors that affect the causation of a disease at a population level is useful in identifying evidence-based indicators (Füssel and Klein, 2004). Additionally, using a suitable framework for indicator development assists in structuring the thinking about links between causes and effects (Niemeijer and de Groot, 2008).

Several frameworks have been developed for public and environmental health indicators by different research bodies and organisations (Briggs, 2003, WHO, 1999).

The applicability of the frameworks for the development of health indicators in the context of climate change has been reviewed (Füssel and Klein, 2004). Hambling et al (2011) reviewed eleven frameworks for developing environmental health indicators for climate change and health, and assessed them for characteristics such as suitability for indicators, having health and environment components. The frameworks also included interventions (Hambling et al., 2011). They suggested the 'Driving force-Pressure-State-Exposure-Effect-Action' (DPSEEA) framework to be the most appropriate for developing environmental health indicators to assess, measure and monitor the impacts of climate change on human health (Hambling et al., 2011). This framework has been used to describe the nexus between environment and health and is applicable to environmental health indicators in a wide range of situations (Corvalán et al., 2000). However, challenges to the application of this framework for the context of climate change have been addressed by Füssel et al (Füssel and Klein, 2004). One challenge is that climate-sensitive diseases are caused by complex interactions between climatic and non-climatic risk factors such as socioeconomic and environmental settings, and the framework does not consider non-climatic confounding (Füssel and Klein, 2004).

#### 2.1.3.3 Selection process and criteria for the development of indicators

***Selection process for the development of indicators***

The development of indicators can be a long process taking several steps into account, and in many studies no formal selection of indicators and criteria are mentioned, and the lack of a properly documented indicator selection process is a major issue (Niemeijer and de Groot, 2008). There have been, however, a few studies that explained their selection of indicators. The United States Environmental Protection Agency explained the process of climate change indicator selection. They recommend starting with identifying and developing a list of candidate indicators based on a scientific literature review and stakeholder engagements, then screening those indicators against criteria to evaluate the quality of scientific and technical data and information (USEPA, 2014a). The development of the US climate-related health indicators was a collaborative effort of state-level environmental health experts established by the Council of State and Territorial Epidemiologists (CSTE) (English et al., 2009). The first stage of the development process was the literature review to identify outcomes and actions related to climate change. Potential data sources were identified for the suggested indicators with priority given to available longitudinal data sets. Finally, an analysis of data availability, completeness and temporality was conducted (English et al., 2009).

Another study, focusing on vulnerability to natural disasters, suggested nine phases in the process of developing indicators (Birkmann, 2006). These are: defining the goal, scoping (target group, associated purpose for which indicator will be used, spatial bounds and time frame), identifying the conceptual framework, defining selection criteria, identifying potential indicators, choosing a final set of indicators, analysing indicator results, preparing and presenting report, and assessing indicator performance (Birkmann, 2006).

### *Criteria for the development of indicators*

Indicators need to be developed based on certain criteria (Birkmann, 2006). Robust indicators should be scientifically valid and responsive to changes, and access to accurate data is necessary (Birkmann, 2006). A Canadian study evaluated climate-related health outcome indicators against the five following criteria: specificity, data availability, quality, comparability over time and place, and relevance to planning - and concluded that excess daily all-cause mortality due to heat was seen to be the most appropriate indicator for quantifying climate change health effects in Canada (Cheng and Berry, 2013). The USEPA uses ten properties to screen and select climate change indicators. There needs to be: 1) trends over time, 2) actual observations, 3) broad geographic coverage, 4) peer-reviewed data (peer-review status of the indicator and the quality of the underlying source data), 5) evaluation of the uncertainty and variability of each indicator's underlying data, 6) usefulness, 7) connection to climate change, 8) transparency, 9) an indicator that can be understood by the public, and 10) feasibility in constructing the indicator (USEPA, 2014a). Hambling offers a list of 17 criteria for climate health indicators based on World Health Organisation studies on environmental health indicators; however, emphasises on credibility, specificity, sensitivity and being amenable to adaptive actions are the four essential criteria (Hambling et al., 2011).

#### 2.1.3.4 Vulnerability to climate change

There has also been a growing body of literature about vulnerability to climate change (Reid et al., 2009, Rosenthal et al., 2014, Loughnan et al., 2014, Ho et al., 2016). Some studies focused on identifying vulnerable groups using different methodologies (Zhang et al., 2013, Zhang et al., 2017, Hansen et al., 2013) such as surveys (Nitschke et al., 2013). Vulnerable subgroups include older people, those with chronic conditions and mobility issues, outdoor workers, and those in coastal and flooding prone areas (Balbus and Malina, 2009). Some studies addressed protective factors that decrease vulnerability including increasing green space areas and lower population density (Harlan et al., 2006).

Others studies used spatial analysis to identify areas vulnerable to the impacts of climate change (Zhu et al., 2014, Wolf and McGregor, 2013, Tomlinson et al., 2011, Tan and Chadbourne, 2014). These add to the knowledge base of a range of risk factors that exacerbate the heat-health effects at individual and community level as well as the geographical variations of vulnerability within cities (Wolf et al., 2015).

There are several examples for the development of heat vulnerability assessment tools around the globe. In China, a study showed geographical variations of heatwave-related vulnerability in Guangdong Province. Higher health vulnerability was observed mainly in areas where there was lower socioeconomic status and higher exposure to heatwaves - the number of days with the daily maximum temperature over 35º C was selected (Zhu et al., 2014). Spatial analysis of heat vulnerability has been undertaken in different cities in the UK (Schuster et al., 2014, Wolf and McGregor, 2013, Tomlinson et al., 2011). For example, a heat vulnerability index developed for London showed that living in poor quality housing, being elderly and living alone were among factors which increased vulnerability to heat. Moreover, areas at higher risk seemed to be more exposed to heat including high populated areas and inner cities areas with urban heat islands (Wolf and McGregor, 2013).

Vulnerability can be inversely related to the ability to adapt to climate change. The adaptive capacity of countries in Europe has been assessed using a range of indicators including: knowledge and awareness; resources for technology and capacity to undertake research; access to transport, good health and health care infrastructure; effectiveness of government institutions; and economic resources (Suk et al., 2014). Countries with higher adaptive capacities, such as in Scandinavia and central Europe, will likely be less affected by climate change and therefore generally less vulnerable than areas with lower adaptive capacities (Suk et al., 2014).

The contribution of risk factors to increased heat vulnerability can differ according to geographical location (Reid et al., 2009). A national spatial analysis in the United States showed that a distinct variation in heat vulnerability was concentrated in central city areas. A range of risk factors was used to develop a heat vulnerability index and areas with the lowest number of air conditioners were found to have the highest heat vulnerability (Reid et al., 2009). Rosenthal et al (2014) undertook a within-city analyses of heat vulnerability in New York. The results showed a variation in heat-related mortality that was correlated with socioeconomic factors such as low income, access to air conditioning, educational level, housing quality as well as environmental factors such as green spaces and land surface temperatures (Rosenthal et al., 2014). Similarly, a Canadian study showed that unemployment was a risk factor for heat mortality in Vancouver (Ho et al., 2016).

Information about vulnerable subgroups of the population is important to target interventions accordingly. It has been suggested that climate health indicators should be used in vulnerability assessments of local health departments and incorporated into adaptation and mitigation plans (Houghton and English, 2014). However, although vulnerability indices and maps can be used as effective tools for raising awareness and communication with policymakers, it is not clear whether they have translated into policies and preventive actions (Wolf et al., 2015).

The scientific evidence provided by the above-mentioned studies shows how heterogeneous patterns of vulnerability factors can be for different cities or regions. Although methodologies for the development of climate health indicators and indices can be similar, a generic set of indicators does not seem to capture the health impacts of climate change in different areas with dissimilar weather-related hazards, vulnerability characteristics and datasets (Füssel, 2010).

### 2.1.4 Gaps in the current knowledge

This review has considered the notion of health impacts of climate change on population health and the need for indicators to monitor such impacts. Despite the numerous studies on the impact of climate change and vulnerability factors exacerbating adverse health effects, several knowledge gaps are identified in the literature, suggesting the need for future research directions.

With an increase in intensity and frequency of extreme weather events, climate change impacts are expected to be significant in Australia (CSIRO and BOM, 2014). The events put considerable pressure on the health sector, and adaptation and preparation for climate change have been deemed important by Australian authorities (SA Health, 2014). However, an Australia-specific set of health indicators for climate change that would enable decision makers to evaluate and monitor health impacts and assist in the formulation of adaptation plans has yet to be developed.

In Australia, readily available indicators for monitoring the impact of climate change are mainly environmental indicators, such as temperature, rainfall and air pollution data. A number of Australian studies have assessed the impact of climate change on human health in Australia, especially in regard to heatwaves. However, the feasibility of health data (e.g. heat- and climate-change related morbidity and mortality data) to be used as climate health indicators, in association with climate data, has not been fully investigated.

The paucity of information regarding stakeholder involvement in the development of indicators and utilisation of climate-health research in policy environments warrants more research to explore the perspective of stakeholders about their needs and usefulness of the indicators. This type of information is vital in filling gaps between scientific evidence and policymaking (Wolf et al., 2015, Weber et al., 2015). Hence the engagement of stakeholders in the design and development of climate health indicators may be a more appropriate approach to ensure that the results ultimately meet the stakeholders' needs.

These are a few examples that can direct future research on indicators in the context of climate change and human health. Given gaps in current knowledge, other possible recommendations for future research are discussed in Chapter 6.

### 2.1.5 Aim of this research

The aim of this research is to provide evidence for the development of health-related indicators of climate change for South Australia, and propose means to establish these indicators.

## 2.2 Australian studies: a systematised review of the impact of climate change on Australian health with a focus on vulnerability

As identified above, a set of evidence-based climate-health indicators are needed for use in Australia. The process of developing indicators begins with a literature review; hence, this second part of the chapter reviews the scientific evidence concerning the health impacts of climate change in Australia and factors that influence vulnerability to climate change, as a basis for developing potential climate-health indicators in Australia.

### 2.2.1 Introduction

As mentioned in the previous section, indicators are required to track changes in health outcomes, monitor trends over time and to assess human health vulnerability to climate change (WHO, 1999). Indicators can be useful tools in simplifying complex links between the environment, health and vulnerability, (Von Schirnding, 2002) and can turn data into relevant information for improving communication with the public and decision-makers, and contribute to policy development (Von Schirnding, 2002). While several studies on health-related indicators of climate change have been conducted elsewhere (English et al., 2009, EEA, 2014, Cheng and Berry, 2013) as discussed earlier, they may not necessarily be applicable for Australia. For example, the incidence of West Nile Virus, which has been suggested as an indicator for the US (English et al., 2009), is not relevant to Australia. Also, indicators must be developed on the basis of existing data (WHO, 1999) and the data collected in Australia can differ from that overseas. Moreover, Australia is a vast country with variations in climate; therefore, different indicators may need to be in place in different states.

The first step of the development of climate health indicators, as explained earlier, begins with a literature review to suggest a list of candidate indicators based on scientific evidence (USEPA, 2014a, English et al., 2009). The purpose of this review is to provide evidence for the development of climate health indicators for Australia.

### 2.2.2 Methods

A systematized search of literature reflecting the impact of climate change on health in Australia was conducted using generic logic grids for Scopus, PubMed, Web of Science and Google Scholar (Table 2.1). English language articles using the search terms: “climate change’, ‘indicators’, ‘global warming’, ‘health’, ‘climate-sensitive diseases’ and ‘Australia’ were searched. Other variations of the keywords such as ‘heat’, ‘drought’, ‘flood’, ‘bushfires’, ‘morbidity’, ‘mortality’ and ‘vector-borne diseases’ were also included. No time limitation was considered; however, it was noted that the number of publications concerning indicators has increased substantially since 2008.

The titles and abstracts sourced from the search were read, and those studies meeting at least one of the following criteria were retained:

- Indicating the direct health effects of heatwaves, droughts, floods, bushfires in Australia
- Investigating the indirect health effects of vectors and air pollution such as $O_3$ or aeroallergens in Australia
- Identifying or assessing health vulnerability to climate change among Australians

**Table 2.1 Generic logic grid for the literature search**

| CONCEPTS | HEALTH | STUDY AREA | CLIMATE CHANGE |
|---|---|---|---|
| ALTERNATIVE KEYWORDS | Health | Australia | Climate change |
| | **OR** | | **OR** |
| | Health outcomes | | Heatwaves |
| | **OR** | | **OR** |
| | Diseases | | Global warming |
| | **OR** | | **OR** |
| | Illnesses | | Heat |
| | **OR** | | **OR** |
| | "Climate-sensitive diseases" | | Drought |
| | **OR** | | **OR** |
| | Morbidity | | Flood |
| | **OR** | | **OR** |
| | mortality | | Bushfires |

OR

AND

A total of 57 papers from an initial screen of 192 papers meeting the inclusion criteria were used as a basis for suggesting climate health indicators. The results are presented using components of the DPSEEA framework (Hambling et al., 2011) as mentioned in Section 2.1.3. However, the framework does not take into account factors such as socioeconomic status which contributes to vulnerability. Therefore, a vulnerability component has been added to this framework as shown in Figure 2.1. The modified framework is used to structure the findings of this review.

### 2.2.3 Results

The review of literature has revealed there is a suite of climate-related health outcomes in Australia. The majority of the Australian literature has focused on a range of adverse health outcomes as a result of extreme heat, heat and air pollution-related illnesses, and infectious diseases linked to rising temperatures, heavy rainfall and flooding. There have also been a growing number of studies on vulnerability to extreme heat and determinants of vulnerability. This evidence can inform the development of potential climate health indicators for Australia. Using the modified DPSEEA framework (Figure 2.1) the indicators have been categorised as follows: (1) driving forces of climate change, (2) pressure indicators of climate change, (3) state of the climate indicators, (4) exposure indicators, (5) vulnerability indicators, (6) effects indicators and (7) successful actions taken to reduce the health effects of climate change. These elements of the framework are presented in Sections 2.2.3.1 to 2.2.3.7, respectively. Also, relevant indicators for each component of the framework are mentioned in Figure 2.1. Note, potential indicators of vulnerability and health effects are presented in Table 2.2 and Table 2.3, respectively.

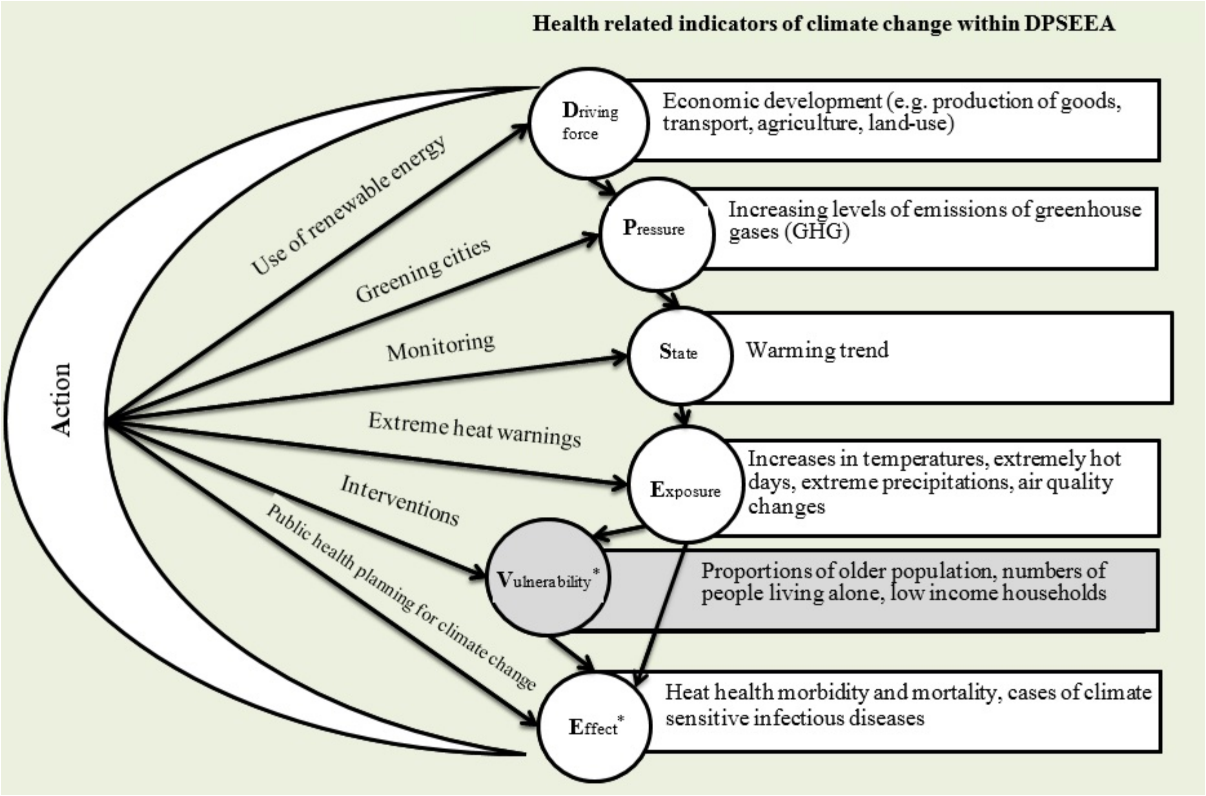

**Figure 2.1 Figure 1: Driving force-Pressure–State-Exposure-Effect –Action framework with the addition of Vulnerability, adapted from (Corvalán et al., 1999)**

*: Potential indicators of vulnerability and health effects presented in Table 2.2 and Table 2.3 respectively

### 2.2.3.1 Driving forces of climate change

Population growth and economic development have been identified as the main driving forces behind the anthropogenic activities that have resulted in a rise in greenhouse gases (GHG) leading to climate change (Pachauri et al., 2014). In Australia, driving forces behind GHG emissions are primarily due to: stationary energy emissions, transport fuel emissions, indirect emissions from electricity, fugitive emissions from fuels, industrial processes, waste emissions, agriculture and land use and forestry (CCA, 2014). Indicators of driving forces of climate change could also include annual urban population growth, numbers of motor vehicles (per 1,000 people) and annual electricity generation from non-renewable energy (World Bank, 2015).

#### 2.2.3.2 Pressure indicator of climate change

Pressure on the environment, generated by driving forces, can be measured using indicators such as levels of GHG emissions. These emissions as a result of energy, industrial processes, waste, agriculture and land use, pose pressure on the environment. It is estimated that 549,445.84 Gigagrams of GHG were emitted in Australia in 2013 (AGEIS, 2015). Limiting the magnitude of future climate change requires large and sustained net global reductions in GHG emissions (CSIRO and BOM, 2014). The estimated level of GHG emissions from different sectors by year and state can be accessed through the Australian National Greenhouse Gas Inventory (AGEIS, 2015).

#### 2.2.3.3 State of the climate indicators

The state of the environment changes in response to this pressure (Corvalán et al., 2000) and results in warming of the atmosphere and oceans. Global surface temperature is the most telling indicator of climate change and $1^{o}$C of warming has occurred in the Australian region since 1910 (BOM and CSIRO, 2016). Rainfall is another environmental indicator and measurements have shown that rainfall averaged across all of Australia has slightly increased since 1900 with the largest increases in the northwest of the country. Average rainfall in southern Australia is projected to decrease, with a likely increase in drought frequency and severity (BOM and CSIRO, 2016). These environmental indicators are used to routinely monitor the changing state of the climate.

#### 2.2.3.4 Exposure indicators

Adverse health effects can occur as a result of exposure to climate hazards and extreme weather conditions. In Australia, warming has been linked to longer and more frequent heatwaves, long-term drought conditions and an increase in extreme fire-weather days. Since 2001, the number of extreme heat records in Australia has exceeded that of extreme cool records by almost 3 to 1 for daytime maximum temperatures, and almost 5 to 1 for night-time minimum temperatures, respectively (CSIRO and BOM, 2014). There has been an increase in extreme fire-weather, and a longer fire season, across large parts of Australia since the 1970s (CSIRO and BOM, 2014). The frequency of extreme rainfall has increased in Australia; and in 2011 heavy rainfall in Queensland resulted in extensive flooding (Arblaster et al., 2015) and subsequent health effects (Turner et al., 2012). Tropical cyclones are projected to decrease in number but increase in intensity (CSIRO and BOM, 2014). Changes in numbers and intensity of these weather conditions can be used as indicators.

#### 2.2.3.5 Vulnerability indicators

To develop indicators of vulnerability to climate change that can be used to guide the development of adaptation policies, an understanding of the multi-faceted nature of vulnerability is required. In Australia, a number of studies identifying determinants of vulnerability to the health impacts of climate change mainly focus on heatwaves.

A quantitative study in Adelaide found that living alone, receiving help from community services, having health problems and low socioeconomic status were risk factors during a severe 2009 heatwave in Adelaide (Zhang et al., 2013). Furthermore, a qualitative study in three Australian cities has shown other risk factors for culturally and linguistically diverse communities including language barriers, low literacy, perception of heat risk to health, poor quality housing, high power costs and lack of access to transport (Hansen et al., 2014). Another qualitative study in rural and remote communities in South Australia found similar risk factors (Williams et al., 2013). Adaptive behaviours have been associated with reducing vulnerability to heat, and high knowledge about heatwaves; being married or having contacts and social bonds; and high levels of education and income have been shown to be protective (Akompab et al., 2013).

A study in South Australia assessed vulnerability to climate change by incorporating socioeconomic and environmental data on a geospatial basis (Tan and Chadbourne, 2014). Thirteen indicators for socioeconomic vulnerability were identified. These were: low income, unemployment, low educational attainment, housing tenure, older age, disability, single-parent households, indigenous status, newly arrived migrants, lack of English proficiency, lack of car ownership and internet accessibility. These were overlaid with rainfall and mean temperature in five environmental settings in South Australia. The study found residents in the urban coastal/inland, rural coastal and river land areas were at higher risk of being impacted by climate change over the next decades (Tan and Chadbourne, 2014).

Another analysis of spatial vulnerability to heat was undertaken in Australian capital cities using eleven vulnerability risk factors (Loughnan et al., 2014). Vulnerability factors to heat included: the presence of urban heat islands, older age, a high concentration of single-person households, high population density, ethnicity, low socioeconomic status, a high number of aged care facilities, poor accessibility to emergency services, and need for assistance (Loughnan et al., 2014). However, these risk factors were not equally attributed to increased risk in all the cities. For example, measures of disability and accessibility to emergency services by travelling time were found to be good predictors of vulnerability in Adelaide; while in Brisbane single persons aged over 65 years and urban design (i.e. low accessibility of residents in some areas to emergency response services and higher probability of delayed ambulance arrival due to urban design) were the best predictors of vulnerability (Loughnan et al., 2013).

Given these findings from the literature review, potential indicators of vulnerability addressed in the Australian literature are presented in Table 2.2.

**Table 2.2 Potential indicators of vulnerability to heat**

| Vulnerability factor | Indicator | Reference |
|---|---|---|
| Age | Percentage of people aged above 65 years | (Loughnan et al., 2014) |
| Isolation | Numbers of people living alone, one-parent families with dependent children and couples with no dependent children | (Hansen et al., 2014), (Loughnan et al., 2014), (Zhang et al., 2013)<br>(Nitschke et al., 2013) |
| Socioeconomic status (SES) | Percentage of low-income families | (Hansen et al., 2014)<br>(Loughnan et al., 2014)<br>(Zhang et al., 2013) |
| Need for assistance | Numbers of people with disabilities | (Loughnan et al., 2014)<br>(Zhang et al., 2013)<br>(Nitschke et al., 2013) |
| Existing health issues | Numbers of people with chronic diseases | (Hansen et al., 2014)<br>(Zhang et al., 2013)<br>(Nitschke et al., 2013) |
| Language barriers | Numbers of people not fluent in English | (Hansen et al., 2014) |
| Low literacy | Percentage of full-time participation in secondary school education at age 16 | (Hansen et al., 2014) |
| Aged care facilities | Numbers of aged care facilities | (Loughnan et al., 2014) |
| Access to emergency services | Numbers of emergency services within a postcode area | (Loughnan et al., 2014) |

#### 2.2.3.6 Effects indicators

Numerous health effects as a result of exposure to extreme heat, air pollution and extreme precipitation have been reported in the Australian literature. The literature suggests that adverse health outcomes can be categorised into four groups relevant to the development of climate health indicators: heat-health outcomes, air pollution-related health outcomes, climate-sensitive infectious diseases, and injuries and death due to extreme weather events, as discussed below. However, it should be noted that not all health conditions discussed below are due to, or associated with, environmental exposures, and not all environment-related health effects are mentioned (Corvalán et al., 2000).

***Heat-health outcomes***

The most obvious connections and the most researched associations between climate change and health are those linked with extreme weather events including extreme heat. The health outcomes include increases in excess mortalities and morbidity.

A two-fold increase in mortality due to extreme heat is predicted by 2020 in the six largest Australian cities (Hennessy, 2011). Heat was responsible for 4555 deaths during the period 1900 - 2011, equating to 55% percent of all natural hazard deaths reported in Australia (Coates et al., 2014). In Victoria, 374 heat-related deaths were recorded during a 2-week heatwave in early 2009 (Hennessy, 2011). High temperatures have also been associated with increases in mortality in Sydney, NSW, during 1997 to 2007 (Wilson et al., 2013) and in Brisbane, Queensland, during 1996 to 2004 (Tong et al., 2012). In Perth, Western Australia, an increase in maximum temperature above 34–36 °C was associated with increases in daily mortality during 1994-2008 (Williams et al., 2012b). Additionally, increases in mortalities attributed to mental and behavioural disorders have been observed among the 65- to 74-year age group and in persons with schizophrenia, schizotypal, and delusional disorders during heatwaves in Adelaide (Hansen et al., 2008a).

As well as mortality, extreme heat can trigger the onset of a range of poor health outcomes (Bi et al., 2011) resulting in increases in morbidity, as seen in different cities in Australia during heatwaves. Indicators of morbidity can be numbers of ambulance callouts, hospitalisations and emergency department presentations.

During extreme heatwaves in 2008 and 2009 in Adelaide, ambulance call-outs were increased by 10% and 16% respectively, compared to previous heatwaves (Nitschke et al., 2011a). In Brisbane, increases in ambulance call-outs for respiratory and cardiovascular diseases were seen during heatwaves in 2000-2007, especially in the older population (Turner et al., 2013).

Hospital admissions have been shown to increase during high temperatures in Sydney, NSW (Wilson et al., 2013) and in Adelaide, a 14-fold increase in direct heat-related admissions was observed during the 2009 heatwave, and a three-fold increase during the 2008 event and previous heatwaves (Nitschke et al., 2011a). Also in Adelaide, hospitalisations have been shown to increase for persons with mental disorders (Hansen et al., 2008a) and renal disease during heatwaves compared with non-heatwave periods (Hansen et al., 2008b). As heatwaves become more frequent, the burden of renal morbidity may increase in susceptible individuals as an indirect consequence of global warming (Hansen et al., 2008b).

The literature shows that emergency department presentations also increase during high temperatures. In Perth, Western Australia, a study showed that an increase in maximum temperature above 34–36 °C was associated with increases in emergency department presentations during 1994-2008, particularly for renal-related presentations (Williams et al., 2012b). In Brisbane, also, a study showed increases in emergency hospital admissions during the period 1996 to 2004 (Tong et al., 2012).

As well as heat-related mortality and morbidity, other health outcomes can be associated with climate change, as mentioned above and discussed in more detail below. These include adverse health outcomes due to climate-related air pollution exposure (e.g. dust, bushfires, high $O_3$ concentrations and aeroallergens) and climate-sensitive diseases. In summary, a list of climate-related health outcomes is presented in Table 2.3.

**Table 2.3 Climate-related diseases and conditions in Australia**

| Health outcome | References |
|---|---|
| ***Heat-related*** | |
| Mortality (all-cause) | (Tong et al., 2010) (Bi et al., 2008) (Nitschke et al., 2011a) |
| Mortality due to cardiovascular diseases | (Bi et al., 2008) |
| Mortality due to renal diseases | (Williams et al., 2012b) |
| Mortality of people with mental disorders | (Hansen et al., 2008a) |
| Respiratory morbidity | (Turner et al., 2013) |
| Cardiovascular morbidity | (Turner et al., 2013) |
| Direct heat-related hospital admission | (Nitschke et al., 2011a) |
| Mental morbidity | (Hansen et al., 2008a) |
| Renal morbidity | (Nitschke et al., 2011a) (Hansen et al., 2008b) (Williams et al., 2012b) |
| Preterm birth | (Wang et al., 2013) |
| ***Air pollution related*** | |

| | |
|---|---|
| All-cause mortality | (Vaneckova et al., 2008) |
| Mortality due to circulatory disease | (Vaneckova et al., 2008) |
| Mortality due to respiratory disease | (Vaneckova et al., 2008) |
| Mortality due to cardiovascular diseases | (Tong et al., 2010) |
| Respiratory hospital admission | (Chen et al., 2006) |
| Allergic asthma | (Haberle et al., 2014) (Beggs and Bennett, 2011) |
| Allergic rhinitis (hay fever) | (Medek et al., 2012) (Beggs and Bennett, 2011) (Johnston et al., 2009) |
| ***Climate-sensitive infectious diseases*** | |
| Salmonellosis | (Zhang et al., 2012) (Zhang et al., 2008) (Bambrick et al., 2008) (Hall et al., 2011) |
| Campylobacteriosis | (Bambrick et al., 2008) (Hall et al., 2011) |
| Cryptosporidiosis | (Bambrick et al., 2008) |
| Shigellosis | (Bambrick et al., 2008) |
| Leptospirosis | (Lau et al., 2010) |
| Barmah Forest Virus disease | (Naish et al., 2013) (Harley et al., 2011) (Jacups et al., 2008) |
| Dengue | (Hill et al., 2014) (Harley et al., 2011) (Banu et al., 2011) (Kearney et al., 2009) (Bambrick et al., 2008) (Woodruff et al., 2005) |
| Ross River virus disease | (Werner et al., 2012) (Harley et al., 2011) (Russell, 2009) (Tong et al., 2008) (Jacups et al., 2008) (Tong et al., 2004) |
| Murray Valley encephalitis | (Harley et al., 2011) (Russell, 2009) |
| Kunjin | (Harley et al., 2011) |
| Melioidosis | (Harley et al., 2011) |

### *Air pollution health outcomes and the link with climate change*

Exposures to air pollutants have been shown to have adverse effects on human health leading to increases in some cardiorespiratory diseases and related mortality (Lave and Seskin, 2013). In terms of climate change, the main air pollutants of concern are ozone ($O_3$), particulate matter (PM) and aeroallergens such as pollen, all of which can be influenced by meteorological conditions and climate change. Several studies have investigated the contribution of high levels of $O_3$ to mortality during heatwaves (Grizea et al., 2005, Filleul et al., 2006, Ren et al., 2008). These studies emphasise the need to evaluate $O_3$ levels when estimating the heat-related health impacts of heatwaves. A number of studies have been conducted on this issue in Australia. A study in Brisbane showed that $O_3$ contributed to excess deaths in the 2004 heatwave but these were mainly attributed to temperature (Tong et al., 2010), whilst another study in Sydney showed that maximum temperature affected increases in deaths and a moderate correlation between daily maximum temperature and $O_3$ was found (Vaneckova et al., 2008). A study in Adelaide on heat-related mortality and morbidity showed the strongest associations between daily temperatures and daily rates of ambulance call-outs and emergency department presentations, (particularly for mental health and heat-related illness) when taking $O_3$ and $PM_{10}$ (particulate matter in which 50% of particles have an aerodynamic diameter of less than 10 μm) into account (Williams et al., 2012a).

Hot, windy weather can lead to bushfires. With climate change, bushfires associated with more frequent heatwaves and days of extreme fire danger can therefore lead to increases in particulate pollution (Hansen et al., 2009). A Brisbane study showed increases in daily respiratory hospital admission rates with increasing levels of $PM_{10}$ during both bushfire and non-bushfire periods. However, this relationship was stronger during bushfire periods (Chen et al., 2006).

Changes in temperature and rainfall and seasonality associated with climate change have the potential to impact on the amount of airborne pollen, pollen allergenicity, pollen seasons and pollen distribution. These can have consequent impacts on allergic diseases and conditions such as asthma and hay fever (Beggs, 2004, Beggs and Bennett, 2011). An increase in the allergenicity of pollen and prevalence of seasonal allergic disease has been associated with increasing atmospheric $CO_2$ concentrations (Singer et al., 2005, Rogers et al., 2006). Meteorological factors such as temperature, wind speed and humidity can influence the production of pollen; and with temperature increases due to climate change, the frequency of pollen-induced respiratory allergy may also increase (D'amato and Cecchi, 2008, Beggs and Bennett, 2011, Beggs, 2010).

Climate change mitigation strategies aim to reduce $CO_2$ which may consequently reduce the production of pollen (Beggs, 2010). Management of a number of allergenic plant species in populated areas, early warning systems for aeroallergens, bushfires, or dust storms and monitoring of the atmospheric environment on a regular basis (not only during periods of poor air quality) are adaptation options that have been suggested for Australia (Beggs and Bennett, 2011). However, although the impact of climate change on allergic diseases has been studied in Europe, North America and Japan, there are only few studies conducted in Australia (Beggs and Bennett, 2011). Surveillance studies using aeroallergens data may be useful in the future as indicators of climate change in Australia.

### ***Climate-sensitive infectious diseases***

Food-borne infections caused by pathogens such as *Salmonella* and *Campylobacter* have strong seasonal cycles and it is expected incidence will increase with rising temperatures (Hall et al., 2002). Gastrointestinal illness can also be caused by other food-borne bacteria such as *Staphylococcus aureus* if storage temperatures are compromised (Kjellstrom and Weaver, 2009).

The transmissibility of some zoonotic diseases (acquired from vertebrate animals) may also be affected by increasing temperatures and changes in precipitation patterns associated with climate change (Mills et al., 2010). Heavy rainfall and flooding lead to deterioration in the quality of surface water and ground water sources, and warmer temperatures aid the proliferation of waterborne pathogens including certain bacteria, viruses, protozoa, toxigenic algae, and helminths (Hall et al., 2002, Hunter, 2003).

One such water-borne disease is leptospirosis which is often associated with flooding and heavy rainfall events, and may occur more frequently in the future in flood-prone areas of Australia (Lau et al., 2010). Sea level rise also poses risks to freshwater supplies and sanitation systems (McMichael and Lindgren, 2011, Green et al., 2010). Additionally, droughts can lead to a concentration of water pollutants in surface water (Kjellstrom and Weaver, 2009) and conventional drinking water supplies may need to be supplemented/ replaced with other sources (Dale et al., 2010).

Climate change can change the incidence and geographical distribution of vector-borne diseases such as Ross River Virus (RRV), Barmah Forest Virus (BFV), and dengue fever (Harley et al., 2011). Changes in temperature and rainfall can have wide-ranging effects on vector survival, replication, activity, habitat and availability of breeding sites, as well as the incubation period and transmission of pathogens. Rainfall is the most important driving factor of RRV in many areas of Australia (Werner et al., 2012). Temperature and tides have also been associated with mosquito abundance and rates of RRV (Werner et al., 2012). However, evidence for the association of RRV transmission with flooding has been reported as being circumstantial in one study (Tall et al., 2014).

A Queensland modelling study has predicted future risk of BFV disease transmission using maximum and minimum temperatures, rainfall, socioeconomic index, low tide and high tide as predictors (Naish et al., 2013). For dengue, the main mosquito vectors are *Aedes aegypti* and *Aedes albopictus*. Whilst *Ae. aegypti* exists in north Queensland, *Ae. albopictus* does not currently exist in Australia, although new models predict its spread into mainland Australia from the Torres Strait Islands. Differences in the habits of these mosquitoes might make the control mechanisms currently used for *Ae. aegypti* less effective for *Ae. albopictus*. Moreover, *A. albopictus* has a higher rate of transmission of disease-causing virus from female-infected mosquitoes to offspring, which may increase the risk of endemicity (Hill et al., 2014). Climate change predictions of increased rainfall may also increase transmission of other vector-borne diseases such as Murray Valley Encephalitis and Kunjin encephalitis in northern Australia (Harley et al., 2011).

Surveillance data of the infectious diseases discussed above are routinely collected in Australia. These data may be used as indicators of health impacts of climate change. However, when investigating and interpreting the impact of climate change on infectious diseases, it is important to consider non-climatic factors (Banu et al., 2011) such as the role of mosquito control programs on the mosquito-borne diseases. A study on the local government control programs for RRV management in Queensland showed a number of factors in planning that can affect the RRV disease rates (Tomerini et al., 2011). Human cases of these climate-sensitive infectious diseases may therefore be used as potential indicators of climate change. A list of climate-sensitive diseases in Australia is shown in Table 2.3.

### ***Injuries and death due to extreme weather events***

The final of the four groups of effect indicators relevant to the development of climate health indicators is injuries and death due to extreme weather events. The number of some extreme events such as heavy rainfall and bushfires has increased in Australia (CSIRO and BOM, 2014). Tropical cyclones occur in northern Australia over the wet season and the intensity of these is projected to increase with climate change (CSIRO and BOM, 2014). Heavy rainfall in Queensland led to extensive flooding in 2010-2011 (Arblaster et al., 2015) resulting in 33 deaths, the most from a single flood event in Australia since 1916 (Zhong et al., 2013). A subsequent health impact assessment of these 2011 summer floods in Brisbane showed that residents whose households were directly affected by flooding reported poor physical health such as respiratory health and mental health such as psychological distress (Alderman et al., 2013).

As mentioned in Section 1.4, bushfires are common during summers in SA and fire weather may be considered as a possible indicator of climate change. Bushfires during 1967 to 1999 lead to 223 deaths and over 4000 injuries (Ladds et al., 2017). Examples are the 1983 Ash Wednesday bushfires with 28 deaths in SA and 47 in Victoria; a 2005 Eyre Peninsula fire in SA resulting in nine deaths and more than 110 people injured; and the 2007 Kangaroo Island bushfire with one fatality (CFS, 2017b). A more recent fire at Sampson Flat (SA) in 2015, led to 134 people being injured (CFS, 2017a).

The Australian Disaster Resilience knowledge hub has a database of disasters that have occurred in Australia (AIDR, 2017). The database is searchable by category including bushfire, cyclone, flood and severe storm; by region and time period. It includes information about insurance costs of disasters, death and injuries and uses different resources such as case studies, multimedia sources and research to report on the events (AIDR, 2017). However, there are limitations to this database as not all the events are included. For example, a bushfire which occurred in 2007 on Kangaroo Island could not be found in the database. Another limitation is that when events occur in more than one state (such as the Ash Wednesday bushfires), numbers of deaths, injuries and other losses are not reported accordingly. Therefore, it is difficult to find estimates of losses and casualties by state to be used as climate-health indicators.

#### 2.2.3.7 Actions taken to reduce the health effects of climate change

Many of the projected health impacts of climate change may be minimized through mitigation and adaptation strategies in health-related sectors (Campbell-Lendrum et al., 2007). Indicators can be used to take actions in response to reducing the impact of climate change. As the modified DPSEEA illustrates (Figure 2.1) actions can be taken at each step of the causal chain. Indicators such as the use of renewable energy and the number of heatwave early warning systems which are higher up in the framework, are often more useful to set adaptation and mitigation policies and take effective actions at the root causes of health effects (Von Schirnding, 2002).  Indicators associated with effects such as excess morbidity due to extreme heat are useful for monitoring the climate-health effects and health service delivery (Von Schirnding, 2002). Examples of actions taken for the modified DPSEEA framework are presented here.

***Investment on renewable energy***:

Use of renewable energies has been proposed as mitigation indicators of climate change (English et al., 2009). The Australian Government has invested $10 billion in renewable energy since 2001 until 2015 when the report was published and an estimated $20 billion is expected to be invested between 2015 and 2020 (Australian Government, 2015). The Government, through CSIRO, also supported around 350 scientists to research new energy technologies for Australia and investigate policy initiatives to reduce emissions, according to a 2014 report (CCA, 2014).

***Greening cities***:

Mitigation of climate change by sustainable urban design such as greening cities has health co-benefits and can be used as mitigation indicators (WHO, 2011b). As an example of greening cities, the City of Sydney has developed a Greening Sydney Plan in response to climate change. The plan helped implement 17 community gardens across the Local Government Area (LGA) and install 14 rain gardens for treating stormwater before discharge to the main stormwater system (DIT, 2013).

***Monitoring:***

The Australian Bureau of Meteorology (BOM) and CSIRO routinely monitor and forecast weather and climate and regularly release their data and analysis as summaries of the state of the climate (CSIRO and BOM, 2014).

***Extreme heat warning (South Australia):***

The State Emergency Service (SES) is the Hazard Leader for Extreme Weather in South Australia and during the summer the SES works closely with the Bureau of Meteorology. When average daily temperatures of 32$^{o}$C or above are predicted for three or more consecutive days, the SES will issue an extreme heat warning to the public via a media release in advance of the event (SES, 2015). This action may reduce the increased health burden associated with extreme heat. Climate-health indicators could be used to evaluate the effectiveness of the warning systems (See section 4.3).

***Intervention: Telecross REDi as a South Australian example***

Since January - February 2009, when South Australia suffered a heatwave that claimed many lives and hospitalised many more, a service called Telecross REDi has been activated during heatwaves by the South Australian Department for Communities & Social Inclusion. It assists registered vulnerable and isolated people cope with extreme weather events by telephoning them three times per day during heatwaves to check on their welfare (Australian Red Cross, 2015).

***Public health planning for climate change:***

Lastly, the development of climate change adaptation plans for cities and states can be used as adaptation indicators of climate change (Cameron et al., 2011). Australian Government Health Departments are currently working on identifying human health impacts of climate change, vulnerable groups and adaptation strategies. The Victorian Department of Health and Human Services, for example, is undertaking an integrated impact assessment of climate change, health and vulnerabilities (VIC Health, 2015). The South Australian Public Health Council has deemed preparing for climate change one of the four priority areas for further planning and action by local government. Actions taken by local governments include preparing regional adaptation plans in SA and ensuring that the public health implications of climate change are addressed in the plans (SA Health, 2013).

### 2.2.4 Discussion

This systematized review of Australian literature aimed at providing scientific evidence as a basis upon which climate health indicators can be developed. Findings were structured using the modified DPSEEA framework, presenting links among various environmental and social factors that affect health in the context of climate change.

Examples of indicators for each level of the framework have been provided that can be used to take actions in reducing the health effects of climate change. Indicators at the upper level of the framework such as the numbers of greening city plans and instalments of rain gardens for treating stormwater could be used for mitigation and adaptation purposes. Indicators in the middle of the framework, for example weather and air quality data, can be selected to use for monitoring the state of the climate. The health effects become tangible and more direct moving to the lower levels of the modified framework.

In this current study, special attention was given to suggest evidence-based indicators of vulnerability and health effects. Findings revealed that Australian studies have provided a reasonable understanding of the health impacts of climate change and determinants of vulnerability (Hansen et al., 2013, Hansen et al., 2011, Williams et al., 2013, Nitschke et al., 2013, Webb et al., 2014, Zhang et al., 2013). Amongst the health effects heat-related mortality and morbidity are strongly related to climate change. In several studies heat-related mortality and morbidity increased with extreme temperature even when adjusted for air pollution; showing that heat-related cases are sensitive to changes in climate. Hence, based on the evidence gathered in this literature review, these are recommended as the most appropriate indicators for Australia.

Air pollution health outcome indicators such as cardiovascular diseases (Lave and Seskin, 2013) are less sensitive and specific as indicators of climate change (as cardiovascular diseases can be linked to a number of causes totally unrelated to air pollution or climate-related air pollution) and can be less amenable to adaptive actions than direct heat-related morbidity and mortality.

Amongst climate-sensitive infectious diseases salmonella infection has been shown to have a strong seasonal cycle. Increases in notifications of salmonellosis have been linked to the impact of warm season temperature (Milazzo et al., 2015). Raising awareness of the risk of incorrect storage of food on food safety programmes during warmer weather may help reduce the incidence of salmonellosis which is a notifiable disease in Australia. These data can be accessed through Departments of Health and are likely the best measure for surveillance and tracking.

Health outcomes such as injuries and death due to extreme events are not well documented in the literature; however, if suitable data were collected on a national basis this would be useful to examine potential climate change trends and would indicate the effectiveness of disaster warnings.

This literature review has found that indicators of physical and spatial determinants of vulnerability that may increase exposure to heat include the effect of urban heat islands, land cover, urban design, and population density (Loughnan et al., 2013). Apart from biological determinants of vulnerability such as older age and health issues, cultural and economic factors can also increase susceptibility (Loughnan et al., 2013). These include lack of literacy, low SES, living alone, needing assistance, being born overseas, and being a recent arrival and/or not fluent in English (Hansen et al., 2014). These can be used as potential indicators of vulnerability to heat. Lack of access to transport, numbers and distribution of aged care facilities in an area, and accessibility to emergency services are institutional determinants of vulnerability that can be used as indicators to measure adaptive capacity. Data are available for most of the indicators discussed here. The ABS has statistics available on a wide range of economic and social issues that can be used for the vulnerability indicators.

Few Australian studies have investigated the determinants of vulnerability on a spatial basis in Australia and further research should be conducted in this field. This would prove useful for policymakers and decision-makers to more accurately identify and locate vulnerable populations and consequently propose targeted public health preventative actions.

### 2.2.5 Conclusion

A range of potential evidence-based indicators has been identified through reviewing the literature and using the adapted DPSEEA framework to connect climate change-related exposures with effect indicators that are modified by vulnerability factors. Some indicators have shown a very high level of weight of evidence; while other health outcomes are less conclusive. At present the strongest environmental health indicators of climate change in the Australian context are:

- Excess heat-related morbidity (such as ambulance callouts and hospital admissions)
- Excess heat-related mortalities
- Notifications of climate-sensitive infectious diseases, for example salmonellosis

These can be used to measure the adverse health effects of climate change, subject to collaborations between researchers and policymakers in implementing the evidence. Health policymakers can use these indicators as tools of communication with other sectors for developing policies which aim to reduce the health effects associated with climate change.

The next step in the process of developing indicators is identifying data sets that are available for long periods of time and applicable at the local level as the use of longitudinal data sets has been emphasised in other studies (English et al., 2009). Stakeholder engagement is also necessary for identifying and using datasets and understanding the requirements of those who will use the indicators for measuring climate-related health effects and assessing the factors perceived to increase people’s vulnerability to the changing climate in Australia.

# CHAPTER 3

# Climate-health indicators development: A qualitative study of stakeholders' views

## Overview

This chapter explores South Australian stakeholders' perspectives on the development, and usefulness of climate health indicators, using semi-structured interviews with key informants and service providers from government and non-government stakeholder organizations in SA. Key criteria for the utility of indicators are identified as well as the main issues that stakeholders encounter in developing indicators. A journal article based on the findings of this chapter was published in the International Journal of Environmental Research and Public Health (Navi et al., 2017) and can be found in Appendix B.

## 3.1 Introduction

Australian public health authorities require data for use as indicators to measure and monitor health effects of climate change and to evaluate the effectiveness of public health adaptations and interventions (SA Health, 2014). In health research in general, and particularly in areas such as indicator development, it is important to define from the start the purpose of an indicator. Therefore, stakeholder involvement at an early stage is essential to establish their views on the usefulness and purpose of, indicators (Delnoij et al., 2010). The involvement of a broad range of stakeholders from sectors other than health is also necessary, because climate change issues are intersectoral, affecting a multitude of different areas and government departments (Spickett et al., 2011, Corvalán et al., 2000).

A study by Weber et al (2015) focusing on indicators for mapping human vulnerability to extreme heatwaves, found that engaging stakeholders from city councils and local institutions was helpful in indicator development and could lead to more practical and policy-relevant indicators (Weber et al., 2015). Moreover, the study received recommendations from stakeholders emphasising that visual representation of indicators at the neighbourhood level can assist local government to implement appropriate measures to mitigate the impacts of extreme heat events (Weber et al., 2015). Other studies have asserted the usefulness of using currently available data as climate health indicators (Cheng and Berry, 2013, English et al., 2009). However, the perceptions of local stakeholders are essential to establish needs and priorities in this regard.

The use of mixed methods has been increasing in environmental health research, with qualitative techniques such as interviews being used in combination with quantitative methods to collect rich, comprehensive data, provide methodological flexibility and gain a well-rounded view of the issues under study (Brown, 2003). This study using a qualitative approach, is, to the author's knowledge, the first attempt to explore stakeholders' views about the usefulness of indicators and their requirements for measuring climate change-related adverse effects on health. Issues relating to data availability, factors perceived to increase vulnerability to the changing climate, criteria required for robust indicators, and issues faced in developing and using indicators were some of the issues explored.

## 3.2. Methods

Using a qualitative approach, engagement with stakeholders via interviews was undertaken to guide the development of indicators and explore their perceptions (Weber et al., 2015), regarding presently available data and barriers to the development of indicators. Outlined below are the details of the study setting, theoretical perspective, sampling, data collection and analysis.

### 3.2.1 Recruitment

Using purposive sampling (Palinkas et al., 2015), potential participants were identified. These included key informants and service providers from state and local government, and non-government organisations in South Australia for which climate change and its impacts were very relevant in their day-to-day work. Potential participants from, for example, the health sector, environmental agencies and emergency service organisations were contacted and provided with an information sheet clarifying the purpose of the study, explaining the interviews and the anonymity of participants, and the confidentiality of information collected (Appendix C). Details of the complaints procedure were also provided (Appendix D). Those interested in participating were contacted again to arrange a convenient time for an interview and asked to sign an informed consent form seeking their permission to record the interview (Appendix E). In total, 21 participants were recruited.

Ethics approval for this study was granted from the Human Research Ethics Committees at the South Australia Department for Health and Ageing (SA Health) and the University of Adelaide (No. HREC/14/SAH/193) (Appendix F).

### 3.2.2 Data Collection

Face-to-face semi-structured interviews were undertaken between May to December 2015, with a further two interviews conducted in January 2016 at the participants' place of employment. Interviews were digitally recorded and were generally between 30 and 60 minutes in duration.

Respondents were asked about: (i) the need to develop health-related indicators of climate change, (ii) data availability and accessibility, (iii) the usefulness of indicators, (iv) factors that increase vulnerability or increase resilience to climate change, (v) and particular issues in the development of indicators (Table 3.1). They were also given the opportunity to raise other issues they considered relevant. Audio-files and data were stored on a password-protected computer at the University of Adelaide.

**Table 3.1 Interview topic guide.**

| Questions |
|---|
| 1. Can you tell me if your organisation collects data regarding extreme weather events, emergencies or natural disasters and if so what type of data this might be? |
| 2. What is (are) the source(s) of these data and are they routinely collected on a local or national scale? (Secondary question: How are the data collected and is it accessible to researchers?) |
| 3. Is it just your organisation that collects the data or there is a collaboration of organisations? |
| 4. Are you interested in climate change indicators currently for your work? |
| 5. How useful do you think this data would be as an indicator to track the progression of climate change, or the health effects of climate change over time, and if so, how? |
| 6. Are there any data that you think would be useful to collect that might be used as indicators of health outcomes of, or vulnerability to, climate change? |
| 7. Why do you think you would need them? |
| 8. What should they look like? |
| 9. How would you use them? |
| 10. What do you think would be the barriers to collecting these data and their use as indicators? |
| 11. Is there anything else you would like to add about how we can use indicators to measure impacts of climate change? |

### 3.2.3 Data Analysis

Recorded interviews were transcribed verbatim using the qualitative analysis software package NVivo 10 (QSR International Pty Ltd., Doncaster, Vic, Australia) and de-identified to protect confidentiality. An inductive approach was taken to explore the data using thematic analysis to identify recurring themes (Braun and Clarke, 2006). This involved a stepwise process starting with reading and re-reading the transcripts and making notes. Passages of text displaying similar concepts were assigned to aptly named codes. These were later collated or merged into the major themes emerging from the data. The analysis sought to consider both the frequency of the theme in the data set, and the meaningfulness of the noted theme. This joint basis for considering what is, and what was not a theme (and related sub-themes), was essentially made on the basis of how well the theme captured something meaningful about the data in relation to the research question (Braun and Clarke, 2006). With the input of supervisors, transcripts and audio recordings were checked several times for accuracy and clarification when required.

### 3.2.4 Theoretical Perspective

The theoretical perspective of this study stems from a critical realist position, as described by Willig (2013). This approach has been widely used as a tool to link climate change studies including mitigation policy and actions on global warming with other areas of knowledge such as social activities and climate outcomes (Cornell and Parker, 2010). In critical realism, an inherent subjectivity in the production of knowledge is evident (Gray, 2013). It posits that data are not a direct reflection of what is going on in the world; rather, it presupposes that the interpretation of qualitative data is required in order to develop our understanding of the underlying structures of the phenomena of interest (Willig, 2013). In the current context, a critical realism approach aids in understanding stakeholders’ views on the usefulness and development of indicators to measure the health impacts of climate change.

## 3.3 Results

In total, there were 21 participants from different organizations: 13 from state government, three from local government, one from emergency services, two independent consultants working with state and local government, and two academics (Table 3.2). The expertise and knowledge of participants were diverse, as organisations that are concerned with the issue of climate change differ in terms of the nature of data they generate or use and services they provide. Five main themes with sub-themes were generated from analysis of the interview data (Table 3.3). These are discussed in detail below with example quotes from the participants.

**Table 3.2 Respondent categories by role.**

| **Respondents** | **Number** |
|---|---|
| State government manager/director | 5 |
| State government officer | 8 |
| Local government officer | 3 |
| Emergency services personnel | 1 |
| Non-government consultant | 2 |
| Academic | 2 |
| **Total** | 21 |

Participants spoke about climate change-induced extreme weather events and environmental changes including heatwaves, droughts, and sea level rise. They described the associated adverse health effects such as increases in food-borne diseases on hot days. They also thought that changes in climate had resulted in hotter weather, and were concerned about extreme heat posing a serious risk to the health of vulnerable people. They were aware that the health effects of climate change are not, and will not be, equally distributed.

> *“there seems to be more hotter weather and we work with vulnerable older people and vulnerable people in general, so heat is something that is getting more difficult for them to manage.”*
>
> (Local government officer 1)

Participants mentioned factors that can increase vulnerability to climate change. A local government officer explained that in their area a third of the population do not have internet access and that can make them vulnerable in terms of emergencies and heatwaves. They were also concerned about people whose first language was not English, as this may increase isolation. As well as ethnicity, other vulnerability factors mentioned included age, needing assistance, ill health, living alone, lack of transport, low level of education, lack of employment, low level household income, financial stress, and lack of social connectedness. Participants also recognized the importance of vulnerability considerations in planning and delivering interventions, and emphasized the need to build community resilience.

**Table 3.3 Identified themes and sub-themes.**

| Theme | Sub-theme |
|---|---|
| 1- Purpose of using indicators | Tracking and monitoring<br>Monitoring disease trend<br>Measuring adaptation<br>Evaluation and assessment<br>Tools for communications with policymakers |
| 2- Data for indicators development | |
| 3- A good indicator | Based on available data<br>Tailored for context<br>Based on a link between environment and diseases<br>Spatial representation of indicators<br>Specificity of indicators |
| 4- Issues and barriers | The problem of climate change is a new and complex area<br>Variability of risk factors in different regions<br>Lack of resources<br>Data and methodological issues |
| 5- Alternative indicators | |

### 3.3.1 Purpose of using indicators

Participants were keen for health-related indicators of climate change to be available and spoke of how they would use indicators, the types of data that would be useful as indicators and data that are currently available, what makes a good indicator, and issues and barriers to the development of indicators. The different purposes for the use of indicators were outlined. These included (i) tracking changes in the environment and monitoring the impacts, the effects that long and short-term changes in climate might have on the health of people and the environment, (ii) monitoring diseases trends (iii) measuring adaptation, (iv) evaluating actions taken, and (v) as tools for communication.

#### 3.3.1.1 Tracking changes in the environment and monitoring impacts on people

Respondents explained that they use indicators to track environmental changes and monitor impacts that the changes might have on the health of people and the environment. Data that monitor trends over time for rainfall, soil conditions, and droughts, for instance, were useful, and these could also be used as ways to mitigate the associated health impacts. They thought indicators that can monitor the health impacts of climate change over both short periods of time and long-term are required.

> *"we need indicators for climate change and health... that describe diseases in relation to climate and environment"*
>
> (Academic researcher 2)

> *"… we can monitor any impacts of climate change whether it would be on how… rainfall might be changing, drying conditions for soil, which has impact on management of open space and reserves, but also so we can monitor the impacts on the community, and obviously, health has a huge part of this so that is where this kind of work and developing a really strong indicators set, short-term and long-term, would be really valuable."*
>
> (Local government officer 1)

> *"I think it's difficult to in a short space of time to link any changes or any impacts to climate change…Climate changes is as I said a long-term impact"*
>
> (State government manager 2)

#### 3.3.1.2 Monitoring Disease Trends

It was mentioned that indicators could be used to monitor disease trends and anomalies in surveillance data which may indicate an abnormally high number of disease cases such as heat-related health outcomes. Participants also mentioned that meteorological indicators such as heavy rainfall could be used as potential predictors of disease outbreaks as mosquito-borne diseases can increase with rainfall and the expansion of standing waters in coastal areas due to sea level rise.

> *“what we do is to look at outbreaks of diseases so if we see anything for a particular disease which is above what we normally expect to see then would initiate a public health response and investigate why it is increasing, what is going on, but we also use that data to monitor trends over time and we also use it as well for particularly vaccine preventable diseases to also monitor and evaluate the effectiveness of the vaccination or other public health interventions.”*
>
> (State government officer 2)
>
> *"currently the issues which arise is probably heat and health, salmonella..."*
>
> (State government officer 4)
>
> *“I think rainfall is linked to many diseases indirectly and ... rainfall would be very good indicator for human health”.*
>
> (Academic researcher 2)
>
> *“sea level rise will create more incursion of new breeding sites”.*

(State government officer 1)

#### 3.3.1.3 Measuring adaptation

A recurrent theme identified in the data was the use of indicators for measuring human adaptation to climate change and how communities function or respond to extreme weather events including drought. A government officer believed that some adaptations to climate change could provide co-benefits for a healthier lifestyle. For example, areas of green space in cities can be used not only to measure adaptation to climate change, but also to promote physical activities in the community.

> *" Indicators as they impact on not just climate change but also on other health-related outcomes... ... for example increase shade and green space are important for increasing physical activities....... also is important for climate change agenda."*

(State government manager 1)

> *"I think if you actually did have a set of indicators that really showed this is the impact on health and wellbeing of people from maybe events or slow incremental changes like drought …, I think that actually could be a very powerful tool for actually taking further action in terms of mitigating climate change or adapting to it."*

(State government officer 1)

#### 3.3.1.4 Evaluation and assessment

Participants stated that indicators could be used for the evaluation of public health plans and the effectiveness of programs and interventions to reduce the impacts of climate change. They also mentioned the importance of using indicators for vulnerability assessments and environmental impact assessments in order to provide evidence for continued funding of successful programs.

> *"in terms of process, I think we need to know what action is happening on the ground to see if it does make an impact on health outcomes and on environment."*
>
> (State government manager 1)

> *"Well I have used indicators in strategic environmental assessment and in environmental impact assessment and then into integrated vulnerability assessment".*
>
> (Local government officer 2)

#### 3.3.1.5 Tools for communications with policymakers

Participants stated that indicators can be used as tools for communication and to present information to the public or stakeholders in a simplified way. They said using indicators for the evaluation of climate change mitigation and adaptation programs and activities is important. They also expressed views on various ways of presenting information such as graphs and maps which could be useful to policymakers and the general public (see Section 3.3.3.4).

> *“In our current environment, politically we need (indicators) to speak to our policymakers"*
>
> (State government officer 5)

### 3.3.2 Data for the development of indicators

The types of data that are collected by participants’ organisations included (i) environmental monitoring data such as air and water quality data, (ii) disease surveillance data, (iii) weather modelling and prediction data and (iv) survey data. Some organisations did not generate their own data and were dependent on data generated by the ABS, or other governmental organisations. Respondents discussed data that were available to them that could be used as health and environmental indicators, and the way it can be accessed. The types of data discussed included:

(i) South Australia’s Environment Protection Authority (EPA) for example, provide monthly and quarterly air pollution quality summaries and reports online, and daily air quality data over long periods of time that can be made available by request (Environment Protection Authority South Australia).

(ii) Disease surveillance data in the form of monthly numbers of notifiable infectious disease cases can be accessed through the National Notifiable Diseases Surveillance System in Australia (NNDSS Working Group). However, more detailed health data such as daily records requires ethics approval from the data custodians.

(iii) Weather modelling and prediction data are provided by the BOM and CSIRO (BOM and CSIRO, 2016). Across the state there are 60 monitoring stations for collecting weather data, which are available online.

(iv) Some local governments survey residents by phone in order to gain subjective self-reported data on different levels of vulnerability and resilience of communities to adverse events. It was mentioned that subjective data can reveal how people will function in terms of extreme weather and this information needs to be collected.

> *"Another thing we are trying to figure out is how do we use the indicators and data to identify those sort of trigger points… which ... could be when people tell us that they cannot cope anymore…. so yes, we still trying try to figure out what indicators do we use".*
>
> (Local government officer 1)

### 3.3.3 What makes a good indicator?

Interviewees spoke of different criteria that need to be met in order to establish robust indicators. They believed that indicators should be: (i) based on available data, (ii) tailored for context, (iii) based on a link between environment and diseases, (iv) spatially presented and (v) specific, as outlined below.

#### 3.3.3.1 Available data

There was a strong interest among participants in developing indicators and they were keen to utilise readily available data, explaining that long-term data are needed to show trends. It is not only easier and more practical to use already available data, but it could also accelerate actions as it allows monitoring of issues of concern, both retrospectively as well as in the future.

> *"I think that would be very important to link the indicators with data that has been collected already. That gives you a very good picture going back as well ... but it also gives you more confidence that the data will be collected going in to the future"*
>
> (State government officer 3)

> *"I found temperature to be a good one (indicator) to focus .......mortality data is good, morbidity data if you choose right morbidity data is pretty good"*
>
> (State government manager 2)

#### 3.3.3.2 Tailored for context

Some respondents spoke of the value of using existing data from the ABS, which can be used as indicators in certain contexts. For example, information about the economic and social conditions of people and households within an area can be useful as indicators of vulnerability to climate change. However, the current indices are not ideal in all cases and participants believed that indicators need to be tailored for specific purposes. One participant spoke about how they believed Socioeconomic Indexes for Areas (SEIFA) index (ABS, 2011b) for example, is not an ideal indicator of vulnerability when applied to country areas, perhaps due to the relatively small heterogeneous populations in cities and regions in large rural areas.

> *"what we also wanted to know is although those indices overall are quite good to give you a big picture, sometimes … having a group indices might not be necessarily the best for how we want to assess the data so for different risk factors we want particular indicators rather than group indices."*

(Local government officer 3)

#### 3.3.3.3 Based on a link between environment and diseases

Aligning with the literature, participants thought that indicators need to meet the criterion of credibility (Briggs, 2003) and should be based on a known link between climate and health. For example, in the following quotes, the participants discuss rainfall and temperature as environmental indicators and the link with infectious diseases:

> *"I think the two of them (rainfall and temperature) make good variables because they are so easy to measure, and so often both are linked to diseases either together or independently… Rainfall and temperature are two of the best indicators"*

(Academic researcher 2)

> *"We already know there is an association with temperature and Salmonella."*

(Academic researcher 1)

#### 3.3.3.4 Spatial representation of indicators

Participants suggested that the representation of indicators in the form of maps would increase clarity and ease of understanding for users. Interviewees explained there was a demand for spatial data analysis that can be used to produce maps to visually represent one or more indicators. They also thought that data presentation in the form of maps would clearly reveal areas of change, both spatially and temporally. Maps can also save many words, graphs and tables in reports and provide a basis for comparison where required. For example, spatial representation of indicators could be used by stakeholders to show areas of vulnerability to climate change, such as where flooding or sea level rise is likely to occur, or where certain health outcomes are greatest.

> *"one map tells an amazing story …, I think that those maps are incredibly powerful for talking with local government councils."*
>
> (State government officer 3)

> *"people find it easy to look at a map and say okay so where do the old people live, where is going to be flooded … lots of types of vulnerabilities to different risk factors."*
>
> (Non-government consultant 1)

#### 3.3.3.5 Specificity of indicators

While presenting a list of indicators might be helpful to stakeholders, participants stated they needed to be practical, specific and fit for purpose. For example, disease data may be required in specific formats such as disease notifications or cases hospitalized, depending on the purpose. Another example is age as a vulnerability indicator, as older age is often a risk factor, particularly for heat-related illness (Loughnan et al., 2014). However, specific age categories need to be defined as required to be a suitable indicator, as outlined in this quote:

> *"what we did first of all, we looked at the, I guess the traditional definitions of vulnerability … we had initially aged over 60 and someone said no, people over*

> *60, it's not over 60 now, it should be over 75 … because people are more healthy and stronger as they are getting older now?"*
>
> (Non-government consultant 1)

### 3.3.4 Issues and barriers

Interviewees realised that developing indicators for climate change is not a straightforward process. A range of issues was noted including that climate change is a new and complex area; varying risk factors are present in different regions; lack of resources (money, knowledge and skills); and data and methodological issues.

#### 3.3.4.1 The problem of climate change being a new and complex area

Respondents spoke of the difficulty in understanding the relationship between climate change and human health and wellbeing, especially for vulnerable populations. Some mentioned that developing indicators for climate change is a new and complex process for them, and interrelationships between factors that impact human health make it difficult to find indicators for monitoring that kind of effect. They also mentioned that some impacts of climate change may be only seen in the long-term. It was suggested that we should develop short-term as well as long-term indicators for the effects that can be best observed over long periods of time (see Section 3.3.1.1) and that annual or bi-annual reports would be useful to monitor the progress of climate change effects and adaptation.

> *"I think it is a good idea to have a report annually or every 2 years ... you could have then every ten years a bigger report which would be more meaningful for*

> *other indicators...that we have not noticed on a yearly level but you can see on a longer term."*
>
> (State government officer 4)

### 3.3.4.2 Variability of risk factors in different regions

Discrete risk factors are salient in different areas of South Australia due to regional climate variability. Whereas heatwaves occur almost everywhere in the state; there are certain areas prone to sea level rise, floods and bushfires. This can cause difficulties in the development and application of indicators. Although South Australian councils work together collaboratively on climate change adaptation plans across whole regions (Resilient East, 2016), issues in local environments differ and councils do not necessarily face the same issues. For example, coastal area communities might see themselves more vulnerable to flooding from sea level rise than those who live far from the coasts as encapsulated in this quote:

> *"in different regions, there's different climate variables so in terms of climate we had sea-level rise, flooding, and bushfire risk, … we also looked at increasing heat. I think sea level rise obviously goes up in some areas, and some areas are bushfire prone while others aren't."*
>
> (Non-government consultant 1)

### 3.3.4.3 Lack of resources

Another issue raised by stakeholders was a lack of resources in terms of specific skill sets and funding. It was claimed that while indicators may be developed there are few people skilled in the use of the data for planning and vulnerability assessment in their organisations. The need to integrate local and scientific knowledge to make informative decisions was mentioned and that data needs to be viewed in the context of local communities and environments. This may lead to some areas and vulnerable communities being overlooked.

> *"If you do not have the right people in the room and with any knowledge you can really skew what vulnerability was, or is, and we have seen that in some of our adaption plans for regions, we did not have certain people in the room, that whole area sort of got missed."*
>
> (Non-government consultant 1)

Respondents mentioned that lack of resources limits what they are able to do in terms of their goals, and strategic actions. Funding and resources are often insufficient to hire experts and specialists that can create models and analyse data and generally funding is allocated mainly to infrastructure. Research was viewed as fulfilling an important role in providing an evidence base and collaborating with research institutes and universities was deemed important.

> *"Resources is a really really big barrier and issue for us in terms of what we are able to do, you know often resources don't meet expectations and there is lot of expectations about what we could be doing and it is already very difficult to match that."*
>
> (State government officer 5)

#### 3.3.4.4 Data and Methodological Issues

Data access and methodological problems can arise in terms of data collection. These can include: lack of robust data; data inconsistency and non-comparability due to changes in methods and technology; gaps in data; and not having a central repository of data.

A lack of robust diagnostics and data for some climate-sensitive diseases is a limitation to the development of health-related indicators of climate change. For example, disease surveillance experts spoke of logistical issues with laboratory testing for arboviruses (transmitted by mosquitoes) and the problem of false positives or new testing methods creating inconsistencies in the data.

> *"The problem is there is so much cross-reactivity that it does send up lots of false positives so you do not know if it is real result or not."*
>
> (State government officer 2)

There are also problems with developing long-term environmental indicators due to changes in technology over time. An environmental scientist said that current air pollution monitoring instruments are different from instruments used 30 years ago, and this makes comparisons of current data with previous data problematic. Another example is inconsistencies over time in methods used for flood mapping. Moreover, gaps in data for some locations impedes the use of current data as indicators, and attempts to retrofit data can decrease data accuracy substantially.

A respondent also alluded to the significance and yet lack of, subjective data that are needed to measure community resilience to climate change impacts. They said it is difficult to gather data on how people perceive changes and develop resilience to extreme weather events and emergencies. An understanding of how individuals and communities prepare for, and respond to emergency situations would be useful, as would people's perceptions of when weather extremes would exceed coping abilities. As outlined in the quote below, this type of data would be useful to stakeholders involved in emergency management planning and service provision.

> *"I think a lot of data that we perhaps do not have access to and we simply do not get it, … is that community perception data, so what … does the community need? When do they think it is getting to the point that they cannot function well in a particular climate situation or particular emergency situation? That's probably something we do not have enough of, we don't have even systems really to do that well, that would be really valuable to have … it is more that perception data that we are not very good at gathering."*
>
> (Local government officer 1)

Respondents also mentioned that a central repository of data is essential for more efficient ways to manage and use data as indicators. They are aware of available information but often it was not easy to access.

> *"We know that government has got lots of information as well, and, there is a barrier there, because there is difficulty in sharing the information, and depositing all the information in one place where everybody can use it"*
>
> (Local government officer 2)

### 3.3.5 Alternative indicators

Participants mentioned alternative data sources that could be helpful in terms of monitoring and tracking changes due to climate change. Some suggested using environmental indicators as a proxy for health indicators. For example, a higher abundance of mosquitoes due to warmer conditions can increase the risk of mosquito-borne diseases in humans (Bai et al., 2013), and consequently the surveillance of mosquito populations could be an indication of potential mosquito-borne pathogens. While this could be useful, there are many other factors such as the immune status of host populations and socioeconomic conditions that influence disease transmission (Sutherst, 2004). Using general practitioner data as health indicators for morbidity was another alternative indicator mentioned by one participant.

> *"one type of data that I think is not easy to collect and readily available that could be very informative in detecting not human disease but human pathogens, so what is happening with vector-borne disease at the moment, …, is our ability to detect viruses in the field."*
>
> (Academic researcher 2)

> *"in terms of climate change eventually you have to bring in GP data because there is also lots of information about pre-existing diseases about people who have issues, chronic diseases issues, because you know that … they are prone to be very vulnerable."*
>
> (State government officer 4)

## 3.4 Discussion

The aim of this study was to explore stakeholders' needs and requirements for the development of climate change indicators, their view on robust indicators, and purposes for which they would use indicators. Our results revealed that stakeholders' believed there would be a tangible impact of climate change on human health and indicators would be required to measure the impacts. As rising temperature is the environmental indicator most commonly cited in climate change studies (IPCC, 2014a), participants specifically mentioned increases of heat-related illnesses and death due to climate change. This is supported in the scientific literature which has reported increased heat-related health outcomes as a result of rising temperature (Intergovernmental Panel on Climate Change, 2014, Kovats and Kristie, 2006, Bi et al., 2011, Sun et al., 2014, Bobb et al., 2014).

Health outcome indicators presently available in Australia include heat-related mortality and morbidity such as ambulance callouts and hospital admissions, and communicable disease data on food-borne and vector-borne diseases. Similar data are collected in other countries, and excess mortality and morbidity are being used as health indicators of climate change in the United States (English et al., 2009), Canada (Cheng and Berry, 2013) and Europe, (EEA, 2016, Bittner et al., 2013).

However, in terms of climate-sensitive infectious diseases, the global burden of diseases is not well quantified, as infectious diseases differ across the world, hence indicators cannot be standardised globally. For example, salmonellosis, dengue and Ross River virus were mentioned by participants in this study and also have been linked with climate change in Australian studies (Zhang et al., 2012, Werner et al., 2012, Hill et al., 2014). However, different climate-sensitive infectious diseases that do not occur in Australia, such as West Nile viruses and Lyme disease, have been suggested as suitable indicators in North America (English et al., 2009, Cheng and Berry, 2013). It is therefore important to have indicators that are locally relevant and fit for purpose.

Changes in other climatic events such as rainfall, flood and sea level rise were also mentioned as indicators of climate change. According to the Australian Bureau of Transport Economics, flood has been the most costly disaster type in Australia, followed by severe storms and cyclones (Ladds et al., 2017). However, data on human health impacts of floods can be difficult to source, although one study has shown that heavy rainfall and consequent extensive flooding in Queensland in 2010–2011 attributed to 33 deaths (Zhong et al., 2013). The Insurance Council of Australia provides cost estimates of natural disasters such as death and injuries by hazard type (Ladds et al., 2017), and these could be a potential source of data on injuries and mortality from extreme weather events.

It was clear from the narratives that stakeholders would use indicators for different purposes such as identifying trends over time and monitoring the impact of climate change, taking preventive actions, measuring adaptation, assessing public health plans, and as tools for communication.  However, this depends largely on their requirements. Indicators would provide useful information for local governments when planning for climate change. Preventing development in areas prone to flooding and/or bushfire, and increasing community education and awareness regarding extreme heat are examples of key priorities considered in the South Australian regional climate change adaptation plans (Resilient East, 2016). However, to the author’s knowledge, records of climate-related adverse events such as flood, bushfire and storm are not kept in an inclusive database in SA. Rather, different organisations and departments keep these records. If these data were managed systematically and centrally, information may be more accessible and useful as ongoing surveillance indicators of climate change.

The results of this study have shown that often planning and implementation of interventions requires an understanding of community resilience to extreme weather events, and it can be difficult defining the questions to ask community members to ascertain perceptions of risk and resilience. A recent study by Béné et al focused on understanding factors that influence people's resilience in fishing communities in Fiji, Ghana, Sri Lanka and Vietnam that have experienced natural disasters in the past (Béné et al., 2016). The authors used a self-assessment questionnaire built around the strategies adopted by households to respond to past floods and tropical storms with questions focussed on how people responded; and if such events were to happen again in the near future, how they believed they would be able to recover. These types of questions on perceived resilience can be informative and a starting point for local government surveys to gauge community resilience to severe weather events.

Indicators can also be used to evaluate the progress and success of plans and actions taken, and to assess how adaptation activities differ from regular development activities. This is consistent with findings of other studies that suggest using indicators for evaluation of the effectiveness of heat-health warning systems (HHWS) (Kovats and Kristie, 2006). However, only few studies have evaluated their effectiveness (Bassil and Cole, 2010) due to the challenges and complexities involved (Bittner et al., 2013) and the lack of robust indicators for evaluation (Bassil and Cole, 2010). However, indicators have been used in Europe to assess the usefulness of heat-health action plans (Bittner et al., 2013) showing that European countries are partially prepared for the next major heat-wave. For heat-health actions plans to be functional and effective, evaluation on a regular basis is necessary (Bittner et al., 2013) and indicators can be useful for this purpose.

Five criteria for climate health indicators were suggested by stakeholders. These were that indicators be: (i) based on available data, (ii) tailored for context, (iii) credible, (iv) specific, and (v) can be represented spatially. Participants' views were consistent with recommendations from other studies that the spatial presentation of indicators as maps can be effective in raising awareness and informing policy and decision making (Wolf et al., 2015). In the US, spatial representation of community determinants of heat vulnerability at a national scale provided an index for nationwide comparison which had important implications for identifying areas for targeted interventions (Reid et al., 2009).

The five criteria mentioned are similar, but not as wide-ranging, as those identified by other studies for environmental health indicators (WHO, 1999, Briggs, 2003) and climate change environmental health indicators (Hambling et al., 2011, Cheng and Berry, 2013). Other criteria could also be considered in the development of suitable indicators, such as cost-effectiveness (Hambling et al., 2011) and quality and integrity of the collected data (Cheng and Berry, 2013).

This study has shown that stakeholders are interested in using climate health indicators to detect trends over time. Inconsistencies in data and accessibility to data can be problematic, as identified in other studies (Weber et al., 2015). This can arise for several reasons such as changes in technology over time, gaps in data, and the use of different methods to collect data. Lack of funding and resources within organisations and for research was also a barrier.

### 3.4.1 Limitations

The strength of this study is that participants were from widely different organisations, thereby providing a broad picture of stakeholders’ needs and the issues they face with developing indicators. Based on the similarities in activities, needs and issues of participants with organisations in other states, the key findings may be applicable across Australia.

However, one of the limitations of the study is that interviewees were from SA only, and other stakeholders, interstate, may have different views or need for different data. Also, as weather and climate characteristics and the health burden related to climate change can also vary by region, not all indicators suggested in this study are necessarily useful for other areas. Notwithstanding, given that climate change issues and the related adverse health outcomes have no borders, this study may have wider relevance.

## 3.5 Conclusion

In response to Research Question 2 “What do stakeholders need as climate health indicators and what are the criteria that make a good indicator?”, this study identified the stakeholder requirements and criteria for robust indicators. It highlights the importance of stakeholder engagement in developing climate health indicators. Clearly, developing indicators for climate change is not a straightforward process. Stakeholders’ requirements were identified to be long-term data consistency, the use of systematic methodologies in dealing with data, resources for research and analysis, and tackling problems in relation to the variability of risk factors in different regions in their adaptation planning and developing indicators. Nevertheless, indicators that seem to be easiest to use and interpret by stakeholders and meet the criteria include environmental indicators such as temperature and rainfall, and health outcome indicators including heat-related mortality and morbidity (such as ambulance callouts and hospital admissions). The main criteria that were identified to be of most importance for robust indicators were credibility, specificity, data availability, being tailored for context, and that they can be spatially represented.

This study shows a high level of stakeholders' awareness of the health impacts of climate change and the need for indicators that can monitor health trends and inform policymaking. Local and state governments have paid special attention to identifying groups vulnerable to climate change; however, current indicators are not always useful in identifying the most vulnerable. These may include individuals who may be socially isolated, ill, or disadvantaged for reasons that may not be listed in current databases. Integration of resilience and vulnerability assessments is recommended to provide a complete story for policymakers and planners in health and emergency services to aid in preparation, response and recovery when facing climate change and future extreme weather events.

# CHAPTER 4

# Spatial aspects of heatwaves and health in metropolitan Adelaide

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## Overview

This chapter uses health data including ambulance callouts, hospital admissions and emergency department presentations from the South Australian Department for Health and Ageing, temperature data from The Australian Bureau of Meteorology and vulnerability data from The Australian Bureau of Statistics to explore relevant associations between heat and health. In so doing, it addresses Research Question 3: “What places are more at risk of health impacts during heatwaves?” and Research Question 4: “What are the characteristics of people that make them more vulnerable to heat impacts?”. It explores which of the vulnerability factors, namely age, living alone and socioeconomic status and others, may contribute to increased health outcomes during heatwaves in suburbs of metropolitan Adelaide. A spatial analysis was undertaken to examine the feasibility of using existing weather, socioeconomic and health data as composite climate health indicators.

## 4.1. Introduction

The health effects of heatwaves is a significant problem in Adelaide and other cities in Australia (Nitschke et al., 2011a, Department of Health, 2009, Tong et al., 2012, Bi et al., 2011). It is also predicted that heatwaves will increase over time in Australia (BOM and CSIRO, 2016). Studies in Adelaide have shown significant increases in ambulance callouts and direct heat-related and renal disease hospital admissions during extreme heatwaves (Nitschke et al., 2011a, Hansen et al., 2008b). Many studies in other parts of the world have shown associations between ambulance callouts, hospital admissions and emergency department presentations and extreme heatwaves, confirming adverse health impact of heat on population health (Cerutti et al., 2006, Bassil et al., 2010, Alessandrini et al., 2011, Williams et al., 2012a, Miyatake et al., 2012, Schaffer et al., 2012, Turner et al., 2013, Sun et al., 2014).

Moreover, there is a growing body of literature using spatial pattern analysis highlighting areas that are at higher risk of heat-related morbidity and mortality compared to other areas. For example, ambulance callouts during extremely hot days in Toronto, Canada were mapped to investigate the spatial variability of areas with excess ambulance callouts and concluded that the excess was seen predominantly within industrial areas (Dolney and Sheridan, 2006). A US study investigated the use of heat vulnerability maps to better predict areas of potential concern regarding heat-related effects. Variables that may indicate vulnerability to heat were explored such as education, race, poverty, social isolation, household air conditioning, vegetation cover and pre-existing health conditions. Findings revealed that areas with the highest air conditioner prevalence had the lowest heat vulnerability values (Reid et al., 2009). In a similar study in New York city, low income, poor housing conditions, co-morbidities among elderly, the lack of green spaces and access to air conditioning were found to be the main risk factors of heat-related mortality (Rosenthal et al., 2014). An index of vulnerability developed in the above-mentioned studies was used to create maps that provide geographical distribution of the highest risks of health outcomes. Incidence Rate Ratios (IRRs) during heatwaves and their correlation with vulnerability factors within cities and across the US were calculated by using census data (Reid et al., 2009, Rosenthal et al., 2014).

Geographical distribution of heat-related mortality in Sydney showed that older people in some parts of Sydney were more vulnerable (Vaneckova et al., 2010). In Adelaide, risk factors to heat-related adverse health effects have been identified from a combination of qualitative (Hansen et al., 2013) and quantitative studies (Zhang et al., 2013, Nitschke et al., 2013, Loughnan et al., 2014). Quantitative studies in Adelaide found that poor quality housing, language barriers, low literacy, receiving help from community services and having renal diseases were risk factors for health problems during a heatwave in Adelaide. While there have been several epidemiological studies conducted in Adelaide, spatial studies have been sparse. One study revealed that geographical patterns of emergency department visits increased in the outer northern and southern suburbs of Adelaide during hot days and suggested that disability and access to emergency services could be useful vulnerability indicators (Loughnan et al., 2014).

It has been suggested that increased morbidity during heatwaves could be largely reduced with targeted preventive actions and intervention plans and programs (Weisskopf et al., 2002, Nitschke et al., 2016). To assist with prevention, it has been suggested that indicators could be used to identify areas at high risk of heat-morbidity and associated risk factors that may exacerbate these health effects; furthermore, they could be used to monitor the trend of negative health impacts of climate change and evaluate effectiveness of public health programs (Houghton and English, 2014). Development of environmental health indicators and incorporating them into the local public health surveillance system could potentially be useful in locating clusters of vulnerable populations (Houghton and English, 2014).

This chapter has two objectives: to investigate spatial patterns of ambulance callouts, hospital admissions and emergency department presentations during heatwaves across metropolitan Adelaide (averaged heatwaves; and, before and after a heat warning system was introduced (i.e. 2009 vs 2014)); and to identify risk factors/vulnerability factors that may explain the disparities in the geographical distribution of the adverse health effects. Statistical and spatial analytical methods were used and the results are presented in two parts. Firstly, the distribution of health outcomes during heatwaves (averaged heatwaves, and 2009 vs 2014 heatwaves to evaluate the effectiveness of the public health warning system); secondly the results of a vulnerability analysis are presented, combining heat-health indicators with selected vulnerability factors.

## 4.2 Materials and Methods

This section comprises the epidemiological study design, data collection and two types of analyses, namely statistical and spatial analytical methods. Statistical analyses were used to investigate relationships between heat and health outcomes and also to explore risk factors that exacerbate the health effects. Spatial methods were used to provide perspectives on climate-related health outcomes, geographic variations and how a place can influence population health (Diez Roux, 2001). A flow chart of various types of data collected and analyses undertaken, is presented in Figure 4.1.

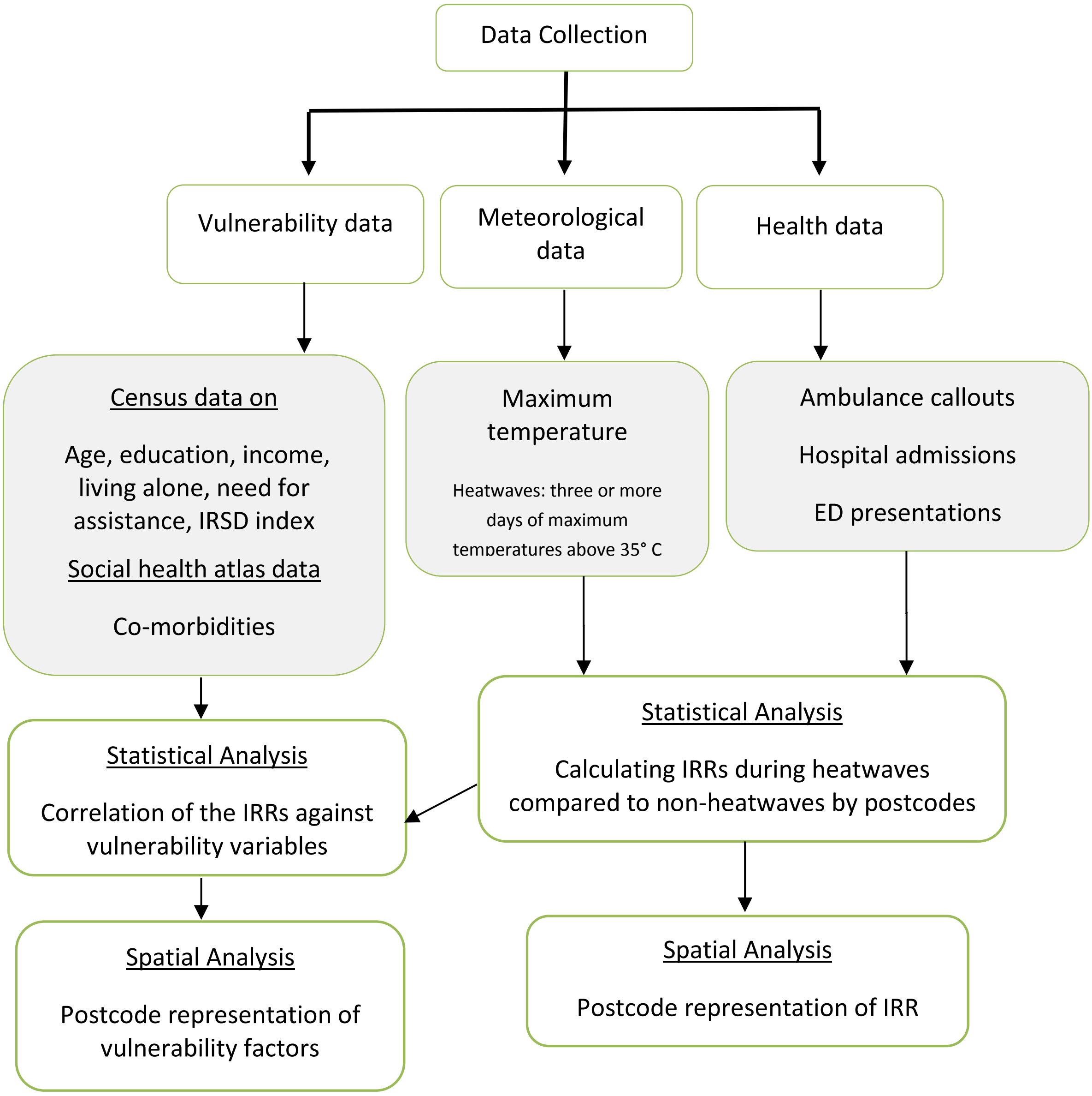

**Figure 4.1** **Flowchart of data collection, statistical and spatial analyses (IRR = Incidence rate ratio)**

### 4.2.1 Data collection and management

Three main types of data were collected, namely health outcomes, meteorological and vulnerability data. Health data included ambulance callouts, hospital admissions and emergency department visits, and meteorological data consisted of daily maximum temperature to define heatwaves. Vulnerability data were also collected and categorised for the purpose of this study into three groups covering environmental, socioeconomic and co-morbidity data as detailed below.

#### 4.2.1.1 Health data

***Ambulance callouts***

De-identified ambulance callout data for metropolitan Adelaide for the period 1 July 1993 to 31 March 2014 were sourced from the South Australian Ambulance Service (SAAS). The study area of metropolitan Adelaide was defined as those suburbs with postcodes listed between 5000 and 5200 (excluding postcodes 5131, 5132, 5133 and 5139 due to a very small population size that inhibits statistical analysis at postcode level). The pre-defined categories for ambulance callouts from the SAAS included assault, blunt trauma, falls, sport, motor vehicle accidents and other road injuries, cardiac, respiratory and neurological conditions. Patient demographic data included age group and postcode of suburbs attended by SAAS.

***Hospital admissions and emergency department presentations***

The study period was defined as 1 January 2004 to 31 March 2014. This is different from the study period for ambulance data. Hospitalisation data for the following diseases were used and summated for each postcode: cardiovascular (ICD-9: 390-4599;

ICD-10: I00-99), respiratory (ICD-9: 390-4599; ICD-10: I00-99), mental and behavioural disorders (ICD-9: 290-294-9; ICD-10: F00-F999) and renal (ICD-9: 580-599; ICD-10: N00-N399) diseases, together with a category for direct heat-related conditions comprising “dehydration”, “heat and sunstroke” and “exposure to excessive heat” (ICD-9: 2765, 992, E900; ICD-10: E86, T67, X30) (Nitschke et al., 2011a). These conditions were chosen based on evidence in the scientific literature (Navi et al., 2016) as explained in detail in Chapter 2. Patient demographics data included 5-year age grouping and postcodes of residence.

#### 4.2.1.2 Meteorological data

Maximum temperature was considered the most appropriate metric to use based on previous studies (Nitschke et al., 2007, Nitschke et al., 2016). Temperature data were obtained from the South Australian Bureau of Meteorology Adelaide (Kent Town) monitoring station, a central location considered to be representative of conditions across the city. The Kent Town weather station (023090) was used as it is in the Adelaide CBD and has been used in many previous studies to represent conditions across the Adelaide metropolitan area (Xiang et al., 2014, Milazzo et al., 2015, Nitschke et al., 2016). Seasons were defined as warm (October to March) and cool (April to September), and heatwaves were defined as three or more days when daily maximum temperatures reached or exceeded 35°C (Nitschke et al., 2007). As the focus of the study was heat-related, only data for the warm season were used in the analyses.

#### 4.2.1.3 Vulnerability data

Several studies in Australia and overseas have investigated risk factors that make people more vulnerable to the health effects of heat. These factors or vulnerability characteristics as referred to in this study, are categorized into three groups: environmental, co-morbidities and socioeconomic (Table 4.1). All the characteristics have been selected based on previous studies which found them to be risk factors for heat-related morbidity (Zhang et al., 2013, Nitschke et al., 2013, Hansen et al., 2014, Loughnan et al., 2013, Reid et al., 2009). This has been explained in details in Chapter 2 (literature review). However, some of the risk factors, such as using air conditioners and taking medication for pre-existing disease were not available at the postcode level. Vulnerability characteristics which were used for analysis of this research are presented in Table 4.1 and the data collection for each group explained below accordingly.

**Table 4.1 Vulnerability characteristics obtained through different sources at the postcode spatial unit for metropolitan Adelaide.**

| Data type | Data source |
|---|---|
| ***Environmental characteristics***<br>Green space (%) | Daker, M, Public open space data 2016 for metropolitan Adelaide, Centre for Population Health Research, University of South Australia, Adelaide. |
| ***Co-morbidities***<br>Diabetes (%)<br>High blood cholesterol (%)<br>Mental & behavioural problems (%)<br>Disease of the circulatory system (%)<br>Hypertension (%)<br>Respiratory disease (%)<br>Asthma (%)<br>Chronic obstructive pulmonary disorder (%)<br>Musculoskeletal disease (%)<br>Arthritis (%) | PHIDU, Torrens University, Australia* |
| Poor self-assessed health status | Australian Bureau of Statistics |
| **Socioeconomic characteristics**<br>Living alone (%)<br>Need for assistance (%)<br>Seniors (aged 65 and above) (%)<br>Low income (%)<br>Low education (%)<br>Poor language (%)<br>Index of Relative Socioeconomic Disadvantage (IRSD) score | Australian Bureau of Statistics** |

* Public Health Information Development Unit (http://www.phidu.torrens.edu.au/notes-on-the-data/demographic-social/irsd), ** https://www.censusdata.abs.gov.au/webapi/jsf/login.xhtml

### *Environmental characteristic*

Based on evidence which has been addressed in Chapter 2, vegetation density has been found to have an impact in reducing urban air temperature, and higher heat-health outcomes have been associated with less green spaces (Harlan et al., 2006). The proportion of green spaces in each postcode was therefore used as an environmental variable.

Two databases were used to determine the vulnerability characteristic green space. These were obtained from the School of Natural and Built Environments, at the University of South Australia (Daker et al., 2016). The first database represents public open space and the second database represents the non-public open spaces. Public open space is defined as land that is accessible and available for use by the public, such as active spaces (sporting facilities and children's playgrounds) and passive recreation spaces (i.e. for walking, sitting and social functions, and cycling) (Daker et al., 2016). Non-public open spaces refer to any spaces not within the definition of "public open space". The largest number of the non-public open spaces consisted of roadside vegetation (narrow open spaces alongside or the middle of a highway, or wide areas with dense vegetative cover) (Daker et al., 2016). The sum (in square kilometres) of public open space and non-public open space areas for each postcode was calculated, and by using the total area of each postcode, the percent of green space in each postcode was calculated.

### *Co-morbidities*

Co-morbidities have been shown to be a risk factor for heat-health effects in several studies (Hansen et al., 2014, Zhang et al., 2013, Nitschke et al., 2013). In this research, co-morbidities refer to two groups of data: 1) chronic diseases, and 2) poor self-assessed health status. The prevalence of chronic diseases data are estimates for the spatial area, not measured values, collected through ABS National Health Survey from the 2011- 2013. These data were obtained from the Public Health Information Development Unit (PHIDU). (PHIDU is located in Adelaide and was established with Australian Government funding, to provide information on a broad range of health and wellbeing at national, regional and small area levels for Australia). Data were available in small area units that differed from postcode units. As the number of cases in Statistical Areas Level 2 (SA2) from the ABS Australian Statistical Geography Standard (ABS ASGS) 2011, was too small to map, PHIDU developed a set of areas called Population Health Areas (PHA), which comprise larger SA2s and aggregated smaller SA2s. PHAs were converted to postcode level for the purpose of this research analysis. The process of conversion from PHA to postcode is explained in Appendix G. It should be noted that there are uncertainties with the use of co-morbidity data at the PHA level as it is only an estimate of chronic diseases based on the National Health Survey (2011- 2013) and not actual observations. However, this was the only available data on co-morbidities for Adelaide.

### *Socioeconomic characteristics*

A range of vulnerability factors have been indicated in the literature suggesting higher vulnerability to heat-health impacts in people with low income, low education, those who cannot speak English, people who live alone, people who need assistance with core activities and older age people (Nitschke et al., 2013, Zhang et al., 2013). In this study, these risk factors are referred as socioeconomic vulnerability characteristics and the related data were available from the ABS ‘TableBuilder’ webpage (ABS, 2017). Data were available by the number of people per postcode. Using the total population of each postcode, also downloaded from ABS 'TableBuilder' (ABS, 2017), the percent of the population per spatial unit for each of the characteristics was calculated. This was the case for all socioeconomic characteristics except for the Index of Relative Socioeconomic Disadvantage (IRSD) which has a score range from 120 to around 1200.The score takes into accounts the percentage of each variable within an area and the variable weight in correlation with other variables. IRSD is a metric developed by the ABS that summarises variables that indicate relative disadvantage. IRSD consists of 20 variables from different dimensions, all of which are listed in Table 4.2.

**Table 4.2 Variables included in the Index of Relative Socioeconomic Disadvantage (ABS, 2011a).**

| DIMENSION | VARIABLE DESCRIPTION |
|---|---|
| Income | % People with income between $1 and $20,799 |
| Education | % People aged 15 years and over whose highest level of educational attainment is a Certificate Level III or IV qualification |
| | % People aged 15 years and over who have no educational attainment |
| | % People aged 15 years and over whose highest level of educational attainment is Year 11 or lower (includes Certificate Levels I and II; excludes those still at secondary school) |
| Employment | % People (in the labour force) who are unemployed |
| Occupation | % Employed people classified as Machinery Operators and Drivers |
| | % Employed people classified as Labourers |
| | % Employed people classified as Low-Skill Sales Workers |
| | % Employed people classified as Low-Skill Community and Personal Service Workers |
| Housing | % Occupied private dwellings with one or no bedrooms |
| | % Occupied private dwellings paying less than $166 per week in rent (excluding $0 per week) |
| | % Occupied private dwellings requiring one or more extra bedrooms (based on Canadian National Occupancy Standard) |
| Other | % Families with children under 15 years of age and jobless parents |
| | % Occupied private dwellings with a dialup internet connection |

|  |  |
|---|---|
|  | % People aged under 70 who need assistance with core activities due to a long-term health condition, disability or old age |
|  | % People who do not speak English well |
|  | % Occupied private dwellings with no cars |
|  | % Occupied private dwellings with no Internet connection |
|  | % Families that are one parent families with dependent offspring only |
|  | % People aged 15 and over who are separated or divorced |

This index ranks areas on a continuum from most disadvantaged to least disadvantaged (ABS, 2011a). It has a base of 1000 with scores below 1000 indicating relatively greater disadvantage and those above indicating relative lack of disadvantage (PHIDU, 2011).

### 4.2.2 Statistical analysis

Regression analysis is the most important statistical process for estimating the relationships among variables and is used to investigate the relationship between a response or dependent variable and one or multiple independent or predictor variables (Bender, 2009). The association between heatwaves and health outcomes of interest was investigated using regression analysis as part of a case-series design (Nitschke et al., 2011a). This study design is suitable as the exposure (heatwaves) is transient, and the health outcome is abrupt (Farrington and Whitaker, 2006). To estimate relative risk, exposure during the case window (the period of heatwaves), is compared to risk exposure during the control window, i.e. the period of non-heatwaves in the warm season (Nitschke et al., 2011a). As each case serves as its own control; individual susceptibility factors can be controlled for by design, eliminating the effects of confounding (Farrington and Whitaker, 2006, Whitaker et al., 2006).

Poisson regression was used in this research to analyse heat-related morbidity in Adelaide. Data management and analyses were performed using Stata/IC 13.1

(StataCorp LP, College Station, TX). Incidence Rate Ratios (IRR) of ambulance callouts, hospital admissions and emergency department visits and 95% confidence intervals (CI) were calculated during heatwaves compared to non-heatwave periods, by postcode. Analyses were performed on data stratified into warm season (October to March). Values of $P < 0.05$ were considered to be statistically significant. Negative binomial regression was used where appropriate, to account for the issue of over dispersion (Nitschke et al., 2011a).

To investigate the relationship between health outcome variables (i.e. IRRs of ambulance callouts, hospital admissions and emergency department visits) and vulnerability variables (e.g. living alone, and low socioeconomic status (Table 4.7)) Pearson correlation was used (Rosenthal et al., 2014).

Stata codes for statistical analyses are presented in Appendix H.

### 4.2.3 Spatial analysis

The role of place in human health has a long history (Hippocrates and Adams, 2007). Age, existing chronic diseases, socioeconomic and other variables vary from one place to another and can influence the risk of the diseases. One of the objectives of the study was to determine vulnerable populations to climate change in terms of geographical distribution. Geographic information system (GIS)-based mapping is a sensible approach to evaluate the vulnerability of a population based on social and demographic characteristics that are often unevenly distributed (Nuckols et al., 2004, Jarup, 2004). The spatial relationship characterization of environmental, health, and social indicators has important implications for policymakers and could be used to prioritize actions in areas with potentially modifiable health determinants (Saib et al., 2015). Spatial analysis was used in this study for two purposes:

- To investigate spatial patterns of increased morbidity during heatwaves in metropolitan Adelaide and identify heat susceptible suburbs, and
- To explore how this is related to vulnerability characteristics on a spatial scale

For visual representation of data, postal areas (POAs) were used as the spatial unit. The latest version of the Postal Areas shapefile for the Adelaide metropolitan area was obtained from the ABS website (ABS, 2017). It should be noted that the ABS Postal Areas do not always match with Australia Post's postcodes. However, they are often used for spatial analysis of this kind and is by far the best approximation to postcode areas (Taylor, 2014) which were designed for the Australian postal service, not as spatial units. The Adelaide metropolitan area consists of 126 postcodes/POAs.

For the first part of the analysis, the IRRs of ambulance callouts, emergency department (ED) visits and hospital admissions during heatwaves were compared to non-heatwave periods (see section 4.2.2). Using postcode of suburb of ambulance attendance for ambulance callouts, and postcode of patient’s address for ED visits and hospitalisations, data were merged with the Postal Areas shapefile using postal areas as the spatial unit, in ArcMap 10.3.1 (ESRI Corp., Redlands, CA, USA). Choropleth maps of the above-mentioned health outcomes were created for the period of study.

Additionally, maps of these health outcomes for the severe Adelaide heatwaves of 2009 and 2014 were created to evaluate the effectiveness of the public heatwave warning implemented after the 2009 heatwave (Nitschke et al., 2016). During the extreme heat event in 2009, health outcomes sensitive to heat, specifically those mentioned in section

4.2.1.1. were increased compared to non-heatwave periods during summer (Nitschke et al., 2011a).

Secondly, to investigate how vulnerability characteristics can explain heat-related morbidity on a spatial basis, vulnerability variables that were shown to have a statistically significant correlation with health outcomes, (including: IRSD, people who live alone, and people who need assistance with core activities), were mapped using methods outlined in 4.2.1.3.

## 4.3. Results

The results are presented in two sections. In Section 4.3.1 the effects of heat on morbidity in metropolitan Adelaide are presented in three parts: ambulance callouts (4.3.1.1), hospital admissions (4.3.1.2) and emergency department presentations (4.3.1.3).

In Section 4.3.2 the findings of the vulnerability analyses are presented in an attempt to explain disparities in geographical distribution of risk of health outcomes during heatwaves in Adelaide. As in Section 4.3.1, the three parts of this section cover ambulance callouts (4.3.2.1), hospital admissions (4.3.2.2) and emergency department presentations (4.3.2.3).

In each subsection findings are presented for:

(a) The effects of averaged heatwaves during the period 1993-2014 for ambulance callouts and 2004-2014 for hospital admissions and emergency department presentations, and,

(b) The results during two extreme heatwaves (2009 and 2014).

Point estimates of IRRs were categorised regardless of their statistical significance and colour coded for visual representation of the IRRs. IRRs point estimate below 1.00 indicate no increased risk during heatwaves and IRRs point estimates ≥1.00 are an indication of increased risk. Additionally, postcodes with statistically significantly increased IRRs (p-values<0.05) were encircled with a solid red line.

## 4.3.1 Heat-health effects

### 4.3.1.1 Ambulance callouts

***(a) Averaged heatwaves***

Data were available from 1 July 1993-31 March 2014. The total number of ambulance callouts during 1994-2014 was 1,566,142. More than half of this number (786,296) occurred during the warm seasons, which is 6,446 more ambulance callouts than in the cold seasons. During the heatwave days there were 222.2 callouts per day (48216/ 217), that is, an 8% increase in the daily average number of callouts during heatwaves compared to non-heatwaves.

The results of the regression analyses for ambulance callouts are presented in Figure 4.2. As shown in the map, more than half of Adelaide postcodes show point estimates of IRRs above 1.00 during heatwaves 1994-2014, with the highest point estimate IRR of 1.26 for postcode 5140. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. These postcodes are mainly distributed in Adelaide's western, inner, northern and some southern suburbs.

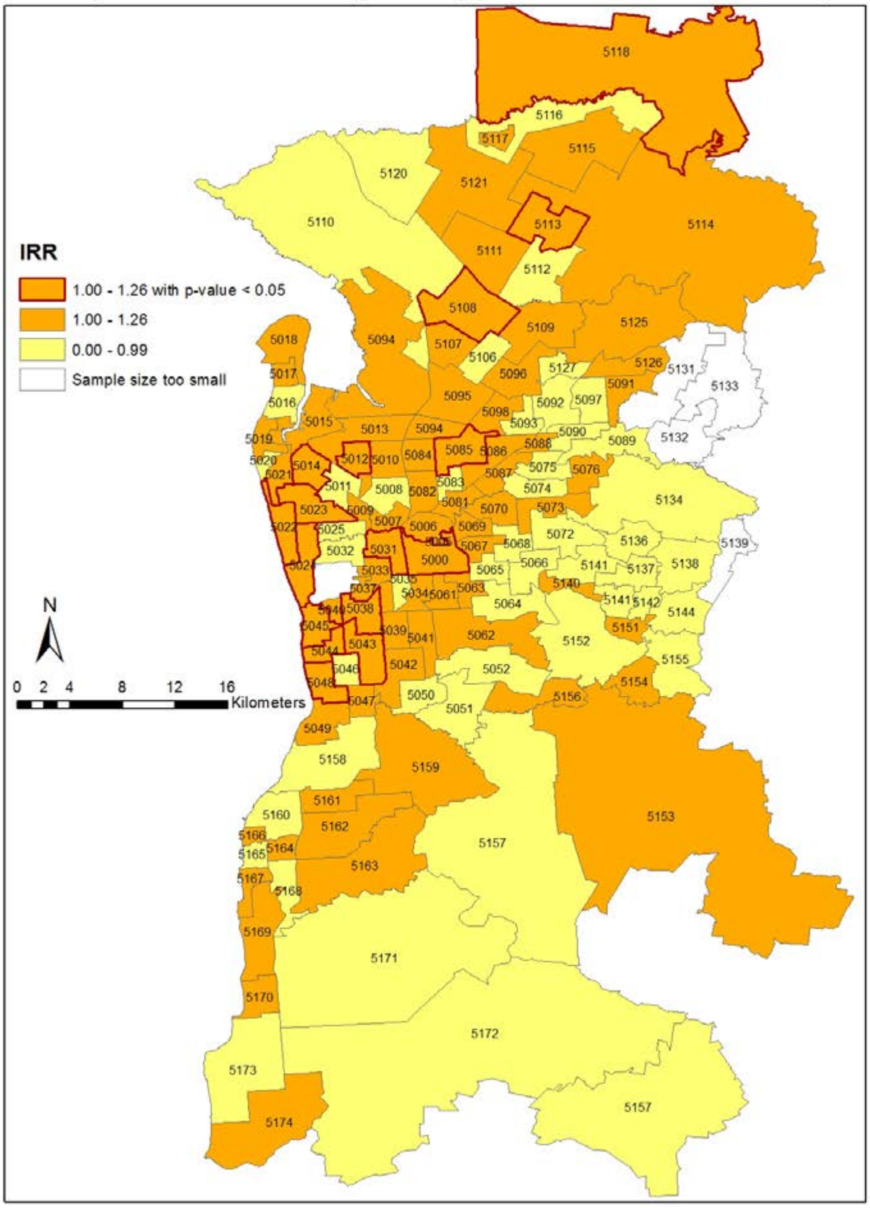

**Figure 4.2** IRR of ambulance callouts during heatwaves compared to non-heatwaves by postcode in metropolitan Adelaide 1993 - 2014. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. The postcode areas with statistically significant increases in health outcomes during heatwaves are depicted with a red border.

There are 16 postcodes with a statistically significant point estimate above 1.00 which are shown with a red border in Figure 4.2 and are also presented in Table 4.3.

**Table 4.3 Incidence rate ratio (IRR) and 95% confidence intervals for postcodes with increases in ambulance callouts during heatwaves 1993-2014.**

| POA | Suburbs | IRR | 95%CI |
|---|---|---|---|
| **5000** | Adelaide CBD | 1.08 | 1.04 - 1.13 |
| **5012** | Athol Park, Mansfield Park, Woodville Gardens, Woodville North | 1.15 | 1.05 - 1.26 |
| **5014** | Albert Park, Alberton, Cheltenham, Hendon, Queenstown, Royal Park | 1.08 | 1.00 - 1.18 |
| **5022** | Grange, Henley Beach, Henley Beach South, Kirkcaldy, Tennyson | 1.15 | 1.06 - 1.24 |
| **5023** | Findon, Seaton, Seaton North | 1.13 | 1.05 - 1.21 |
| **5024** | Fulham, Fulham Gardens, West Beach | 1.15 | 1.05 - 1.25 |
| **5031** | Mile End, Mile End South, Thebarton, Torrensville, Torrensville Plaza | 1.10 | 1.00 - 1.20 |
| **5038** | Camden Park, Plympton, Plympton Park, South Plympton | 1.14 | 1.00 - 1.23 |
| **5043** | Ascot Park, Marion, Mitchell Park, Morphettville, Park Holme | 1.07 | 1.00 - 1.14 |
| **5044** | Glengowrie, Somerton Park | 1.10 | 1.01 - 1.21 |
| **5045** | Glenelg, Glenelg East, Glenelg Jetty Road, Glenelg North, Glenelg South | 1.10 | 1.03 - 1.17 |
| **5048** | Brighton, Dover Gardens, Hove, North Brighton, South Brighton | 1.09 | 1.01 - 1.18 |
| **5085** | Clearview, Enfield, Enfield Plaza, Northfield, Northgate | 1.09 | 1.01 - 1.17 |
| **5108** | Paralowie, Salisbury, Salisbury Downs, Salisbury North, Salisbury North Whites Road | 1.06 | 1.01 - 1.12 |
| **5113** | Davoren Park, Davoren Park North, Davoren Park South, Elizabeth Downs, Elizabeth North, Elizabeth Park, Elizabeth West, Elizabeth West Dc | 1.10 | 1.03 - 1.17 |
| **5118** | Bibaringa, Buchfelde, Concordia, Gawler, Gawler Belt, Gawler East, Gawler River, Gawler South, Gawler West, Hewett, Kalbeeba, Kangaroo Flat, Kingsford, Reid, Ward Belt, Willaston | 1.09 | 1.02 - 1.18 |

### *(b) 2009 vs 2014 heatwave*

The comparison of IRRs of ambulance callouts during 2009 and 2014 indicates a decrease in IRRs in 2014 for many postcodes (Figure 4.3). These postcodes include 5014, 5015, 5016, 5033 and 5045 in the western suburbs, 5072 in the east, 5092 in the north-east, and 5113 in the outer northern suburbs of Adelaide. These postcodes had the highest IRRs in 2009. However, despite the decrease, all of the above-mentioned postcodes IRRs remained above 1.00 in 2014.

The postcodes with increased IRRs in 2009 and 2014 are shown in Figure 4.3 and are presented in Table 4.4; the postcode areas with statistically significant increases in health outcomes during the 2009 and 2014 heatwaves are depicted with a red border. Amongst them, for two postcodes - 5174 (Sellicks Beach and Sellicks hill suburbs) which is located in the south west of Adelaide, and 5126 (Fairview Park, Surrey Downs, Yatala Vale suburbs) located to the north of Adelaide - IRRs increased from 1.83 in 2009 to 2.86 in 2014, and 1.72 in 2009 to 2.91 in 2014, respectively.

**Table 4.4 Postcodes with IRR above 1.00 and p-value < 0.05 during extreme heatwaves in 2009 and 2014**

| POA | IRR (2009) | 95% CI | IRR (2014) | 95% CI |
|---|---|---|---|---|
| **5014** | 1.92* | 1.17 - 3.15 | 1.37 | 0.89 - 2.10 |
| **5035** | 2.47* | 1.26 - 4.84 | 1.25 | 0.67 - 2.32 |
| **5089** | 2.44* | 0.99 - 6. 05 | 1.15 | 0.47 - 2.80 |
| **5113** | 1.59* | 1.08 - 2.36 | 1.30 | .93 - 1.81 |
| **5072** | 2.08* | 1.17 - 3.70 | 1.87* | 1.19 - 2.95 |
| **5107** | 1.89* | 1.14 - 3.16 | 1.66* | 1.09 - 2.52 |
| **5126** | 1.72 | 0.59 - 4.98 | 2.91* | 1.48 - 5.72 |
| **5174** | 1.83 | 0.3 - 10.90 | 2.86* | 1.31 - 6.22 |

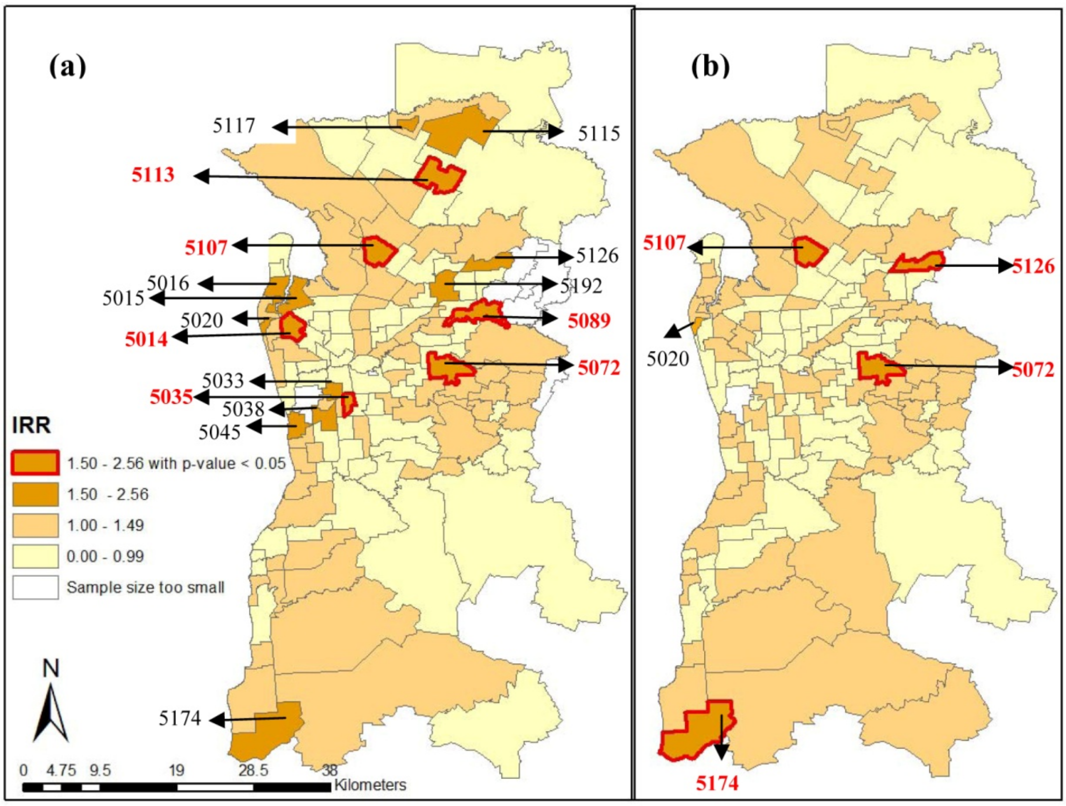

**Figure 4.3** IRR of ambulance callouts during (a) 2009 and (b) 2014 heatwaves in Adelaide. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. The postcode areas with statistically significant increases in health outcomes during heatwaves are depicted with a red border.

There were differences in the spatial patterns of IRRs in the averaged map for heatwaves (1993-2014) (Figure 4.2) compared with the maps of heatwaves in 2009 and 2014 (Figure 4.3). Postcodes with IRR above 1.00 are concentrated in the inner postcodes of metropolitan Adelaide (excluding eastern postcodes), some outer northern and southern postcodes in the averaged map, while inner postcodes did not seem to be at risk during heatwaves 2009 and 2014.

#### 4.3.1.2 Hospital admissions

##### *(a) Averaged heatwaves*

The regression analysis of hospital admissions during heatwaves compared to non-heatwaves period in the warm season, at postcode level, showed that IRRs ranged from 0.55 to 1.41. Postcodes where residents had a higher risk of hospital admissions during heatwaves were mainly clustered in central Adelaide excluding outer eastern suburbs, which had too few observations for analysis (Figure 4.4).

The IRR point estimates of hospital admissions (Figure 4.4) are in three categories. The dark yellow category shows postcodes with point estimates of IRRs above 1.00 where there is an increased risk of hospitalisation during heatwaves compared to non-heatwave periods; and the light-yellow category are postcodes with IRRs below 1.00 where there are not increased risks of hospitalisation during heatwaves. Areas with low numbers of observations are shown in white in the map. Only postcode 5000 (Adelaide CBD) with IRR 1.17 was found to be statistically significant (CI: 1.01 - 1.35) and is shown with a red border.

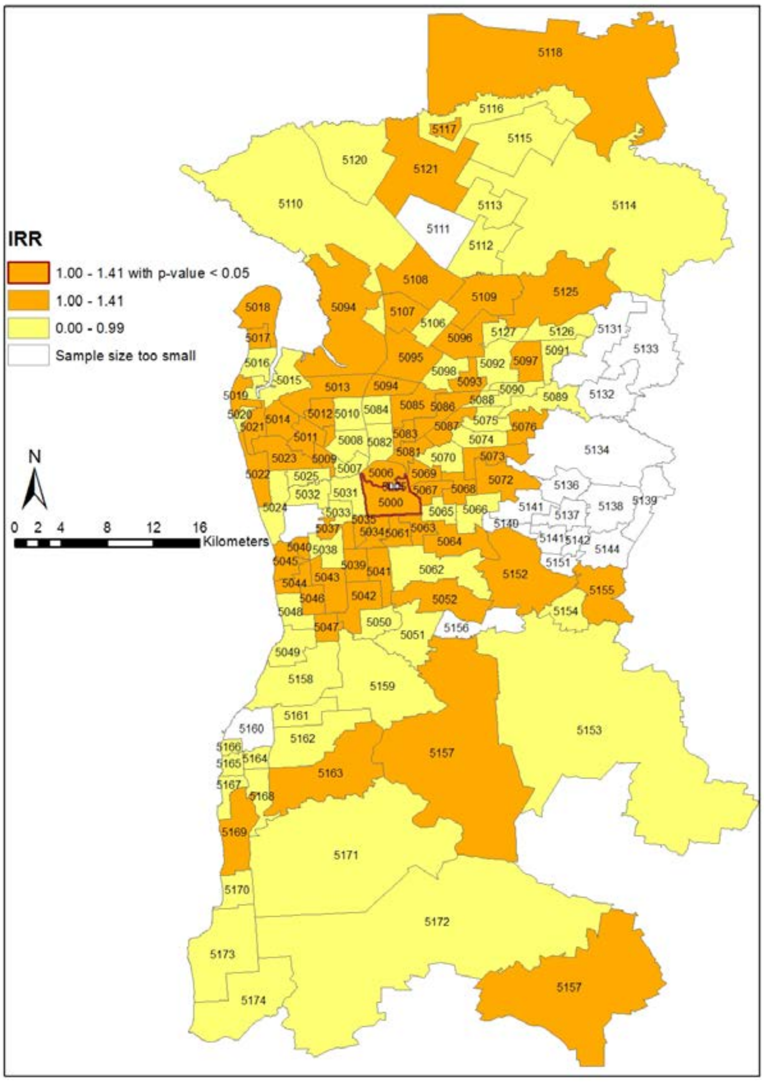

**Figure 4.4 IRR of hospital admissions during heatwave compared to non-heatwave by postcode in Adelaide 2004-2014. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. The postcode areas with statistically significant increases in health outcomes during heatwaves are depicted with a red border.**

### *(b) 2009 vs 2014 heatwave*

Comparison between hospital admissions during the 2009 and 2014 heatwaves showed point estimates of IRRs between 0.19 and 3.85 in 2009, and 0.30 to 2.70 in 2014. <u>In Figure 4.5a there are seven postcodes shown in a darker shade indicating IRR point</u>

estimates above 2.00 in 2009. Decreases in the IRRs in 2014 can be seen in all seven postcodes (Figure 4.5b).

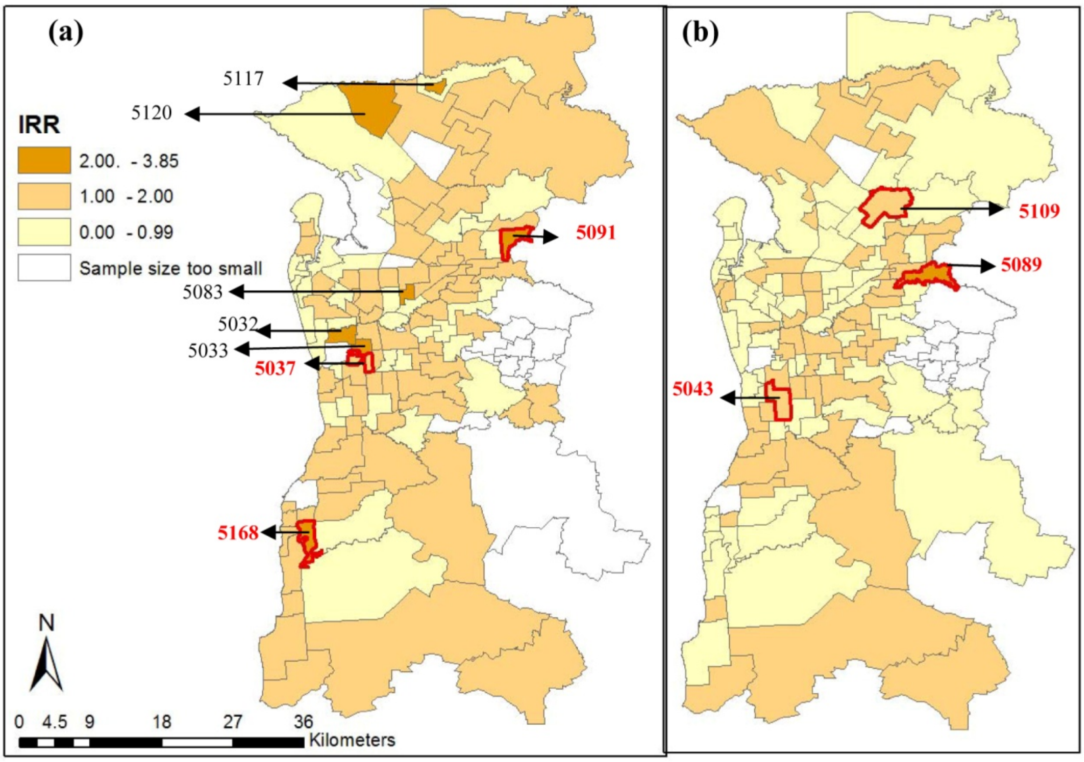

**Figure 4.5 IRR of hospital admission during s (a) 2009 and (b) 2014 heatwaves in Adelaide. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. The postcode areas with statistically significant increases in health outcomes during heatwaves are depicted with a red border and font.**

In 2009 three postcodes (5037, 5091 and 5168) showed statistically significant increases in hospitalisations during heatwaves compared to non-heatwave periods. In 2014 postcodes 5043, 5089, and 5109 showed statistically significant increases in IRR (Table 4.5).

**Table 4.5 Postcodes with IRR above 1.00 and p-value < 0.05 during extreme heatwaves in 2009 and 2014**

| POA | IRR (2009) | 95% CI | IRR (2014) | 95% CI |
|---|---|---|---|---|
| **5037** | 1.87* | 1.16-3.00 | 0.70 | 0.36 - 1.36 |
| **5091** | 2.74* | 1.27-4.80 | 1.74 | 0.89 - 3.49 |
| **5168** | 2.26* | 1.16-4.41 | 0.96 | 0.41 - 2.24 |
| **5043** | 1.15 | 0.79 - 1.67 | 1.46* | 1.05-2.03 |
| **5089** | 1.29 | 0.55 - 3.04 | 2.70* | 1.11-6.58 |
| **5109** | 1.20 | 0.78 - 1.82 | 1.56* | 1.09-2.24 |

Analysis of hospitalisations for averaged heatwaves (2004-2014) (Figure 4.4) show a similar spatial pattern of IRRs to that of the 2009 heatwave (Figure 4.5a).

#### 4.3.1.3 Emergency department presentations

***(a) Averaged heatwaves***

The regression analysis of emergency department visits for 2004-2014 during heatwaves compared to non-heatwaves shows IRRs between 0.47 and 1.72. As in Figure 4.2 and Figure 4.4, Figure 4.6 shows three shades. Firstly, postcodes with IRR below one are shown in a lighter shade of yellow; and secondly, postcodes with IRR between 1.00 and 1.72 are shaded darker yellow. Postcodes with statistically significant increased IRRs are shaded darker yellow with a red border. Postcodes with too few observations for analyses are white (Figure 4.6). There were six postcodes (5000, 5009, 5013, 5034, 5039, 5042) found to have statistically significant increases in emergency department visits.

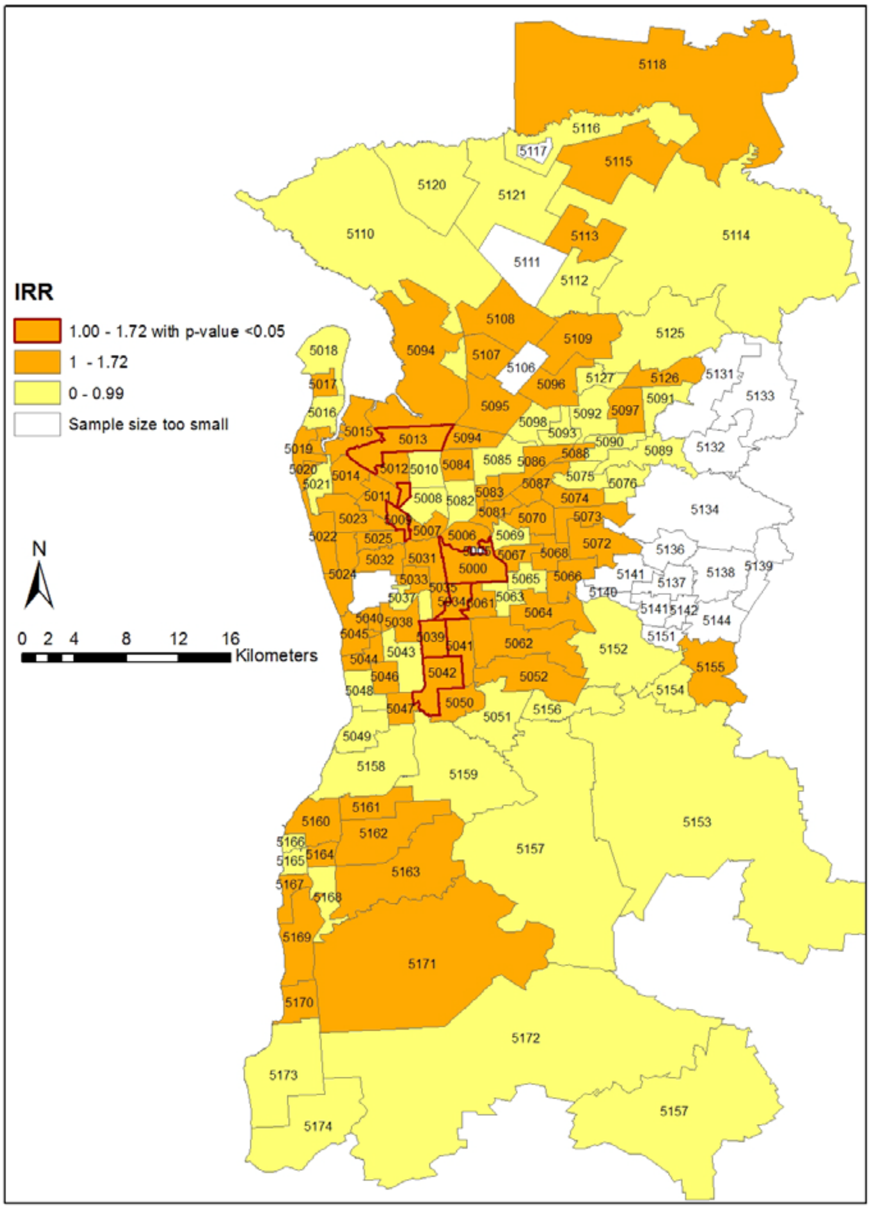

**Figure 4.6** IRR of emergency department visits during heatwaves compared to non-heatwaves in Adelaide 2004-2014. Postcodes with positive, statistically significant IRR's are bordered in red.

**Table 4.6 Incidence rate ratio (IRR) and 95% confidence intervals for postcodes with increases in emergency department during heatwaves 2004-2014**

| POA | Suburbs | IRR | 95%CI |
|---|---|---|---|
| **5000** | Adelaide CBD | 1.14 | 1.03-1.26 |
| **5009** | Allenby Gardens, Beverley, Kilkenny | 1.26 | 1.02-1.55 |
| **5013** | Gillman, Ottoway, Pennington, Rosewater, Rosewater East, Wingfield | 1.24 | 1.09-1.41 |
| **5034** | Clarence Park, Goodwood, Kings Park, Millswood, Wayville | 1.26 | 1.04-1.53 |
| **5039** | Clarence Gardens, Edwardstown, Melrose Park, Melrose Park Dc | 1.19 | 1.01-1.41 |
| **5042** | Bedford Park, Clovelly Park, Flinders University, Pasadena, St Marys | 1.23 | 1.06-1.43 |
| **5094** | Cavan, Dry Creek, Gepps Cross | 1.71 | 1.03-2.84 |

### *(b) 2009 vs 2014 heatwave*

Comparison of the IRR for 2009 and 2014 heatwaves showed a range between 0.31 and 4.16 during 2009. The range of point estimates decreased to between 0.47 and 2.01 during the 2014 heatwave. As can be seen from Figure 4.7 five postcodes with the highest IRR in 2009 are presented in a darker shade. Decreases in the IRR in 2014 from 2.19 to 1.03 can be seen in all five postcodes and from 4.16 to 1.11 for postcodes 5037 and 5160 respectively. Postcodes 5126, 5083 and 5170 had IRRs below 1.00. Two postcodes, 5044 (IRR: 1.59, 95% CI: 1.02-2.48) and 5048 (IRR: 1.69, 95% CI: 1.15-2.48) were statistically significant in 2009. There was no postcode with statistically significant increases in emergency department visits during the 2014 heatwaves.

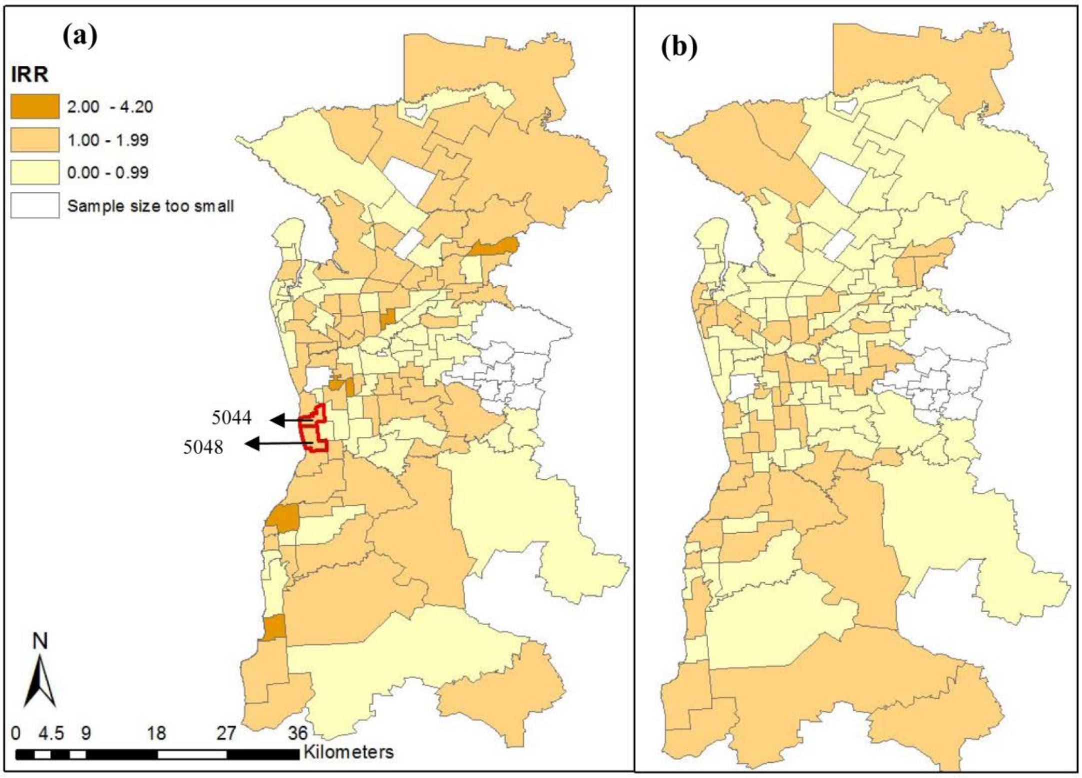

**Figure 4.7 IRR of emergency department visits during (a) 2009 and and (b) 2014 heatwaves in Adelaide. Postcodes with IRR above 1.00, presented in a darker shade, indicate an increased risk of heat-health effects. The postcode areas with statistically significant increases in health outcomes during heatwaves are depicted with a red border.**

There were differences in the spatial patterns of IRRs in the map for averaged heatwaves (2004-2014) (Figure 4.6) compared with the maps of 2009 and 2014 (Figure 4.7). Some outer northern and southern postcodes were at risk at 2009, while they seemed at no risk in the averaged heatwaves map. Also, some inner eastern postcodes were found at risk of emergency department visits during heatwaves over the 2004-2014 period (Figure 4.6) while they had IRRs below 1.00 for 2009 (Figure 4.7a).

### 4.3.2 Vulnerability factors and heat-related morbidity

It is apparent from the results of the last sections that morbidity during heatwave events was unevenly distributed in metropolitan Adelaide. This section investigates whether vulnerability characteristics have contributed to the differentials in the geographic distribution of the risks to health during heatwaves.

First, bivariate relationships between the morbidity rate ratios (IRR of ambulance callouts, hospital admissions and emergency department visits) and each of the vulnerability variables were analysed using Pearson correlation (Table 4.7). The results showed that four risk factors, namely the percent of older people (hospitalisations), people who need assistance (ambulance call outs), people who live alone (hospitalisation and ambulance call-outs) and IRSD scores (ambulance call-outs) were significantly correlated with the higher risk of morbidity during heatwaves. Maps of the four vulnerability factors are provided and presented in Figures 4.8-4.11. There was no significant positive relationship between estimated co-morbidities and IRR of ambulance callouts, hospital admissions and emergency department visits (Table 4.7). While there are some negative significant correlations for co-morbidities in Table 4.7, co-morbidities are based on a very minimal data collected during the National Health Survey and only a few people would have been selected by postcode thereby reducing the reliability of the data.

As Figure 4.8 shows, a higher percentage of people aged 65 and above reside in the western and eastern postcodes of metropolitan Adelaide as well as in some inner southern postcodes. The map of IRSD index (Figure 4.9) shows that the inner and outer northern postcodes, and some outer southern postcodes are the most socioeconomically disadvantaged compared to the rest of metropolitan Adelaide. People who live alone are mainly concentrated in the CBD and inner postcodes (Figure 4.10). Finally, those who need assistance with core activities reside in the inner and some outer northern postcodes (Figure 4.11).

The statistically significant postcodes with the highest ranking averaged IRR for ambulance callouts, hospital admissions and emergency department presentations were selected and the presence of the four vulnerability factors and their possible impact explored. Moreover, postcodes with high point estimates in 2009 that continued to be at high risk during 2014 heatwaves, (in spite of the introduction of a heatwave warning system in 2009) were also investigated.

Considerable multi-collinearity of all of the relevant predictor variables, namely IRSD, percent of older people, needing assistance and living alone, impeded progression to a multivariate analysis. Further multi-collinearity can lead to biased estimates, high standard errors and makes it difficult to assess the relative importance of the predictor variables (Alexopoulos,, 2010).

**Table 4.7 Descriptive statistics and Pearson's correlation of Vulnerability factors to heat -related hospitalisations, emergency admissions and ambulance callouts, Adelaide Metro region, 2004-2014**

| Vulnerability factors | Descriptive Statistics | | | | | Correlations with IRR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Hospitalisation IRR | | | Emergency IRR | | | Ambulance IRR | | |
| | N | Mean | Min | Max | SD | N | r | p-value | N | r | p-value | N | r | p-value |
| ***Socioeconomic status*** | | | | | | | | | | | | | | |
| IRSD score | 126 | 1006.6 | 744.0 | 1117.4 | 74.3 | 112 | 0.038 | 0.694 | 122 | -0.042 | 0.643 | 119 | -.195* | **0.034** |
| Low income (%) | 130 | 24.8 | 0.0 | 77.6 | 6.9 | 113 | -0.177 | 0.061 | 125 | -0.033 | 0.717 | 122 | 0.022 | 0.806 |
| ***Neighbourhood characteristics*** | | | | | | | | | | | | | | |
| Green space (%) | 125 | 18.3 | 0.0 | 92.5 | 18.1 | 113 | 0.019 | 0.846 | 125 | 0.102 | 0.259 | 122 | -0.063 | 0.490 |
| ***Measures of possible social isolation*** | | | | | | | | | | | | | | |
| Living alone (%) | 130 | 10.1 | 0.0 | 19.2 | 3.9 | 113 | .262** | **0.005** | 125 | 0.128 | 0.154 | 122 | .223* | **0.014** |
| Need for assistance (%) | 130 | 4.9 | 0.0 | 10.8 | 2.1 | 113 | 0.116 | 0.221 | 125 | 0.024 | 0.793 | 122 | .179* | **0.049** |
| Seniors (aged 65 and above) (%) | 130 | 15.4 | 0.0 | 28.8 | 4.8 | 113 | .222* | **0.018** | 125 | 0.076 | 0.403 | 122 | 0.050 | 0.586 |
| ***Health and risk characteristics*** | | | | | | | | | | | | | | |
| Diabetes (%) | 130 | 5.4 | 3.3 | 10.7 | 1.4 | 113 | 0.082 | 0.388 | 125 | 0.094 | 0.296 | 122 | 0.081 | 0.376 |
| High blood cholesterol (%) | 130 | 28.1 | 23.3 | 33.9 | 2.2 | 113 | -0.065 | 0.495 | 125 | 0.008 | 0.933 | 122 | -.199* | **0.028** |
| Mental and behavioural problems (%) | 130 | 14.8 | 12.7 | 19.1 | 1.6 | 113 | -0.054 | 0.568 | 125 | 0.054 | 0.551 | 122 | 0.143 | 0.117 |
| Disease of the circulatory system (%) | 130 | 17.5 | 11.0 | 24.6 | 2.2 | 113 | -0.057 | 0.546 | 125 | 0.042 | 0.645 | 122 | 0.022 | 0.814 |
| Hypertension (%) | 130 | 11.4 | 7.2 | 15.2 | 1.3 | 113 | -0.063 | 0.505 | 125 | 0.011 | 0.905 | 122 | -0.101 | 0.269 |
| Respiratory disease (%) | 130 | 31.2 | 24.2 | 36.4 | 3.0 | 113 | -.320** | **0.001** | 125 | -0.102 | 0.257 | 122 | -0.141 | 0.122 |
| Asthma (%) | 130 | 10.6 | 6.6 | 13.6 | 1.2 | 113 | -.235* | **0.012** | 125 | -0.063 | 0.484 | 122 | -0.151 | 0.097 |
| Chronic obstructive pulmonary disorder (%) | 130 | 2.3 | 1.5 | 3.3 | 0.3 | 113 | -0.144 | 0.128 | 125 | 0.013 | 0.885 | 122 | 0.064 | 0.480 |
| Musculoskeletal disease (%) | 130 | 29.5 | 22.7 | 36.2 | 2.2 | 113 | -0.142 | 0.135 | 125 | 0.039 | 0.669 | 122 | -0.068 | 0.458 |
| Arthritis (%) | 130 | 16.4 | 9.4 | 22.0 | 2.1 | 113 | -0.085 | 0.372 | 125 | 0.058 | 0.521 | 122 | 0.020 | 0.825 |
| Poor self-assessed | | | | | | | -0.026 | 0.779 | | 0.042 | 0.634 | | 0.159 | 0.078 |

* P ≤ 0.05 and ** P ≤ 0.01

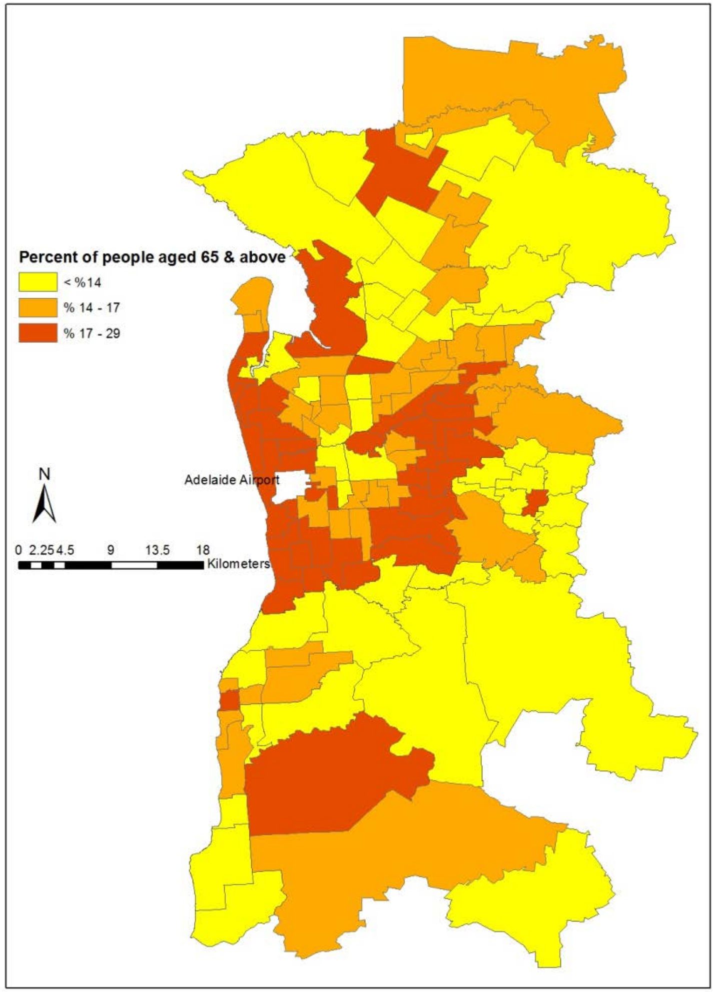

**Figure 4.8 Percent of people aged 65 and above per postcode in metropolitan Adelaide.**

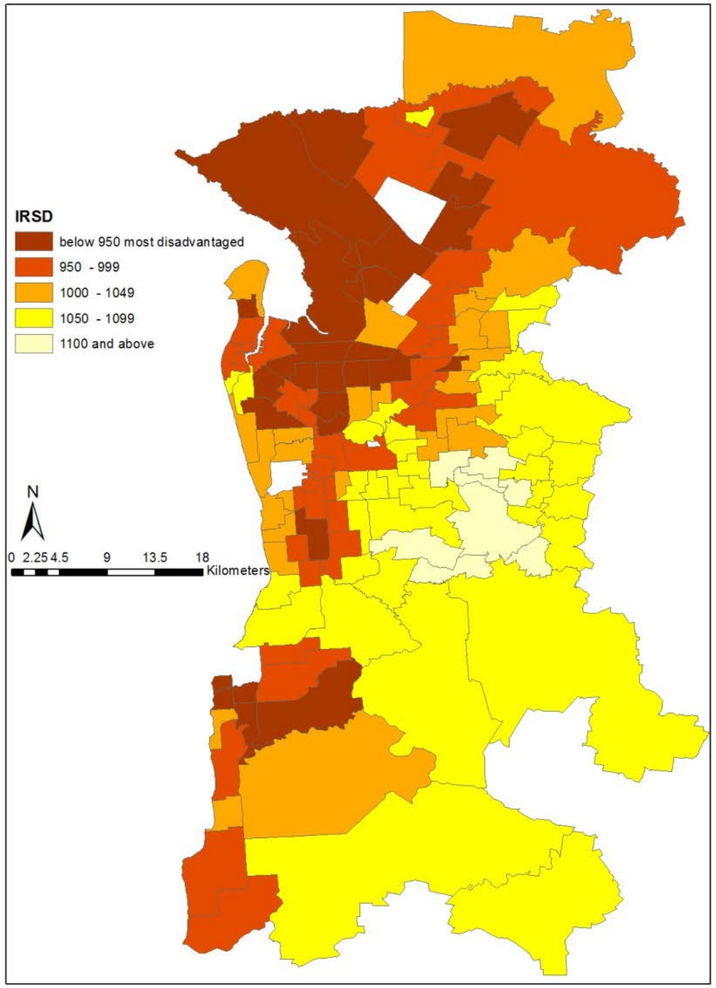

**Figure 4.9 The IRSD score per postcode in metropolitan Adelaide.**

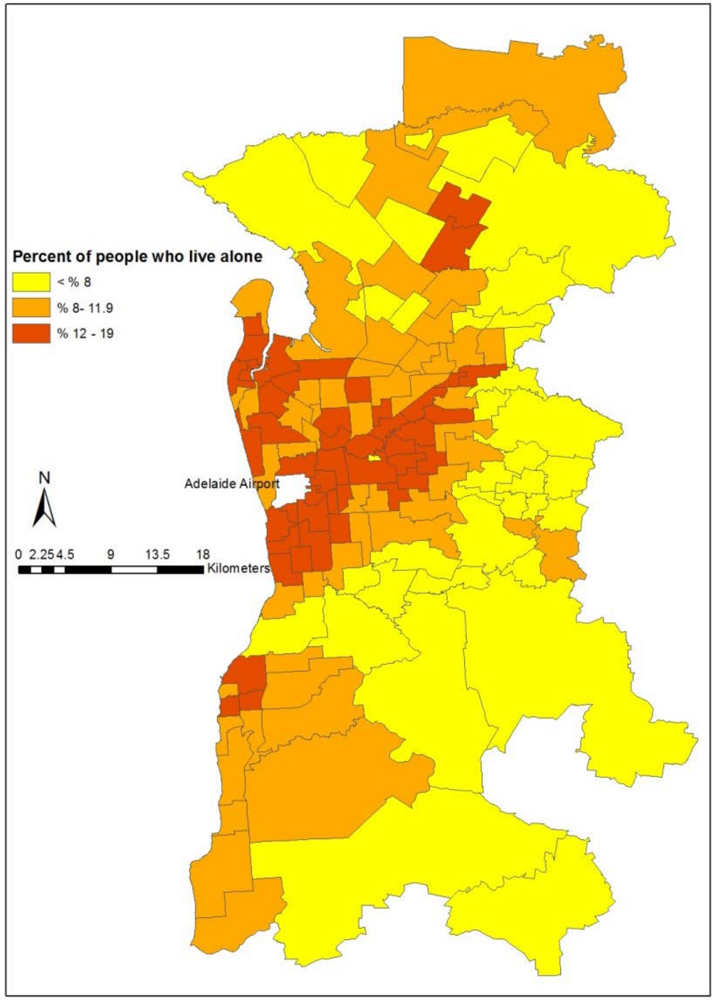

**Figure 4.10** Percent of people who live alone per postcode in metropolitan Adelaide.

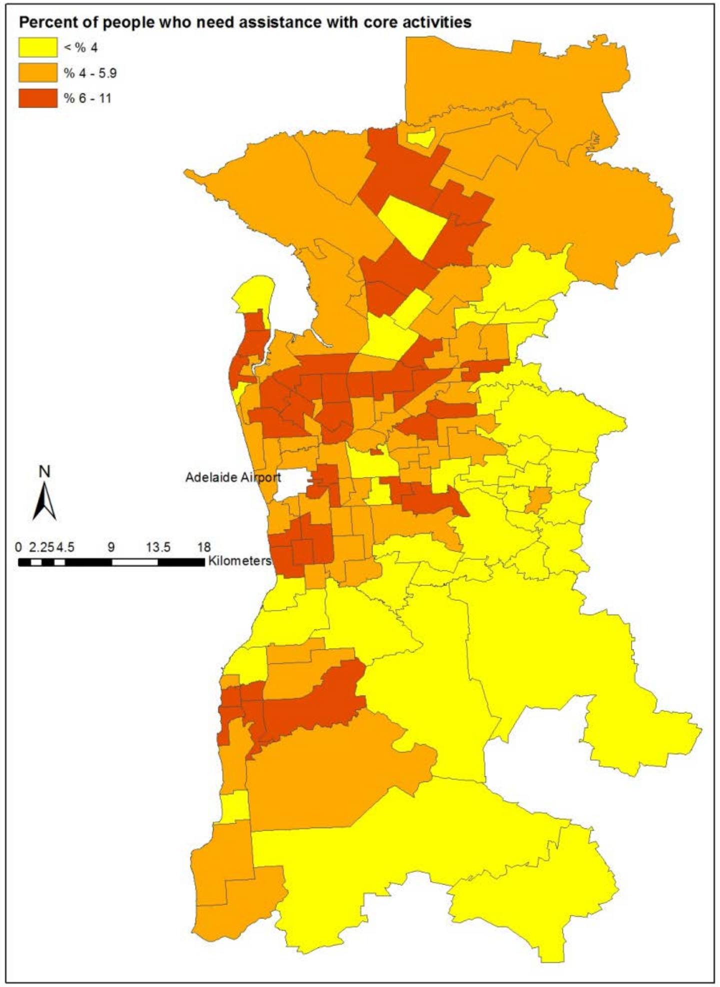

**Figure 4.11** Percent of people who need assistance with core activities per postcode in metropolitan Adelaide.

#### 4.3.2.1 Ambulance callouts

##### *a) Averaged heatwaves*

The IRRs of ambulance callouts showed a significant, positive correlation with people who live alone and need assistance with core activities, and a significant negative correlation with IRSD score (the lower the IRSD score the more disadvantaged the postcode). The five highest ranking postcodes for IRR of ambulance callouts were investigated for noticeable factors that may have been instrumental in increasing health risks during heatwaves (Table 4.8).

**Table 4.8 Postcodes with statistically significant IRRs of ambulance callouts during 1993 to 2014 heatwaves, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR (1993-2014) | IRSD | Living alone | Needing assistance | Elderly |
|---|---|---|---|---|---|
| 5023 | 1.13* | **924** | **2203 (13.82%)** | **1315 (8.25%)** | **3333 (20.91%)** |
| 5038 | 1.14* | 994 | **2384 (16.53%)** | 609 (4.22%) | **2344 (16.25%)** |
| 5022 | 1.15* | 1044 | **1850 (12.6%)** | 757 (5.1%) | **2665 (18.1%)** |
| 5024 | 1.15* | 1041 | 1429 (11%) | 658 (5%) | **2987 (23%)** |
| 5012 | 1.15* | **831** | 1006 (10.3%) | **612 (6.3%)** | 1196 (12.3%) |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

In postcodes 5023, 5038, 5022 and 5024 the percentage of older people is very high (>75th ≥18.4% and 90th ≥21.7% percentile) compared to the average for the Adelaide metropolitan area); three of those postcodes 5023, 5038, 5022 also have a high percentage of people who live alone compared to the average. Postcode 5012 is a very disadvantaged area; its low socioeconomic score and the high percentage of people in need of assistance with core activities could have played a role in increased vulnerability (Table 4.8).

### *b) 2009 vs 2014 heatwave*

As seen in Figure 4.3, after the 2009 heatwave a heat warning system was established in Adelaide and consequently many suburbs experienced less heat-related morbidity during the 2014 extreme heatwaves. However, there were suburbs that still had an IRR above 1.00 in 2014, indicating a risk of heat-related morbidity (ambulance callouts). Risk factors at the postcode level were examined for any possible explanation for areas with greater risk of heat-related morbidity (Table 4.9).

**Table 4.9 IRR of ambulance callouts during 2009 and 2014 heatwaves at higher at risk postcodes, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR 2009 | IRR 2014 | IRSD | Living alone | Needing assistance | Elderly |
|---|---|---|---|---|---|---|
| 5113 | 1.59* | 1.30 | **744** | 2243(12%) | **1675(8.9%)** | 2694 (14.4%) |
| 5107 | 1.89* | 1.66* | **902** | 1111(7.25%) | 929(6%) | 1729 (11.2%) |
| 5014 | 1.92* | 1.37 | **941** | **1716 (14%)** | **845 (7.3%)** | **2020 (17.4%)** |
| 5035 | 2.47* | 1.25 | 1031 | **892 (15.21%)** | 278 (4.74%) | 791 (13.94%) |
| 5072 | 2.08* | 1.87* | 1042 | 1348(11.2%) | 585(4.8%) | **2328 (19.4%)** |
| 5174 | 1.83 | 2.86* | 968 | 578(7.2%) | 103(4%) | 256 (10%) |
| 5126 | 1.72 | 2.91* | 1053 | 475(6.5%) | 232(3.2%) | 859 (11.9%) |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

Postcodes 5113, 5107 and 5014 are relatively disadvantaged areas based on the IRSD scores. Postcode 5113 which is located in the northern part of Adelaide and includes the suburb of Elizabeth Downs, has an IRSD of 744. That is the lowest score in the Adelaide metropolitan area and people living in this area are considered the most socioeconomically disadvantaged.

Postcodes 5014 in the north west including the suburb of Albert Park and 5035 in the south including the suburb of Black Forest 5035 have a high percentage of people living alone (above 75th percentile).

Suburbs in postcode 5072 in the east which includes Magill, have high IRSD scores and are considered socioeconomically advantaged areas. There are however a high percentage of older people (19.4%) in this postcode. This is higher than the ABS estimate of 16% for the population aged 65 years and above, in metropolitan Adelaide (ABS, 2016a) and might be the main risk factor for being at risk of calling an ambulance during heatwaves.

An unexpected increase of ambulance callouts was observed in postcodes 5174 and 5126 during the 2014 heatwave. Postcode 5174 has a low IRSD score of 968 and this might be a vulnerability factor for increased ambulance callouts during heatwaves. Also, the location of the beachside postcode of 5174 might attract people for recreational activities during heatwaves and influence ambulance callouts. While for postcode 5126, nothing was found to explain the increased risk of heat-related morbidity, there might be unaccounted vulnerability factors that were not included in the investigation.

#### 4.3.2.2 Hospital Admissions

##### *a) Averaged heatwaves*

The percentage of people living alone and aged 65 plus were positively correlated with hospital admissions. The only statistically significant postcode at p-value < 0.05 was postcode 5000, i.e. Adelaide CBD. This postcode has the highest percentage of people who live alone in metropolitan Adelaide and a lower IRSD score of 978 (Table 4.10). Upon closer investigation using the map of hospital admissions (Figure 4.4) and the vulnerability maps (Figures 4.8 - 4.11), some postcodes with the highest IRR, although not statistically significant, show a relationship with vulnerability factors which are explained below and presented in Table 4.10.

The five highest ranking suburbs for IRR of hospital admissions during heatwaves were 5121, 5094, 5037, 5040 and 5081. Postcodes 5121 and 5094 are located in northern Adelaide, where the IRSD is lower compared to other parts of metropolitan Adelaide. Moreover, postcode 5094 has a very high percentage (>90th percentile) of older people.

Postcodes 5037 and 5040 located near Adelaide airport, also have a very high percentage of older people. Finally, postcode 5081 (including Walkerville) which is located near the CBD also includes a high percentage of people 65 plus years of age (Table 4.10).

**Table 4.10 IRR of hospital admissions during heatwaves of 2004-2014 at higher at risk postcodes, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR | IRSD | Living alone | Needing assistance | Elderly |
|---|---|---|---|---|---|
| 5000 | 1.17* | **978** | **2426 (19.19%)** | 272 (2.15%) | 968 (7.65%) |
| 5121 | 1.41 | **958** | 127 (10%) | **92 (7.1%)** | 327 (13%) |
| 5094 | 1.22 | **902** | 74 (9%) | 35 (4.4%) | **149 (25%)** |
| 5037 | 1.22 | 998 | **1459 (14%)** | **759 (7.5%)** | **2020 (20%)** |
| 5040 | 1.20 | 1008 | 238 (12%) | 100 (4.3%) | **557 (24%)** |
| 5081 | 1.28 | 1065 | 1074 (12%) | 435 (5%) | **1684 (19%)** |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

### *b) 2009 vs 2014 heatwave*

Although the IRR of hospitalisation decreased for many postcodes during heatwaves compared to non-heatwaves from 2009 to 2014, three postcodes - 5033, 5091 and 5089, maintained a high IRR of 1.13, 1.74 and 2.70, respectively, even after the introduction of the heatwave warning system. Upon closer investigation it was found that postcode 5033 is a relatively socioeconomically disadvantaged area with an IRSD score of 962, it also has a high number of people living alone and needing assistance with core activities (>75th percentile). The number of older people in postcode 5091 is high compared to the average for Adelaide postcodes (Table 4.11).

Reasons for the unexpected increase in 2014 heatwaves at postcode 5089 are not evident from the analysis of this study (Table 4.11).

**Table 4.11 IRR of hospital admissions during 2009 and 2014 heatwaves at higher risk postcodes, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR 2009 | IRR 2014 | IRSD | Living alone | Need assistance | Elderly |
|---|---|---|---|---|---|---|
| 5033 | 2.22* | 1.13 | **962** | **1155(%14.7)** | **574 (7.3%)** | 1340 (17%) |
| 5091 | 2.47* | 1.74 | 1016 | 534 (%7.2) | 202 (2.7%) | 1261 (17%) |
| 5089 | 1.29 | 2.70* | 1074 | 354 (%5.3) | 187 (2.8%) | 935 (14%) |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

### 4.3.2.3 Emergency department presentations

#### *a) Averaged heatwaves*

No statistical correlation was found between vulnerability characteristics and a higher rate of emergency department presentations. However, comparing postcodes of statistically significant IRR above 1.00 with maps of vulnerability (Figures 4.8-4.11), revealed that postcodes 5000, 5039 and 5013 have a high percentage of people who live alone with 19.19%, 15.27% and 13% respectively (> 75th percentile). Postcode 5013 has also a high number of people needing assistance (> 75th percentile) and a low IRSD (<25th percentile) status.

Postcode 5094 with the highest IRR of 1.71 during 2004-2014, has a low population of 790 persons, 149 out of which are aged 65 or above (i.e. 25%). This high number of older people might be the reason for the high rate of emergency department visits during heatwaves. Moreover, postcode 5042 also has a high number of older people accounting for 25% of its population which might play a role in the increased risk of emergency department presentations.

**Table 4.12 IRR of emergency department during 2004-2014 heatwaves at higher risk postcodes, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR | IRSD | Living alone | Needing assistance | Elderly |
|---|---|---|---|---|---|
| 5000 | 1.14* | 978 | **2426 (19.19%)** | 272 (2.15%) | 968 (7.65%) |
| 5039 | 1.19* | 986 | **1268 (15.27%)** | 457 (5.50%) | 1271 (15.31%) |
| 5013 | 1.24* | **868** | **1303(13%)** | **724(7.32%)** | 1414(14.3%) |
| 5094 | 1.71* | **902** | 74 (9%) | 35(4.43%) | **149 (25%)** |
| 5042 | 1.23* | 984 | 1210 (11.64%) | 489 (4.70%) | **2003 (19.26%)** |
| 5009 | 1.26* | 976 | 575(11%) | 266(5.3%) | 737(14.9%) |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

### *b) 2009 vs 2014 heatwave*

Two postcodes of 5044 and 5048 with statistically significant IRRs above 1.00 during 2009 heatwave (Figure 4.7 a) were compared with vulnerability maps (Figures 4.8-4.11). These postcodes have a high percentage of people who are aged 65 and above, people living alone and also need assistance with core activities (> 75 percentile) (Table 4.13).

**Table 4.13 IRR of emergency department during 2009 and 2014 heatwaves at higher risk postcodes, and the number and percent of the population in the postcodes with vulnerability factors.**

| POA | IRR in 2009 | IRR in 2014 | IRSD | Living alone | Needing assistance | Elderly |
|---|---|---|---|---|---|---|
| 5044 | 1.59* | | 1041 | **1612 (15.47%)** | 634 (6.08%) | **2464 (23.66%)** |
| 5048 | 1.69* | | 1013 | **1816 (13.46%)** | **1103 (8.17%)** | **3100 (22.98%)** |

* statistically significant at p-value < 0.05
n(%) = number and percent of the population in the postcodes with vulnerability factors.
**Bold** = > 75th percentile for living alone, needing assistance and elderly
**Bold** = <25th percentile for IRSD

## 4.4. Discussion

Increases in ambulance callouts, hospital admissions and emergency department presentations during heatwaves suggest these data are useful as climate change health indicators for heat and health. It has to be also considered that heatwaves will increase over time. Previous studies have established associations between heatwaves and health outcomes in Adelaide and other Australian cities (Hansen et al., 2008b, Hansen et al., 2008a, Nitschke et al., 2011a, Department of Health, 2009, Khalaj et al., 2010, Williams et al., 2012b, Tong et al., 2010). This current research showed that when IRRs are considered by postcode, a more diverse picture of risk appears indicating that the risks are unequally distributed. As spatial representation of indicators was deemed important by the stakeholders, it potentially increases the utility of these data as indicators to monitor the health impacts of climate change.

The postcode of the patient's residence (or pick-up point for ambulance call-out) was included in the dataset which made the spatial analysis feasible. Spatial representation of indicators has been mentioned as an important criterion for robust indicators by stakeholders and has several implications for public health interventions, for planning and in the development of policies (Navi et al., 2017). Previous studies have already used local heat vulnerability maps validated in combination with health outcome data (Reid et al., 2009, Ho et al., 2016, Rosenthal et al., 2014). These are useful tools for targeted interventions for the most vulnerable populations.

Comparison of heat-related morbidity between the heatwaves of 2009 and 2014 showed decreases in many suburbs during the 2014 heatwaves. This is consistent with a recent study in Adelaide (Nitschke et al., 2016) that evaluated public heatwave warning systems implemented after 2009 in metropolitan Adelaide. Awareness of heatwaves and accurate and timely heat alert systems has also been found to be a core element of heat-health action plans and preparedness for future heatwaves in Europe (Bittner et al., 2013). This demonstrates that heat-health outcome data can not only be used to monitor the status of morbidity during heatwaves, but also can be used as an indicator to assess the success of preventive programs in reducing the effects of heatwaves on population health.

Risk factors identified to increase the risk of health outcomes include co-morbidities, older age, socioeconomic status and elements of the natural and built environment. In this study, living alone, needing assistance, being older and residing in an area with low IRSD were factors that made people more vulnerable to the health effects of heat in Adelaide. This is consistent with previous Adelaide studies. A case-crossover study in Adelaide showed that receiving assistance from community services, living alone, socioeconomic disadvantage and no private health insurance were risk factors for direct heat-related hospitalization during the 2009 Adelaide heatwave (Zhang et al., 2013). Also, an Adelaide survey among people aged 65 and over showed that this group of people may underestimate potential consequences of adverse health effects during extreme heat (Nitschke et al., 2013). Needing assistance was found to be another risk factor influencing ill health in the same study.

International studies showed a similar pattern. In New York city, neighbourhood factors such as low income, limited air conditioning access, low educational status, housing quality and low rates of home ownership and green spaces, exacerbated morbidity during extreme heat (Rosenthal et al., 2014). A Canadian study showed that mortality during heatwaves had the strongest spatial correlation with unemployment in Vancouver (Ho et al., 2016). Therefore, quantitative analysis, including spatial analysis of vulnerability factors and heat-health outcomes proved useful in establishing populations at risk in these studies.

This study showed no correlation with low income, education and English proficiency individually; however, when IRSD was used (which comprises education, income, employment and housing - see Table 4.2), associations were found with a higher risk of ambulance callouts during heatwaves in Adelaide. A study in Sydney did not find IRSD to be a significant risk factor for increased mortality during heatwaves (Vaneckova et al., 2010). Furthermore, no correlation with green space was found to influence heat-related morbidity in this study which is consistent with the Sydney study (Vaneckova et al., 2010). However, overseas studies have shown the existence of green space to be correlated with a decreased risk of heat illnesses by reducing the urban heat island effect (Reid et al., 2009).

The percentage of people aged 65 years and over was statistically associated with increasing IRRs of hospital admission in Adelaide at the postcode level. More than 12,000 excess deaths during the 2003 heatwave in France, one of the deadliest heatwaves, were also reported among elderly people due to co-morbidities and disability in this particular age group (Vandentorren et al., 2006). Other Australian and overseas studies have also shown that older people are at higher risk of heat-related morbidity and mortality. This is particularly important for Adelaide as the population aged 65 years and above increased from 15% to 16% in metropolitan areas between 2010 and 2015 (ABS, 2016a) and projections show this age group will make up 23% of Australia's population in 2056 (ABS, 2016b).

The vulnerability analysis undertaken in this study revealed several areas with IRRs above 1.00 correlating with a high (above 75th percentile) proportion of the population aged 65 or above. These postcodes include 5044 (23.66 %), 5024 (23%), 5048 (22.98%), 5023 (20.91%), 5042 (19.26%)), and 5022 (18.1%). This highlights that targeted interventions for older people during heatwaves should be considered in some areas of Adelaide.

A line of research using temperature and disease outcomes data in recent years has provided a reasonable understanding of the impact of heat on human health in Adelaide. Extending this by taking vulnerability into account and looking for risk factors spatially, is a growing area of interest. To the best of the author’s knowledge, there has been only one study in Adelaide in the peer-reviewed literature that investigated vulnerability and heat-health outcomes in a spatial context (Loughnan et al., 2013). The authors mapped the number of emergency department visits for the period of 2004-2010 and used a vulnerability index (comprising of demographic, environmental and health variables) to provide a spatial pattern of heat vulnerability within metropolitan Adelaide (Loughnan et al., 2013). As well as emergency department presentations, this current study added ambulance callouts and hospital admission to the analysis and identified new areas in need of interventions to address the present risk factors. Loughnan and colleagues used the number of ED presentations and showed spatial patterns of increased risk of ED presentations in outer suburbs to the north and south of the city (Loughnan et al., 2013). This current study used IRR of ED presentations and revealed increased risk of emergency department presentations in the inner-city region and outer western suburbs as well in addition to outer north and south areas suggested by Loughnan et al. (Figure 4.6). This might suggest using IRR of health effects, which takes into account morbidity incidence during non-heatwaves, might be a better indicator than using just the number of health outcomes.

Statistical analysis showed certain vulnerability characteristics to be correlated with heatwave-related morbidity. The correlated risk factors might not always provide a perfect explanation for an area at high risk. This was mainly because not all possible risk factors were available at the postcode level or at the population level. Nevertheless, representing a spatial pattern of morbidity during heatwaves and comparing this with vulnerability maps can provide insights into high risk areas that might be overlooked by just statistical analysis. For example, there was no statistically significant correlation between vulnerability characteristics and higher IRRs of emergency department presentations during heatwaves. However, the spatial analysis of vulnerability factors was able to explain the increased risk of emergency department presentations for some postcodes. Overall, the closer inspection of postcodes with increased IRRs showed evidence of multiple vulnerability factors at high percentage levels. This has implications for local governments who may wish to introduce strategies to mitigate the risks of heatwave-related morbidity in their council areas.

### 4.4.1 Limitations

This is an ecological study and assumed that the whole population was exposed to the same level of exposure to heat. Temperatures recorded in meteorological stations do not necessarily reflect the level of personal exposure if individuals stay indoors. Moreover, maximum temperature used for heat-health analysis was obtained from one station only. A study in Sydney on spatial analysis of heat-related mortality showed 4 º C differences in higher average temperatures from a meteorological station located inland in a highly populated region of Sydney with another station located on the coastal area (Vaneckova et al., 2010). Near-surface air temperature measurements were not available across metropolitan Adelaide at the spatial resolution required for this analysis.

Additionally, with an ecological study everyone within the postcode was assumed to have the same level of income, education, etc. Therefore, results have to be interpreted at the population level of each postcode, where the data is aggregated and presented as average characteristics of the population as a whole (ecological fallacy)(Wang et al., 2017).

The vulnerability data used in the analysis of this study were obtained from ABS census data for 2011 as it was the most recent data available at the time of analysis. Assumptions were made that characteristics such as education level and employment etc., have not changed hugely over a few years.

Data required for spatial analysis came from different sources and each set of data has different boundaries. For example, although the postcode level used to aggregate health data is highly correlated with ABS postal areas, there are discrepancies between postcode and ABS postal areas in outer suburb areas (Taylor, 2014, Hansen, 2010). Postal areas are often used for spatial analysis of this kind, and is by far the best approximation to postcode areas (Taylor, 2014) which were designed for the Australian postal service, not as spatial units.

Some postcodes had small population sizes (hence, wide confidence intervals), and therefore, were not suitable for fine-level statistical analysis. This reduced the power of statistical testing and may have reduced the ability to achieve statistical significance in many suburbs. However, analysis of vulnerability-health effects suggests that living alone, needing assistance with core activities and being socioeconomically disadvantaged act as effect modifiers for the ecological relationship between neighbourhood vulnerability characteristics and higher rates of heat-morbidity in Metropolitan Adelaide.

It should be noted that postcodes recorded for ambulance callouts are locations where ambulances attended to patients and might not necessarily be the residential postcodes of patients.

Co-morbidities put people at higher risk of heat illnesses and death during extreme heat (Schwartz, 2005) and this has been found to be the case in Adelaide (Zhang et al., 2013, Zhang et al., 2017). Nevertheless, the results of the spatial regression analysis showed that co-morbidities such as diabetes, high blood cholesterol, and hypertension were not correlated with increases in ambulance callouts, hospital admission and emergency department visits. It should be noted that there are a number of limitations with the use of co-morbidity data at the level of the spatial unit (PHA) generated by PHIDU in this current study. As explained before, PHIDU uses PHA as the spatial unit, not postcodes. PHA is a larger spatial unit than postcode and assigning the number of people with co-morbidities of a larger geographical unit to a smaller geographical unit can decrease the accuracy of data. Secondly, the number of people with co-morbidities in each PHA is an estimate of chronic diseases based on the National Health Survey (2011- 2013) and the modelled prevalence estimates are not based on observations. While these estimates are statistically reliable at the national or state/territory level, they might not be at the PHA or postcode level. This is a limitation which may have significantly influenced the results. Notwithstanding, this was the only available data on co-morbidities at this level.

Several studies have shown geographical distributions of vulnerable populations by mapping the determinants of vulnerability. However, many have not been verified by patterns of heat-related morbidity and mortality health outcomes. In this study, there were instances where the presence of vulnerability factors could not explain the high risk of heat-morbidity and vice versa. However, not all vulnerability factors addressed in the literature were used in the analysis in this study, mainly due to lack of such data at the postcode level. Notwithstanding, living alone and being aged were highly relevant for an increased risk of morbidity during heatwaves in many postcodes. These vulnerability factors have been found to be linked with increased deaths during the 2009 heatwave in other studies in Adelaide (Zhang et al., 2017). Identifying these two groups of people has important implications for interventions and adaptation planning to reduce heat vulnerability among those who live alone and who are aged 65 and above.

## 4.5. Conclusion

This study, through statistical and spatial analysis has addressed Research Question 3: "What places are more at risk of health impacts during heatwaves?" and Research Question 4: "What are the characteristics of people that make them more vulnerable to heat impacts?" Findings have indicated that the rates of morbidity during extreme heat are differential across Adelaide's suburbs and that Adelaide's western, inner, northern, and some southern suburbs had a higher risk of health outcomes during heatwaves. The spatial patterns of the health impacts were correlated with some vulnerability factors. Four vulnerability factors, i.e. age 65 and over, living alone, needing assistance with core activities and low IRSD, may have contributed to heat-health effects in those suburbs. This has important implications for health care centres and local General Practitioners because of the predicted increases in the proportion of elderly people (Ward et al., 2011) as co-morbidities and the need for assistance with core activities are more common in this population.

The results of this composite analysis can be used to inform climate-health indicators. The indicators met the criteria of credibility, specificity, data availability, were tailored for context, and were spatially represented. These requirements of an indicator have been addressed by stakeholders, as set out in a previous chapter, and may have several implications at local and state level. They can be used for monitoring the health effects of heatwaves, evaluation of heat-health plans and to provide evidence for interventions targeted for vulnerable populations. With climate change projections into the future indicating increases in temperature, maps of areas with high heatwave-related morbidity and mortality provide a supportive tool for health promotion programs and adaptations to climate change.

# CHAPTER 5

# Integration of Findings and Discussion

## Overview

This chapter discusses the thesis, presenting key findings of the study as a whole. It brings together findings of the previous chapters: literature review (Chapter 2), stakeholder consultations (Chapter 3), and statistical and spatial analysis (Chapter 4), and addresses heat-health effects and modifying vulnerability risk factors.

First, the findings as a whole are discussed (Section 5.1). Second, the identified framework for the development of indicators and the current literature outlines an evidence-based selection of heat-related health and vulnerability indicators (Section 5.2). The challenges faced in developing and using indicators are discussed in Section 5.3. Based on the study findings, a set of robust climate health indicators for metropolitan Adelaide are proposed (Section 5.4) – i.e. maximum temperature, heat-related morbidity and vulnerability indicators. Other potential indicators are then discussed including morbidity and mortality due to extreme weather events, climate-related air pollution health effects, and climate-sensitive infectious diseases (Section 5.5). Finally, the strengths and limitations of the research are also discussed (Section 5.6).

## 5.1 Introduction

This research, to the best of author’s knowledge, is the first to use an integrated qualitative and quantitative approach to provide evidence for health-related climate change indicators.

An extensive literature review of the international and Australian literature revealed a range of quantitative measures that can be used as potential indicators of health effects and vulnerability. The review also highlighted that the DPSEEA framework is a useful framework for the development of indicators. Modified by the addition of a vulnerability component, this framework can enhance understanding of the linkages between exposure to the range of environmental hazards due to climate change, and the consequential health effects, particularly in vulnerable subpopulations. This is discussed further in Section 5.2.

Second, extensive stakeholder engagement was undertaken involving interviews with key informants and service providers from state and local government, and non-government organisations in South Australia (Chapter 3). Findings revealed that indicators can serve as an important tool for monitoring and decision making and provide direction for collaborating efforts between health departments, environmental agencies and local governments on reducing the health impacts of climate change.

The spatial temporal analysis of ambulance callouts, hospital admissions and emergency department presentations has yielded an insight into the non-uniform distribution of the health effects in metropolitan Adelaide (Chapter 4). This analysis highlighted areas of the metropolitan Adelaide which had higher risks of morbidity during extreme heat. Previous studies provided ample evidence for risk factors. Some of the modifying vulnerability factors with positive effects on morbidity in this study were being older, needing assistance, living alone and low socioeconomic status. For other risk factors, for example, pre-existing diseases and no air conditioning, data were either not available or imprecise. It is possible, that there are further yet unknown risk factors.  Nevertheless, the findings in this study have important implications for policymakers in South Australia who need to consider population vulnerability to climate change and use this information for policy, adaptation planning and interventions to save money and minimise the health impacts of heat on the population.

Overall, the findings have suggested evidence-based indicators, within the DPSEEA framework, that can be selected to monitor the health effects of climate change.

## 5.2 The process of developing climate-health indicators for Adelaide

A modified DPSEEA framework is suggested for the development of climate health indicators. The DPSEEA framework has been found useful to describe the nexus between environment and health and is applicable to environmental health indicators in a wide range of situations (Corvalan et al. 2000) including climate change (Hambling et al. 2011). However, this framework does not include non-climatic factors such as socioeconomic and environmental settings that often contribute to the health outcomes (Füssel and Klein, 2004) and increase vulnerability to climate change (IPCC, 2014b, Woodward et al., 2014). To include such factors, the DPSEEA framework has been adapted and a vulnerability component added (Navi et al., 2016). This modified DPSEEA framework helps to link exposure, vulnerability and health effects in a structured manner and develop a set of indicators based on the association of heat and health outcomes incorporating vulnerability risk factors such as older age, and living alone. This framework highlights the need to take action at all levels of the framework and to especially focus on mitigating climate change generated by driving forces, and exposure to climate-related events. This preventive approach is preferred to, but does not replace, the health interventions and treatment of consequential health effects of climate change (Corvalán et al., 1999).

Informed by literature reviews, this research has suggested a list of potential indicators including data on heat-health effects, air pollution health effects, climate-sensitive infectious diseases; and injuries and death due to extreme weather events (Navi et al., 2016). Through data exploration and stakeholder consultations the development of some heat-related indicators has been found to be feasible for Adelaide. Data are available for many of the indicators suggested in this study. The Bureau of Meteorology and CSIRO provide weather and environmental data, for instance. The ABS has population statistics available on a wide range of economic and social issues than can be used for vulnerability indicators. Surveillance data of daily health outcomes including ambulance callouts, hospital admissions and emergency department visits are routinely collected in Australia.

Furthermore, statistical and spatial analyses were undertaken to explore associations between heat and health outcomes, and how risk factors of vulnerability modified heat-morbidity on a spatial basis. The process of indicators development as summarised in Figure 5.1, was similar to other relevant indicator studies in other countries. For example, English et al started the process with a scientific literature review in order to provide evidence-based indicators (English et al., 2009). The engagement of stakeholders has also been found as a necessary step in the development of a set of locally relevant indicators for identifying populations vulnerable to heatwave events (Weber et al., 2015). Screening indicators against certain criteria was also deemed important for assuring the quality of scientific and technical data and information (USEPA, 2014a).

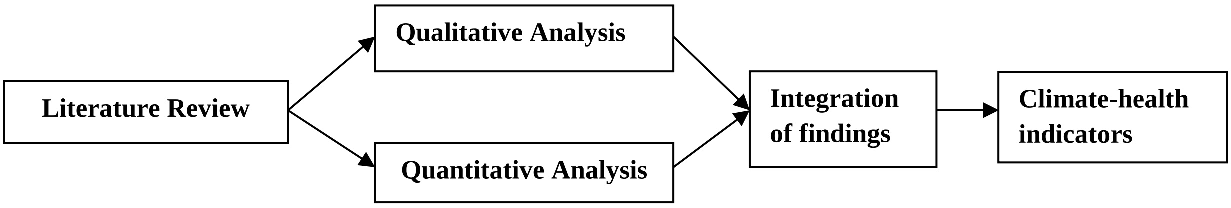

**Figure 5.1 The process undertaken in the development of climate health indicators**

Five main criteria have been identified as being important by the stakeholders participating in this research. They mentioned that climate health indicators should be (i) based on available data; (ii) specific; (iii) credible; (iv) tailored for context, and (v) able to be represented spatially. These criteria are similar, but not as wide-ranging, as those identified by other studies for environmental health indicators (WHO, 1999, Briggs, 2003) and climate change environmental health indicators (Cheng and Berry, 2013, Hambling et al., 2011).

## 5.3 Challenges faced in developing and using indicators

This study has shown that stakeholders are interested in this issue and require climate health indicators and evidence-based policy approaches to detect trends over time. Despite the need for evidence-based indicators, some problems may be encountered. Stakeholders raised a range of issues including gaps in data, inconsistent and non-comparable data due to the use of different methods to collect data and changes in technology over time, and lack of funding and resources for research.

The stakeholders recommended making the indicators visually represented and calculating the indicators at a neighbourhood scale to drive action. This is consistent with findings of overseas studies on mapping human vulnerability to extreme heatwaves in the US (Weber et al., 2015). The issue, however, as addressed by an US study is that obtaining data as spatial data layers is not available for all indicators (Weber et al., 2015).

One of the issues for preparation and adaptation to climate change is the limited details and uncertainty about climate projections (Mearns, 2010). One of the stakeholders raised concerns about projecting the magnitude of climate-related events for their region. They believe that they can manage an emergency situation but there is a large amount of uncertainty about the level of capability and capacity for managing catastrophic events.

> *"We certainly can manage it when it gets to a certain point but then after that what we going to do and it comes almost to move from emergency management to that level of catastrophe management for instance, it gets so difficult in a heatwave that our volunteers cannot function."*
>
> Local government officer

This is consistent with challenges addressed during workshop discussions on the development of societal indicators for national climate assessment in the US (Kenney et al., 2012).

Findings of this study revealed that indicators are needed as a way of communications with policymakers and would play an important role in gaining political and financial support. Lack of financial resources and political support from central government was considered a big challenge in implementing climate change adaptation plans for local authorities in other countries (Barnett et al., 2015, Crabbé and Robin, 2006, Eisenack et al., 2014, Moser and Ekstrom, 2010, Porter et al., 2015).

Other studies also identified issues in the use of evidence in policymaking. For example, a NSW study revealed that health policymakers rarely use research to inform policy agendas or to evaluate the impact of policies; but rather to inform policy content (Campbell et al., 2009). The use of evidence in policymaking therefore needs to be reinforced and this requires policymakers to have skills and competencies in the assessment of the weight of evidence from scientific studies (Bowen and Zwi, 2005). Policymakers need to be in close collaboration with the research community for methodological developments, being informed by the available evidence on health problems and possibilities for interventions (Murray and Lopez, 1996). On the other hand, researchers should have an understanding of overall policymaking processes and that evidence needs to be provided not only to introduce a problem but also in its adaptation and implementation (Bowen and Zwi, 2005).

## 5.4 Heat-vulnerability-health effect indicators for Adelaide

The findings of this research suggest three groups of data that should be used together as a composite set of climate health indicators: maximum temperature, heat-related morbidity (i.e. ambulance callouts, hospital admissions and emergency department presentations) and risk factors of vulnerability (living alone, needing assistance and low socioeconomic status). Other vulnerability risk factors, for example pre-existing chronic illnesses, also play a role, (Nitschke et al., 2013, Zhang et al., 2013) but the quality of data prevents its use for small area quantitative assessment. Nevertheless, these factors can be used by primary health practitioners in their assessment of their patients for preventive advice purposes. Air conditioning availability was another important risk factor identified in previous Adelaide studies, (Nitschke et al., 2013, Zhang et al., 2013) but no spatial data was available in this in instance.

### 5.4.1 Maximum Temperature

Air temperature has been used as an environmental indicator to monitor the progression of climate change and studies have suggested maximum temperature as a suitable indicator to track climate change (English et al., 2009). The Australian BOM has comprehensive datasets of temperature as well as maps and graphs that can be used to monitor the state of climate at state or national level (BOM, 2017a). For the city of Adelaide (Kent Town station) temperature data are available from 1977 in various ways such as days of maximum temperatures above 30° C, 35° C and 40 ° C (BOM, Accessed 2017). It is therefore feasible to use temperature as exposure indicators and monitor changes over long periods of time for South Australia. A graph of days with maximum temperatures above 35° C for the city of Adelaide for the 40 years from 1976-2016 (Appendix A) shows an upward trend for the frequency of these days and the highest recorded maximum temperature of 45.7° C in 2009.

In terms of health effects, daily maximum temperature has been used as an index of heat exposure to analyse the heat-health effects in many epidemiological studies (Kaiser et al., 2001, Filleul et al., 2006, Dolney and Sheridan, 2006, Nitschke et al., 2007, Tong et al., 2010, Bi et al., 2011). That temperature is a good indicator of climate change and health effects due to being easily measurable and the known links with some climate-sensitive diseases and temperature related morbidity was mentioned by the stakeholders (Navi et al., 2017). Temperature therefore provides a platform for heat heath analysis and a suitable indicator that can be categorized to suit relevant definitions of heatwaves. For example, in Adelaide and SA, the heatwave definition of three or more consecutive days when daily maximum temperatures reached or exceeded 35°C has been used for previous heat-health studies (Nitschke et al., 2011a) and in this study analysis. An average of the minimum overnight and maximum daily temperature is also used to identify when heat health warnings should be activated (SA Health, 2016). Another new metric introduced by BOM is the excess heat factor (EHF) for use in Australian heatwave identification, monitoring and forecasting (Nairn and Fawcett, 2014).

Although temperature data are free of charge and easily accessible from BOM, there are few weather stations in Adelaide making spatial coverage of temperature variations a challenge. A higher density of the stations should give insights into microclimate temperature variability across different suburbs (Harlan et al., 2006).

### 5.4.2 Heat-related morbidity

The three health indicators - ambulance callouts, hospital admissions and emergency department presentations, were evaluated against the four main criteria mentioned by stakeholders and met the criteria of availability, spatial representation of indicators, credibility and specificity. Findings of heat-health analysis in this study showed increases in ambulance callouts, hospital admissions and emergency department presentations during heatwaves (defined as being three or more consecutive days when daily maximum temperatures reached or exceeded 35°C) compared to non-heatwaves in Adelaide. These findings suggest these data are useful as climate-related health indicators, particularly as heatwaves will increase with climate change (BOM and CSIRO, 2016). The link between heatwaves and health outcomes has been established in previous studies in Adelaide (Hansen et al., 2008b, Hansen et al., 2008a, Nitschke et al., 2011a) and also in other Australian cities (Department of Health, 2009, Khalaj et al., 2010, Williams et al., 2012b, Tong et al., 2010).

Several studies overseas used mortality data during heatwaves to map heat vulnerability (Rosenthal et al., 2014, Schuster et al., 2014, Ho et al., 2016). However, in Adelaide excess mortality during extreme heatwaves is relatively low, but significant increases in morbidity were seen during heatwaves. Examples include 14-fold increases in direct heat-related hospital admissions and 16% increase in total ambulance callouts during the 2009 heatwave (Nitschke et al., 2011a). Therefore, IRRs of ambulance callouts, emergency department presentations and hospital admissions during heatwaves compared to non-heatwaves were chosen as climate health indicators.

The spatial analysis of the three health outcomes associated with heatwaves revealed that the health effects vary within postcodes and that generally Adelaide's western, inner, northern, and some southern suburbs had a higher risk of ambulance callouts during heatwaves. Central Adelaide suburbs also showed higher risk of emergency department visits and hospital admissions during heatwaves. The small sample size in some postcodes is acknowledged, reflecting a lack of power. Nevertheless, this uneven distribution of health effects justified an investigation into risk factors of vulnerability in certain neighbourhoods.

### 5.4.3 Indicators of vulnerability

This study showed that low socioeconomic status (which comprises low educational attainment, low income and a number of other different factors), older age, needing assistance with daily activities and living alone, as explained in Chapter 4, were associated with higher risks of ambulance callouts, emergency department presentations and hospital admissions during heatwaves in Adelaide. This is consistent with previous research that investigated whether place-based characteristics can increase vulnerability to climate change, especially heatwaves, and rendered people at higher risk of heat-related morbidity (Reid et al., 2009). A within-city analysis of heat vulnerability in New York city which took into account similar vulnerability factors and also verified them with heat-mortality relationship analysis, suggested that neighbourhood factors such as low income, air conditioning access, low educational status, housing quality, rates of home ownership and low presence of green space exacerbated heat-related morbidity (Rosenthal et al., 2014). Additionally, a Canadian study showed that heat-related mortality had the strongest spatial correlation with unemployment in Vancouver (Ho et al., 2016).

To reduce the health effects of climate change, strategies should be directed towards reducing human vulnerabilities (IPCC, 2014b). A study in Adelaide has shown that people who had education after high school and those who had higher income were more likely to have good adaptive behaviours during a heatwave (Akompab et al., 2013). Raising awareness and education about the health risk of heatwaves and adaptive behaviours can lead to increasing resilience and reducing vulnerability (Hajat et al., 2010). Using indicators suggested in this study can help to prioritise areas and communities where vulnerabilities are highest and the need for resilience is greatest.

The vulnerability indicators of low income and unemployment, incorporated into IRSD scores, are linked to indicators of sustainable development. Adaptation strategies aimed at longer-term sustainable development to reduce poverty can help in addressing the underlying vulnerability factors to the health impacts of climate change (IPCC, 2014b).

A general conclusion on the basis of the findings of this study and literature review is that there is considerable potential to reduce human vulnerability to climate change through adaptation strategies at individual, local and national levels.

### 5.4.4 Using indicators for the evaluation of heat-health warning system (HHWS)

The indicators of heat-related morbidity were used to compare health effects during two extreme heatwaves (in 2009 and 2014) at the postcode level in metropolitan Adelaide (Section 4.3.1) as a means of evaluating the efficacy of the HHWS. Introduced after the 2009 heatwave, the Adelaide HWWS is an all-government approach with the State Emergency Service (SES) as the ‘Hazard Leader’ for heat. When an average daily temperature of ≥32°C is forecasted for three or more days, BOM issues heatwave warnings to the public through the media (Nitschke et al., 2016).

HHWS have been implemented in several other countries (Lowe et al., 2011a) and the evaluation of the effectiveness of HWWS is deemed to be important in the WHO/WMO framework (WMO, 2015). Morbidity and mortality associated with heatwaves have been considered to be useful measures for the evaluation of HHWS effectiveness (Bittner et al., 2013). Some international studies have evaluated the effectiveness of HWWS using reductions in mortality, in the US (Weisskopf et al., 2002), France (Fouillet et al., 2008), Italy (Morabito et al., 2012), Hong Kong (Chau et al., 2009) and China (Tan et al., 2007).

Comparing morbidity during the two extreme heatwaves of 2009 and 2014 in Adelaide, this current study showed decreases in ambulance callouts, hospital admissions and emergency department visits across many suburbs. After the 2009 heatwave the SES introduced a heat wave warning system (see section **2.2.3.7**) whereby a public alert is announced when average daily temperatures of 32°C or above are predicted for three or more consecutive days (SES, 2015). The Red Cross also activated Telecross REDi at this time to assist registered vulnerable and isolated people cope with extreme weather events (Australian Red Cross, 2015). It is beyond the scope of the present study to attempt to disentangle the separate effects of these strategies. Nevertheless, the findings of this study suggest a lowering of heat-related morbidity after the interventions were introduced in 2009. This is consistent with a recent evaluation of the Adelaide heatwave warning system by (Nitschke et al., 2016). The results of this current study show the usefulness of the climate-health indicators in the evaluation of HHWS. Also, the health indicators developed in this study show that spatial representations of risk at postcode level, have important implications for formulating interventions to suit local needs (Koppe et al., 2004).

## 5.5 Other climate-health indicators

In the process of undertaking this study, and in searching the published and grey literature, it became obvious that several other sources of data may be useful as health indicators of climate change. These include injuries and death due to extreme weather events; health effects due to increased climate-related air pollution; and climate-sensitive infectious diseases. These have been discussed here briefly and are amenable to future research.

### 5.5.1 Injuries and death due to extreme weather events

Assessing the health impacts of climate-related extreme weather is a challenge based on evidence that extreme weather events such as bushfires, storms, and flooding are projected to increase in Australia (BOM and CSIRO, 2016). Furthermore, a large proportion of the population is exposed to these events (Ladds et al., 2017). Health impacts associated with extreme weather events are mainly death and injuries. For example, bushfires impacted human health between 1967 and 1999 when there were 223 deaths and over 4,000 injuries in Australia (Ladds et al., 2017). In Queensland in 2010–2011 extensive flooding resulted in 33 deaths (Zhong et al., 2013) and people affected by the flooding reported poor respiratory health and psychological distress (Alderman et al., 2013). Additionally, infectious diseases such as leptospirosis and melioidosis can be associated with flooding and heavy rainfall events, and may occur more frequently in the future in flood-prone areas of Australia (Cheng et al., 2006, Lau et al., 2010). However, using these data as indicators of climate change is problematic as they can be difficult to source at a local level.

A study that assessed different databases for natural disasters in Australia has found the Insurance Council of Australia Natural Disaster Event List as the most consistent and reliable estimate of insured losses to Australian households (Ladds et al., 2017). However, the database only includes household insured losses, and death and injuries and uninsured losses are not included (Ladds et al., 2017). Moreover, to enable appropriate assessment of extreme weather events, there should be a consensus definition of such events. For example, a flood event requires a clear definition. An international study using indicators to monitor health effects of climate change, referred to flood as those flood events associated with rain and storm surges, not those which are caused by rising sea levels, tsunamis, volcanic eruptions, and melting snow and ice (Watts et al., 2016).

This lack of systematic surveillance makes monitoring the climate-health impacts and measuring adaptive capacity to extreme events due to climate change, problematic. If suitable data were collected on a national basis this would be useful to examine potential climate change trends and would indicate the effectiveness of disaster warnings. It would also have international implications for global climate health indicators as the number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population is one of the UN indicators to measure resilience and adaptive capacity to extreme weather events as result of climate change (United Nations, 2016).

### 5.5.2 Health effects related to increased climate-related air pollution

Some climate-related events such as bushfires and dust storms can increase the concentration of air pollutants such as particulate matter ($PM_{10}$ and $PM_{2.5}$) and deteriorate air quality (Johnston et al., 2011). These events are projected to increase with climate change (McTainsh and Lynch, 1996, BOM and CSIRO, 2016) and raise concerns about the associated health effects (Johnston et al., 2011, Chen et al., 2006, Morgan et al., 2010). The associated health effects include respiratory diseases, particularly asthma (Johnston et al., 2002, Chen et al., 2006, Johnston et al., 2009) and mental health issues especially among farmers (Polain et al., 2011, Berry et al., 2011). These health effects can be used as climate health indicators. These indicators, however, are outside the scope of the study, but incorporating air quality data in to the set of temperature-health outcomes-vulnerably analysis might become necessary in the future. Attempts have been made here to illustrate a brief picture of the data availability of indicators of climate-driven air pollution in South Australia. The pollutants of particular interest are particulate matter ($PM_{10}$ and $PM_{2.5}$) due to dust and bushfire smoke, and ozone ($O_3$), the levels of which increase with sunlight and heat in the presence of nitrous oxides (WHO, 2005b).

#### 5.5.2.1 Particulate matter

Air quality data were obtained from the South Australian EPA and graphed over time (Figure 5.2) to look for any possible trends and how air quality might be affected by climate-related events such as bushfires. The World Health Organisation air quality guideline for 24-hour mean of $PM_{10}$ is 50 $\mu g/m^3$ (WHO, 2005b). Graphs of $PM_{10}$ for the city of Adelaide show that $PM_{10}$ exceeded these guidelines on a number of days. The details of air quality for each station and time period of data can be found in Appendix I. Monitoring $PM_{10}$ and all air pollutants over time and responsiveness of air quality protection programs to lowering pollution levels is of great importance considering increases in greenhouse gases and the large number of people that are exposed (Landrigan et al, 2017).

To investigate reasons for days of reduced air quality, records of BOM and other resources including the National Environment Protection Council (NEPC) annual reports and an Adelaide University study focusing on the health effects of heatwaves and air pollution in Adelaide (Hansen, 2010), were explored for climate-related events such as bushfires and dust storms. Findings are presented in Figure 5.2 and explained below; confirming the impacts of climate-related events on the poor air quality on the selected examples.

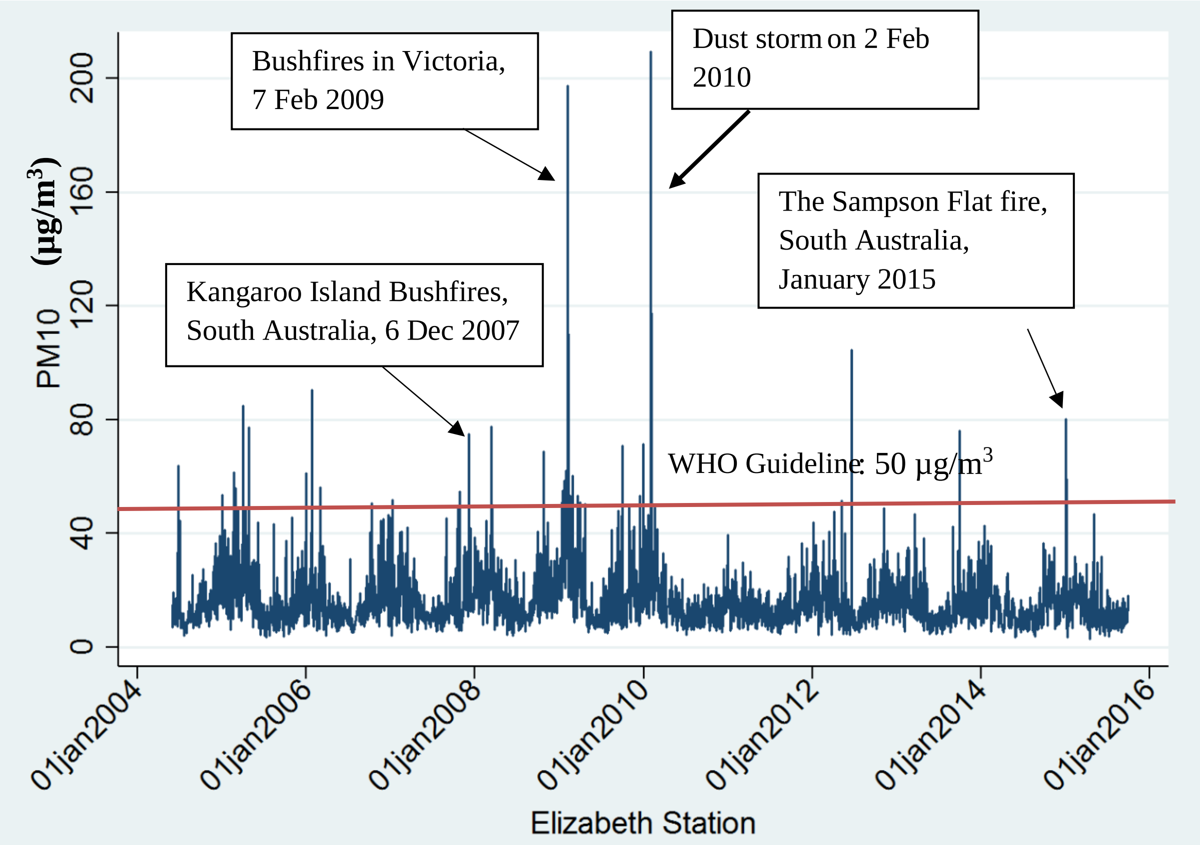

**Figure 5.2** **The level of $PM_{10}$ (µg/$m^3$) at Northern Adelaide (Elizabeth station: -34.675665, 138.649778) during 2004-2016**

- On 7 February 2009 $PM_{10}$ was recorded as 108.7 µg/m3 and 197.5 µg/m3 in Western Adelaide and Northern Adelaide respectively. Figure 5.2 shows the readings from the Elizabeth monitoring station on this date when the State of Victoria experienced extreme bushfire conditions. The change in wind direction exacerbated the fire behaviour and the smoke plumes from the fires affected air quality in Adelaide, situated 700 km northeast from Melbourne (Hansen, 2010).
- The effect of the Sampson Flat fire in January 2015 was also captured at the Elizabeth station (Figure 5.2). The Sampson Flat fire was a severe bushfire in the Adelaide

Hills, burning 125 square kilometres with losses including 27 homes (Bardsley et al., 2015).

- Another example of air quality deterioration can be seen on 6th of December 2007 when the smoke from Kangaroo Island bushfires during 6-14 December 2007 affected Adelaide air quality (Figure 5.2).
- $PM_{10}$ of 209.5 µg/m3 was recorded at the Elizabeth station on 2 February 2010. The National Environment Protection Council (NEPC) annual report 2010-2011 viewed weather conditions as the major determinant of $PM_{10}$ exceedance of standards (NEPC, 2012). Records of BOM Severe Storms Archive show strong wind in parts of South Australia on that day (BOM, 2017c).

This brief descriptive analysis shows that bushfires and dust storms can emit particulate matter and deteriorate air quality in Adelaide. This, in turn, can increase the risk of adverse health effects such as respiratory and cardiovascular diseases (Hansen et al., 2012). The air pollution-health impact relationship analysis after these events can be used as indicators to monitor the impact of climate change on population health but is beyond the scope of the present study.

#### 5.5.2.2 Ozone

Ozone concentrations are predicted to increase during summer time with climate change (Knowlton et al., 2004). While overseas studies have demonstrated the association between high levels of $O_3$ and mortality during heatwaves (Filleul et al., 2006, Grizea et al., 2005, Ren et al., 2008), in Australia contrary views have been reported. A Brisbane study showed that $O_3$ contributed to excess deaths in the 2004 heatwave (Tong et al. 2010), while $O_3$ and $PM_{10}$ were found to be non-significant in a heat-mortality analysis among the elderly in Sydney (Vaneckova et al., 2010). Studies about health effects of climate-driven air pollution in

Adelaide are limited. A study in Adelaide on heat-related mortality and morbidity showed $O_3$ and $PM_{10}$ as confounding factors (Williams et al. 2012a). A recent study found an increased risk of asthma hospital admissions among children per 10 ppb increment in $O_3$ levels during the warm season in Adelaide (Chen et al., 2016).

The WHO air quality guideline for $O_3$ is 100µg/m$^3$ (WHO, 2000) which is the same as the Australian ambient air quality standard (WHO, 2005b). However, The United States Environmental Protection Agency revised their standard for $O_3$ in 2015 to 0.070 parts per million (ppm) in order to increase protection for public health, especially for children and people with respiratory diseases (USEPA, 2015). In metropolitan Adelaide, none of the air quality monitoring stations showed exceedance of the national guidelines for $O_3$ concentrations for the period of 2002-2015 for which data were available.

As mentioned earlier $O_3$ data were obtained from the South Australian EPA. The highest level of $O_3$ recorded during the study period was 97 µg/m$^3$ on 11 March 2008 when the maximum temperature was 38.4° C, in the Elizabeth station in the northern Adelaide suburb of Elizabeth. Current levels of $O_3$ in Adelaide meet national air quality standards. As health effects occur below standards (Sousa et al., 2013) and predictions of increases in temperatures will also increase $O_3$ levels (Knowlton et al., 2004), regular tracking of $O_3$ over time for monitoring trends, is recommended.

### 5.5.3 Climate-sensitive infectious diseases

A range of climate-sensitive diseases in Australia was identified through the literature review (Chapter 2). This included an excess of food-borne diseases such as salmonellosis (Milazzo et al., 2015), campylobacteriosis (Hall et al., 2002), cryptosporidiosis and shigellosis during summer (Bambrick et al., 2008) as well as vector-borne diseases such as Barmah Forest Virus (BFV), dengue fever and Ross River Virus (RRV) associated with increased rainfall (Harley et al., 2011). An increase in the incidence of these climate-sensitive infectious diseases suggests they could be considered as potential health indicators of climate change. These diseases are reported to the Australian National Notifiable Diseases Surveillance System and considered by the stakeholders of this study as the best possible measure for surveillance and tracking. Once the disease surveillance group notes the incidence of any of the notifiable diseases above normally expected levels, a public health response is initiated. These data may be useful as adaptation indicators of climate change.

There are challenges however, with using these data, as addressed by the stakeholders. One issue is that the number of cases reported to the National Notifiable Diseases Surveillance System is only a fraction of the number actually occurring in the community. This is because many cases may be mild and would not seek medical attention and/or have a biological sample tested at the correct time in the illness phase in order for the disease to be deemed a laboratory confirmed notifiable case (Hall et al., 2008). There is also a national issue with laboratory testing to correctly identify pathogens and false positive results can be reported by laboratories (Hall et al., 2008). Moreover, access to information pertaining to daily numbers of reported cases of these diseases requires ethics approval which could be a barrier for researchers investigating the suitability of these data as indicators.

Using climate parameters such as rainfall and temperature as predictive indicators for vector-borne diseases was addressed by the stakeholders in this study. This is consistent with findings of other studies (WHO, 2005a). Predictions of dengue distributions by spatio-temporal modeling of temperature and precipitation were suggested to be useful for developing a dengue alert system in Brazil (Lowe et al., 2011b, Lowe et al., 2013). However, it is important that the emphasis be made on communicating the link between environmental parameters and the health effects when using environmental indicators as a proxy for health effects indicators (Kenney et al., 2012).

## 5.6 Strengths and limitations of the research

### 5.6.1 Strengths

The development of climate-related health indicators is a relatively new process at the national and international level (Watts et al., 2016) and the absence of a properly documented indicator selection process is an issue for stakeholders. A major strength of this study is its breadth in undertaking four main stages of indicator development namely literature review; engagement of stakeholders (qualitative analysis); identification of data availability and analysis of data (quantitative analysis); and synthesising findings and suggesting robust indicators. This forms the foundation of the process of developing indicators that can be further refined in the light of new data or for different cities and regions.

The use of modified DPSSEA framework to present how climate change can affect human health, and using indicators for taking actions at each level of the framework to tackle the health effects provides a new approach to this global issue of public health. The use of indicators for informing public health interventions to vulnerable populations; and for communicating health risks associated with climate change can reduce the burden climate change can put on health services.  The indicators can also be used for evaluation of the impacts in the absence of public health interventions and adaptations in the future.

The qualitative and quantitative case studies have provided a more comprehensive understanding of the research problem and have led to the selection of robust indicators. The stakeholders interviewed in this study were from several different sectors comprising government, non-government, and academic institutions, thereby portraying a widespread picture of stakeholders' needs for indicators and the issues that they face with the development process. The quantitative case studies represented different aspects of the relationship between heatwaves and the adverse health effects providing a context-specific approach to the development of climate-health indicators.

### 5.6.2 Limitations

This study has several limitations. While the maps presented in this study can be used as a resource for researchers and public health policymakers to better understand the geographic distribution of health conditions during heatwaves and vulnerability factors, caution should be used in making direct causal links between the health conditions and the vulnerability factors. In any ecological study it is assumed that the whole population are exposed to the same level of exposure or have the same level of income, education, etc. (ecological fallacy)(Wang et al., 2017), therefore information presented in the maps should be only used to make inferences of the areas not the individual residing in each postcode.

As climate change is projected to increase the frequency and intensity of heatwaves (BOM and CSIRO, 2016), indicators suggested in this study, namely ambulance callouts, hospital admissions and emergency department visits during heatwaves compared to non-heatwaves, can be used to measure the direct and acute health effects of climate change. However, these indicators are not exhaustive to measure and monitor the impact climate change can have on human health. In the longer term, impacts of climate change on mental health and wellbeing will be an issue of particular importance; however, such health effects cannot be measured currently (Watts et al., 2016). Relevance and feasibility of long-term indicators such as the impacts of drought on mental health were not investigated in this research.  Other potential climate health indicators have been addressed in this study, but require further research and consideration on their robustness and usefulness, including injuries and death due to extreme weather events; health effects related to increased climate-related air pollution; and climate-sensitive infectious diseases.

This research explored the understanding of climate-health indicators within a small group of stakeholders in South Australia. Others interstate may have different views or access to different data. Also, as weather and climate characteristics in South Australia can differ from those of other states and regions, and the health burden related to climate change can also vary geographically, not all indicators suggested in this study are necessarily applicable to other areas. Furthermore, the vulnerability risk factors identified for Adelaide might not be applicable elsewhere. Also, new research might provide insight on new indicators due to different data availability or climate variability, addressing different issues and factors of population vulnerability.

Although this research has attempted to provide more insight about the links between climate and health by suggesting a set of exposure, vulnerability and health effect indicators in a framework, indicators of air pollution associated with heat such as $O_3$ were not included in the analysis of morbidity during heatwaves. This could be considered in future studies to take into account all possible influencing factors on the adverse health effects of heat exposure and climate change.

# CHAPTER 6

# Conclusions and Recommendations

Findings from this study highlight the careful selection of exposure, vulnerability and health data in maximising the sensitivity and efficiency of the indicators. They also reveal that health outcomes during heatwaves and relevant temperature constructs can be readily used as indicators for monitoring the impact of climate change on population health.

Heat–morbidity analysis showed that health outcomes were not evenly distributed in metropolitan Adelaide suburbs. It is concluded that risk factors include being older, living alone, needing assistance and being socioeconomically disadvantaged, and these exacerbate the risk of health outcomes. Thus, vulnerability is an important consideration in understanding climate health effects and is particularly relevant for local authorities considering targeted interventions in the community.

This research showed the modified DPSEEA framework is suitable for presenting relationships among factors that affect health in the context of climate change. It is also useful for working collaboratively to maximise the utility of indicators for monitoring and decision making. As the framework illustrates, many of the effective strategies to reduce the health impacts can be undertaken in non-health sectors.

The engagement of relevant government and non-government organisations is required in the process of indicator development to ensure that the indicators are robust and fit for purpose. The stakeholders raised several issues including lack of resources and access to data which were consistent with findings of similar studies elsewhere. They particularly found difficulty in measuring people's resilience to climate change and extreme weather events, an area which is not well understood and requires more research in Australia.

This research, in accordance with other literature, identified the older population as a vulnerable group to the health impacts of heatwaves. Between 1996 and 2016, the proportion of the Australian population aged 65 years and over increased from 12.0% to 15.3%, and from 1.1% to 2.0% for people aged 85 years and over (ABS, 2016a). This trend is set to continue as the population ages. With increases in temperatures under current climatic conditions, and an increase in the number of older people in Australia this could become a significant public health challenge and requires the most effective targeted interventions, and adaptation strategies and policies to protect the health of vulnerable people. These interventions can then be evaluated to determine their efficacy in reducing heat-related morbidity, in older people.

The indicators suggested in this study can be used for a range of purposes including measuring health effects during heatwaves over years and monitoring trends, communications with policymakers and assessment of interventions. Comparisons of heat-morbidity before and after the implementation of a heatwave warning system in Adelaide suggested the success of public health interventions in reducing the health effects. Some studies in the United States have shown that mortality during heatwaves has declined in recent years due to interventions and adaptations (Bobb et al., 2014). The climate health indicators will be then valuable in the long-term for monitoring how well we adapt to climate change as well as projecting the health burden due to increased heatwaves in the absence of interventions and adaptation planning.

## 6.1 Policy implications

To date there have been no specific environmental health indicators of climate change developed for Australia and this study attempts to formalise and justify some basic indicators. It is envisaged that representing indicators deduced from the literature and structured into the specified framework would assist public health planners and policymakers to see the links between the environment, vulnerability, health effects and actions. Climate heath indicators developed in this study have insights from stakeholders and as a result have implications for decision-makers in local and state governments.

- Stakeholders recommended making the indicators visually represented to reveal areas at higher risk, accompanied with vulnerability maps and to make comparisons among local areas. Maps presented in Chapter 4 are the spatial aspect of indicators and could be made available for local governments and state government departments in South Australia.

- The tracking over time of heatwave-associated morbidity in council areas can be useful for local government climate adaptation plans. This information can be useful in assessing if people in the community are becoming adapted to climate change and in making policy recommendations at the local level.

- Climate change-related health indicators may also have implications for longer-term planning and urban design. This could be relevant for other sectors such as the instalment of air quality monitoring stations, and educational activities raising awareness about the health impacts of climate change. They may also inform the development of parks and recreational areas as evidence has shown improved well-being among people visiting green spaces during heatwaves in Italy and the UK (Lafortezza et al., 2009). Using morbidity during heatwaves as a climate health indicator can identify areas more at need for the development of parks and green spaces within cities to increasing cities' resilience to extreme heatwaves and reducing the urban heat island effect. Adaptation policies in terms of housing can have health co-benefits by improving house design and construction materials to reduce exposure to heat (WHO, 2011a).

## 6.2 Recommendations

The recommendations of this thesis target the research community, as well as environmental and public health agencies involved in data collection and management.

### 6.2.1 Researchers

**It is recommended that new research should be conducted in other jurisdictions and states to develop indicators that fit the local setting.** This case study of South Australia has identified the vulnerability risk factors that affect heat-health outcomes in Adelaide, but these may be site-specific and not necessarily applicable elsewhere to the same extent. Also, new research might provide insight on new indicators due to different data availability, climate variability, and the nuances of population vulnerability. Using a similar methodology to this research however, is recommended to have some standardization for facilitating comparison at the national level. This also would be beneficial for communicating knowledge between states.

This research did not exhaustively address all possible health effects from every type of extreme event in Australia. The main focus of this study was acute health effects associated with heatwave events due to South Australia’s hot dry climate and predictions of more frequent and intense heatwaves. Also, the perspectives of stakeholders involved in this research were suggestive of climate health indicators that capture acute health effects. **Further research should focus on assessing the impact of other climate-related weather events, such as bushfires, floods and droughts, on population health**. Although some studies have been undertaken, to the author’s knowledge these events are not recorded and stored in an inclusive database. This highlights a potential area for future research.

Moreover, as well as acute health effects, there are longer-term health effects, such as mental health issues, as a result of climate-related extreme events. For example, depression and stress symptoms in children have been shown to be associated with floods in different countries such as the US, the Netherlands and Poland (Ahern et al., 2005). Increased rates of post-traumatic stress disorder have also been linked to bushfires (McFarlane et al., 1997, McFarlane and Van Hooff, 2009, Galletly et al., 2011). Health effects of such events are not well documented in the literature in Australia. As these events are projected to increase over time, future research on new indicators that can capture the long-term impacts of climate variation on human health over time is recommended.

**New research on the secondary impacts of climate-related extreme events is recommended.** The disruption of essential infrastructure due to extreme weather events and how this might impact access to health care and emergency response services is poorly understood. Severe storms in September 2016 in SA resulted in a state-wide power outage and 17 patients had to be transferred from an Adelaide hospital to other health centres (SBS-News, 2016). It is unknown if there were additional unreported health impacts. This kind of event may become more common as a US study warned that there would be an increased risk of failures in essential infrastructure including power, transportation, and communication systems, due to increasing extreme weather events (USGCRP, 2016). This lack of studies to link disaster-related infrastructure impacts to health outcomes in Australia warrants future research directions in this area.

### 6.2.2 Agencies

**A central repository for all data that is accessible by those who are responsible for reporting on the impacts of climate change is recommended.** Currently stakeholders and data analysts, who need to investigate the relationship between climate change-related extreme weather events and the health effects, have problems in gathering such data. If suitable data were collected, this would make it easier to examine potential climate change trends and would indicate the effectiveness of adaptation plans and disaster warnings.

**Finally, it is recommended that there be an interdisciplinary surveillance group established to routinely monitor trends over time and conduct climate health relationship analysis to report annually on a series of indicators.** This would provide opportunities for several sectors across government, including the health sector, to use indicators, and to work together towards common goals using a health lens in the context of climate change.

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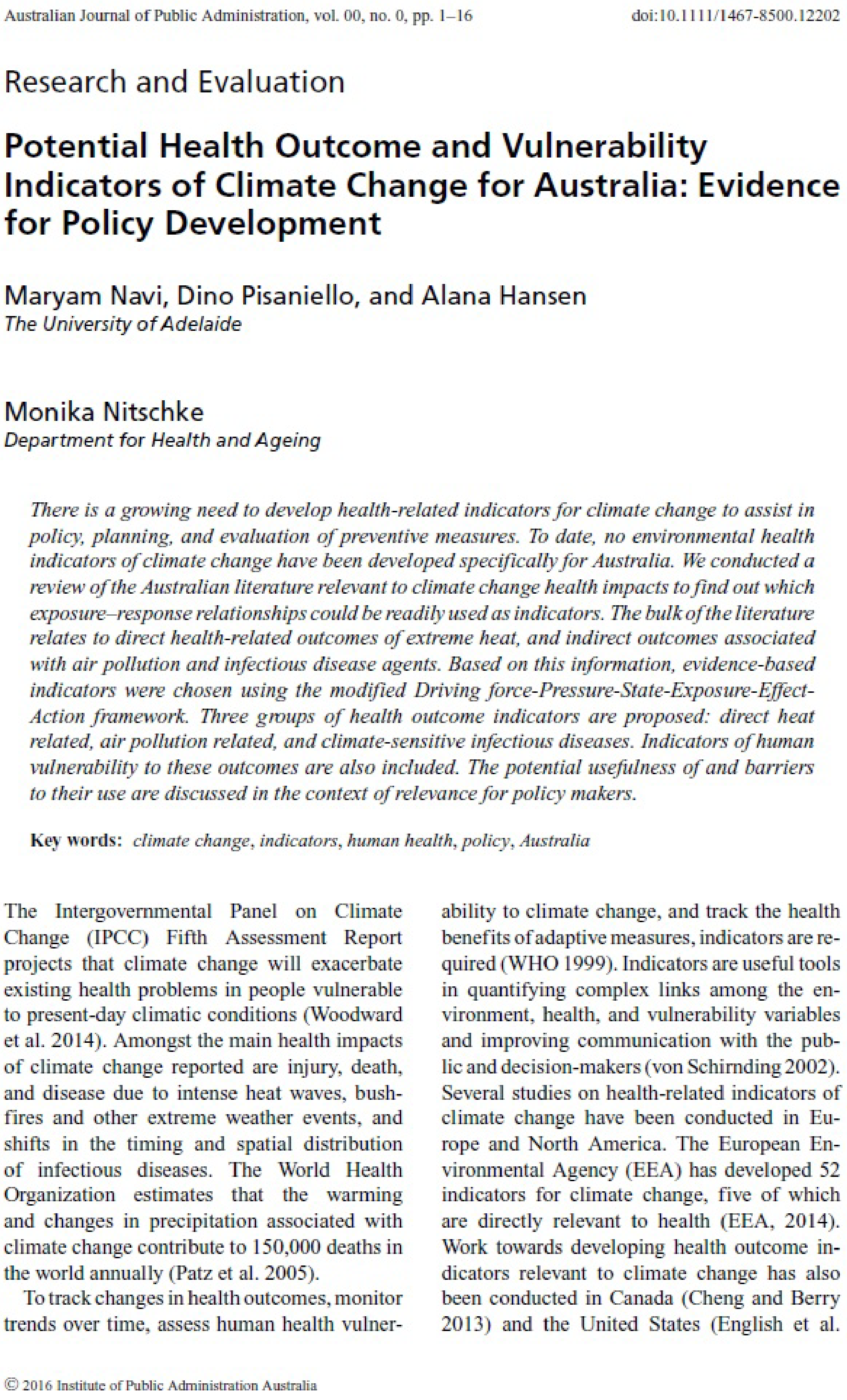
# APPENDICES

# APPENDIX A Published journal article 1



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Research and Evaluation

## Potential Health Outcome and Vulnerability Indicators of Climate Change for Australia: Evidence for Policy Development

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*There is a growing need to develop health-related indicators for climate change to assist in policy, planning, and evaluation of preventive measures. To date, no environmental health indicators of climate change have been developed specifically for Australia. We conducted a review of the Australian literature relevant to climate change health impacts to find out which exposure–response relationships could be readily used as indicators. The bulk of the literature relates to direct health-related outcomes of extreme heat, and indirect outcomes associated with air pollution and infectious disease agents. Based on this information, evidence-based indicators were chosen using the modified Driving force-Pressure-State-Exposure-Effect-Action framework. Three groups of health outcome indicators are proposed: direct heat related, air pollution related, and climate-sensitive infectious diseases. Indicators of human vulnerability to these outcomes are also included. The potential usefulness of and barriers to their use are discussed in the context of relevance for policy makers.*

**Key words:** *climate change, indicators, human health, policy, Australia*

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report projects that climate change will exacerbate existing health problems in people vulnerable to present-day climatic conditions (Woodward et al. 2014). Amongst the main health impacts of climate change reported are injury, death, and disease due to intense heat waves, bushfires and other extreme weather events, and shifts in the timing and spatial distribution of infectious diseases. The World Health Organization estimates that the warming and changes in precipitation associated with climate change contribute to 150,000 deaths in the world annually (Patz et al. 2005).

To track changes in health outcomes, monitor trends over time, assess human health vulnerability to climate change, and track the health benefits of adaptive measures, indicators are required (WHO 1999). Indicators are useful tools in quantifying complex links among the environment, health, and vulnerability variables and improving communication with the public and decision-makers (von Schirnding 2002). Several studies on health-related indicators of climate change have been conducted in Europe and North America. The European Environmental Agency (EEA) has developed 52 indicators for climate change, five of which are directly relevant to health (EEA, 2014). Work towards developing health outcome indicators relevant to climate change has also been conducted in Canada (Cheng and Berry 2013) and the United States (English et al.

2009), where indicators have been classified into six groups – environmental, morbidity and mortality, vulnerability related, mitigation, adaptation, and policy related. These include environmental indicators (including maximum temperature, ozone ($O_3$) concentrations, and pollen counts), health-related indicators (e.g. excess mortality and morbidity due to extreme heat), and indicators of vulnerability (e.g. older people living alone and poverty status) (English et al. 2009). In Australia, climate change impacts are expected to be significant (CSIRO and BoM 2014), but to date no health-related indicators of climate change have been developed. Thus, there is a need to develop a set of evidence-based health-related indicators for climate change specifically for use in Australia, as weather and climate characteristics in the southern hemisphere can differ to those in Europe and the United States and the health burden related to climate change can also vary by region (English et al. 2009). Suitable indicators should be based upon Australian data to enable the monitoring of local trends and evaluation of adaptation plans possible.

It is critical to select indicators that are scientifically supported to reflect the impacts of climate change on population health. As there are a range of other factors such as behavioural and socioeconomic factors that can influence health (McMichael et al. 2003), an understanding of the pathways from driving forces of environmental hazards to health outcomes and the selection of a suitable framework for the development of indicators is essential to support broader analysis of the consequences for policy (Corvalán et al. 1999). The aim of this study is to propose evidence-based health outcome and vulnerability indicators of climate change for Australia that may be useful for decision makers in identifying trends and formulating action plans.

## Methods

To identify the health effects of climate change relevant for Australia, a search of literature reflecting the impact of climate change on health in Australia was conducted using the Scopus, PubMed, and Web of Science databases and Google Scholar. English-language articles using the search terms climate change, indicators, global warming, health, and climate-sensitive diseases were searched. Other variations of the keywords such as heat, drought, flood, bushfires, morbidity, mortality, and vector-borne diseases were also included (Table 1).

The titles and abstracts sourced from the search were read, and those studies meeting at least one of the following criteria were retained:

- Indicating environmental changes that can have impact on human health
- Investigating direct health effects of heat waves, droughts, floods, bushfires and indirect health effects of climate change
- Identifying or assessing health vulnerability to climate change among Australians.

To describe linkages between climate change and human health and to suggest potential indicators for the health effects of climate change based on literature review results, a public health focused framework for environmental health indicators, namely 'Driving force-Pressure-State-Exposure-Effect-Action' (DPSEEA; Corvalán et al. 1999; (Hambling et al. 2011), was selected. This framework has been shown to be useful to describe the nexus between environment and health and applicable to environmental health indicators in a wide range of situations (Corvalán et al. 2000) such as climate change (Hambling et al. 2011). However, this framework does not include non-climatic factors such as socioeconomic and environmental settings that often contribute to the health outcomes (Füssel and Klein 2004) and increase vulnerability to climate change (Woodward et al. 2014). Therefore, it has been recommended that it be extended in a flexible way to include relevant non-climatic confounding factors (Füssel and Klein 2004) that contribute to vulnerability as identified by English et al (2009). To consider the role of such factors, we have adapted the DPSEEA framework and added a vulnerability component (Figure 1).

Table 1. Literature search using logic grid

| **Concepts** | Outcome | Population | Exposure |
|---|---|---|---|
| **Alternative keywords** | Health<br>**OR**<br>Health outcomes<br>**OR**<br>Diseases<br>**OR**<br>Illnesses<br>**OR**<br>“Climate sensitive diseases”<br>**OR**<br>Morbidity<br>**OR**<br>mortality | Australia | Climate change<br>**OR**<br>Heat waves<br>**OR**<br>Global warming<br>**OR**<br>Heat<br>**OR**<br>Drought<br>**OR**<br>Flood<br>**OR**<br>Bush fires<br>**OR**<br>storm |

OR

AND

## Results

The findings from the literature review showed that there is a significant body of work outlining the potential effects of climate change, weather, and air pollution on human health in Australia. The sourced evidence informed the development of potential environmental health indicators of climate change for Australia. Using the modified DPSEEA framework, the indicators have been categorised as follows: (1) driving forces of climate change, (2) pressure indicators of climate change, (3) state of the climate indicators, (4) exposure indicators, (5) vulnerability indicators, (6) effects indicators, and (7) successful actions taken to reduce the health effects of climate change.

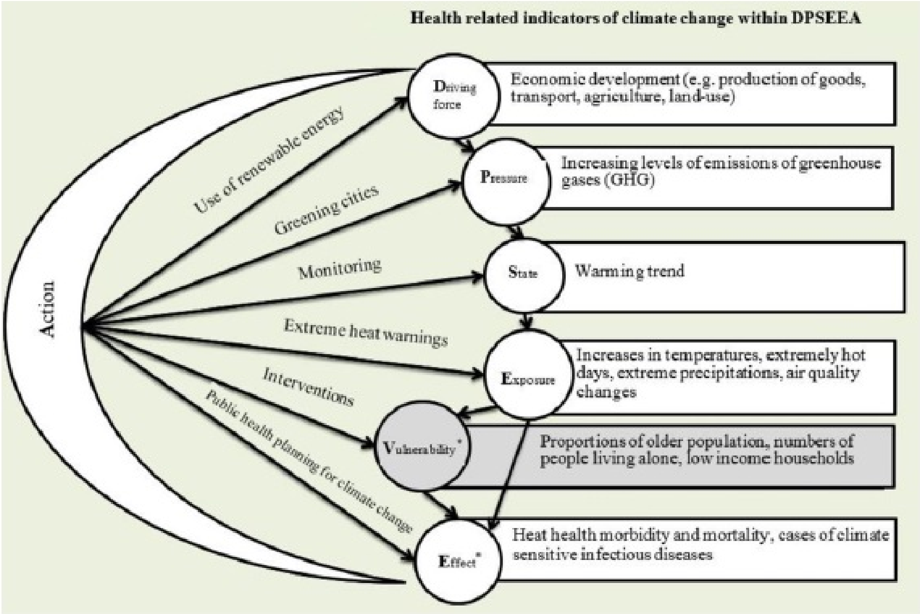
### *Driving Forces of Climate Change*

Population growth and economic development have been identified as main driving forces behind the anthropogenic activities that have resulted in a rise in greenhouse gas emissions leading to climate change (Pachauri et al. 2014). In Australia, driving forces behind greenhouse gas (GHG) emissions are primarily due to the following: (1) stationary energy emissions, transport fuel emissions, indirect emissions from electricity, fugitive emissions from fuels; (2) industrial processes; (3) waste emissions; (4) agriculture; and (5) land use and forestry (CCA 2014). These could include annual urban population growth, numbers of motor vehicles (per 1,000 people) and annual electricity generation from non-renewable energy (World Bank 2015).

### *Pressure Indicator of Climate Change*

Pressure on the environment, generated by driving forces, can be measured using indicators such as levels of greenhouse gas emissions. These emissions as a result of energy, industrial processes, waste, agriculture, and land use pose pressure on the environment. It is estimated that 549,445,840 tonnes of greenhouse gases were emitted in Australia in 2013 (AGEIS 2015). Limiting the magnitude of future climate change requires large and sustained net global reductions in greenhouse gases (CSIRO and BoM 2014). The estimated level of emissions can be accessed through the Australian National Greenhouse Gas Inventory (AGEIS 2015).

**Figure 1. Driving force-Pressure-State-Exposure-Effect-Action Framework with the addition of Vulnerability.**



Source: Adapted from Corvalán et al. (1999). *Potential indicators of vulnerability and health effects have been presented in Tables 2 and 3, respectively.

### *State of the Climate Indicators*

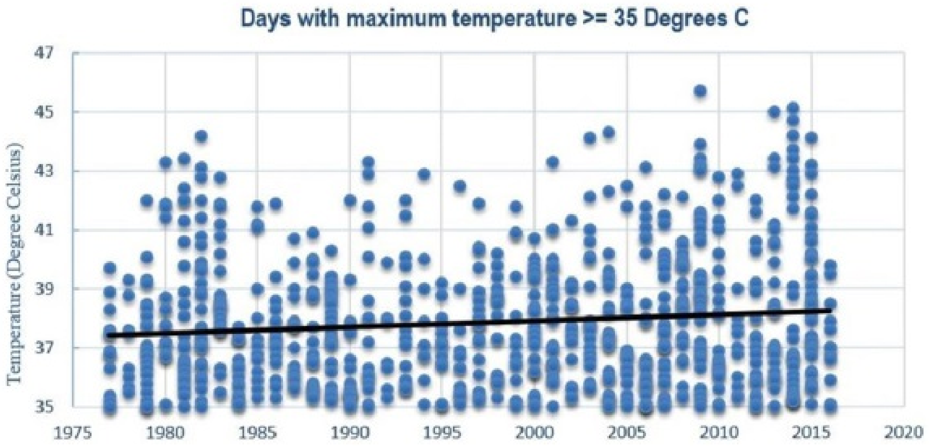
Environmental changes can occur due to increases in greenhouse gas emissions and these include warming of the atmosphere and oceans (Corvalán et al. 2000). Global surface temperature is the most telling indicator of climate change and almost 1°C of warming has occurred in the Australian region since 1910 (CSIRO and BoM 2014). These environmental indicators are used to routinely monitor the changing state of the climate.

### *Exposure Indicators*

Adverse health effects can occur as a result of exposure to climate hazards and extreme weather conditions. In Australia, warming has been linked to heat waves, long-term drought conditions, and an increase in extreme fire-weather days. Higher temperatures affect human health at the higher end of the distribution and therefore days above 35°C are of particular concern. To exemplify extreme heat increases over time for the city of Adelaide in South Australia, a city which has experienced a number of extreme heat waves recently, data were obtained from the Bureau of Meteorology website, where data were available since 1977. Days with maximum temperature equal or above 35°C were graphed over the last 40 years (Figure 2). The black line shows the trend of very hot days and maximum temperature that have increased over years.

There has been an increase in extreme fire weather, and a longer fire season, across large parts of Australia since the 1970s (CSIRO and BoM 2014). The frequency of extreme rainfall has increased in Australia; and in 2011 heavy rainfall in Queensland resulted in extensive flooding (Arblaster et al. 2015) and subsequent health effects (Turner et al. 2012).

**Figure 2. Numbers of Days with Maximum Temperature ≥35°C for the City of Adelaide (Kent Town Station) during Period 1977–2016.**
**Data Source: Bureau of Meteorology, Climate Data Online, accessed 2016.**



Tropical cyclones are projected to decrease in number but increase in intensity (CSIRO and BoM 2014). Changes in numbers and intensity of these weather conditions can be used as indicators.

### *Vulnerability Indicators*

The IPCC Fifth Assessment Report has described the risk of climate-related impacts as the interaction between climate-related hazards and the exposure and vulnerability of human and natural systems (IPCC 2014). Therefore, to be useful for the development of indicators of the exposure-health impacts pathway and to guide the development of adaptation policies, an understanding of multidimensional inequalities that cause vulnerability is required. Taking this into account, we have added vulnerability to the DPSEAA framework and potential indicators of vulnerability addressed in the Australian literature are presented (Table 2).

Periods of extreme heat are predicted to increase with climate change and certain sections of the population are more at risk of heat-related health outcomes. Loughnan et al. identified a range of vulnerability risk factors to heat such as age, living alone, and socioeconomic status (2014). A quantitative study in Adelaide found that receiving help from community services was a risk factor of health problems during the 2009 heat wave in Adelaide (Zhang et al. 2013). Several studies have shown that having a higher number of co-morbidities such as renal problems, mental disorders, cardiovascular disease, ischemic heart disease, cerebral disease, diabetes, and respiratory diseases increase the risk of being affected by heat (Nitschke et al. 2013; Reid et al. 2009). Furthermore, a qualitative study in three Australian cities has shown other risk factors including poor quality housing, language barriers, and low literacy (Hansen et al. 2014). Another qualitative study in rural and remote communities in South Australia (SA) found similar risk factors (Williams et al. 2013). Health system related indicators such as number of aged care facilities and accessibility to emergency services have also been mentioned as determinants of vulnerability (Hansen et al. 2014; Loughnan et al. 2014).

### *Effects Indicators*

Numerous health effects as a result of exposure to extreme heat, air pollution, and extreme precipitation have been reported in the

**Table 2. Factors that increase vulnerability to extreme heat**

| Vulnerability factor | Indicator | Reference |
|---|---|---|
| Age | Percentage of people aged above 65 | Loughnan et al. (2014) |
| Isolation | Numbers of people living alone, one-parent families with dependent children, and couples with no dependent children | Hansen et al.(2014), Loughnan et al. (2014), Zhang et al.(2013), Nitschke et al. (2013) |
| Socioeconomic status (SES) | Percentage of low-income families | Hansen et al. (2014), Loughnan et al. (2014), Zhang et al. (2013) |
| Need for assistance | Numbers of people with disabilities | Loughnan et al. (2014), Zhang et al. (2013), Nitschke et al. (2013) |
| Existing health issues | Numbers of people with chronic diseases | Hansen et al. (2014), Zhang et al. (2013), Nitschke et al. (2013) |
| Language barriers | Numbers of people not fluent in English | Hansen et al. (2014) |
| Low literacy | Percentage of full-time participation in secondary school education at age 16 | Hansen et al. (2014) |
| Aged care facilities | Numbers of aged care facilities | Loughnan et al. (2014) |
| Access to emergency services | Numbers of emergency services within a postcode area | Loughnan et al. (2014) |

Australian literature. The literature suggests that the adverse health outcomes can be categorised into three groups relevant to the development of environmental health indicators: heat–health outcomes, air pollution health outcomes, and climate-sensitive infectious diseases, as discussed below. However, not all health conditions discussed below are due to, or associated with, environmental exposures, and not all environment-related health effects are mentioned (Corvalán et al. 2000).

### *Heat–Health Outcomes*

The most obvious connections between climate change and health are those linked with extreme weather events including extreme heat. Heat has been responsible for 4555 deaths during 1900–2011, which is 55% of all natural hazard deaths reported in Australia (Coates et al. 2014). In Victoria, 374 heat-related deaths were recorded during a 2-week heat wave in early 2009 (Hennessy 2011). High temperatures have also been associated with increases in mortality in Sydney, New South Wales (Wilson et al. 2013), and in Brisbane, Queensland (Tong et al. 2010). In Perth, Western Australia, an increase in maximum temperature above a threshold was associated with increases in daily mortality, particularly in renal-related emergency department presentations (Williams et al. 2012b). Also, increases in mortalities attributed to mental and behavioural disorders have been observed among older persons with schizophrenia, schizotypal, and delusional disorders during heat waves (Hansen et al. 2008a). In the absence of adaptation, increases in mortality due to extreme heat have been predicted to occur in Australian cities (Hennessy 2011).

As well as mortality, extreme heat can increase morbidity (Bi et al. 2011). During extreme heat waves in 2008 and 2009 in Adelaide, ambulance call-outs were increased by 10% and 16%, respectively, compared to previous heat waves (Nitschke et al. 2011). Additionally, a Brisbane study showed increases in ambulance call-outs for respiratory and cardiovascular diseases during heat waves, especially in the older population (Turner et al. 2013). High temperatures have been associated with increases in hospital admissions in Sydney (Wilson et al. 2013) and a 14-fold increase in direct heat-related admissions was observed during the 2009 heat wave in Adelaide (Nitschke et al. 2011). Cause-specific hospital admissions have been shown to be increased for mental

**Table 3. Climate-sensitive health conditions reported in Australia**

| Health outcome | References |
|---|---|
| **Heat related** | |
| Mortality (all-cause) | Tong et al. (2010), Bi et al. (2008), Nitschke et al. (2011) |
| Mortality due to cardiovascular diseases | Bi et al. (2008) |
| Mortality due to renal diseases | Williams et al. (2012b) |
| Mortality of people with mental disorders | Hansen et al. (2008a) |
| Respiratory morbidity | Turner et al. (2013) |
| Cardiovascular morbidity | Turner et al. (2013) |
| Direct heat related hospital admission | Nitschke et al. (2011) |
| Mental morbidity | Hansen et al. (2008a) |
| Renal morbidity | Nitschke et al. (2011), Hansen et al. (2008b), Williams et al. (2012b) |
| Preterm birth | Wang et al. (2013) |
| **Air pollution related** | |
| All-cause mortality | Vaneckova et al. (2008) |
| Mortality due to circulatory disease | Vaneckova et al. (2008) |
| Mortality due to respiratory disease | Vaneckova et al. (2008) |
| Mortality due to cardiovascular diseases | Tong et al. (2010) |
| Respiratory hospital admission | Chen et al. (2006) |
| Allergic asthma | Haberle et al. (2014), Beggs and Bennett (2011) |
| Allergic rhinitis (hay fever) | Medek et al.(2012), Beggs and Bennett (2011), Johnston et al.(2009) |
| **Climate-sensitive infectious diseases** | |
| Salmonellosis | Zhang et al. (2008, 2012), Bambrick et al. (2008), Hall et al. (2011) |
| Campylobacteriosis | Bambrick et al. (2008), Hall et al. (2011) |
| Cryptosporidiosis | Bambrick et al. (2008) |
| Shigellosis | Bambrick et al. (2008) |
| Leptospirosis | Lau et al. (2010) |
| Barmah Forest Virus disease | Naish et al. (2013), Harley et al. (2011), Jacups et al. (2008) |
| Dengue | Hill et al. (2014), Harley et al. (2011), Banu et al. (2011), Kearney et al. (2009), Bambrick et al. (2008), Woodruff et al. (2005) |
| Ross River virus disease | Werner et al. (2012), Harley et al. (2011), Russell (2009), Tong et al. (2004, 2008), Jacups et al. (2008) |
| Murray Valley encephalitis | Harley et al.(2011), Russell (2009) |
| Kunjin | Harley et al. (2011) |
| Melioidosis | Harley et al. (2011) |

disorders (Hansen et al. 2008a) and renal disease during heat waves compared with non-heat wave periods in South Australia (Hansen et al. 2008b). In Perth, high temperatures were associated with increases in emergency department presentations during 1994–2008, particularly in renal-related emergency department presentations (Williams et al. 2012b). Additionally, a study in Brisbane during the summers of 2000–2010 found a significant association between heat waves and preterm births (Wang et al. 2013). Table 3 shows a list of heat related health outcomes, some of which could be used as environmental health indicators of climate change.

### *Heat-related Air Pollution Health Outcomes and the Link with Climate Change*

Exposures to air pollutants have been shown to have adverse effects on human health leading to increases in cardiorespiratory morbidity and mortality (Lave and Seskin 2013). Levels of $O_3$, particulate matter (PM), and pollen are influenced by meteorological conditions that will be affected by climate change. With events such as heat waves and droughts increasing, the frequency of days with unhealthy levels of these air pollutants may also increase (USEPA 2012).

Studies overseas have predicted that $O_3$ levels will increase with climate change (Knowlton et al. 2004) and demonstrated the association between high levels of $O_3$ and mortality during heat waves (Filleul et al. 2006; Grizea et al. 2005; Ren et al. 2008). Few studies have been conducted on this issue in Australia. A study in Brisbane showed that $O_3$ contributed to excess deaths in the 2004 heat wave but these were mainly attributed to temperature (Tong et al. 2010), whilst another study in Sydney showed a moderate correlation between daily maximum temperature and $O_3$ (Vaneckova et al. 2008). A study in Adelaide on heat-related mortality and morbidity showed the strongest associations with daily temperatures when taking $O_3$ and $PM_{10}$ into account (Williams et al. 2012a).

Bushfires associated with the more frequent heat waves and days of extreme fire danger in Australia can lead to increases in particulate pollution (Hansen et al. 2009). A Brisbane study showed increases in daily respiratory hospital admission with increasing levels of $PM_{10}$ during both bushfire and non-bushfire periods. However, this relationship was stronger during bushfire periods (Chen et al. 2006).

Changes in temperature, rainfall, and seasonality associated with climate change have the potential to impact on the amount of airborne pollen, pollen allergenicity, and pollen seasons (Haberle et al. 2014). These can have consequent impacts on allergic diseases and conditions such as asthma and hay fever (Beggs and Bennett 2011; Haberle et al. 2014). Although an increase in the allergenicity of pollen and prevalence of seasonal allergic disease has been associated with increasing atmospheric $CO_2$ concentrations (Rogers et al. 2006; Singer et al. 2005), there is a paucity of literature on the impact of climate change on allergic diseases in Australia (Beggs and Bennett 2011). Nevertheless, data relating to respiratory/allergic disease and respiratory mortality related to increased pollens may be potential health outcome indicators of climate change.

### *Climate-sensitive Infectious Diseases*

Foodborne infections caused by pathogens such as *Salmonella* and *Campylobacter* have strong seasonal cycles (Hall et al. 2002). A summer excess of these infections along with cryptosporidiosis and shigellosis has been reported in Australia and it is likely that higher temperatures will increase these outcomes (Bambrick et al. 2008).

Heavy rainfall and flooding leads to deterioration in the quality of surface and ground water sources, and warmer temperatures aid the proliferation of waterborne pathogens including certain bacteria and viruses (Hall et al. 2002; Hunter 2003). Water-borne diseases such as leptospirosis and melioidosis can be associated with flooding and heavy rainfall events, and may occur more frequently in the future in flood-prone areas of Australia (Cheng et al. 2006; Lau et al. 2010). Sea-level rise also poses risks to freshwater supplies and sanitation systems (Green et al. 2010; McMichael and Lindgren 2011). Additionally, droughts can lead to an increase in concentration of water pollutants in surface water (Kjellstrom and Weaver 2009).

Climate change can affect the incidence and geographical distribution of vector-borne diseases such as Barmah Forest Virus (BFV), dengue fever, and Ross River Virus (RRV; Harley et al. 2011). Changes in temperature and rainfall can have wide-ranging effects on vector survival, replication, activity, habitat and availability of breeding sites, and the incubation period and transmission of pathogens. Rainfall, temperature, and tides have been associated with mosquito abundance and rates of RRV in Australia (Werner et al. 2012). Climate change predictions of increased rainfall may increase transmission of other vector-borne diseases such as Murray Valley Encephalitis and Kunjin encephalitis in northern Australia (Harley et al. 2011). While *Aedes aegypti* is the primary vector for dengue in north Queensland (Hill et al. 2014), the other main vector (*Ae. albopictus)* has recently been detected at the Port of Cairns in far north Queensland (ABC 2015) and has been predicted to spread into mainland Australia (Hill et al. 2014). Human cases of these environment-related infectious diseases may therefore be used as potential health indicators of climate change.

### *Injuries and Death Due to Floods and Storms*

The number of heavy rainfall events has increased in Australia (CSIRO and BoM 2014). Heavy rainfall in Queensland led to extensive flooding in 2010–2011 (Arblaster et al. 2015). The flood resulted in the most deaths from a single flood event in Australia since 1916 (Zhong et al. 2013), with 33 deaths directly attributed to the event (Zhong et al. 2013). A health impact assessment of the 2011 summer floods in Brisbane showed that residents whose households were directly affected by flooding reported poor physical health such as respiratory health and mental health such as psychological distress. (Alderman et al. 2013). Tropical cyclones occur in northern Australia over the wet season and the intensity of these is projected to increase with climate change (CSIRO and BoM 2014). The health outcomes of extreme events such as these that cause flooding and high winds are not well documented in the literature; however, if suitable data were collected on a national basis this would be useful to examine potential climate change trends and would indicate the effectiveness of disaster warnings.

### *Actions Taken to Reduce the Health Effects of Climate Change*

Many of the projected health impacts of climate change may be minimized through mitigation and adaptation strategies (Campbell-Lendrum et al. 2007). Examples of actions taken in response to reducing the impact of climate change are presented here for each level of the DPSEEA framework (Figure 1).

The Australian government has invested $10 billion in renewable energy since 2001 and an estimated $20 billion is expected to be invested between now and 2020 (Australian Government 2015). The government is also supporting the research of new energy technologies for Australia. In terms of monitoring, government departments routinely monitor and forecast weather and climate, and regularly release data and analysis summaries of the state of the climate (CSIRO and BoM 2014).

Extreme heat warnings have been used in cities around the world in recent years. In SA, an extreme heat warning is issued to the public via a media release when average daily temperatures of 32°C or above are predicted for three or more consecutive days (SES 2015). This action may reduce the increased health burden associated with extreme heat. Also part of the SA Health Extreme Heat Strategy since 2009, when SA suffered a heat wave that claimed many lives (SA Health 2015), is a service called Telecross REDi. Activated by the South Australian Department for Communities & Social Inclusion, this service assists vulnerable and isolated people cope by having volunteers regularly call them during heat waves (Australian Red Cross 2015).

Public health planning for climate change is being undertaken by government at all levels in Australia. The Victorian Department of Health and Human Services, for example, is undertaking an integrated impact assessment of climate change, health, and vulnerabilities (VIC Health 2015). Additionally, the SA Public Health Council has identified preparing for climate change as one of the four priority areas for further planning and action by local government. Actions taken by local governments include preparing regional adaptation plans and ensuring that the public health implications of climate change are addressed (SA Health 2013).

## Discussion

Quantifying the health impacts of climate change is complex due to a nexus among factors such as climatic, environmental, economic, and social that affect the causation of a disease on a population level (Füssel and Klein 2004). To integrate diverse data and to use them to understand the impact of climate change on human health and wellbeing, environmental health indicators are needed that make the link between climate change and health. Given the complexity of the issue, using a suitable framework to develop these indicators is warranted. In a review of potential frameworks, the DPSEEA has been identified as the most suitable for environmental health indicators of climate change (Hambling et al. 2011). However, this framework does not consider vulnerability as one of the core components of climate-related impacts (IPCC 2014). Vulnerability has therefore been added to the framework, because of the role it plays in intensifying adverse health effects and limiting adaptation behaviours. Vulnerability indicators can also assist in identifying target populations for interventions.

Heat-related health outcome indicators can include data relating to total and cause-specific morbidity and mortality such as direct heat-related illnesses comprising dehydration, heat and sunstroke, and exposure to excessive heat. Heat-related air pollution indicators inferred through the literature are data relating to health outcomes associated with $O_{3,}$ $PM_{10}$ due to dust or bushfires, or aeroallergens. These may include respiratory (allergic asthma, allergic rhinitis, or hay fever) and cardiovascular conditions. Climate-sensitive infectious diseases such as dengue, Barmah Forest virus disease, Ross River virus disease, and salmonellosis can be used as potential health indicators of changes in temperature and precipitation that can affect mosquito populations or food and water safety.

Climate change health-related indicators should meet the criteria of (1) credibility (based on a known link between climate and health), (2) specificity (directly related to a specific issue of climate change and health concern), (3) being amenable to adaptive actions, and (4) sensitivity to changes in climate and less sensitive to alternative (non-climate) explanations (Hambling et al. 2011). Suggested indicators should be weighed against these criteria in order to find out the most appropriate indicators. Direct heat related morbidity and mortality meet these necessary criteria.

The most obvious connections between climate change and health are those linked with extreme weather events including extreme heat. Heat-related health mortality and morbidity are directly related to the issue of climate change and health and the data can be used as an indicator of climate change. There are also indirect health issues of climate change that are more difficult to quantify (Myers and Bernstein 2011). Heat-related deaths and illness are generally preventable through reaching out to people at risk and informed interventions (USEPA 2014). Public warnings of high temperature that increase awareness of the risk connected to exposure to high temperatures and provide specific advice on how people adapt the behaviour and protect themselves can reduce heat-related impact (Koppe et al. 2004). For example, an extreme heat preparedness plan developed in the city of Milwaukee after a 1995 heat wave showed about 50% decrease in heat-related deaths during the 1999 heat wave (Weisskopf et al. 2002). In several studies, heat-related mortality and morbidity increased with extreme temperature even when adjusted for pollution; that shows heat-related cases are sensitive to changes in climate. Meeting all four criteria, heat-related morbidity and mortality are recommended as the most appropriate indicators for Australia.

Air pollution health outcomes indicators such as cardiovascular diseases are less sensitive and specific as indicators of climate change and can be less amenable to adaptive actions than direct heat-related morbidity and mortality, because these can also be associated with non-climate related air pollution.

Amongst climate-sensitive infectious diseases, salmonella infection has shown a strong seasonal cycle. Increases in notifications of salmonellosis have been linked to the impact of warm season temperature (Milazzo et al. 2015). Raising awareness of the risk of incorrect storage of food through food safety programmes during warmer weather may help reduce the incidence of salmonellosis, which is a notifiable disease in Australia. These data can be accessed through Departments of Health and are likely the best measure for surveillance and tracking.

Data are available for most of the indicators suggested here. The Bureau of Meteorology provides environmental data in conjunction with the CSIRO. The Australian Bureau of Statistics (ABS) has statistics available on a wide range of economic and social issues than can be used for the vulnerability indicators. Surveillance data of the health outcomes addressed above are routinely collected in Australia. However, some of the climate change related health outcomes such as adverse effects of droughts on farmers' mental health (Berry et al. 2011) and increasing asthma prevalence or symptom exacerbations due to dust and pollen may only be assessed over a long-term basis. Short-term routine surveillance may not be adequate and specialist repeated surveys may be more useful as long-term environmental health indicators of climate change.

### *Relevance to Policy*

Policy makers require an evidence-based policy approach with unbiased peer-reviewed evidence (Banks 2009) and seek evidence within the local context. Although indicators for climate change and human health developed or proposed overseas (Cheng and Berry 2013; EEA 2014; English et al. 2009) can inform our study, they may not necessarily be applicable for Australia for different reasons. Impacts attributed to climate change are not uniform across the world. Also, indicators must be developed on the basis of already existing data. (WHO 1999). Types of data that are collected in Australia can be different from overseas. Additionally, not all adverse health outcomes seen across the world are relevant in Australia (e.g. West Nile Virus, which has been suggested as an indicator for the United States (English et al. 2009), does not occur in Australia). Despite the need for evidence by policy makers, some problems may be encountered. A NSW study revealed that health policy makers rarely use research to inform policy agendas or to evaluate the impact of policies; but rather to inform policy content (Campbell et al. 2009). The use of evidence in policy making therefore needs to be reinforced and this requires policy makers to have skills and competencies in the assessment of the weight of evidence from scientific studies (Bowen and Zwi 2005). Policy makers need to be in close collaboration with the research community for methodological developments, being informed by the available evidence on health problems and possibilities for intervention (Murray and Lopez 1996). On the other hand, researchers should have an understanding of overall policy-making processes and that evidence needs to be provided not only to introduce a problem but also in its adaptation and implementation (Bowen and Zwi 2005).

To date there have been no specific environmental health indicators of climate change developed for Australia and this paper attempts to formalise and justify some basic indicators. It is envisaged that representing indicators deduced from literature into the frame work would assist public health planners and policy makers to see the links among environment, vulnerability, health effects, and actions. To reduce the health effects of climate change, efforts should be multi-faceted and involve a broad range of stakeholders. There is ongoing research on the suitability of the suggested indicators, their usefulness, data availability, and practicality of the indicators.

## Conclusion

A range of potential evidence-based indicators have been identified through reviewing literature and using the adapted DPSEEA framework to connect climate change related exposures with effect indicators that are modified by vulnerability factors. Some indicators have shown a very high level of weight of evidence and met the criteria, while other health outcomes are less conclusive. At present, the strongest environmental health indicators of climate change in the Australian context are the following:

- Excess in heat-related morbidity (such as ambulance callouts, emergency and hospital admissions)
- Excess in heat-related mortalities
- Notifications of climate sensitive infectious diseases, for example salmonellosis.

These may be used to measure the adverse health effects of climate change, subject to collaborations between researchers and policy makers in implementing the evidence. Health policy makers can use these indicators as tools of communication with other sectors for developing polices that aim to reduce the health effects associated with climate change.

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# APPENDIX B Published journal article 2

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MDPI

*Article*

## Developing Health-Related Indicators of Climate Change: Australian Stakeholder Perspectives

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**Abstract:** Climate-related health indicators are potentially useful for tracking and predicting the adverse public health effects of climate change, identifying vulnerable populations, and monitoring interventions. However, there is a need to understand stakeholders' perspectives on the identification, development, and utility of such indicators. A qualitative approach was used, comprising semi-structured interviews with key informants and service providers from government and non-government stakeholder organizations in South Australia. Stakeholders saw a need for indicators that could enable the monitoring of health impacts and time trends, vulnerability to climate change, and those which could also be used as communication tools. Four key criteria for utility were identified, namely robust and credible indicators, specificity, data availability, and being able to be spatially represented. The variability of risk factors in different regions, lack of resources, and data and methodological issues were identified as the main barriers to indicator development. This study demonstrates a high level of stakeholder awareness of the health impacts of climate change, and the need for indicators that can inform policy makers regarding interventions.

**Keywords:** indicators; climate change; health outcome; vulnerability; stakeholder

### 1. Introduction

The progression of climate change is notable in Australia, where the mean surface air temperatures, sea-level rise, and ocean acidification are projected to continue on an upward trajectory [1]. Australia's climate has warmed by around 1 °C since 1910, and over the past 15 years, the frequency of very warm months has increased five-fold, with more hot days and fewer cool days predicted [1].

One of the 17 goals of The United Nations Sustainable Development Goals (SDGs) is to take urgent action to combat climate change and its impacts [2]. Climate change impacts directly and indirectly on human health, as shown in several Australian studies [3,4]. Substantial heat-related morbidity and mortality have been reported in association with extreme heatwaves [5–10], and air pollution events due to bushfires and dust storms have been associated with mortality and increased hospitalizations [11,12]. These events are predicted to increase with climate change [13–15]. A changing climate can also affect the transmission of climate-sensitive mosquito-borne diseases such as dengue fever and Ross River virus disease [16–18], in addition to food-borne diseases such as salmonellosis [19–21].

Health-related climate change indicators are quantitative measures to monitor the effects of climate change on population health [22] and should be based on a sound link between the exposure to environmental hazards and human health effects [23]. Studies have noted aims to track health effects

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of climate change using several indicators such as excess morbidity and mortality due to extreme heat; number of injury, death, and mental health outcomes due to extreme weather events including floods and droughts; cases of environmental infectious diseases; and health outcomes related to air pollution and aeroallergens [22,24,25]. These indicators can also be used to assess the effectiveness of public health adaptation strategies and plans. For example, health-related indicators developed in 51 member states of the World Health Organization (WHO) in Europe have had important implications in evaluating heat preparedness planning in the region [26].

At present, in Australia, indicators of environmental change are distinct and separate from indicators of health. The Bureau of Meteorology (BOM) and The Commonwealth Scientific and Industrial Research Organization (CSIRO) are currently using climate data such as temperature and rainfall to monitor the state of the climate and to predict how climate is likely to change in the future [1]. The Australian Institute of Health and Welfare is one of the national organizations which reports on cause-specific health indicators such as asthma and selected infectious diseases [27]. While associations between human health and environmental data have been explored in some cases such as the health impacts of extreme heat waves in 2008, 2009, and 2014 in Australia [28–30], a set of regular health-related climate change indicators has yet to be implemented. These indicators would be useful to policymakers and public health authorities to measure and monitor the health effects of climate change over time, identify vulnerable populations, and evaluate the effectiveness of interventions [31].

Prior to developing indicators, it is important to define from the start the purpose of the indicators, who will use them, and how they will be used. Therefore, stakeholder involvement at an early stage of indicator development is essential to establish views on the usefulness of and requirements for indicators [32]. The involvement of a broad range of stakeholders from sectors other than health is also necessary, because climate change issues are intersectoral, affecting a multitude of different areas and government departments [33].

The aim of this study is to explore stakeholders' needs and requirements for measuring and tracking the adverse health effects of climate change and the factors perceived to increase people's vulnerability to the changing climate. This study, conducted in Adelaide, the capital of the state of South Australia, examines the criteria required to produce robust indicators from the perspective of stakeholders, and the issues they face in developing and using indicators.

## 2. Materials and Methods

The development of environmental health indicators is complex and requires a deep and nuanced understanding of the needs of stakeholders. A qualitative approach was used in this study to explore the perceptions of the relevant stakeholders, ascertain details about data and information that is essential for stakeholders, and understand the barriers that need to be overcome in developing useful indicators.

### 2.1. Theoretical Perspective

Analysis was undertaken from a critical realist position, as described by Willig [34]. This approach has been extensively used in studies that examine climate-related issues, including mitigation policy and energy technology debates, and relationships between social activities and climate outcomes [35]. Critical realism is a theoretical approach to data analysis concerned with characterizing the nature of reality, whilst acknowledging that a person's "reality" is bounded by multiple meanings made available to them in the social context [36]. In this way, participants' views are considered contingent upon locally available knowledge and, thus, analysis does not assume that data constitutes a direct reflection of reality. Rather, it presupposes that interpretation of data is required in order to develop a contextualized understanding of the underlying structures of the phenomenon under examination [34]. In the present study, critical realism aids in understanding stakeholders' views on the usefulness and development of indicators to measure the health impacts of climate change, backgrounded against the current social context.

### 2.2. Recruitment

Face-to-face semi-structured interviews were held with key informants and service providers from the state and local government, and non-government organizations in South Australia. Using purposeful sampling [37], potential participants were identified and contacted by the research team who provided information about the study and an invitation to participate. The potential participants were asked about their willingness to participate and were assured of data confidentiality.

Participants included individuals from the health sector, environmental agencies, emergency service organizations, and academics, all working in areas affected by climate change. In total, there were 21 participants from Adelaide, South Australia.

### 2.3. Data Collection and Analysis

Data collection was undertaken from May 2015 to January 2016. Interviews were conducted at participants' place of employment and were between 30 min to one hour in duration. All respondents provided informed consent before the interviews proceeded.

Participants were asked about the need to develop health-related indicators of climate change, data availability, and views of stakeholders about the usefulness of indicators, factors that increase vulnerability or increase resilience to climate change, and issues in indicator development (Table 1).

**Table 1.** Interview topic guide.

| **Question** |
|---|
| Can you tell me if your organization collects data regarding extreme weather events, emergencies or natural disasters and if so what type of data this might be? |
| What is (are) the source(s) of these data and are they routinely collected on a local or national scale?<br>(Secondary question: How are the data collected and is it accessible to researchers?) |
| Is it just your organization that collects the data or there is a collaboration of organizations? |
| Are you interested in climate change indicators currently for your work? |
| How useful do you think this data would be as an indicator to track the progression of climate change, or the health effects of climate change over time, and if so, how? |
| Are there any data that you think would be useful to collect that might be used as indicators of health outcomes of, or vulnerability to, climate change? |
| Why do you think you would need them? and what should they look like?<br>How would you use them? |
| What do you think would be the barriers to collecting these data and their use as indicators? |

All interviews were digitally recorded and transcribed using the qualitative analysis software package NVivo 10 (QSR International Pty Ltd., Doncaster, Australia). Transcripts and recordings of the interviews were de-identified to protect confidentiality.

Methodologically, data were explored inductively using thematic analysis to identify recurring patterns within the data, as proposed by Braun and Clarke [38]. This involved a stepwise process starting with the transcription of the recorded interviews, reading and rereading the text, and noting down initial ideas. Passages of text that displayed similar ideas or concepts were coded and later refined in an iterative process, and finally assigned to particular codes. Codes were then collated into potential themes that were refined and named accordingly.

### 2.4. Ethics Approval

Ethics approval was granted from the Human Research Ethics Committees at the South Australia Department for Health and Aging and the University of Adelaide (No. HREC/14/SAH/193).

## 3. Results

Of the 21 participants, 14 were from state or local governments, two were consultants, two were academics, and one was from emergency services (Table 2). The expertise and knowledge of the participants were diverse, as organizations and individuals differed in terms of the data they generate or use, services they provide, and their need for indicators. Analysis of the interview data generated five main themes with sub-themes. Themes related to the purpose of using indicators, types of data, criteria for selection of indicators, issues, and alternative indicators (Table 3).

**Table 2.** Respondent categories by role.

| Respondents | Number |
|---|---|
| State government manager/director | 5 |
| State government officer | 8 |
| Local government officer | 3 |
| Emergency services personnel | 1 |
| Non-government consultant | 2 |
| Academic | 2 |
| Total | 21 |

**Table 3.** Identified themes and sub-themes.

| Theme | Sub-Theme |
|---|---|
| Purpose of using indicators | Tracking and monitoring<br>Monitoring disease trend<br>Measuring adaptation<br>Evaluation and assessment<br>Tools for communications with policy makers |
| Data for indicators development | |
| A good indicator | Based on available data<br>Tailored for context<br>Based on a link between environment and diseases<br>Spatial representation of indicators<br>Specificity of indicators |
| Issues and barriers | The problem of climate change is a new and complex area<br>Variability of risk factors in different regions<br>Lack of resources<br>Data and methodological issues |

Participants noted a range of climate change-induced extreme weather events and environmental changes including heat waves, heavy rainfall, droughts, and sea level rise that were potentially linked to adverse effects on human health. They described adverse health effects such as increases in food-borne diseases on hot days, the risk of mosquito-borne diseases that increases with rainfall, and the expansion of standing waters in coastal areas due to sea level rise.

Participants thought that changes in climate had resulted in hotter weather, were concerned about extreme heat posing a serious risk to the health of vulnerable people, and were aware that the health effects of climate change are not, and will not be, equally distributed. They mentioned factors contributing to vulnerability including: age, needing assistance, ill health, poor English language proficiency, being alone, lack of transport, low level of education, lack of employment, low level household income, financial stress, ethnicity, no access to internet connections, and lack of social connectedness. They also recognized the importance of vulnerability considerations in planning and delivering interventions, and emphasized the need to build community resilience.

Participants were keen for health-related indicators of climate change to be available and spoke of how they would use indicators, the types of data that would be useful as indicators and the data that are currently available, what makes a good indicator, and issues and barriers to the development of indicators. These issues emerged as the main themes identified from the narratives, as outlined below.

### *3.1. Purpose of Using Indicators*

Participants explained the different purposes for which indicators could be used, based on their needs and interests. These included: (i) monitoring and tracking changes in the climate, and the impacts that long and short-term changes might have on human health and the environment; (ii) monitoring disease trends; (iii) measuring adaptation; (iv) evaluating actions taken; and (v) as tools for communication.

#### 3.1.1. Tracking Changes in the Environment and Monitoring Impacts on People

Participants explained that they use indicators to track environmental changes and monitor impacts that the changes might have on the health of people and the environment. They said they use data that monitors trends over time for temperature, rainfall, soil conditions, droughts, and sea level rise, and these could also be used as ways to mitigate the associated health impacts. This also highlights a gap in data that they need for monitoring the impact of extreme weather events on people and for emergency management.

> *" . . . we can monitor any impacts of climate change whether it would be on how . . . rainfall might be changing, drying conditions for soil, which has impact on management of open space and reserves, but also so we can monitor the impacts on the community, and obviously health has a huge part of this so that is where this kind of work and developing a really strong indicators set, short term and long term, would be really valuable".* (Local government officer 1)

> *"I think if you actually did have a set of indicators that really showed this is the impact on health and wellbeing of people from maybe events or slow incremental changes like drought . . . , I think that actually could be a very powerful tool for actually taking further action in terms of mitigating climate change or adapting to it".* (State government officer 1)

Changes in the frequency and intensity of rainfall was mentioned as a good environmental indicator for climate change due to being easily measurable and the known links with some climate-sensitive diseases. An environmental expert also spoke about wind erosion and dust occurring during droughts, and the usefulness of indicators to monitor air quality. An officer in government raised the issue of sea level rise and the expansion of saline water bodies in coastal areas that can consequently increase densities of salinity-tolerant vector mosquitos as *"sea level rise will create more incursion of new breeding sites"*.

#### 3.1.2. Monitoring Disease Trends

It was mentioned that indicators could be used to monitor disease trends and anomalies in the data indicating an abnormally high number of cases warranting public health interventions. Some food borne diseases such as salmonellosis can increase with high temperatures, as can mosquito-borne diseases after heavy rainfall. Interviewees thought that indicators could help monitor case numbers and evaluate the use of interventions. They also mentioned that meteorological indicators such as heavy rainfall could be used as potential predictors of disease outbreaks.

#### 3.1.3. Measuring Adaptation

Participants stated that indicators could be used to measure human adaptation to climate change and how communities function or respond in extreme weather events. Annual or bi-annual reports would help to monitor the progress of climate change adaptation.

A government officer believed that some adaptations to climate change could provide co-benefits for healthier lifestyles. For example, areas of shade or green space in cities can be used not only to measure adaptation to climate change, but also to promote physical activity in the community.

#### 3.1.4. Evaluation and Assessment

A recurrent theme identified in the data was the use of indicators for the evaluation of public health plans and the effectiveness of programs and actions to reduce the impacts of climate change. Also mentioned was the importance of using indicators for vulnerability assessments and environmental impact assessments in order to provide evidence for the continued funding of successful programs and to assess if adaptation and preventive strategies are successful.

> *"In terms of process, I think we need to know what action is happening on the ground to see if it does make an impact on health outcomes and on environment"*. (State government officer 2)

Indicators have been used in Europe to assess the usefulness of heat-health action plans [26], showing that European countries are partially prepared for the next major heat-wave. For heat health actions plans to be functional and effective, evaluation on a regular basis is necessary [26] and indicators can be useful for this purpose.

#### 3.1.5. Tools for Communication with Policy Makers

Participants stated that indicators can be used as tools to fill communication gaps between scientists and policymakers. They said that using indicators for an evaluation of climate change mitigation and adaptation programs and activities are critical in the current political environment. They expressed views on various ways of presenting information to policymakers and the general public, such as graphs and maps.

Participants' views were consistent with recommendations from other studies that the visual presentation of indicators as maps can be effective in raising awareness and informing policy and decision making [39]. Spatial representation of community determinants of heat vulnerability at a national scale in the USA has provided an index for nationwide comparison which has important implications for identifying areas for targeted interventions [40].

### *3.2. Data for Indicators Development*

Interviewees mentioned that the types of data collected by organizations include: (i) environmental monitoring data such as air and water quality data; (ii) disease surveillance data; (iii) weather modelling and prediction data; and (iv) survey data. Some organizations did not generate their own data and were dependent on data generated by the Australian Bureau of Statistics (ABS), or other government organizations. Respondents discussed data that were available to them that could be used as health and environmental indicators, and the way that it can be accessed.

The Environment Protection Authority South Australia, for example, publishes monthly and quarterly air pollution quality summaries and reports online, and daily air quality data over long periods of time that can be made available by request [41]. Disease surveillance data in the form of monthly numbers of notifiable infectious disease cases can be accessed through the National Notifiable Diseases Surveillance System in Australia [42]. Weather modelling and prediction data are provided by BOM and CSIRO [1]. Sixty automatic stations are available in South Australia for collecting weather data, which are available online. In terms of survey data, some local governments undertake local surveys by phone in order to gain subjective self-reported data on different levels of vulnerability and the resilience of communities in terms of an adverse event. It was mentioned that subjective data can reveal how people will function in terms of extreme weather and this important information needs to be collected.

### 3.3. What Is a Good Indicator?

Interviewees spoke of different criteria that robust indicators need to meet. They believed that indicators should be: (1) based on available data; (2) tailored for context; (3) based on a link between environment and diseases; (4) able to be spatially presented; and (5) specific.

#### 3.3.1. Based on Available Data

Participants believed that indicators should be based on available data such as health statistics and environmental data. It is not only easier to use already available data, but also allows the monitoring of issues of concern retrospectively, as well as into the future.

> *"I think that would be very important to link the indicators with data that has been collected already. That gives you a very good picture going back as well . . . but it also gives you more confidence that the data will be collected going in to the future"*. (State government officer 3)

#### 3.3.2. Tailored for Context

The Australian Bureau of Statistics (ABS) collects vast amounts of data that can be used as indicators in certain contexts. For example, information about the economic and social conditions of people and households within an area can be useful as indicators of vulnerability to climate change. Participants believed that indicators need to be tailored for specific purposes and the current indices are not ideal in all cases. One participant spoke about how they believed Socio-Economic Indexes for Areas (SEIFA) index [43], is not an ideal indicator of vulnerability when applied to country areas, perhaps due to the relatively small heterogeneous populations in large rural areas.

#### 3.3.3. Based on a Link between Environment and Diseases

Credibility is one of the criteria for a robust indicator [44]. Interviewees explained that indicators should be based on a known link between climate and health. In the following quote, the participant discusses rainfall and temperature as environmental indicators and the link with infectious diseases:

> *"I think the two of them (rainfall and temperature) make good variables because they are so easy to measure, and so often both are linked to diseases either together or independently . . . Rainfall and temperature are two of the best indicators"*. (Academic researcher 1)

Salmonellosis, dengue, and Ross River virus have been mentioned by interviewees of this study and also have been linked with climate change in Australian studies [17,45,46]. However, different climate-sensitive infectious diseases that do not occur in Australia, such as West Nile viruses and Lyme disease, have been suggested as suitable indicators in North America [22,25]. It is therefore important to have indicators that are locally relevant and fit for purpose.

#### 3.3.4. Spatial Representation of Indicators

Interviewees explained there was a demand for the spatial analysis of data that can be used to produce maps to visually represent several different indicators at once. They thought that data presentation in the form of maps would clearly reveal the areas of change, spatially and temporally, whilst saving many words, graphs, and tables in reports. For example, they can be used by stakeholders to show where flooding is likely to occur, areas of vulnerability, or where certain health outcomes are greatest.

> *"One map tells an amazing story compared to what you could, I think that those maps are incredibly powerful for talking with local government councils"*. (State government officer 1)

> *"People find it easy to look at a map and say ok so where do the old people live, where is it going to be flooded ... lots of types of vulnerabilities to different risk factors"*. (Non-government consultant 1)

#### 3.3.5. Specificity of Indicators

Participants' responses showed that developing a list of indicators might be helpful to stakeholders, but to be practical to use, they need to be specific and fit for purpose. For example, disease data may be required in specific formats such as disease notifications or cases hospitalized. Another example is age as a vulnerability indicator. An older age is a risk factor for heat-related illness, but specific age categories need to be defined as required to be a suitable indicator, as outlined in this quote:

> *"what we did first of all, we looked at the, I guess the traditional definitions of vulnerability ... we had initially age over 60 and someone said no, people over 60, it's not over 60 now, it should be over 75 ... because people are more healthy and stronger as they are getting older now"*. (Non-government consultant 1)

### 3.4. Issues and Barriers

Interviewees did not find developing indicators for climate change a straightforward process. A range of issues were noted and are categorized as: climate change is a new complex area; varying risk factors are present in different regions; lack of resources (money, knowledge, and skills) and data; and methodological issues.

#### 3.4.1. Climate Change Is a New and Complex Area

Respondents spoke of the difficulty in understanding the relationship between climate change and human health and wellbeing, especially for vulnerable populations. Some mentioned that developing indicators for climate change is a new and complex process for them, and interrelationships between factors that impact human health make it difficult to find suitable indicators. They also mentioned that some impacts of climate change may only be seen in the long term.

> *"I think it's difficult to, in a short space of time, to link any changes or any impacts to climate change ... Climate change is, as I said, a long-term impact"*. (State government manager 1)

One of the interviewees suggested that, in response to the issue of the long-term effects of climate change, short term as well as long-term indicators need to be available.

> *"I think it is a good idea to have a report annually or every 2 years, that could be quite good if you decide on a very narrow band of the most important indicators, you could have then every ten years a bigger report which would be more meaningful for other indicators, how is it getting worse? Or can we actually adapt? These are really the questions and things that we have not noticed on a yearly level but you can see on a longer term"*. (State government officer 4)

#### 3.4.2. Variability of Risk Factors in Different Regions

Discrete risk factors are salient in different areas of South Australia due to regional climate variability. While heatwaves occur across the state, there are specific areas prone to sea-level rise, floods, and bushfires. This may cause difficulties in the development and application of indicators. Although South Australian councils work together on climate change adaptation plans across broad regions, issues in local environments are different and councils do not necessarily face the same issues.

> *"In different regions, there's, different climate variables so in terms of climate we had sea-level rise, flooding, and bushfire risk ... we also looked at increasing heat. I think sea level rise obviously goes up in some areas, and some areas are bushfire prone while others aren't"*. (Non-government consultant 1)

### 3.4.3. Lack of Resources

Not having knowledgeable people in the planning and vulnerability assessment may lead to some vulnerable communities being overlooked. Respondents claimed that data need to be viewed in the context of local communities and environments. They added that integrating local and scientific knowledge is necessary to make informed decisions.

Respondents mentioned that having a lack of resources limits what they are able to do in terms of their goals and strategic actions. Funding and resources are often insufficient to hire data specialists and analysts. Research was viewed as fulfilling an important role in generating an evidence base and collaboration with research institutes and universities was deemed important.

> *"Resources is a really really big barrier and issue for us in terms of what we are able to do, you know often resources don't meet expectations and there is lot of expectations about what we could be doing and it is already very difficult to match that".* (State government officer 1)

### 3.4.4. Data and Methodological Issues

Data and methodological issues arise in terms of data collection for health-related and environmental indicators of climate change. Issues mentioned include: lack of robust data; data inconsistency and non-comparability due to changes in methods and technology; gaps in data; and not having a central repository of data.

A lack of robust diagnostics and data for some climate-sensitive diseases is a limitation to the development of health-related indicators of climate change. Disease surveillance experts spoke of logistical issues such as laboratory testing for Arboviruses (viruses transmitted by arthropod vectors such as mosquitoes) and the problem of false positives or new testing methods creating inconsistencies in the data.

Changes in technology over time also cause problems with long-term environmental indicators. An environmental scientist said that current air pollution monitoring instruments are different from the instruments used 30 years ago, which would make comparisons of current data with previous data problematic. Another example is inconsistencies over time in the methods used for flood mapping. Moreover, gaps in the data for some locations impedes the use of current data as indicators and attempts to retrofit data can substantially decrease data accuracy.

A respondent also alluded to the significance, and yet lack of, subjective data that are needed to measure the community resilience to climate change impacts. They said that it is difficult to gather data on how people perceive changes and develop resilience to extreme weather events and emergencies. An understanding of how individuals and communities prepare for and respond to emergency situations would be useful, as would their perceptions of when weather extremes would exceed coping abilities. It was said that this type of perception data would be useful to stakeholders involved in emergency management planning and service provision.

> *"I think a lot of data that we perhaps do not have access to and we simply do not get it, . . . is that community perception data, so what . . . does the community need? When do they think it is getting to the point that they cannot function well in a particular climate situation or particular emergency situation? That's probably something we do not have enough of, we don't have even systems really to do that well, that would be really valuable to have . . . it is more that perception data that we are not very good at gathering".* (Local government officer 1)

Respondents also mentioned that a central repository of data is essential for more efficient ways to manage and use data as indicators. They are aware of available information, but they did not find it easy to access.

> *"We know that government has got lots of information as well, and, there is a barrier there, because there is difficulty in sharing the information, and depositing all the information in one place where everybody can use it".* (Local government officer 2)

### 3.5. Alternative Indicators

Respondents provided recommendations on using alternative data that can be helpful in terms of monitoring and tracking changes. Some suggested using environmental indicators as a proxy for health indicators. For example, the surveillance of mosquito populations could be an indication of mosquito-borne pathogens. However, it should be noted that there are many other factors such as the immune status of host populations and socioeconomic conditions that influence disease transmission [47]. Using general practitioner (GP) data as health indicators for morbidity was mentioned by one participant.

> *"One type of data that I think is not easy to collect and readily available that could be very informative in detecting not human disease but human pathogens, so what is happening with vector-borne disease at the moment, . . . , is our ability to detect viruses in the field".* (Academic scientist 1)

> *"In terms of climate change eventually you have to bring in GP data because there is also lots of information about pre-existing diseases about people who have issues, chronic diseases issues, because you know that . . . they are prone to be very vulnerable".* (State government officer 4)

## 4. Discussion

The aim of this study was to explore stakeholders' needs and requirements for the development of climate change indicators, their view on robust indicators, and the purposes for which they would use indicators. Stakeholders use indicators for different purposes such as identifying trends over time and monitoring the impact of climate change, taking preventive actions, measuring adaptation, assessing public health plans, and as tools for communication. However, this largely depends on their requirements.

Our results revealed that stakeholders believed that there would be a tangible impact of climate change on human health and that indicators would be required to measure the impacts. As rising temperature is the environmental indicator most commonly cited in climate change studies [48], participants specifically mentioned increases of heat-related illnesses and death due to climate change. This is supported in the scientific literature which has reported increased heat-related health outcomes as a result of rising temperature [49].

Readily available and accessible data for monitoring the impact of climate change are mainly environmental indicators, such as temperature, rainfall, and air pollution data. Health outcome data presently collected in Australia include heat-related mortality and morbidity such as ambulance callouts and hospital admissions, and communicable disease data on food-borne and vector-borne diseases. Similar data are collected in other countries, and in the United Sates [22], Canada [25], and Europe [26,50], excess mortality and morbidity are being used as health indicators of climate change. However, ethics approval is required for accessing health data and resources also need to be made available to undertake relationship analysis to describe links between climate change and human health. The provision of useful environmental health indicators, will require the service of experienced epidemiologists who can undertake quantitative analysis of environment and health associations on a regular basis to capture trends in climate change-related health outcomes.

For the achievement of Sustainable Development Goals, countries are expected to report progress on the United Nations SDG indicators, and resources should be specifically allocated for this purpose. The indicators include the number of deaths, missing persons, and persons directly affected by disasters, in addition to the proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies [2]. The development of environmental health indicators of climate change will aid in monitoring the progress of the SDGs. According to the Australian Bureau of Transport Economics, flood has been the most costly disaster type in Australia, followed by severe storms and cyclones [51]. However, data on human health impacts of floods can be difficult to source, although a study has shown that heavy rainfall and consequent extensive flooding in Queensland in 2010–2011 attributed to 33 deaths [52]. The Insurance Council of

Australia provides cost estimates of natural disasters such as death and injuries by hazard type [51], and these could be a potential source of data on injuries and mortality from extreme weather events.

Indicators provide useful information for local governments when planning for climate change. Preventing development in areas prone to flooding and/or bushfire, and increasing community education and awareness regarding extreme heat, are examples of key priorities considered in the South Australian regional climate change adaptation plans [53]. However, to the authors' knowledge, records of climate-related adverse events such as flood, bushfire, and storm are not kept in an inclusive database in South Australia. Rather, different organizations and departments keep these records. If these data were managed systematically and centrally, information may be more accessible and useful as indicators of climate change.

The results of this study have shown that the planning and implementation of interventions often requires an understanding of community resilience to extreme weather events, and it can be difficult to define the questions to ask community members to ascertain perceptions of risk and resilience. A recent study by Bene et al. focused on understanding the factors that influence people's resilience in fishing communities in Fiji, Ghana, Sri Lanka, and Vietnam that have experienced natural disasters in the past [54]. The authors used a self-assessment questionnaire built around the strategies adopted by households to respond to past floods and tropical storms. Questions focused on how people responded, how they would respond if such events were to happen again in the near future, and how they believed they would be able to recover. These type of questions can be informative and a starting point for local government surveys to gauge community resilience to severe weather events.

Participants explained that indicators should be: (i) based on available data; (ii) tailored for context; (iii) credible; (iv) represented spatially; and (v) specific. These criteria are similar, but not as wide-ranging, as those identified by other studies for environmental health indicators [23,44] and climate change environmental health indicators [25,55]. Other criteria could also be considered such as cost effectiveness [55] and the quality and integrity of the collected data [25].

This study sought to explore the understanding of indicators development within a small group of stakeholders in South Australia. Others, interstate, may have different views or access to different data. Also, as weather and climate characteristics in South Australia can differ between states and regions, and the health burden related to climate change can also vary geographically, not all indicators suggested in this study are necessarily applicable to other areas. Nevertheless, the participants were from several different sectors comprising government, non-government, and academic institutions, thereby providing a wide-ranging picture of stakeholders' needs for indicators and the issues that they face with the development process. Based on the similarities in the activities, needs, and issues of the participants in other states, the key findings may be useful to policymakers and stakeholders across Australia. Furthermore, given that climate change issues and the related adverse health outcomes have no borders, this study may have an even wider relevance.

## 5. Conclusions

The study findings have shown the relevance of stakeholder engagement in the process of indicator development to assess their needs and the criteria that are required to ensure that the indicators are robust. The findings show that developing indicators for climate change is not a straightforward process. A range of issues were addressed and included the variability of risk factors for different regions, the potential lack of resources, and data and methodological issues. The four criteria that were of most importance for robust indicators were credibility, specificity, data availability, and being spatially represented. Indicators that seem to be easiest to use and to interpret by stakeholders, and which meet the above criteria, include: environmental indicators such as temperature and rainfall, health outcomes including heat-related mortality and morbidity, and notifications of climate-sensitive diseases. Local and state governments have paid special attention to identifying vulnerable groups; however, current indicators are not always useful in identifying the most vulnerable individuals who may be socially isolated, ill, or disadvantaged for reasons that may not be listed in current databases. The integration of resilience and vulnerability assessments is recommended to provide a more complete story for policy makers and planners in the health and emergency services to aid in the preparation, response, and recovery when facing climate change and future extreme events. This study shows a high level of stakeholders' awareness on the health impacts of climate change and the need for indicators that can monitor health trends and inform policy making.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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# APPENDIX C Participants Information Sheet

Government
of South Australia
Department of Health

THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

**PROJECT TITLE:** Towards development of health-related indicat

exposure and vulnerability in the context of climate change

**PRINCIPAL INVESTIGATOR:** Prof. Dino Pisaniello

**STUDENT RESEARCHER:** Maryam Navi, PhD candidate

Dear Participant,

You are invited to participate in the research project described below.

**What is the project about?**

*The aim of this research is to develop environmental health indicators related to climate change in Australia, including climate-sensitive health outcomes, and measures of exposure and vulnerability. The project will not only develop indicators to track the health effects associated with environmental change but also to identify areas of vulnerability where protection of public health is most needed by spatial and temporal analysis of climate change- health effects.*

**Who is undertaking the project?**

*This project is being conducted by Maryam Navi; it will form the basis for the degree of PhD at the University of Adelaide under the supervision of Prof Dino Pisaniello, Dr Alana Hansen and Dr Monika Nitschke.*

**Why am I being invited to participate?**

*You have been invited because*

*You are collecting/managing data concerning the environment/climate change/climate-sensitive diseases*

*You are involved with public health policy or planning for public health regarding climate change or environmental change*

*Your previous or current research focussed on climate change and human health*

**What will I be asked to do?**

*You will be asked to participate in a semi structured interview or focus group. A list of questions and topics will be discussed and the interview will be recorded. Confidentiality will be assured.*

**How much time will the project take?**

*The interview will take approximately half an hour. You may be asked if you would allow brief follow up visits or emails if required, to clarify certain issues.*

**Are there any risks associated with participating in this project?**

*Given the nature of the participants and study topic, we find it very unlikely that any adverse events will occur. Questions regarding development of health-related indicators of climate change are low risk questions. Interviews will focus on topics that broadly fall within the professional domain of the interviewees. In the very unlikely event of a participant becoming distressed the interview will be stopped.*

**What are the benefits of the research project?**

*There may not be any direct benefits of this research to you or your organisation. However, the development of indicators will assist planners and researchers to track the health impacts of extreme weather and environmental change over time, and to monitor trends and evaluate interventions. Additionally, this will allow the identification of high risk areas and sub-populations and inform planning for the future impacts of climate change.*

**Can I withdraw from the project?**

*Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the study at any time.*

*Your participation is greatly valued; however, your participation or withdrawal from the study will not disadvantage you in any way.*

**What will happen to my information?**

*Your privacy is very important and you are assured that the strictest measures are taken to ensure confidentiality and only the investigators will have access to your personal details. To maintain confidentiality, your details and transcribed interview data will be stored in a locked cabinet. At the end of the study, the details that could identify you will be destroyed. The researchers will then analyse the data and publish the research findings in academic journals. However, you will not be identifiable from any of the publications.*

**Who do I contact if I have questions about the project?**

*If you have further questions or concerns, you wish to discuss about any aspect of the study, please contact:*

*Principal Researcher, Prof. Dino Pisaniello Ph. 8313 4957, dino.pisaniello@adelaide.edu.au*

*Associate Researcher, Dr Alana Hansen, Ph. 8313 1043, alana.hansen@adelaide.edu.au*

*Associate Researcher, Dr Monika Nitschke Ph. 8226 7126 monika.nitschke@health.sa.gov.au,*

*Student Researcher, Ms. Maryam Navi Ph. 8313 3321, maryam.navi@adelaide.edu.au*

**What if I have a complaint or any concerns?**

*The study has been approved by the Human Research Ethics Committee at SA Health and the University of Adelaide (approval number HREC/14/SAH/193). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. Contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to* hrec@adelaide.edu.au *if you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant. Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.*

**If I want to participate, what do I do?**

*Please contact Ms. Maryam Navi Ph. 8313 3321, maryam.navi@adelaide.edu.au if you wish to participate in the project. You will be asked to sign a consent form prior to the commencement of interviews.*

Yours sincerely,

Maryam Navi BSc, MPhil

PhD candidate, School of Population Health

The University of Adelaide, South Australia 5005

Ph: 61 8 8313 3321

Email: maryam.navi@adelaide.edu.au

# APPENDIX D Information on Complaints Procedure

## CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS

Government of South Australia
Department of Health

THE UNIVERSITY OF ADELAIDE AUSTRALIA

## PROCEDURE

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

| | |
|---|---|
| **Project Title:** | **Towards the development of health-related indicators for health outcomes, exposure and vulnerability in the context of climate change** |
| **Approval Number:** | **HREC/14/SAH/193** |

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project co-ordinator:

| | |
|---|---|
| **Name:** | **Professor Dino Pisaniello** |
| **Phone:** | **Ph. 8313 4957** |

2. If you wish to discuss with an independent person matters related to:

- making a complaint, or
- raising concerns on the conduct of the project, or
- the University policy on research involving human participants, or
- your rights as a participant,

contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to hrec@adelaide.edu.au.

# APPENDIX E Participant Consent Form

Government of South Australia
Department of Health

THE UNIVERSITY OF ADELAIDE AUSTRALIA

1. I have read the attached Information Sheet and agree to take part in the following research project:

| | |
|---|---|
| **Title:** | **Towards the development of health-related indicators for health outcomes, exposure and vulnerability in the context of climate change** |
| **Ethics Approval Number:** | **HREC/14/SAH/193** |

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

3. It has also been explained that my involvement may not be of any benefit to me.

4. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

5. I understand that I am free to withdraw from the project at any time and that this will not affect me, now or in the future.

6. I agree to the interview being audio recorded. Yes ☐ No ☐

7. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

**Participant to complete:** Name: ..................... Signature: --------------------------------

Date: ..........................................................................

**Researcher/Witness to complete:** I have described the nature of the research to --

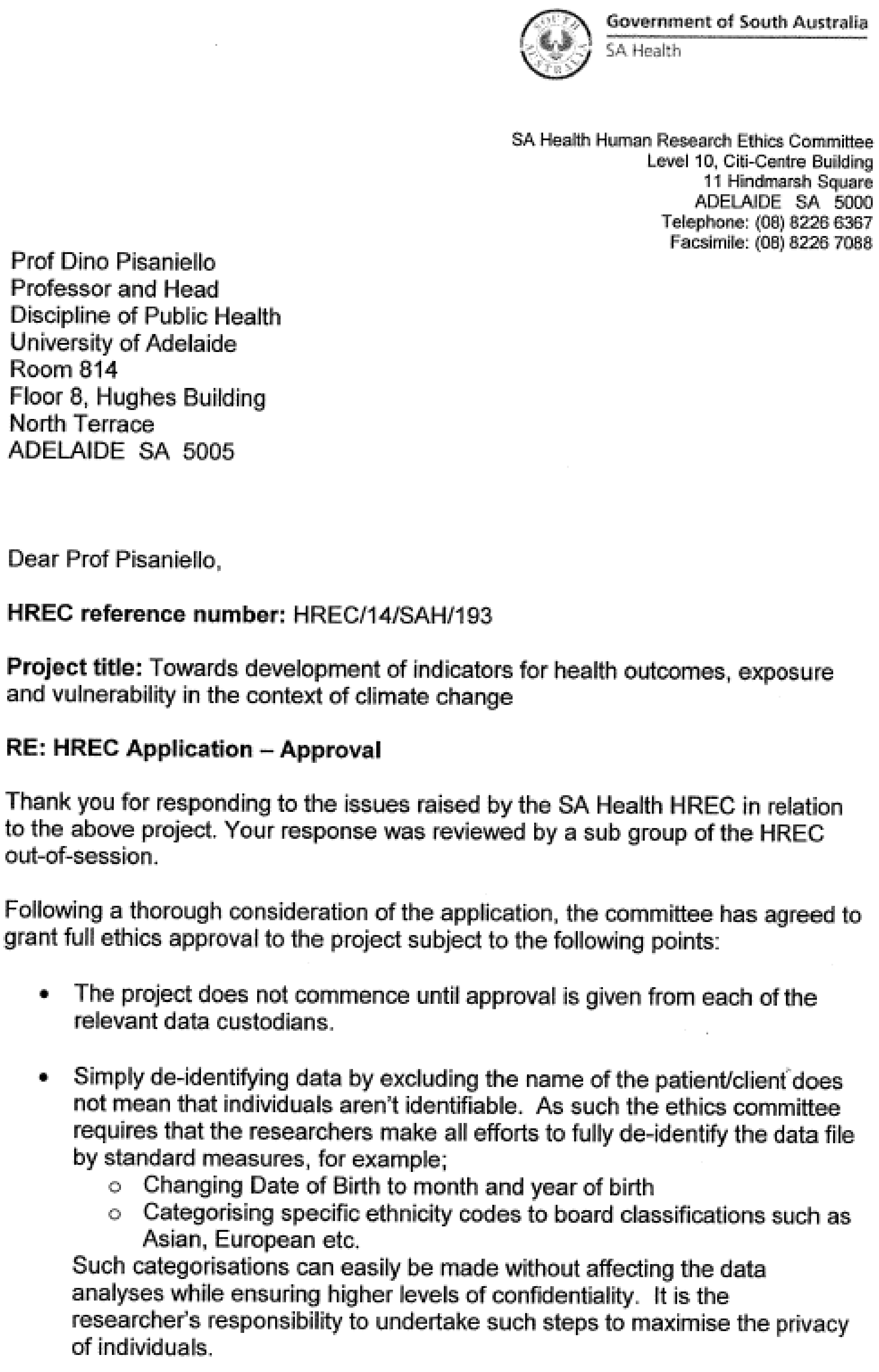
*(print name of participant)*

and in my opinion she/he understood the explanation.

Signature: _____________ Position: __________________________

Date: _______________________

# Appendix F Ethics Approval Letter



Government of South Australia
SA Health

SA Health Human Research Ethics Committee
Level 10, Citi-Centre Building
11 Hindmarsh Square
ADELAIDE SA 5000
Telephone: (08) 8226 6367
Facsimile: (08) 8226 7088

Prof Dino Pisaniello
Professor and Head
Discipline of Public Health
University of Adelaide
Room 814
Floor 8, Hughes Building
North Terrace
ADELAIDE SA 5005

Dear Prof Pisaniello,

**HREC reference number:** HREC/14/SAH/193

**Project title:** Towards development of indicators for health outcomes, exposure and vulnerability in the context of climate change

**RE: HREC Application – Approval**

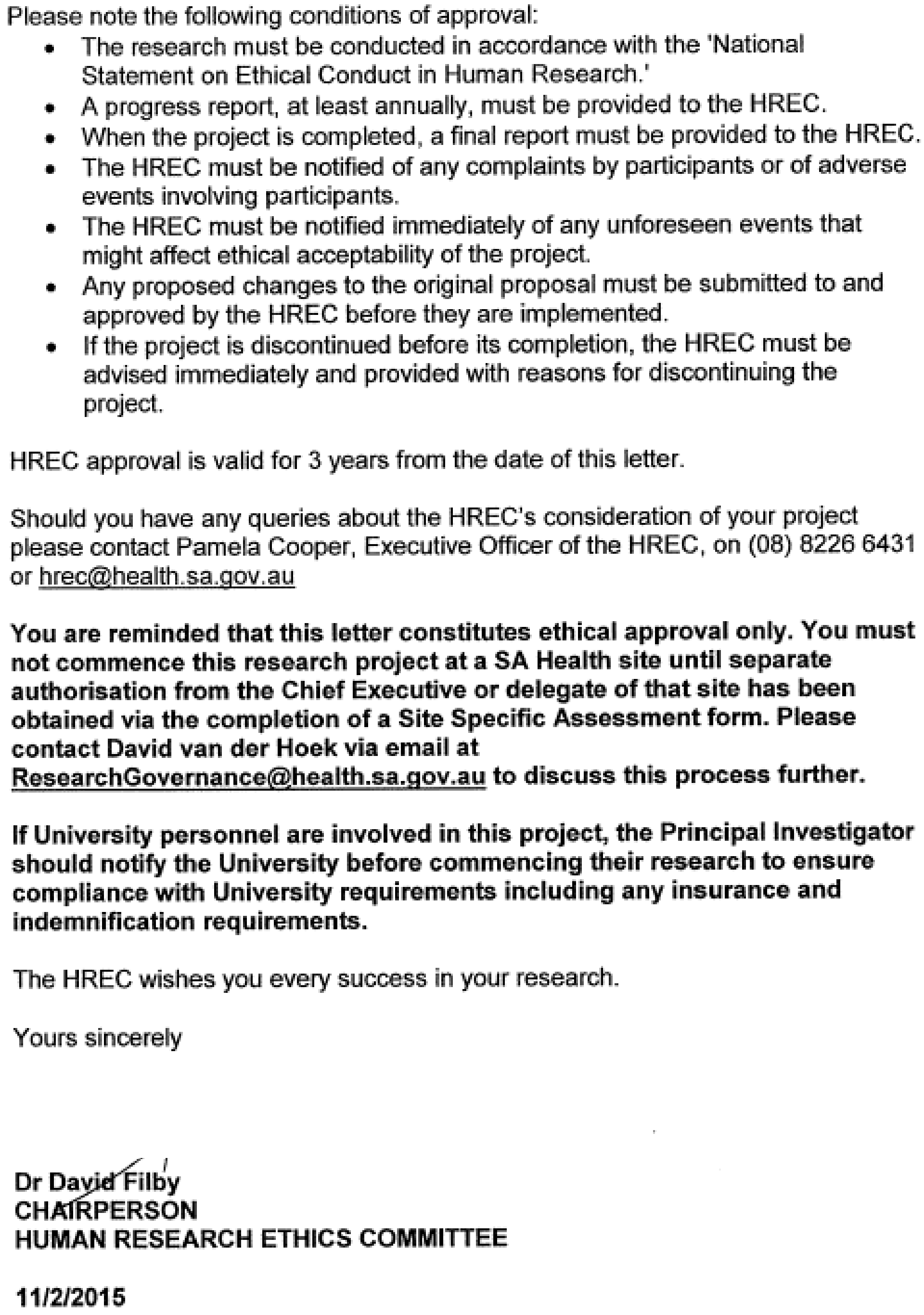
Thank you for responding to the issues raised by the SA Health HREC in relation to the above project. Your response was reviewed by a sub group of the HREC out-of-session.

Following a thorough consideration of the application, the committee has agreed to grant full ethics approval to the project subject to the following points:

- The project does not commence until approval is given from each of the relevant data custodians.

- Simply de-identifying data by excluding the name of the patient/client does not mean that individuals aren't identifiable. As such the ethics committee requires that the researchers make all efforts to fully de-identify the data file by standard measures, for example;
  - Changing Date of Birth to month and year of birth
  - Categorising specific ethnicity codes to board classifications such as Asian, European etc.

  Such categorisations can easily be made without affecting the data analyses while ensuring higher levels of confidentiality. It is the researcher's responsibility to undertake such steps to maximise the privacy of individuals.



Please note the following conditions of approval:

- The research must be conducted in accordance with the 'National Statement on Ethical Conduct in Human Research.'
- A progress report, at least annually, must be provided to the HREC.
- When the project is completed, a final report must be provided to the HREC.
- The HREC must be notified of any complaints by participants or of adverse events involving participants.
- The HREC must be notified immediately of any unforeseen events that might affect ethical acceptability of the project.
- Any proposed changes to the original proposal must be submitted to and approved by the HREC before they are implemented.
- If the project is discontinued before its completion, the HREC must be advised immediately and provided with reasons for discontinuing the project.

HREC approval is valid for 3 years from the date of this letter.

Should you have any queries about the HREC's consideration of your project please contact Pamela Cooper, Executive Officer of the HREC, on (08) 8226 6431 or hrec@health.sa.gov.au

**You are reminded that this letter constitutes ethical approval only. You must not commence this research project at a SA Health site until separate authorisation from the Chief Executive or delegate of that site has been obtained via the completion of a Site Specific Assessment form. Please contact David van der Hoek via email at ResearchGovernance@health.sa.gov.au to discuss this process further.**

**If University personnel are involved in this project, the Principal Investigator should notify the University before commencing their research to ensure compliance with University requirements including any insurance and indemnification requirements.**

The HREC wishes you every success in your research.

Yours sincerely

**Dr David Filby**
**CHAIRPERSON**
**HUMAN RESEARCH ETHICS COMMITTEE**

**11/2/2015**

# Appendix G Conversion of PHA to Postcode

To be able to convert PHA level data to postcode level, some information is required that was obtained from PHIDU:

A table that allocates PHA to SA2

A table that allocates SA2 to SA1

A table that allocates SA1 to postcodes

With these tables one can estimate % of people from PHA that go to each postcode. Then with the number of people with chronic diseases in PHA each and % of PHA to postcode, the number of people with chronic diseases in each postcode can be calculated.

Example:

| POA | % of PHA to postcode | PHA code | Number of people with diabetes mellitus per PHA | Number of people with diabetes mellitus per POA |
|---|---|---|---|---|
| 5000 | 97.45 | 40000 | 425 | 414 |
| 5005 | 2.55 | 40000 | 425 | 11 |

# Appendix H Stata Codes of Statistical Analysis

### Heatwave definition code

```
gen hw_day=0

(next step replaces the middle days of hws with 1; while excluding
any mv from this change)

replace  hw_day=1 if  maxT >=35 & maxT <500 &  maxT [_n-1]>=35 &
maxT [_n-1]<500 & maxT [_n+1]>=35 & maxT [_n+1]<500

 (next step picks up the first days of any heatwaves; you could
include if maxT>=35 but it is not necessary because of previous
step)

replace  hw_day=1 if  hw_day[_n+1]==1

(next step picks up the last days of any heatwaves)

replace  hw_day=1 if  maxT >=35 &  maxT <500 & hw_day[_n-1]==1

[So the number of ‘real changes made’ for steps 2 and 3 should equal
the total number of hws]

check no errors have happened with commands like:

li date maxT if hw_day==1 & maxT<35

li date maxT if hw_day==0 & maxT>=35 (you should get your days with
for maxT come up here)
```

### IRR calculation for ambulance callouts (Poisson analysis by postcode)

```
keep if period==1

gen hw=max(0, hw_day-hw09-hw14)

collapse (mean) yearly hw hw09 hw14 (sum) ambulance, by(date
postcode)

egen gp=group(hw hw09 hw14 yearly)

gen c=1

collapse (mean) yearly hw   hw09 hw14 (sum) days=c  ambulance, by(gp
postcode )

sort postcode
```

```
by postcode: poisson ambulance hw hw09 hw14 i.yearly, exposure(days)
irr
```

**IRR calculation for hospital admissions (Poisson analysis by postcode)**

```
drop if admission_status == "Other"

(419223 observations deleted)

collapse (mean) yearly hw_day hw09 hw14 (sum) Mental Totalcardio
heat_related Renal Respiratory , by( admdate postcode_ch )

gen acute_diseases = Mental + Ischemic + Totalcardio_no_Ishc +
heat_related+  Renal + Respiratory

egen gp=group( hw_day hw09 hw14 yearly)

gen c=1

collapse (mean) yearly hw_day hw09 hw14 (sum)
days=c  acute_diseases  , by (gp postcode_ch)

. drop if postcode_ch==5001

(2 observations deleted)
```

Postcodes with few numbers of observations were deleted. Stata stops Poisson regression with low numbers.

```
 sort postcode_ch

by postcode_ch: poisson  acute_diseases hw_day hw09 hw14 i.yearly,
exposure (days) irr
```

**IRR calculation (Poisson analysis by postcode)**

```
. collapse (mean) yearly hw_day hw09 hw14 (sum) Mental Cardio
Respiratory Renal heat_related , by( Presentation_Date postcode )

. gen acute_diseases = Mental + Cardio + heat_related +  Renal +
Respiratory

. egen gp=group( hw_day hw09 hw14 yearly)

. gen c=1

. collapse (mean) yearly hw_day hw09 hw14 (sum) days=c
acute_diseases  , by (gp postcode )

. sort postcode
```

```
. by postcode : poisson  acute_diseases hw_day hw09 hw14 i.yearly,
exposure (days) irr
```

## Pearson’s correlation

```
pwcorr dependent variable independent variable independent variable
independent variable,sig star(5)
```

sig is to include pvalue in the table of result

star (5) is to put * when the value is statistically significant

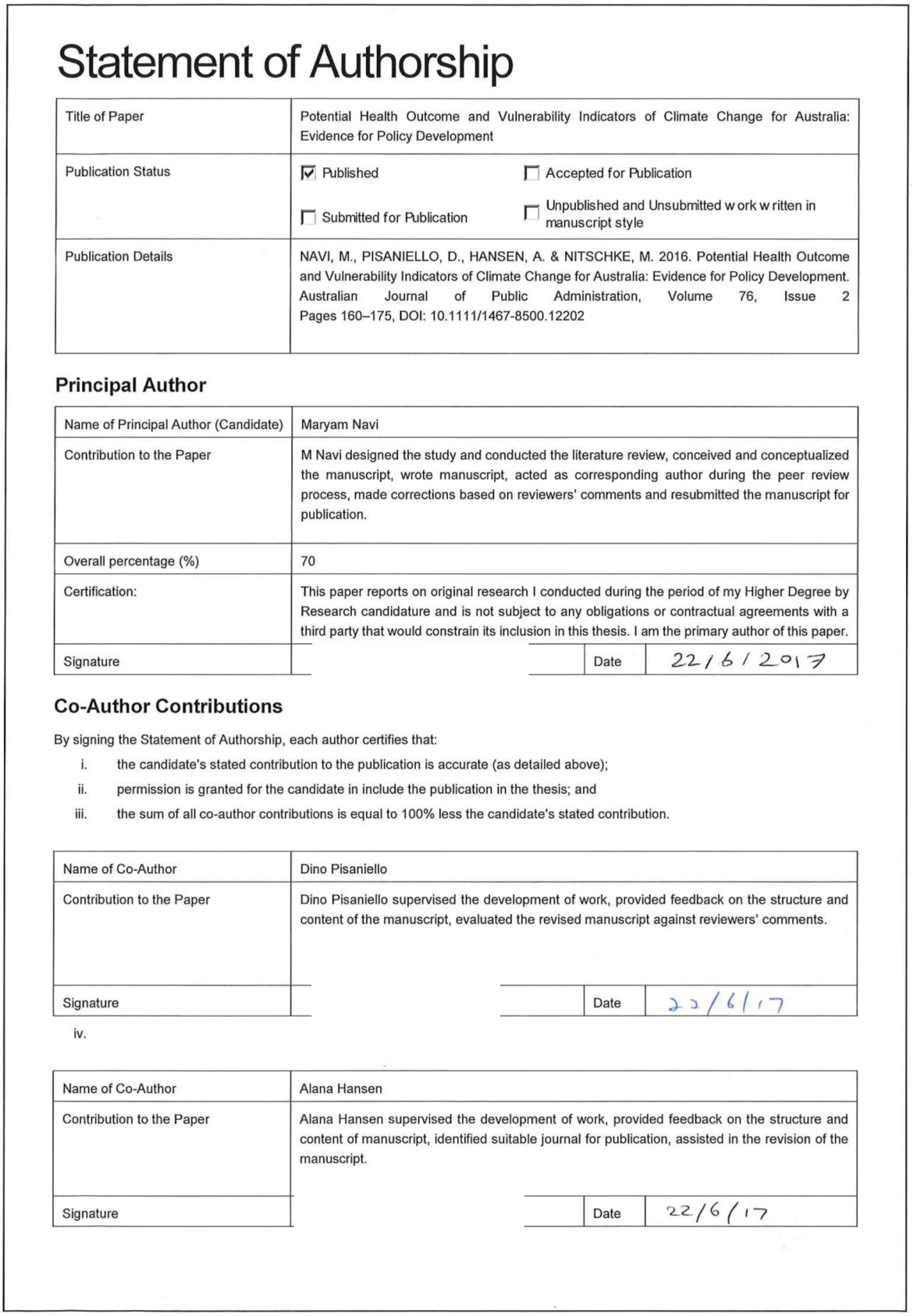
# Appendix I Air Quality Stations and Time Period of Data

Ozone and particulate matters ($PM_{10}$ and $PM_{2.5}$) have been requested from the South Australian EPA. Data are available for eight stations in Adelaide region and two stations in country region. Not all stations record all air pollutants and data is available for different time period for each station (Table 1). Ethics approval is not required, however data should be requested from South Australia EPA. Summary reports are available on EPA websites. It should be noted that South Australian EPA also collects data on Carbon monoxide, Nitrogen dioxide and Sulfur dioxide, but these gases were not included in this research.

**Table I. EPA air quality data available for different pollutants, stations and time periods**

| **Adelaide Regions** | **Ozone** | **$PM_{10}$** | **$PM_{2.5}$** |
|---|---|---|---|
| Adelaide CBD (CBD) | | 2014-2015 | 2014-2015 |
| Western Adelaide (Netley) | 1998-2015 | 2001-2015 | 2001-2015 |
| North western Adelaide (Le Fevre 1) | | 2005-2015 | |
| North western Adelaide (Le Fevre 2) | | 2013-2015 | 2013-2015 |
| Northern Adelaide (Elizabeth) | 2002-2015 | 2004-2015 | |
| North eastern Adelaide (Northfield) | 1978-2015 | | |
| Eastern Adelaide (Kensington) | 2002-2015 | 2002-2009 & 2011-2015 | 2003- 2004 |
| Southern Adelaide (Christies) | 2006-2015 | 2006-2015 | |
| **Country Regions** | | | |
| Oliver St, Pt Pirie | 2002-2005 | 2003-2015 | |
| The Terrace, Pt Pirie | | 2005-2015 | |
| Schulz Park, Whyalla | | 2007-2015 | |
| Walls St, Whyalla | | 2004-2015 | |

# Appendix J Statement of Authorship for Published Journal Article 1



## Statement of Authorship

| | |
|---|---|
| Title of Paper | Potential Health Outcome and Vulnerability Indicators of Climate Change for Australia: Evidence for Policy Development |
| Publication Status | ☑ Published<br>☐ Accepted for Publication<br>☐ Submitted for Publication<br>☐ Unpublished and Unsubmitted w ork w ritten in manuscript style |
| Publication Details | NAVI, M., PISANIELLO, D., HANSEN, A. & NITSCHKE, M. 2016. Potential Health Outcome and Vulnerability Indicators of Climate Change for Australia: Evidence for Policy Development. Australian Journal of Public Administration, Volume 76, Issue 2 Pages 160–175, DOI: 10.1111/1467-8500.12202 |

### Principal Author

| | |
|---|---|
| Name of Principal Author (Candidate) | Maryam Navi |
| Contribution to the Paper | M Navi designed the study and conducted the literature review, conceived and conceptualized the manuscript, wrote manuscript, acted as corresponding author during the peer review process, made corrections based on reviewers' comments and resubmitted the manuscript for publication. |
| Overall percentage (%) | 70 |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. |
| Signature | |
| Date | 22/6/2017 |

### Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | |
|---|---|
| Name of Co-Author | Dino Pisaniello |
| Contribution to the Paper | Dino Pisaniello supervised the development of work, provided feedback on the structure and content of the manuscript, evaluated the revised manuscript against reviewers' comments. |
| Signature | |
| Date | 22/6/17 |

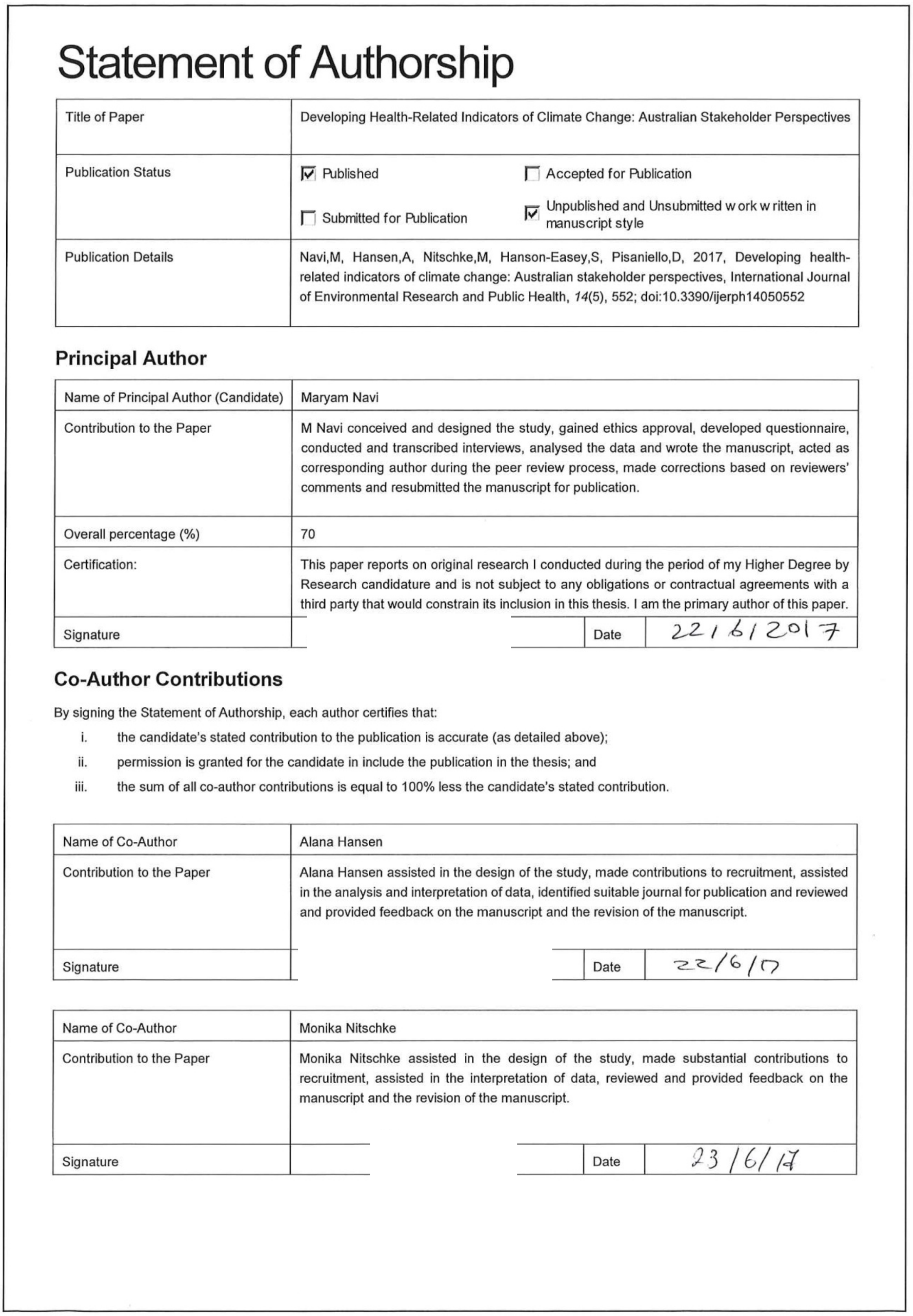
iv.

| | |
|---|---|
| Name of Co-Author | Alana Hansen |
| Contribution to the Paper | Alana Hansen supervised the development of work, provided feedback on the structure and content of manuscript, identified suitable journal for publication, assisted in the revision of the manuscript. |
| Signature | |
| Date | 22/6/17 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Monika Nitschke | | |
| Contribution to the Paper | Monika Nitschke supervised the development of work, provided feedback on the structure and content of manuscript, assisted in the revision of the manuscript. | | |
| Signature | | Date | 23. 6. 17 |

Please cut and paste additional co-author panels here as required.

# Appendix K Statement of Authorship for Published Journal Article 2



# Statement of Authorship

| | |
|---|---|
| Title of Paper | Developing Health-Related Indicators of Climate Change: Australian Stakeholder Perspectives |
| Publication Status | ☑ Published<br>☐ Accepted for Publication<br>☐ Submitted for Publication<br>☑ Unpublished and Unsubmitted work written in manuscript style |
| Publication Details | Navi,M, Hansen,A, Nitschke,M, Hanson-Easey,S, Pisaniello,D, 2017, Developing health-related indicators of climate change: Australian stakeholder perspectives, International Journal of Environmental Research and Public Health, *14*(5), 552; doi:10.3390/ijerph14050552 |

## Principal Author

| | | | |
|---|---|---|---|
| Name of Principal Author (Candidate) | Maryam Navi | | |
| Contribution to the Paper | M Navi conceived and designed the study, gained ethics approval, developed questionnaire, conducted and transcribed interviews, analysed the data and wrote the manuscript, acted as corresponding author during the peer review process, made corrections based on reviewers' comments and resubmitted the manuscript for publication. | | |
| Overall percentage (%) | 70 | | |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. | | |
| Signature | | Date | 22/6/2017 |

## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | | | |
|---|---|---|---|
| Name of Co-Author | Alana Hansen | | |
| Contribution to the Paper | Alana Hansen assisted in the design of the study, made contributions to recruitment, assisted in the analysis and interpretation of data, identified suitable journal for publication and reviewed and provided feedback on the manuscript and the revision of the manuscript. | | |
| Signature | | Date | 22/6/17 |

| | | | |
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| Name of Co-Author | Monika Nitschke | | |
| Contribution to the Paper | Monika Nitschke assisted in the design of the study, made substantial contributions to recruitment, assisted in the interpretation of data, reviewed and provided feedback on the manuscript and the revision of the manuscript. | | |
| Signature | | Date | 23/6/17 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Scott Hanson-Easey | | |
| Contribution to the Paper | Scott Hanson-Easey reviewed and provided feedback on the manuscript and the revision of the manuscript. | | |
| Signature | | Date | 22/6/17 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Dino Pisaniello | | |
| Contribution to the Paper | Dino Pisaniello assisted in in the design of the study, made contributions to recruitment, reviewed and provided feedback on the manuscript and the revision of the manuscript, evaluated the revised manuscript against reviewers' comments. | | |
| Signature | | Date | 22/6/17 |

Please cut and paste additional co-author panels here as required.