

---

# Hot Spots Project

---

A spatial  
vulnerability  
analysis of urban  
populations to  
extreme heat  
events.

---

Dr Margaret Loughnan.  
Professor Neville Nicholls.  
Professor Nigel Tapper.  
Monash Climate,  
School of Geography and  
Environmental Science  
Monash University

---

## Contents

<b>EXECUTIVE SUMMARY .....</b>	<b>3</b>
<i>Background information .....</i>	<i>3</i>
<i>Vulnerability index .....</i>	<i>4</i>
<b>INTRODUCTION .....</b>	<b>6</b>
<b>LITERATURE REVIEW .....</b>	<b>7</b>
<i>Methods .....</i>	<i>7</i>
<b>BACKGROUND .....</b>	<b>8</b>
<i>Climate .....</i>	<i>8</i>
<i>Climate and health .....</i>	<i>8</i>
<i>Which groups are likely to be most susceptible to heat events? .....</i>	<i>10</i>
<i>Implications for public health.....</i>	<i>15</i>
<b>MATERIALS AND METHODS.....</b>	<b>16</b>
<i>Developing the Index.....</i>	<i>16</i>
<i>Variable description .....</i>	<i>19</i>
<i>Validating the vulnerability index .....</i>	<i>25</i>
<i>Statistical analysis.....</i>	<i>28</i>
<b>RESULTS .....</b>	<b>29</b>
<i>Individual variables .....</i>	<i>29</i>
<i>Validating the index.....</i>	<i>31</i>
<b>DISCUSSION .....</b>	<b>34</b>
<b>ACRONYMS .....</b>	<b>45</b>
<b>REFERENCES .....</b>	<b>46</b>
<b>APPENDICES .....</b>	<b>51</b>
APPENDIX 1.....	51
APPENDIX 1A .....	52
APPENDIX 1B.....	54
APPENDIX 1C.....	55

APPENDIX 1D .....	57
APPENDIX 1E .....	58
<b>APPENDIX 2 .....</b>	<b>60</b>
<b>APPENDIX 3 .....</b>	<b>70</b>

## **Executive Summary**

The Australian climate is changing in response to global climate change and the intensity and frequency of extreme weather events, such as floods, droughts and heat waves will change further in the future. Climate change projections for south-eastern Australia include an increase in the number of warm days and nights and an increase in heatwave duration. The potential impact of climate change on human health is a concern for individuals and public health authorities. The adverse health effects of heat waves under current climate conditions are largely preventable, if heat-health action plans can be implemented. Identifying the geographic location of vulnerable persons provides important information for the development and operation of heat adaptation and mitigation strategies.

### **Background information**

In order to direct health care interventions it is important to be able to identify vulnerable groups within society.

- Extreme heat waves or heat waves pose a risk to the health of individuals especially; the elderly, very young, and the chronically ill.
- Risk factors can also include housing characteristics, and socio-economic factors, or environmental risk factors such as urban heat islands.
- The ability of the human body to maintain normal temperature is compromised by the effects of age, chronic diseases, disability, medications, and environmental factors.
- The elderly and very young are most vulnerable due to decreased physiological reserve and chronic disease in the elderly, and reduced regulatory mechanisms in the very young.
- Persons with pre-existing illness, either acute infections or chronic disease are at a greater risk of heat related illness, in particular cardiovascular disease, psychiatric disease, diabetes, obesity, and cancer. Persons taking certain medication may experience compromised thermoregulation and fail to recognise increasing heat loads, and are less likely to adopt protective behaviours.

- Persons with psychiatric illness are at a greater risk of death or heat related illness during periods of hot weather. This may be due to decreased ability to care for themselves, increased agitation, and physiological effects of neurotransmitter activity, or anticholinergic effects of antipsychotic medication.
- Socioeconomic differences in health may include differences in population demography, or living conditions within the built environment.
- Aspects of the physical environment such as air and noise pollution, high concentrations of industry, high-density housing, and reduced green space are characteristics of cities that have been associated with poorer health.
- Research from the USA and Europe has indicated that population vulnerability to heat waves is greater in areas with poorer social and environmental circumstances.
- The urban heat island can exacerbate temperatures in cities. The intensity of the urban heat island varies across cities.
- Building type and construction can exacerbate the health effects of high ambient temperatures.

### **Vulnerability index**

A vulnerability index was constructed using 10 known indicators of health, social and environmental risk factors. This index was mapped to show areas with high – low vulnerability across Melbourne. The index was also tested to identify which of the 10 indicators were associated with the greatest ‘risk’ of adverse health effects during hot weather. Five key indicators were identified; these are areas with large numbers of aged care facilities, areas with families speaking a language other than English at home, areas where elderly people live alone, suburban areas rather than high-density inner suburbs, and areas with a high proportion of elderly and very young citizens.

The greatest effects of hot weather are seen in the elderly but effects are also apparent for adults and children. Elderly persons living in aged care facilities and the elderly living alone are also at a greater risk of heat related mortality and morbidity. In addition persons with poor English language skills are also more vulnerable. In urban areas the urban heat island can increase the air temperature during hot weather. This may be enhanced by poor building design and urban planning resulting in high density housing with limited green

space. The vulnerability index captured both absolute and relative vulnerability better in the urban areas than in the semi-rural areas. The human vulnerability to heat events varies across the Melbourne metropolitan area; the application of this index can help public health authorities target resources for mitigation and adaptation strategies to the areas of greatest need. The research 'tool' can be replicated and adapted for other Victorian or Australian cities.

## Introduction

The Australian climate is already changing and the intensity and frequency of extreme weather events, such as floods, heat-waves and droughts, will change further in the future. Climate change projections for south-eastern Australia include an increase in the number of warm nights and an increase in heat wave duration. The potential impact of climate change on human health in Australia is a growing concern for all. Recent extreme heat waves have caused serious health and social problems in Europe, and the USA particularly in urban areas. These events will continue to pose additional challenges to health risk management, response systems and to the reliability of the power supply and other infrastructure <sup>1</sup>. Coping with change requires a proactive and multidisciplinary approach by governments, health care agencies and non-government organisations. Lessons can be learned from many of the public health outcomes experienced during the recent American and European heat-waves, and actions taken as a result of these events. One of the most important messages is that the adverse health effects of hot weather and heat-waves are largely preventable, at least under current climate conditions if heat-health preparedness plans can be implemented.

In Melbourne the extent of population vulnerability and the spatial distribution of vulnerable populations are still unknown. Predicted climate change for south-eastern Australia suggests that heat waves will increase in duration and minimum overnight temperatures will increase in intensity and frequency <sup>2</sup>. This combination of events implies that there is an increasing likelihood of heat waves in south-eastern Australia, which will potentially be linked to adverse public health outcomes, therefore public health systems in Melbourne should be prepared for future health impacts of climate change. Information relating population vulnerability to geographical location is essential for the development and implementation of heat adaptation and mitigation strategies. The provision of this information creates the ability to target behavioural adaptation strategies and heat wave response plans in the communities with the highest risk of adverse responses to extreme heat.

The aim of this research was to integrate and gather information that defined population vulnerability from a number of sources known to influence population health during periods of extreme heat. Information was selected to outline health, demographic and environmental vulnerabilities. This information was then used to develop a unique methodological design.

## **Literature review**

### **Methods**

A review of the existing peer reviewed and grey literature was conducted at the commencement of the project. This included peer reviewed journal articles from medicine, geography, environmental health, urban structure and design, GIS, GIS and health, climatology, biometeorology.

#### *Peer reviewed publications & keywords*

ISI Web of Science (heat illness\*children) (1950-2008), CINHAL (heat illness, heat stroke, children, elderly) (1980-2008), Medline (heat related illness, heat stroke, 1980-2008), Informit databases

#### *Grey literature*

Government and other International agency reports were identified through World Wide Web searches. Specific attention was given to Government Health Departments in Australia (AIHW, ABS) Europe, the United Kingdom, United States of America, and Canada.

#### *Inclusion criteria:*

Publications were included in the literature search if they were published in English, post-1980, and focused on; health effects of specific heat waves, health effects on vulnerable populations (elderly, sick, children), definitions of threshold temperature and heatwaves, scientific articles discussing climate change, pathophysiological changes associated with

heat (hot weather). Meta-analyses of heatwaves within regions (Europe), health impacts of climate change<sup>3</sup>.

*Exclusion criterion:*

Publications were excluded from the literature search if they were pre -1980, in languages other than English, or focusing on seasonal patterns and the effects of cold weather on health.

## **Background**

### **Climate**

Climate itself is an important determinant of population sensitivity to heat events, because it affects the level of acclimatisation in specific locations.

*Extreme hot weather or heatwave events*

Heatwaves are perhaps the most under-rated weather hazard in Australia, essentially because they are viewed as a 'passive' hazard in contrast to the more widely studied catastrophic hazards such as tropical cyclones and earthquakes. There is no universal definition of a heat wave. The Australian Bureau of Meteorology defines a heat wave as 'a prolonged period of excessive heat'<sup>4</sup>. This definition is solely related to the weather experienced at a given place at a given point in time it does not describe the environmental or societal impacts of that weather. The impacts of heat waves are influenced by the environmental, behavioural and physiological adaptation, which in turn determine environmental exposure to weather.

### **Climate and health**

Climate is one of many factors that can affect health and well being of Australians. The relationships between climate and health follow multiple pathways and complex interactions such as social and economic factors, heredity, and the provision of health services, education and literacy rates. It is however necessary to understand these relationships in order to prevent adverse health effects associated with climate change.

### *Climate change and health: extreme heat waves*

Extreme heat or heat waves pose a risk to individuals especially to the elderly, the very young and the chronically ill. Few studies of climate health relationships have been carried out for Australia and more specifically for Melbourne. However for all the cities around the world there appears to be a point at which the number of adverse health effects start to increase as temperature increases; this is also the case in Melbourne <sup>5</sup>.

### *Determinants of heat related Mortality and Morbidity*

In order to direct health interventions it is important to be able to identify vulnerable groups with at higher risk of mortality/morbidity during heatwaves. There are three main aspects related to identifying vulnerability:

1. The frequency and intensity of individual heat wave events, including the number of days with temperatures above predetermined thresholds.
2. The physiological effects of hot weather on the human body.
3. The demographic structure, urban structure, social circumstance and burden of disease within a community.

### *How heat related mortality and morbidity is defined.*

Although heat related illnesses are described as heat exhaustion and heat stroke, not all deaths or hospital admissions during hot weather are coded as such. Failure of any of the body's vital systems can result in admission to hospital or death of an individual.

### *The effects of heat on the human body*

There is substantial evidence of a relationship between climate and human health. However, disentangling the effect of environmental climatic conditions on human bio-physiology is complex. Human responses to climate are determined by exposure, although human ability to provide adaptive technologies has moderated this effect in many instances. Such modifications include built environments incorporating air-conditioning, which create indoor environments that operate independently of outdoor climatic conditions. In addition, behavioural adaptation to extreme environments can confound the relationship even further. Whilst these modifications affect climate/health

responses at an individual level, quantification of the modified effect is beyond the scope of most studies. Therefore, climate/health relationships are generally studied at the population level where there is abundant evidence that weather affects human health.

### **Which groups are likely to be most susceptible to heat events?**

Some people are more vulnerable than others based on their health, location, culture, or occupation. It is useful to identify populations at risk and to target interventions accordingly. The public health outcomes of heat-waves depend on the level of exposure (timing, frequency, intensity and duration of the heat-wave), the extent of the event and the demographic profile of the exposed population, population sensitivity and the prevention measures in place <sup>1</sup>.

#### *Age*

Age is an important determinant of population vulnerability during heat waves as the very young and the very old have a higher baseline mortality risk <sup>6</sup>. Many epidemiological studies of heat related mortality/morbidity have shown that a larger effect exists for persons over the age of 65 years. This is mainly due to changes in physiological thermoregulatory systems, and limited physiological reserve, as well as the presence of increased rates of chronic disease in older persons. In addition to biophysical reasons for increased risk, social factors are also important. <sup>7,8 1,9 10</sup>.

Infants and children are also at an increased risk of heat-related illness. This is due to inefficient sweating, higher metabolic rate, and their relative inability to control their environment. An increase in exertion also increases the risk for children as does pre-existing infection or illness. However, the effects of increased temperatures on child health have been less rigorously studied, especially the effects of increased temperature on young children less than 6 years of age. Danks et al (2004) reviewed the clinical presentations of very young children during an intense heatwave in Melbourne in 1959. Pre-existing medical conditions, developmental state, acute illness, conditions of the home environment and “maternal ability” were identified as key risk factors <sup>11</sup>. More

recently several new risk factors have been introduced for young children. These include increased car travel, increased participation in competitive sports, and a growing rate of obese and overweight children. This pattern of vulnerability has also been shown in USA<sup>12</sup> and in Japan<sup>13</sup>. In Australia, more children presented to the emergency department at the Westmead Children's hospital in Sydney with fever and symptoms of gastroenteritis as maximum temperatures increased<sup>14</sup>.

### *Pre-existing medical conditions*

The risk of heat related mortality/morbidity is increased for persons with pre-existing illness. This may be an acute phase illness, particularly one associated with fever, or a chronic disease. Pre-existing illness most notably associated with increased risk are cardiovascular disease, psychiatric disease, neurological and cognitive impairment, diabetes, cancer, and obesity<sup>12 15,16</sup>. In addition, some medications used in the treatment of these conditions may increase patient vulnerability by compromising thermoregulation, thermal awareness, and mobility, ability to control their environment and adopt protective behaviours. Persons with cognitive impairment such as dementia, and limited mobility may be at a greater risk of dehydration due to inability to access adequate fluids<sup>17,18</sup>.

People with psychiatric illness are at greater risk of death or heat related illnesses during periods of hot weather. This may be due to decreased ability to care for oneself, increased agitation, physiological effects of neurotransmitter activity, and anticholinergic effects of antipsychotic medication. People with pre-existing psychiatric conditions were 3.6 times more likely to die during the European heatwave in 2003<sup>19</sup>. Persons suffering mental illness are comprised of several different groups such as persons with clinical disease, persons responding to environmental stressors and suicides<sup>17,20-22</sup>. There are considerable gaps in our knowledge of the impacts of climate on these groups. A recent study in Adelaide found that days above a threshold of 26.7°C were associated with an increase of 7.3% in hospital admissions for mental and behavioural disorders<sup>17</sup>.

### *Medications*

Ageing and chronic diseases, as well as their treatment, can considerably increase the risk of hyperthermia and heatstroke. Several drugs can impair thermoregulation during exercise or under conditions of environmental heat stress. Anticholinergic drugs inhibit sweating and therefore reduce heat elimination from the body. Some drugs such as narcoleptics and some antipsychotics have combined anticholinergic and central thermoregulatory effects<sup>18</sup>. In addition overdoses of recreational drugs may also be linked to heat related mortality and morbidity<sup>23</sup>. Amphetamines and cocaine increase metabolic heat production and increase the risk of heat stress<sup>23</sup>. Also excess intake of alcohol can lead to diuresis, dehydration, sedation and altered states of consciousness.

### *Socioeconomic status and heat waves*

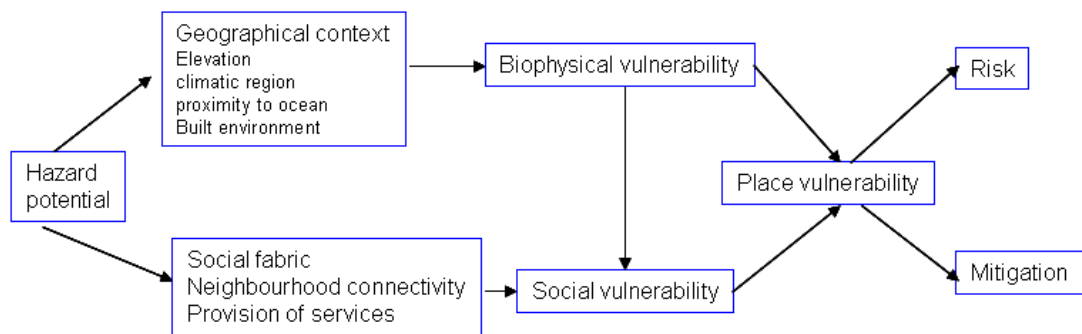
Socio-demographic characteristics can increase the likelihood of death associated with temperature extremes. Several studies from Europe and the USA have identified increased vulnerability for groups with low socioeconomic status, low educational attainment, and certain racial subgroups. The identification of homogenous characteristics of populations that increase vulnerability to temperature extremes across many regions of the world indicates that further research is required to assess how populations will adapt to changes in local climate, either by physiological adaptation, behavioural changes, or by institutional interventions such as weather alerts or changes to urban planning<sup>9,15,24,25</sup>.

Whilst homeless groups are noted as being 'high risk' populations in terms of environmental exposures<sup>26</sup>, specific research describing the effects of hot weather on homeless people appears to be absent from the literature. This group may also be absent from standard mortality/morbidity heat-health estimates. The homeless are more likely to endure maximum exposure to weather and they are also at risk due to compromised health, limited access to care facilities, food and water insecurity<sup>27</sup>, and increased risks from exposure coupled with drug use<sup>28,29</sup>. Heat exposure may also be a secondary risk factor for people made homeless by other weather hazards such as floods.

Ethnicity is another factor that may affect personal exposure to heat. Population segregation into neighbourhood groups dependent on race or ethnicity, can also affect health. Research in the USA suggests that racial segregation results in the unequal distribution of economic resources, and institutional care<sup>7,30,31</sup>. African Americans are at a particularly high risk. However, a lower than expected risk was noted for Latino populations during the Chicago heatwave in 1995<sup>32</sup>.

*Social Vulnerability.*

The social factors that influence or shape the vulnerability of social groups also governs their ability to respond to environmental threats or hazards. Vulnerability is not equally distributed within communities<sup>33</sup> and can be thought of in as situational vulnerability, social resistance and social resilience.



**Figure 1. Hazards of place model of vulnerability. (Adapted from Cutter 2003)<sup>33</sup>.**

The major factors that influence social vulnerability are lack of access to resources (information, knowledge and technology), limited access to political power, social capital, beliefs and customs, available infrastructures and assisted support networks. At the level of the individual factors that influence vulnerability are age, gender, marital status, race, homelessness, socioeconomic status, and seasonal tourists. Furthermore, the quality of human settlements including dwelling size, housing density, housing type, housing structure, orientation, roadways, and green space, all contribute to place vulnerability (see Figure 1).

### *Strenuous outdoor physical activity*

Participating in either occupational or recreational strenuous physical activity outdoors has been recognised as a risk factor for heat stress<sup>34</sup>. Recent studies from Slovenia have shown that military personnel experience decreased mental competency, exertional heat stress, and dehydration when exposed to extreme temperatures<sup>35,36</sup>. The effects are greater for soldiers without a period of acclimatisation<sup>37,38</sup>. This highlights the potential risk for persons participating in strenuous outdoor activity during hot weather in south-eastern Australia where day-to-day variability in the weather limits acclimatisation to heat.

### *The Urban Heat Island*

The urban heat island (UHI) is a phenomenon that occurs in urbanised landscapes where the built areas become warmer, especially during the night than the surrounding rural areas. The UHI can exacerbate the high temperatures in cities. The form and intensity of the UHI varies both spatially and temporally depending on the local meteorological conditions, geography, and urban development<sup>39</sup>. The effects of the UHI can be mitigated by implementing 'cool cities' initiatives<sup>40</sup>. This potentially reduces heat related mortality/morbidity, and reduces energy demands.

### *Buildings and exposure*

People spend most of their time indoors especially if weather conditions are extreme. Evidence from the French heatwave in 2003 has indicated that specific housing characteristics such as brick houses (high thermal mass), houses with poor or no insulation, north facing aspect (Australia), poor ventilation, multi-dwelling structures, living above the second floor, and no green space/vegetation around dwelling were associated with increased risk of mortality/morbidity during heatwaves<sup>16</sup>.

## **Implications for public health**

### *Implementation of heat wave response plans*

The heat wave in Europe in 2003 caught the continent unawares and there was a lack of government heat wave initiatives and implementation plans. The key problem areas identified by the French government after the event were; poor definition of heatwaves and their consequences, lack of knowledge about the 'at risk' population, lack of intervention plans, poor networking and co-ordination between social services and health care agencies, and lack of cooling centres<sup>16,41</sup>. These are similar to the problems identified in the Chicago 1995 heatwave<sup>32</sup>. Subsequent heatwaves in both these regions have resulted in lower mortality. This has been partially attributed to increased public education about hazards associated with heat waves, the identification of temperature at which heat wave conditions become sufficiently hazardous to a population health to warrant the implementation of heat wave response plan, and the successful implementation of heat avoidance measures such as increased air-conditioning and opening of cooling centres.

### *Health surveillance for heat wave mortality/morbidity*

One of the pressing problems for epidemiologists and health demographers is the delay between the collection of mortality/morbidity data and the publishing of the data. These data are often not available on a daily or even a weekly basis thus increases in mortality/morbidity can occur without detection. It may not be until mortuary space or autopsy requests become a problem that authorities are alerted to the crisis. Some countries have consequently decided to use alternative indicators of population stress during heat waves, such as telephone advice centres as is the case in the UK and 911 emergency callouts in Phoenix Arizona<sup>42 43</sup>.

## Materials and Methods

### Developing the Index.

The aim of this research was to develop a vulnerability index that was not only relevant to Melbourne but was comprehensive in its ability to identify vulnerability to heat waves at a population level of analysis, and was simple enough to allow easy replication at various locations. To achieve this goal a multi-variable index was constructed to map population vulnerability across the Melbourne metropolitan region. Index variables were chosen *a priori* from a review of the literature. Many of the variables included in the index were selected from the ABS census data because this information is comprehensive for the Australian population; it is updated every 5 years, and is readily available to researchers. This index was tested using known thresholds for heat related mortality and morbidity in Melbourne, and mapped to provide a spatial guide to heat related vulnerability in the metropolitan area. The relationship between the vulnerability index and the population mortality and morbidity during hot weather were examined using regression analysis, allowing for the identification of which variables provided the most information about population vulnerability during heat events. The difference between absolute and relative vulnerability was also examined by determining the change in vulnerability for each spatial unit between hot days and all other summer days.

### *Design*

A simple and easily replicable research design was developed to create the vulnerability index (see Appendix 1). The vulnerability index was validated by examining the relationships between the vulnerability index and the recorded population mortality and morbidity during hot weather in Melbourne during the study period.

### *Index variables*

We included 10 variables identified *a priori* from the literature review and the appropriate data sources. These are shown in Table 1. A description of the ABS data can be found in Appendix 1. The relevant data were extracted from the databases at the

smallest spatial scale practicable which was Postal Areas (POA). The proportion of each variable in each area was ascribed to a decile rank with the lowest 10% as decile 1 and the highest 10% as decile 10. This was done by exporting the data into SPSS <sup>44</sup> the data being transformed using the visual banding function into bands with a width of 10%. The index variables were calculated so an increase in value reflected an increase in vulnerability. The decile ranks for each variable in each area was then summed to produce an index value for each spatial area. This index value was subsequently mapped using MapInfo <sup>45</sup>. The resulting map provided information about a theoretical prediction of vulnerability and requires validation to determine if the predicted vulnerability corresponds with recorded vulnerability during periods of extreme heat.

The index was composed of three main groups of variables as described in the research design (see Appendix 1). The demographic variables included information about the population distribution of high risk age groups, the numbers of aged care facilities, socioeconomic status of areas, persons living alone and the prevalence of ethnic groups in each area. The environmental variables included information about dwelling type and urban design, population density of high risk populations defined by age groups, and the intensity of the urban heat island. Health variables included were measures of the burden of disease in each area and the proportion of residents with a disability.

**Table 1 risk factors and their respective data sources.**

Variable	Risk factor	Data source
1	Age (65+,0-4)	ABS BCP census data
2	Burden of Disease	DHS health intelligence unit
3	Aged care facilities Nursing homes	Dept Health and Ageing (DHS)
4	SES	ABS SEIFA
5	Urban design (non-single dwellings)	ABS BCP census data
6	Single person households	ABS-BCP
7	Measure of disability	HACC (DHS) ABS
8	Population density	ABS BCP census data
9	Ethnicity	ABS BCP census data
10	UHI	MODIS (Terra) Land Surface Temperature & Emissivity Monthly L3 Global 0.05Deg CMG

## **Variable description**

### *Variable 1 Age*

This variable contains a person's age at last birthday. These data are collected for each person. Age is calculated from date of birth, however if this is not provided, the stated age will be used. For the 2006 census, age is available for 0 to 115 years singly as 5 year age groups <sup>46</sup>. The ABS Basic Community Profile (BCP) provides age in 5 year groups therefore this study also used age in 5 year groups.

Variable 1 (Age) described population vulnerability by selecting specific age groups within the population. The literature review identified age related vulnerability as being over 65 years of age or under 4 years of age. This does not mean that persons excluded from these groups are not vulnerable it simply means that people within these groups are more vulnerable than other members of the community. Age categories 0-4, 65-74, 75-84, and 85 years and over were extracted from the BCP (Table B01) for each Melbourne POA. Total population for each POA was also extracted. Variable 1 is the total number of person aged 65 years and older, and under 4 years as a proportion of total number of persons per POA.

### *Variable 2. Burden of Disease (BoD).*

Pre-existing chronic disease may increase susceptibility to heat related illness and death. Health services planning require information regarding the health status of populations. The total burden estimates portray the relative ranking of the importance of the major diseases confronting the populations in Local Government Areas (LGA). Cancers, cardiovascular disease, mental disorders, neurological and sense disorders and chronic respiratory disease are the major causes of burden identified <sup>47</sup>.

The burden of disease estimates are based on a critical examination of existing data sources to identify the pieces of information that best describe the health status of people in Victoria. Table 2 summarises the main sources of data. A complete list of sources and

an assessment of their limitations is included in the *Victorian Burden of Disease Study: Mortality and Morbidity in 2001* Department of Human Services 2005, Chapter 2.

**Table 2: Burden of disease study data sources** <sup>47</sup>

Population	Deaths	Illness and disability
Australian Bureau of Statistics: Estimated Resident Population 2001	ABS Deaths 1997–2001	Disease registers, surveillance systems and notification systems
Australian Bureau of Statistics: Socioeconomic Indices For Areas (SEIFA)		Population health surveys. Specific epidemiological studies Health service utilisation data Expert opinion

The methods used to estimate the Victorian burden of disease were adapted where necessary to overcome the difficulties inherent in reporting small numbers. Wherever possible health information collected at the LGA level was used. For many important diseases, LGA estimates have been based on what is known about socioeconomic and urban/rural differences in disease occurrence at the state or national level. For a number of minor conditions, information on socioeconomic and urban/rural differences was not available and by default the assumption was made that the rate of occurrence in each LGA is similar to Victoria’s overall estimates. Thus, not all the estimates presented are an exact reflection of the true occurrence of disease in each LGA. However, given the available information sources, these are the ‘best’ estimates possible and in most instances are believed to come close to the disease experience in each LGA <sup>47</sup>.

The BoD data was supplied by the DHS at an LGA level; in order to include this information in the index the BoD for each POA was determined by calculating the BoD as the incidence per 100 persons in each LGA. The incidence in each POA was then estimated based on the total population in each POA of each LGA. This approach assumes that the BoD is highest in areas with larger populations.

*Variable 3. Aged care facilities (ACF).*

Analyses of the European heatwave in 2003 identified residents in aged care facilities as particularly vulnerable. Therefore the number of aged care facilities was included in the index as an indicator of vulnerable populations in each POA.

A list of all the aged care facilities in the Melbourne SD data was supplied by the DHS. However the listed postcodes provided by the DHS were not consistent with the location of the ACF, but with the body corporate or owner organisation. Data for each of the 673 ACF were extracted manually and matched with POA of facility location. The number of aged care facilities in any given POA was calculated, as was the number of aged care facilities in the Melbourne SD. The proportion of ACF in each POA was calculated from the Melbourne total number of ACF, thereby identifying areas with greater numbers of aged care facilities.

*Variable 4. Socioeconomic circumstance. (SEIFA).*

Poverty and income-related variables also modify the heat-health effects of hot weather. In Australia, the ABS has constructed an index of socio-economic status (SEIFA, Socio-Economic Index for Areas). SEIFA describes each geographical area against an Australia wide average on four main determinants of socio-economic status. An expanded description of SEIFA can be found in Appendix 1B.

SEIFA has been constructed with the intention that areas of relative disadvantage have low index values. Low scores on the index of relative disadvantage (IRSD) occur in areas where there are many families with low income, and people with little training or employment in unskilled occupations. A high SEIFA score reflects lack of disadvantage, not a high proportion of advantage.

The age or sex structure of the population within each area is not considered in any of the SEIFA indices. None of the indices includes information about the infrastructure within

each area, such as schools, transport, or medical facilities. This information is important regarding the concept of disadvantage and geospatial activities of residents.

Data were extracted from the ABS files for SEIFA Table 3 Index of Relative Socioeconomic Disadvantage (IRSD) for each POA in Australia. From this data set files for Victoria were extracted, Finally POA files for the Melbourne SD were extracted from the Victorian data. Although SEIFA uses four classifications of disadvantage only the index of relative disadvantage (IRSD) was used in this analysis. SEIFA ranks areas of high disadvantage as low decile values and areas of fewer disadvantages as high decile scores. This study required areas of high disadvantage as high decile values. The SEIFA values were re-ranked from the SEIFA decile provided by ABS to Vulnerability Index decile, for example 1 (SEIFA decile) = 10 (VI decile), 2 = 9 and so on.

#### *Variable 5 Urban Design.*

Urban design was included in the index as this is known to influence thermal comfort and is exacerbated by urban heat islands. Data relating to the urban design in each POA were extracted from the ABS BCP using ABS Table 31 (B 4592-4597 items as dwelling structure). The number of dwellings in each dwelling structure category (see Appendix 1C, Table 3) in each POA was calculated. The definition of each dwelling category is also available in Appendix 1C. The total number of dwellings in each POA was calculated. The total number of dwellings described as single/separate houses was calculated. The total number of dwellings minus the total number of single/separate houses for each POA was used to represent 'higher risk' accommodation. The proportion of dwellings in each POA that represented 'higher risk housing' was then decile ranked.

#### *Variable 6. Single person households.*

Elderly people living alone have been identified as being 'higher risk' than those who are married or living in shared accommodation. Identifying the location of elderly persons living alone was undertaken using BCP Household Characteristics ABS Table B22 (lone person B4055-4057). Data for the total number of households in each POA were extracted. Data for single person households (persons aged 65 years and older) were also

extracted. The proportion of single person households with occupants aged 65 years and older was calculated from the total number of households in each POA.

*Variable 7. Measure of Disability.*

Disabled persons have limited mobility and therefore limited ability to respond to their ambient conditions. This increases their risk of heat stress during episodes of extreme heat. Data were accessed from the BCP, ABS Table B17 (Core activity need for assistance by age and sex, rows B3055-3058). Core activity need for assistance is used to measure the number of persons with a profound or severe disability. People with a profound or severe disability are defined as those people needing help and assistance in 1 or more of the 3 core activity areas of self-care, mobility and communication because of a disability, long-term health condition (lasting 6 months or more), or old age. The total number of persons needing assistance was extracted for each POA. The total number of persons in each POA was also extracted. The proportion of persons with a need for assistance in each POA was calculated from the total number of persons in each POA.

*Variable 8. Population density.*

Areas of high population density often correspond to areas of high urban density and UHI. Of particular interest are areas of high population density of persons within the predefined vulnerable age groups 0-4 years and 65 years and older. The land area in square kilometres of each POA was obtained from the ABS. The population per POA by age group (0-4 years and 65 years and older) was obtained from the ABS BCP. Population density was measured as the number of persons aged 65 years and older, and less than 4 years, per square kilometre and per 100 meters<sup>2</sup>. The method assumes that population is evenly distributed across each POA, but nonetheless will give an indication of high density, medium density and low density for the vulnerable age groups.

*Variable 9. Language spoken at home.*

Comparisons of heat related mortality by race or ethnicity in America show mixed results. This may be due to confounding by socioeconomic status or by dissemination of heat alert information. Ethnicity is an important issue in multicultural societies with respect to

internalisation of information from official sources such as government agencies. This means that whilst alerts are issued from government departments, how this information is received and enacted may depend on the main language spoken within each household. The 'language spoken at home' question on the 2006 Census form is designed to find out which languages other than English are spoken by people at home. This does not give an indication of English 'proficiency' but only an indication of multilingual households or households where the main language spoken is NOT English. Nevertheless, it is a useful indicator of the ethnicity of the population and for the planning and provision of multilingual services. Information pertaining to 'Language spoken at home' was obtained from the ABS BCP Table B12. The total number of persons 'speaking a language other than English' at home was extracted for each POA, as well as the total number of persons in each POA. The percentage of persons speaking a language other than English at home in each POA was calculated.

#### *Variable 10 Urban Heat Island.*

The urban heat island (UHI) is a phenomenon that occurs in urbanised landscapes where the built areas become warmer, especially during the night than the surrounding rural areas. This is due to a number of causes associated with changes to the natural surface as well as anthropogenic changes to the local environment from air pollution and heat emission. The City of Melbourne regularly exhibits a distinct UHI effect<sup>48,49</sup>.

The data for the period November to March were chosen for analysis as it represents the warmer months for Melbourne metropolitan region. Monthly average temperature satellite images from November 2000 to March 2006 were downloaded and then clipped for the Melbourne region. Monthly average images were used for this analysis. This provided the best quality data from day/night-time with clear sky conditions. Day and Night images were multiplied by the Scale factor of 0.02 and temperature units were converted from Kelvin to Celsius.

Data used were satellite based measurements from MODIS (Terra) Land Surface Temperature (LST) & Emissivity Monthly L3 Global 0.05Deg Climate Modelling Grid

(CMG). The level-3 MODIS global Land Surface Temperature (LST) and Emissivity are monthly data and are composed from the daily MOD11C1 product and stored as the averaged values of clear-sky LSTs during a monthly period in a 0.05-degree (5600-meter) geographic CMG. MOD11C3 is a level-3 product comprised of daytime and night-time LSTs, quality assessment, observation times, and view angles, bits of clear-sky days and nights, and emissivity retrieved in Bands 20, 22–23, 29, and 31–32.

For the analysis Version-5 MODIS/Terra Land Surface Temperature/Emissivity products were used, which are validated indirectly through the daily 6-km product, MOD11B1, to Stage 2, meaning that accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts. Although there may be later improved versions, these data are ready for use in scientific publications when monthly averaged LSTs are applications-appropriate.

(Source:[https://lpdaac.usgs.gov/lpdaac/products/modis\\_product\\_table/land\\_surface\\_temperature\\_emissivity/monthly\\_13\\_global\\_0\\_05deg\\_cmg/v5/terra](https://lpdaac.usgs.gov/lpdaac/products/modis_product_table/land_surface_temperature_emissivity/monthly_13_global_0_05deg_cmg/v5/terra))

Each POA was ascribed a mean temperature value based on the gridded Modis temperature data by generating Thessian proximal polygons from point data values of each cell. The mean UHI temperature per POA was attributed to a decile rank with the lowest 10% as decile 1 and the highest 10% as decile 10. Maps of the Melbourne region were created to represent both the daytime and night-time UHI in Melbourne from the satellite data. The Thessian polygons were clipped to the Melbourne POA and then using Intersect and Dissolve commands in ARC GIS (ArcInfo), each POA was assigned a value.

### **Validating the vulnerability index**

Daily recorded mortality and morbidity data for each POA in the Melbourne metropolitan region were used to describe the spatial distribution of health outcomes during heat events, and on all summer days not identified as heat events.

Mortality and morbidity data were obtained at a daily level for each year of study period. The data sets used included the Victorian Admitted Episodes Database (VAED) provided by the DHS, and daily mortality data from the Department of Justice, Registry of Births, Deaths and Marriages. These two data sets were combined to form a composite variable to describe the daily anomalous health outcomes (AHO). All data sets used included a patient spatial identifier which was 'place of residence' recorded as a postcode (POA). The Victorian Emergency Minimum Dataset was not selected for analysis in this study on advice from the Epidemiology Unit of the DHS. The reason suggested was that this database is not complete in its reporting, or spatial coverage of Emergency Departments in Melbourne hospitals.

The daily health outcome anomaly (AHO) was a composite variable comprised of daily emergency admissions to hospital in selected ICD-10 categories (see Table 4 in Appendix 1D) and daily all cause mortality. The daily AHO was calculated by removing the seasonal and short term cycles in the dataset using a seasonal decomposition function in SPSS <sup>44</sup>.

#### *Victorian Admitted Episodes Database (VAED)*

The Department of Human Services collects morbidity data on all admitted patients from Victorian public and private acute hospitals including rehabilitation centres, extended care facilities, and day procedure centres. These data form the Victorian Admitted Episodes Dataset (VAED, formerly VIMD). The VAED comprises a minimum data set containing (de-identified) demographic, administrative, and clinical data. The VAED is audited internally every two years and has a published error rate of 0.9 % (ABS, 2004). A review of the literature guided the selection of disease categories for emergency admissions to hospital. The DHS provided health outcome data for all emergency admissions to hospital in the selected disease categories shown in Table 4 in Appendix 1D. The age group, sex, postcode of usual residence, and principal diagnosis for each admission were selected from the VAED. The dataset consisted of 991,423 admissions to hospital on 2185 consecutive days between 1/1/2001 and 31/12/2006. From these data the

data relating to the POAs for the statistical district of Melbourne were extracted. This data set consisted of 465,868 emergency admissions to hospital on 2185 consecutive days

### *Mortality data*

The daily mortality data were provided by the Department of Justice, Registry for Births Deaths and Marriages. This data set included the numbers of deaths on each day in each POA in the Melbourne SD during the period 01/01/2001 to 31/12/2006. This data set consisted of 2185 consecutive days and 202,944 deaths.

### *Anomalous Health Outcome (AHO)*

The daily numbers of deaths were combined with the daily numbers of emergency admissions to hospital to form a composite variable. This served two functions, firstly to further de-identify the information, and secondly to provide a comprehensive variable of daily anomalous health outcomes. In order to determine the daily AHO it is necessary to remove the long-term trend, the seasonal variation and any shorter-term cycles which may be present in the AHO time series. The daily AHO was de-seasoned to remove seasonal and periodic cycles from the data. A multiplicative decomposition model has been used to remove the trend, the seasonal variation, and any cyclic behaviour in mortality. The mortality time series was decomposed using exponential smoothing, in SPSS<sup>44</sup>. The smoothed time series obtained provided an estimate of the expected or average AHO rate (smoothed or expected death rate = trend × cycle × seasonal factor), for each day during the period of record. The AHO anomaly for each day over the period of record was then calculated as the deviation of the actual AHO for that day from the smoothed AHO (mortality anomaly = actual AHO/ smoothed AHO).

### *Meteorological data*

The Bureau of Meteorology provided daily data on observed maximum and minimum temperatures for Melbourne, from 1/1/2001 to 31/12/2006. From this dataset the daily maximum and minimum temperatures recorded at Melbourne Regional weather station were selected and daily mean temperature (mean T) was determined by averaging the recorded maximum and minimum temperature between 9am one day and 9am the

following day. Threshold temperatures were determined for daily maximum, minimum, and daily mean T using same the method as described in Nicholls et.al. 2008<sup>50</sup>.

### **Statistical analysis**

Data were filtered to select the number of AHO occurring on the selected days exceeding the threshold temperature and the AHO occurring on all other summer days. The incidence rate of AHO per POA was calculated to determine the number of AHO per 1000 persons for both hot days and all other summer days. The AHO incidence rates in each POA were then imported into SPSS<sup>44</sup> for analysis. Decile ranks for AHO in each POA on days exceeding the threshold and all summer days were calculated.

Statistical analysis included a stepwise linear regression. Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables, which best predict the value of the dependent variable. In this case a linear regression would predict which of the independent variables in the vulnerability index best predict the distribution of the AHO (dependent variable). Therefore POA with strong positive relationships between the independent variables and the AHO are better at predicting vulnerability than those POA with inverse or weak associations between the dependent and independent variables. A Pearson Product Moment Correlation matrix was produced as part of the regression analysis. Similarly a condition index for each model was also generated to identify possible co-linearity between index variables. Co-linearity is a problem when some of the variables are not independent. Co-linearity (or multi-co-linearity) is the undesirable situation where the correlations among the independent variables are strong. A condition index greater than 15 indicates a possible problem and an index greater than 30 suggests a serious problem with co- linearity.

The regression analysis used identified which of the variables within the index best explained the spatial distribution of AHO on days exceeding the threshold or on 'hot' days. Variables entered into the stepwise regression were the incidence rate of AHO per POA as the dependent variable; the independent variables entered were the variables used

to construct the vulnerability index (V1 to V10) see Table 1. This analysis identified the best predictors of vulnerability, and at the same time controlled for co-linearity.

Individual variables in the index identified as strong predictors of AHO were weighted using the un-standardised coefficients from the regression analysis. The new weighted variables were used to recalculate the vulnerability index. This was subsequently mapped using MapInfo software <sup>45</sup>.

Decile values for the AHO in each POA on hot days and on all other summer days were calculated. The relative change in AHO in each POA from baseline (all other summer days) and hot days was determined by subtracting the decile value on baseline days from the decile value hot days. The relative change in decile values of AHO in each POA was then mapped using MapInfo software <sup>45</sup>.

## **Results**

The development of the vulnerability index provided results for each variable at each level of the index. Each independent variable was mapped to check the extent and distribution of vulnerability for each variable in the index. The maps are presented in Appendix 2.

### **Individual variables**

#### *Variable 1. Age*

Variable 1 is the total number of person aged 65 years and older, and 4 years and under as a proportion of total number of person per POA. The areas defined as most vulnerable based on age criteria are the inner Melbourne areas (excluding the city of Melbourne), outer urban areas to the south, south east and east of Melbourne including Mornington Peninsula, Cardinia and Yarra Ranges.

### *Variable 2 Burden of Disease*

The total BoD estimates clearly portray the relative ranking of the importance of the major diseases confronting the populations in LGAs. The BoD in the outer urban areas and the urban fringe of Melbourne appears to higher than in the inner suburban areas.

### *Variable 3 Aged Care Facilities*

The proportion of aged care facilities in each POA was calculated from the Melbourne total, thereby identifying areas with greater numbers of aged care facilities. The greatest concentration of aged care facilities is in the inner and middle urban areas of Melbourne, with very few in the inner city area and in the urban fringe.

### *Variable 4 Socioeconomic status*

Socioeconomic status affects health through many pathways, affordable housing, living conditions, and access to services. Areas of lower socioeconomic status were identified in the south-eastern and north-western areas of Melbourne.

### *Variable 5. Urban design*

Where people live and the type of accommodation they live in influences heat intensity and exposure during heat events. Areas with high numbers of high density housing were identified in the inner suburban areas of Melbourne.

### *Variable 6. Single person households (65 years and older)*

Elderly people living alone have been identified as being a 'higher risk' than those who are married or living in shared accommodation. The inner urban areas, eastern bay side suburbs, and some areas on the south-eastern and eastern urban fringe show the highest concentrations of single person households (aged 65 years and older).

### *Variable 7. Disability*

This group has a need for assistance in daily core activities. This variable measured the number of persons with a profound or severe disability. There is no distinct spatial

clustering but higher deciles are evident in the south-eastern and north-western suburbs. The north-eastern area of the Yarra Ranges and south-eastern regions of Cardinia also showed high decile values.

#### *Variable 8. Population density*

The method assumes that population is evenly distributed across each POA, but nonetheless will give an idea of high density, medium density and low density urbanisation. Population density is greatest in the inner Melbourne areas.

#### *Variable 9 Ethnicity*

This variable does not give an indication of English ‘proficiency’ but only an indication of multilingual households or households where the main language spoken is NOT English. Nevertheless, it is a useful indicator of the ethnicity of the population. The highest decile scores for households where a language other than English is spoken show as two distinct areas in the north-western suburbs and the south-eastern suburbs around the greater Dandenong area.

#### *Variable 10 Urban Heat Island*

Daytime/night-time and daily mean UHI values demonstrated a clear UHI in the Melbourne metropolitan region. The night-time UHI was concentrated in the inner Melbourne region with the highest temperature in the CBD. The daytime UHI showed higher temperature in the inner city and western suburbs.

### **Validating the index**

A composite variable of AHO was created to validate the vulnerability index. The threshold temperature for the Melbourne region during the study period was best described using a mean T of 29°C as was recalculated from Nicholls et al (2008) (from here on these days will be referred to as hot days). There were 26 days that exceeded the threshold during the study period. This resulted in 8518 AHO during the 26 day period. There was an average of 327 AHO per day in Melbourne on ‘hot’ days, compared with

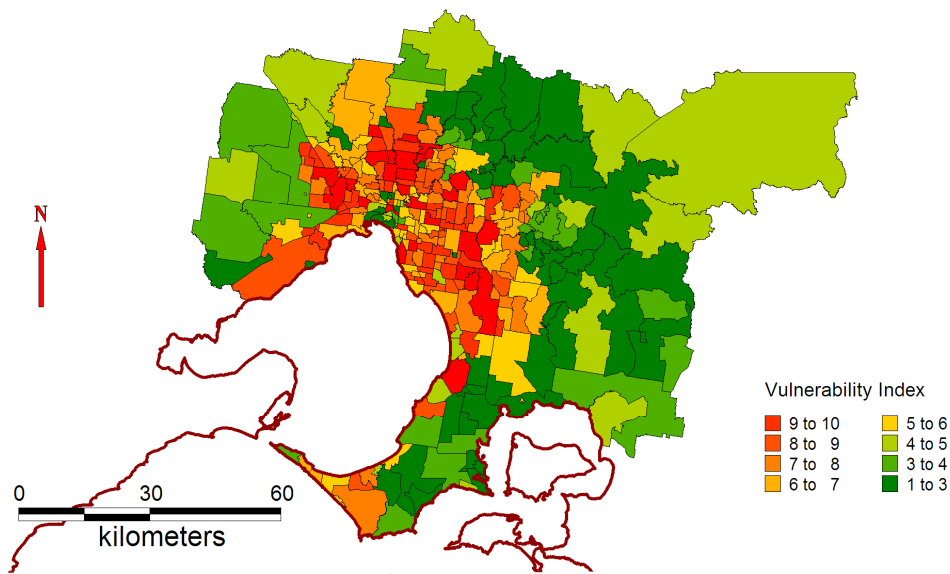
279 AHO per day on all other summer days. This represents a 17% increase in AHO on hot days in summer.

A correlation matrix was generated showing the Pearson Product Moment Correlation of each of the independent variables in the index and the dependent variable AHO. A summary of the results is shown in Table 5 Appendix 1E. There were significant moderate correlations between AHO and the number of aged care facilities, and ethnicity. The relationship between BoD and urban design was not significant, all other variables showed a small but significant relationship with AHO.

The stepwise regression produced five models. Model five was the best predictor of the spatial distribution of AHO on hot days. This included five variables from the 10 variables in the index. These included variable 3 (proportion of aged care facilities), variable 9 (ethnicity), variable 6 (households with single persons over 65 years of age), variable 8 (population density, and variable 5 (urban design). This model suggested that these five variables explained 47 % of the spatial variability on hot days. The proportion of aged care facilities (V3) and the location of ethnic groups (V9) explain 40.9% of the spatial distribution of AHO on hot days. A condition index of 7.2 was not suggestive of multi-co linearity between the variables in this model.

### *The Vulnerability Index*

A map of the weighted vulnerability index demonstrates a clear picture of increased vulnerability shown as orange to red on Figure 2. The highest decile scores are in the inner urban POAs on a northwest to southeast axis which transects the inner city region. There do not appear to be areas of increased vulnerability in the CBD. There are also two other areas of increased vulnerability, one on the southern Mornington Peninsula and the other along the western edge of Port Phillip Bay in the Laverton area.



**Figure 2. A map of the statistical district of Melbourne showing the weighted vulnerability index for each POA.**

Maps were also generated for the AHO on hot days and for the relative change in AHO in each POA. The map of AHO on hot days is in Appendix 3. The AHO on hot days are dispersed throughout the suburban area, south along the Mornington Peninsula and in the south-eastern fringe areas. The pattern broadly resembles that of the predicted vulnerability as shown by the map of the vulnerability index in Figure 2. However there is an interesting anomaly in the north-eastern suburbs where the predicted vulnerability is high but the AHO on hot days is average to low. Some of this variation was explained by calculating the relative change in AHO from baseline (all other summer days) and hot days. Some areas in Melbourne show a substantial increase in AHO on hot days compared to all other summer days but the decile rank still does not reach the high decile category. The vulnerability index was accurately predicting increased vulnerability in these regions. This difference in absolute and relative vulnerability should be taken into account when interpreting and reproducing the index

## Discussion

Heat-related mortality and morbidity are amongst the primary health concerns that are expected to increase as a function of climate change <sup>51</sup>. Population vulnerability is an active process with some people being more vulnerable to heat waves than others based on their health, location, culture, or occupation. It is therefore useful to identify populations at risk and to plan and target interventions accordingly. The public health outcomes of heat-waves depend on the level of exposure (timing, frequency, intensity and duration of the heat-wave), the extent of the event, and the demographic profile of the exposed population, population sensitivity and the prevention measures in place <sup>1</sup>.

The aim of this research project was to gather information that defined population vulnerability to periods of extreme heat in urban areas. To map population vulnerability, and provide government and healthcare agencies with a ‘tool’ for the development of targeted heat-health action plans and help minimise the adverse effects of climate change on the health of urban populations. One of the key outcomes of this research was the development of a ‘tool’ or spatial vulnerability index that was replicable and transferable to other locations. This requirement directed the development of a unique methodological design that encompassed variables describing the health, demographic and environmental vulnerabilities of urban communities. The spatial index was validated using spatially matched data for morbidity and mortality on days exceeding the predetermined heat thresholds in Melbourne. Five variables were identified that explained 47% of the spatial variability in heat related vulnerability. A weighted index was created using these five variables. A map of the weighted index was produced and is shown in Figure 2.

The five variables that best explained population vulnerability were: the percentage of aged care facilities in each POA, ethnicity or households where a the primary language spoken at home was NOT English, elderly people living alone, people living in single dwellings, and areas with a high proportion of elderly and very young citizens. Each of the five variables will be discussed in turn in relation to its contribution to the Melbourne vulnerability index and in terms of the available international literature.

### *Aged care facilities.*

The number of aged care facilities in each POA (as a proportion of all aged care facilities in Melbourne) explained 31% of the spatial variability in the AHO on hot days. This highlights the vulnerability of elderly persons in the community to extreme heat despite being cared for by professionals. The spatial distribution of aged care in Melbourne shows greater numbers of facilities in the eastern and south eastern suburbs. (See Appendix 2 )

The increased vulnerability for the persons living in aged care facilities in Melbourne corresponds with the literature from Europe where the greatest numbers of deaths in the elderly during the 2003 heatwaves were within institutions <sup>10,52</sup>. Some of the most vulnerable persons live within an institutional situation. In France the mortality rate in the 75 years and older group doubled for persons living in retirement homes <sup>53</sup>. Similar situations occurred in Italy, and the UK <sup>25,54</sup>. Furthermore, within the aged care cohort often the less frail were the victims. Personal care in institutions was targeted towards the most vulnerable (frail) but less frail patients made the largest contribution to mortality <sup>16,41,55</sup>. There were several explanations for the observed increase in mortality in aged care facilities. Firstly there was no mandatory regulation requiring air-conditioning in care facilities – therefore for some facilities there were no areas within the buildings for respite from the heat as the duration and intensity of the heat wave progressed. Persons that were recognised as most frail commanded more intense care. Secondly, the European heatwave occurred during the summer vacation period which left many institutions running on minimal ‘holiday’ staff numbers. This meant that not only were relatives and friends on holiday and unable to assist with the care of elderly relatives, but that the remaining staff were also affected by the heat and the increased workload; this would have affected their ability to care for residents <sup>53</sup>. These patterns were not observed in the USA during heatwaves except when air-conditioning failure occurred. The French government has since recommended that all aged care facilities have at least 1 cool room <sup>52</sup>.

Aged care facilities in Melbourne have air-conditioning within the communal living areas but not in residents' bedrooms. This will provide some respite for people who are able to move into the communal areas throughout the day but little relief during the night or for people who are bedridden. Ceiling fans in bedrooms may help in these areas by providing ventilation (air motion over the skin produces some cooling effect). Broadly, it would be expected that living in an aged care facility would be protective unless air-conditioning failed, but this may not be the case. As heat waves are likely to occur during summer holiday periods maintaining staff-resident ratios and relying on support from relatives could also be a problem faced by Australian facilities. The increased level of risk observed for residents of aged care facilities in Melbourne suggests that aged care facilities should be targeted when developing adaptation and mitigation strategies.

### *Ethnicity*

The number of households in each POA where large numbers of persons speak a language other than English at home explained a further 10% of the spatial variability in AHO on hot days. The spatial distribution of ethnicity is clustered along a north-west to south-east axis which transects but does not include all of the inner Melbourne area (see Appendix 2 , Variable 9). These clusters correspond to the industrial areas of Melbourne and are more likely to be areas of lower socioeconomic status. There is a well recognised relationship between area deprivation and poor population health. This may be a result of population demography, limited access to facilities or area characteristics of the local environment such as increased air pollution, noise pollution, high density housing and industry, limited green space, and overcrowded living conditions. Epidemiological examination of mortality and morbidity during heatwaves in Europe, USA, Canada, and the UK indicates that racial minorities living in areas of lower socioeconomic status are at a greater risk<sup>6,8,56</sup>. One notable exception was a decreased risk of heat related mortality in the Latino population in Chicago during the 1995 heat wave<sup>32</sup>. This may have been due to increased social connectedness in this community. There is some evidence that lower income groups in urban areas were more at risk of heat-wave related mortality in the Europe 2003 heat wave, but many studies also show that there was no modification of the

temperature–mortality relationship by socioeconomic status in Europe <sup>54</sup>. Therefore, it is not clear that poor urban populations are more at risk from heat-related mortality in Europe. This corresponds with the results of this study where ethnicity which is often used as a surrogate for low socioeconomic status is suggestive of increased vulnerability, but SEIFA alone was not a strong predictor of increased vulnerability. Therefore it is suggested that there are multifaceted aspects of ethnicity beyond socioeconomic status that determine vulnerability within ethnic groups. Level of education may be a moderating factor. A study in several Italian cities used level of education as an indicator of socioeconomic status as this information is available on individual death certificates. Excess mortality in Rome during the summer of 2003 was 6% in persons with the highest level of education and 18% in persons with the lowest level of education, and a similar pattern was observed in Milan <sup>9</sup>. Level of educational attainment may be related to occupational exposure, as blue collar workers and manual labourers may experience direct exposure to environmental heat. Level of educational attainment was not included in this study but may warrant inclusion in future indexes.

The clustering of neighbourhood groups based on race or ethnicity can also affect health. Research in the USA suggests that racial segregation results in the unequal distribution of economic resources and institutional care, and may also be an important contributor to health inequality. Migrants may also be less familiar with the Australian climatic conditions, and in some regions experience social isolation, hence less communication occurs. Non-English speaking migrants are less likely to understand alert and warning systems, and therefore have a lower likelihood of effective adaptation. This presents a significant problem for the implementation of adaptation and mitigation strategies into non-English speaking households. However in areas where there are strong cultural groups this may facilitate communication in their own language. Thus, policies to improve population health should include analysis of the place where people live as well as the specific needs of minority groups and the individuals themselves.

### *Urban design*

People spend most of their time indoors especially if weather conditions are extreme. Urban design was incorporated into the vulnerability index based on evidence from the Europe 2003 heatwave that indicated building type, structure and orientation were important risk factors in heat-related mortality and morbidity. The risk was greater in regions with high density housing. The urban design variable in this analysis included the proportion of dwellings in each POA that were considered high density. Melbourne is a city with considerable urban sprawl and high density housing is limited to the inner city and inner suburbs. These areas have undergone considerable gentrification in the recent past and are now areas with a younger professional population. This assumption was supported by a Pearson correlation between the proportion of vulnerable age groups and urban design in each POA. This relationship was significant but weak and negative, indicating that as urban density increased the percentage of residents in the vulnerable age groups decreased. The relationship between urban design and AHO on hot days was also negative in this analysis. Indicating that mortality and morbidity on hot days in Melbourne is occurring in suburban areas where people live in houses/single dwelling structures rather than apartments and flats.

Evidence from the French heatwave in 2003 has indicated that brick houses (high thermal mass), houses with poor or no insulation, a north facing aspect (Australia), reduced ventilation, multi-dwelling structures, living above the second floor, bedrooms under the roof, and no green space/vegetation around dwelling were associated with increased risk of mortality/morbidity during heatwaves<sup>16</sup>. Whether or not this was the case for persons suffering heat related mortality and morbidity in Melbourne could not be established by this study.

Air conditioning may be a protective factor for people living in areas with higher density housing in Melbourne. Studies from the USA have indicated that air-conditioning is a protective factor for heat related mortality/morbidity<sup>57</sup>. A decrease in heat related mortality/morbidity over the past two decades was attributed to increased use of air-conditioning<sup>57,58</sup>. Lack of air-conditioning was proposed to explain the increased risk of

38

mortality in inner urban poor Americans during the Chicago heatwaves in 1995<sup>32</sup> and 1999 and the European heat wave in 2003<sup>59</sup>. Increased reliance upon air-conditioning may also become a feature in both Europe and Australia over the coming decades<sup>52,60</sup>.

There are two concerns regarding reliance upon air-conditioning; firstly, power failures either partial or complete are common during heatwaves due to inability for energy providers to meet the increased demand. Secondly, reliance on air-conditioning may alter physiological acclimatisation and increase the susceptibility of some people to heat waves. Melbourne regularly exhibits a distinct UHI surrounding the CBD; the results of the Pearson correlation matrix indicated that the relationship between the mean UHI and AHO on hot days was moderate. This study examined the AHO recorded as a place of residence; it therefore does not reflect the possibility of heat related morbidity or mortality in the workplace or in transit. It is possible that occupational exposure to heat and disruptions to the transportation system will increase the risk of heat related mortality and morbidity in susceptible people. To mitigate against the effects of an intensified UHI associated with climate change, 'cool city' designs that are not reliant on air-conditioned buildings should be incorporated into longer-term urban design and urban planning strategies<sup>40</sup>.

### *Single person households*

Areas with a large number of single person households, where the occupant is aged over 65 years explained only 2% of the spatial variability in AHO. The spatial distribution of vulnerability for this variable shows areas of increased vulnerability in suburban areas surrounding Melbourne, Mornington Peninsula, Tooradin and the Yarra Ranges (see Appendix 2, Variable 6). Elderly people living alone were identified as being at particular risk in Europe during the heat wave in 2003; not leaving home daily and decreased social contact resulted in a threefold increased risk of mortality<sup>19</sup>. It was also apparent that excess mortality was greater in single persons (that is, those not married or cohabiting and this was most apparent for men)<sup>19</sup>. Two studies from France, during the heatwave of 2003, report that the mortality of widowed, single and divorced subjects was

greater than that of married people<sup>53,59</sup>. This may indicate that individuals with less social support were more at risk and that increased social contact was a protective factor. The effects of social isolation or the role of social networks in coping with hazards is not straightforward and requires further research<sup>52</sup>.

The distribution of households consisting of single elderly persons in Melbourne only explained a small amount of the variability in AHO. This may be because persons able to live alone have sufficient ability to protect themselves from heat exposure, have suitable social networks for support during heat events, or have the ability to seek help when required. However, as this variable was selected in the regression model as the fourth most important contributor to population vulnerability it is therefore important not to disregard the risk for the elderly living alone.

#### *Population density*

The final variable in the regression model was the population density (per square kilometre) of persons deemed vulnerable based on their age. That is the population density of persons aged 65 years and older and less than 4 years. This variable explained 2% of the spatial vulnerability of AHO on hot days. This appears to be clustered towards the inner Melbourne suburbs. (Appendix 2 , Variable 8 shows the spatial distribution of the population density of susceptible age groups.)

The increased risk of heat – related mortality and morbidity for the elderly and very young is well documented in the literature<sup>52,61</sup>. Increased vulnerability to heat is noted with increasing age. This is largely due to changes in physiological thermoregulatory systems, and limited physiological reserve, as well as the presence of increased rates of chronic disease in older persons. Many epidemiological studies of heat related mortality/morbidity have shown that a larger effect exists for persons over the age of 65 years<sup>52,61</sup>. In addition to biophysical reasons for increased risk social factors are also important. With respect to the elderly this would include social isolation and living in an institution. There is good evidence based on case control studies showing the importance

of social networks as protective factors reducing the risk of heatwave mortality<sup>62,63</sup>. Areas with high densities of elderly people should focus on maintaining and developing new social networks for elderly people.

It has also been suggested that young children are at particular risk during heat waves as they have reduced regulatory mechanisms against extreme heat. Neonates and infants lack optimal thermoregulatory control. Their greater body surface-mass ratio allows for greater heat transfer between ambient conditions and their bodies<sup>11</sup>. This highlights the important and protective role played by parents and carers of young children. Several secondary risk factors have been established for young children. These include increased car travel, increased participation in competitive sports, and a growing rate of obese and overweight children. This pattern of secondary vulnerability has also been shown in the USA<sup>12</sup> and in Japan<sup>13</sup>.

### *The Vulnerability Index*

When the maps were inspected visually the high decile values of the vulnerability index is consistent with high decile values of the AHO on hot days in the northern and western suburbs, the Dandenong region, eastern bay side, and southern Mornington Peninsula. Visual inspection of the AHO on hot days and the maps of each variable included in the index also clarify the consistent relationships between high decile values. Two areas that appear as high decile values on the weighted vulnerability index that were not expected to rank highly are the Laverton Pt Cook areas and southern Mornington Peninsula. By looking at the maps we can confirm that a moderate to high number of aged care facilities in the Laverton area explain its inclusion in the vulnerability index. This area also shows moderate increase in decile values of AHO on hot days. The southern regions of the Mornington Peninsula show high decile values for elderly persons living alone. High decile values for elderly persons living alone in rural areas are also noted in the Tooradin area and the Yarra Ranges. Neither of these regions features as increased decile values in the vulnerability index but do appear as high decile values in the map of AHO on hot days (the missing POA in the southern Mornington Peninsula has a small population and

is mostly Arthurs Seat and Greens Bush National Parks). This suggests that these areas should be considered in mitigation and adaptation strategies despite their moderate rating in the vulnerability index. An additional region that demonstrates high decile values of AHO on hot days is Cardinia Shire. These regions are not included in the vulnerability index and should also be considered.

The model chosen represents the best prediction of the spatial vulnerability on days exceeding the 29°C threshold in Melbourne. However it may not accurately represent the spatial distribution of vulnerability during extreme heat waves that continue over a number of days. Melbourne experienced its most extreme heat wave on record from the 27th to the 30th of January 2009, over the five days maximum temperatures were 12-15°C above normal over much of Victoria. The temperature was above 43°C for three consecutive days from 28-30 January reaching a peak of 45.1°C on 30 January 2009<sup>64</sup>. During this time there was a 62% increase in all cause mortality, a 77% increase in deaths reported to the coroner, and deaths in the 65 years and older group more than doubled. There were also notable increases in ambulance callouts and GP locum home visits particularly to the elderly, and a large increase in Emergency Department presentations again showing a predominance of elderly patients<sup>64</sup>. Unfortunately the spatial distribution of mortality and morbidity during the January 2009 heat wave could not be made available for inclusion in this study, but considering the extent of the effect noted for the elderly we can assume that the variables representing the numbers of aged care facilities, population density of older persons, and single person households over the age of 65 years would predict the spatial distribution of mortality and morbidity during the January 2009 heat wave quite well.

There are several POA in the inner Melbourne area, especially the north eastern suburbs along the Yarra River that are represented as high decile values on the vulnerability map but are shown as lower decile values in the AHO map. The population demography, health, and environmental variables used to construct the index indicate high vulnerability in this area, but it appears that this group do not suffer high rates of

mortality and morbidity on hot days. However, the decile values in the AHO map are absolute and the change in AHO on hot days may be relative. For example, POA that are recorded as decile 5 – 7 on hot days may be decile 1 – 2 on all other summer days. This would represent a considerable increase in risk, although it is not recorded as such by high decile values of AHO. We are presenting the idea that there are two types of vulnerability; absolute vulnerability where the summer AHO are high and the AHO on hot days are also high (as shown in Appendix 3). However, there is also a relative vulnerability in areas where AHO in summer are average/below average, but the AHO on hot days increase markedly. This change may not result in high decile values but does indicate increased vulnerability in the population in these areas. The change in decile values on hot days and on all other summer days was calculated. This relative change in AHO decile value was mapped (shown in Appendix 3) and compared with the maps of AHO on hot days and the weighted vulnerability index. The map of the relative AHO confirmed that there was considerable change in this region on hot days. The predicted high vulnerability on the weighted vulnerability index for this area was indeed correct despite the lower decile values of AHO. It is important to consider both types of vulnerability when developing adaptation and mitigation strategies.

Some of the secondary characteristics of heat waves that are often overlooked are increased rates of injury, trauma, crime and domestic violence. Heat exposure may also be a secondary risk factor for people made homeless by other weather hazards such as floods and bushfires. These secondary characteristics are currently under-represented in the literature, hence should be the focus of future research. There is a limited opportunity to improve the biophysical thermal capacity of humans; however exposure to extreme heat can be mitigated through behavioural adaptation and technological change, how best to implement these and measure their effectiveness should also provide direction for research in the future.

In summary, the greatest effects of hot weather are seen in the elderly but effects are also apparent for adults and children. Elderly persons living in aged care facilities and the elderly living alone are also at a greater risk of heat related mortality and morbidity. In

addition to biophysical reasons for increased risk, social factors are also important. Other factors that increase the risk of heat stress are living in areas of low socioeconomic status <sup>65,66</sup>, homelessness <sup>26</sup>, and poor English language skills <sup>32</sup>. In urban areas the urban heat island can increase the latent heat load; this may be enhanced by poor building design and urban planning resulting in high density housing with limited green space <sup>39,49,67</sup>. The spatial vulnerability index developed in this study provides valuable information for policy makers and planners, healthcare professionals and ancillary services. Two types of vulnerability were defined by examining the AHO during the summer months. The vulnerability index captured both relative and absolute vulnerability better in the urban areas than in semi rural areas. Each of the Melbourne LGA should be able to identify POA in their jurisdictions that are most at risk. Areas of increased risk within each POA can be identified using local knowledge or by re-examination of the data at a census collection district level. Such information can then be used to direct services such as community education, emergency management, heat-health adaptation strategies, and direct short-term and longer-term redevelopment and refurbishment of existing dwellings to mitigate the effects of heat in urban areas.....

## **ACRONYMS**

BoM – Bureau of Meteorology

BCP - Basic Community Profile

DHS - Department of Human Services

POA - Australian Postal Areas

LGA - Local Government Areas

BoD – Burden of Disease

ACF – Aged care facilities

SD – Statistical district

SEIFA – Socioeconomic index for areas

IRSD – Index of relative socioeconomic disadvantage

CCD – Census collection district

UHI – Urban heat island

LST – Land surface temperature

CMG – Climate modelling grid

CGIA – Census Geographic and Indigenous Area

ASGC – Australian Standard Geographic Classification

SLA – Statistical Local Areas

AHO – Anomalous health outcome

ICD -10 – International Classification of Disease version 10

VI – Vulnerability Index

## REFERENCES

1. WHO. Improving public health responses to extreme weather/heat-waves – EuroHEAT. Technical Summary. Copenhagen: World Health Organisation, 2009.
2. Alexander LV, Arbalster J. Assessing trends in observed and modelled climate extremes over Australia in relation to future projections. *Int J Climatology*. 2008;In Press.
3. WHO. Global Environmental Change <<http://www.who.int/globalchange/climate/en/index.html>>. Accessed 2008 20/9/2008, 2008.
4. BoM. Weather <<http://www.bom.gov.au/weather/wa/sevwx/perth/heatwaves.shtml>>. Accessed 2008 30th September 2007.
5. Loughnan M, Nicholls N, Tapper N. Demographic, seasonal, and spatial differences in acute myocardial infarction admissions to hospital in Melbourne Australia. *International Journal of Health Geographics*. 2008;7(1):42.
6. Kinney PL, O'Neill MS, Bell ML, Schwartz J. Approaches for estimating effects of climate change on heat-related deaths: challenges and opportunities. *Environ Sci Policy*. 2008 Feb;11(1):87-96.
7. O'Neill MS, Zanobetti A, Schwartz J. Modifiers of the Temperature and Mortality Association in Seven US Cities. *Am J Epidemiol*. 2003 June 15, 2003;157(12):1074-82.
8. Smoyer-Tomic KE. Putting Risk in its Place: methodological considerations for investigating extreme event health risk. *Social Science Medicine*. 1998 15/2/04;47(11):1809-24.
9. Michelozzi P. The impact of the summer 2003 heat waves on mortality in four Italian cities. *Eurosurveillance*. 2005;10(7):161-5.
10. Keatinge WR. Death in heat Waves. *British Medical Journal*. 2003 15/2/04;327:512-3.
11. Danks DM, Webb DW, Allen J. Heat Illness in Infants and Young Children: a study of 47 cases. *Wilderness and Environmental Medicine*. 2004;15:293-300.
12. Adcock M, Bines W, Smith F. Heat-Related Illnesses, Deaths, and Risk Factors, Cincinnati and Dayton, Ohio 1999, and United States 1979-1997. City of Cincinnati, MS, Montgomery County; Ohio Dept of Health., 2000. 470-3 p.
13. Nakai S, Itoh T, Morimoto T. Deaths from Heat Stroke in Japan:1968-1994. *Int J Biometeorol*. 1999;43(3):124-7.
14. Lam LT. The association between climatic factors and childhood illnesses presented to hospital emergency among young children. *International Journal of Environmental Health Research*. 2007;17(1):1 - 8.
15. Schwartz J. Who is sensitive to Extremes of Temperature? A case-only Analysis. *Epidemiology*. 2005;16(1): 67-72.
16. Vandentorren S, Suzan F, Medina s, et al. Mortality in 13 French Cities During the August 2003 Heat Wave. *Am J Public Health*. 2004;94(9):1518-20.

17. Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The Effect of Heat Waves on Mental Health in a Temperate Australian City. *EHP*. 2008;116(10):1369-75.
18. Kwok JS, Chan TY. Recurrent Heat-Related Illnesses During Antipsychotic Treatment. *Ann Pharmacother*. 2005 November 1, 2005;39(11):1940-2.
19. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic Factors in Heat Wave Related Deaths: A Meta-analysis 10.1001/archinte.167.20.ira70009. *Arch Intern Med*. 2007 November 12, 2007;167(20):2170-6.
20. Sartore GM, Kelly B, Stain HJ, Fuller J, Fragar L, Tonna A. Improving mental health capacity in rural communities: Mental health first aid delivery in drought-affected rural New South Wales. *Australian Journal of Rural Health*. 2008 Oct;16(5):313-8.
21. Satore GM, Kelly B, Stain HJ. Drought and its effect on mental health - How GPs can help. *Australian Family Physician*. 2007 Dec;36(12):990-3.
22. Staniford AK, Dollard MF, Guerin B. Stress and help-seeking for drought-stricken citrus growers in the Riverland of South Australia. *Australian Journal of Rural Health*. 2009 Jun;17(3):147-54.
23. Marzuk PM, Tardiff K, Leon AC, et al. Ambient Temperature and Mortality from Unintentional Cocaine Overdose. *JAMA*. 1998 June 10, 1998;279(22):1795-800.
24. Medina-Ramon M, Zanobetti A, Cavanagh DP, Schwartz J. Extreme Temperatures and Mortality: Assessing Effect Modification by Personal Characteristics and Specific Cause of Death in a Multi-City Case-Only Analysis. *EHP*. 2006;114(9):1131-6.
25. Michelozzi P, De Sario M, Accetta G, et al. Temperature and summer mortality: geographical and temporal variation in four Italian cities. *J Epidemiol Community Health*. 2006;60:417-23.
26. Kosatsky T, King N, Henry B. How Toronto and Montreal (Canada) respond to heat. In: Kirch W, Menne B, Bertollini R (eds). 4th Ministerial Conference on Environment and Health. Budapest, HUNGARY, 2004:167-71.
27. Dachner N, Tarasuk V. Homeless "squeegee kids": Food insecurity and daily survival. *Social Science & Medicine*. 2002 Apr;54(7):1039-49.
28. Duncan K. Climate change and disaster management: reducing risk, saving lives. In: Brebbia CA (ed). 6th International Conference on Computer Simulation Risk Analysis and Hazard Mitigation. Cephalonia, GREECE, 2008:379-87.
29. Wright N, Oldham N, Jones L. Exploring the relationship between homelessness and risk factors for heroin-related death - a qualitative study. *Drug and Alcohol Review*. 2005 May;24(3):245-51.
30. Franzini L, Spears W. Contributions of social context to inequalities in years of life lost to heart disease in Texas, USA. *Social Science & Medicine*. 2003 2003/11;57(10):1847-61.
31. Subramanian SV, Chen JT, Rehkopf DH, Waterman PD, Krieger N. Comparing Individual- and Area-based Socioeconomic Measures for the Surveillance of Health Disparities: A Multilevel Analysis of Massachusetts Births, 1989-1991 *Am J Epidemiol*. 2006 November 1, 2006;164(9):823-34.

32. Dermatte J, O'Mara MD, Buescher J, et al. Near-Fatal Heat Stroke during the 1995 Heat Wave in Chicago. *Annals of Internal Medicine*. 1998 13/2/04;129(3):173-81.
33. Cutter SL, Boruff B, Shirley L. Social Vulnerability to Environmental Hazards. *Social Science Quarterly*. 2003;84(2):242-61.
34. Luber G, McGeehin M. Climate Change and Extreme Heat Events. *American Journal of Preventive Medicine*. 2008;35(5):429-35.
35. Adam GE, Carter R, Chevront SN, et al. Hydration effects on cognitive performance during military tasks in temperate and cold environments. *Physiology & Behavior*. 2008 Mar;93(4-5):748-56.
36. Lieberman HR, Bathalon GP, Falco CM, Kramer FM, Morgan CA, Niro P. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biological Psychiatry*. 2005 Feb;57(4):422-9.
37. Knapik JJ, Canham-Chervak M, Hauret K, et al. Seasonal variations in injury rates during US Army Basic Combat Training. *Annals of Occupational Hygiene*. 2002 Jan;46(1):15-23.
38. Radakovic S, Maric J, Surbatovic M, Vasiljevic N, Milivojevic M. Influence of acclimatization on serum enzyme changes in soldiers during exertional heat stress. *Vojnosanitetski Pregled*. 2009 May;66(5):359-64.
39. Coutts A. The influence of housing density on the surface energy balance and regional scale circulations across Melbourne, Australia. [Doctoral Thesis]. Melbourne: Monash, 2007.
40. U.S. Environmental Protection Agency. Heat Island Effect. What can be done? <[www.epa.gov/hiri/strategies/index.html](http://www.epa.gov/hiri/strategies/index.html)>. Accessed 2008 13/10/2008, 2008.
41. Kalkstein L, Greene S, Mills D, Perrin A, Samenow J, Cohen JC. Analogue European Heatwaves for U.S. Cities to analyse impacts on heat related mortality. *American Meteorological Society*. 2008 January 2008.
42. Golden JS, Hartz D, Brazel A, Luber G, Phelan P. A biometeorology study of climate and heat-related morbidity in Phoenix from 2001 to 2006. *Int J Biometeorol*. 2008;52:471-80.
43. Leonardi D, Hajat S, Kovats R, Smith G, Cooper D, Gerard E. Syndromic surveillance use to detect the early effects of heat-waves: an analysis of NHS Direct data in England *Social and Preventative Medicine*. 2006;51:194-201.
44. SPSS. Version14 Statistical Package for Social Science. Chicago Illinois; 2006.
45. MapInfo. MapInfo Professional Version 8 Release Build 18. New York: MapInfo Corporation; 2005.
46. ABS. Australian Standard Geographical Classification (ASGC) In: *ABSCat.No.1216.0 (ed). Volume 1, Statistical Geography* Canberra: ABS, 2006.
47. DHS. Background for users of burden of disease estimates for Local Government Areas of Victoria 2001 <<http://health.vic.gov.au/healthstatus/bod>>. Accessed 09/12/2008. DHS, Melbourne, 2008.
48. Coutts A, Beringer J, Tapper N. Impact of increasing urban density on local climate: spatial and temporal variations in the surface energy balance in Melbourne, Australia. *J Appl Met and Climatology*.. 2007;46(4):477-93.

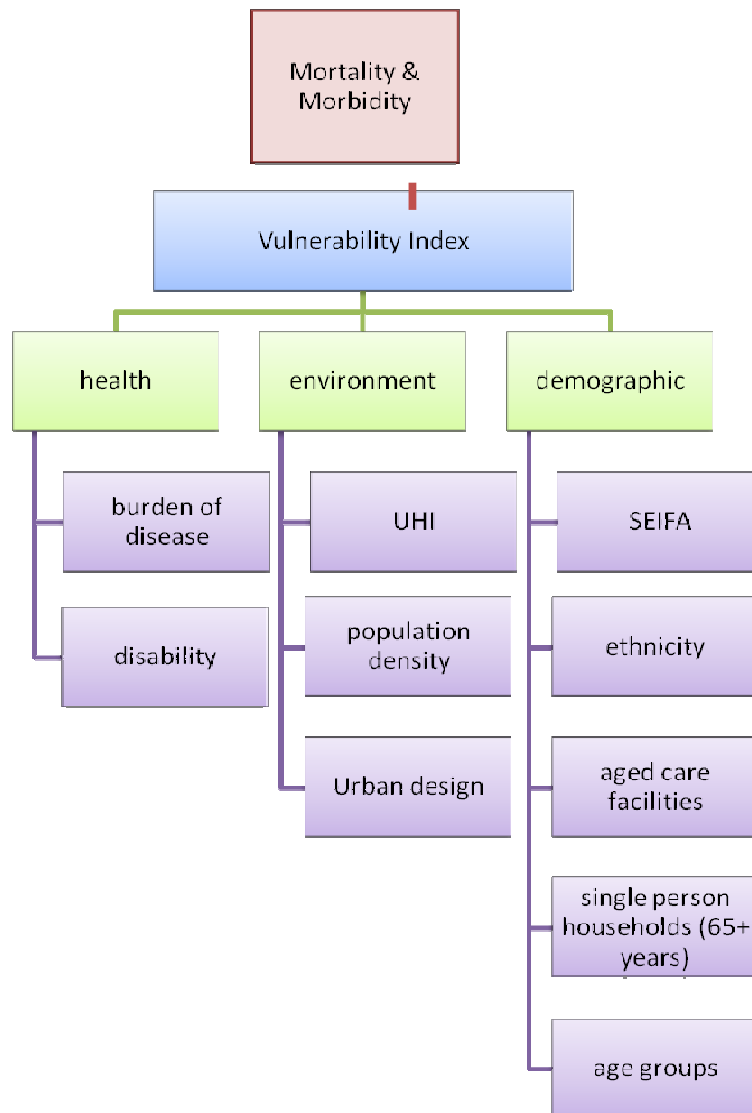
49. Morris CJG, Simmonds I. Associations between varying magnitudes of the urban heat island and the synoptic climatology in Melbourne, Australia. *International Journal of Climatology*. 2000;20(15):1931-54.
50. Nicholls N, Skinner C, Loughnan ME, Tapper N. A simple heat alert for Melbourne, Australia. *Int J Biometeorol*. 2008;52(5):375-84.
51. Johnson DP, Wilson JS. The socio-spatial dynamics of extreme urban heat events: The case of heat-related deaths in Philadelphia. *Applied Geography*. 2009;In Press, Corrected Proof.
52. Kovats RS, Hajat S. Heat stress and public health: A critical review. *Annu Rev Public Health*. 2008;29:41-54.
53. Fouillet A, Rey G, Laurent F, et al. Excess mortality related to the August 2003 heatwave in France. *Int Arch Occup Environ Health*. 2006;80:16-24.
54. Menne B, Matthies F. Improving Public Health Responses to Extreme Weather - Heat waves Copenhagen: WHO, 2009.
55. Laaidi M, Laaidi K, Besancenot J. Temperature-related mortality in France, a comparison between regions with different climates from the perspective of global warming. *Int J Biometeorol*. 2006;51(2):145-53.
56. Frumkin H, Hess J, Lubet G, Malilay J, McGeehin M. Climate change: The public health response. *Am J Public Health*. 2008 Mar;98(3):435-45.
57. Davis RE, Knappenberger PC, Novicoff WM, Michaels PJ. Climate Change Adaptations: Trends in Human Mortality Responses to Summer Heat in the United States. 15th Conference of Biometeorology and Aerobiology 16th International Congress of Biometeorology, 2003.
58. Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM. Changing heat-related mortality in the United States. *Environmental Health Perspectives*. 2002;110(12):1219-26.
59. Vandentorren S, Bretin P, Zeghnoun A, et al. August Heat Wave in France: Risk Factors for Death of Elderly People Living at Home *European Journal of Public Health* 2006;16:583-91.
60. Klienberg E. Heat Wave: A Social Autopsy of Disaster in Chicago. Chicago: Chicago University Press, 2002.
61. Basu R, Samet J. An exposure assessment study of ambient heat exposure in an elderly population. *Environmental Health Perspectives*. 2002;110(12):1219-26.
62. Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD. Heat-related deaths during the July 1995 heatwave in Chicago. *N Engl J Med*. 1996;335:84-90.
63. Semenza JC, McCullough JE, Flanders WD, McGeehin M, Lumpkin JR. Excess hospital admissions during July 1995 heatwave in Chicago. *Am J Prev Med*. 1999;16:269-77.
64. DHS. January 2009 Heatwave in Victoria: an Assessment of Health Impacts. Melbourne: Victorian Government, 2009.
65. Campbell-Lendrum D, Woodruff R. Comparative Risk Assessment of the Burden of Disease from Climate Change. *EHP*. 2006;114(12):1935-41.
66. Ebi KL, Kovats S, Menne B. An Approach for Assessing Human Health Vulnerability and Public Health Interventions to Adapt to Climate Change. *EHP*. 2006;114(12):1930-5.

67. Walker C. Assessing the Temporal and Spatial Variability in Melbourne's Urban Heat Island [Honours]. Melbourne: Monash, 2004. 146 p.

# Appendices

## Appendix 1

*Research design for methodology*



## **Appendix 1A**

### *Description of ABS data Census 2006*

#### **Geographical area.**

Census data are made available for a variety of geographic areas, ranging from very small areas all the way up to State level. The available areas fall into two types - those associated with the Australian Standard Geographic Classification (ASGC), and those described as Census Geographic Areas. The ASGC is the standard geographical classification used for the dissemination of a wide variety of ABS statistical data, including Census data, whilst the Census Geographic Areas are specifically created for the output of Census data. The smallest spatial unit defined by the ASGC is the Census Collection District (CD). It is only defined and published for Census years. It forms the basic spatial unit for both the structures of the ASGC and the Census Geographic Areas. Other levels in the ASGC are reviewed annually, with the exception of Urban Centres/Localities, Remoteness Areas, and Sections of State structures<sup>1,2</sup>.

Data was extracted from the ASGC and Census Geographic Areas Digital Boundaries for 2006 (1<sup>st</sup> release) CD-ROM which contained ABS digital boundaries for ASGC and Census Geographic Areas, used for the dissemination of data from the 2006 Census of Population and Housing. Date of effect of this edition is 01 July 2006. Data was selected to represent the POA or Australian Postal Areas<sup>1,2</sup>.

#### **Basic Community Profile (BCP)**

The BCP provides detailed Census data for small areas in 33 tables containing key Census characteristics of persons, families and dwellings. The data is based on where people were enumerated on Census night.  
<http://www.abs.gov.au/AUSASTATS/abs`@.nsf//web%20pages/Census%20Data`#BCP>, accessed on 20/03/2009.

Data items were identified as per the literature review, relevant data tables were extracted. Data was extracted from the BCP 2006 by selecting the appropriate geographical classification which was Census Geographic and Indigenous Area (CGIA). The CGIA is provided for each spatial classification unit for the whole of Australia. Files for POA for

Australia were extracted. From this data set files for Victoria were extracted. Finally files for the Melbourne SD were extracted from the Victorian data when each of the profiles required was identified.

## ***Appendix 1B***

### *SEIFA*

SEIFA is a theoretical model that uses core variables from the population census to represent socio-economic status. The selection of variables for the construction of the index is divided into three sections. In the first section, the variables are education, income, and occupation, as these variables are fundamental to measuring socio-economic status. In the second section variables are selected to measure aspects of disadvantage. These variables include wealth, living conditions, and access to services. For example, the number of bedrooms in a house, home ownership or rental status, and access to the internet. The variables in the third section are ones that are generally associated with disadvantage rather than specific aspects of disadvantage, such as a high percentage of indigenous people or migrants in an area. These variables do not cause disadvantage but are indicative of some disadvantage in an area. The variables chosen by SEIFA for each level of the index are different, and were chosen to best represent the socio-economic aspects of interest <sup>68</sup> accessed on 12/12/2008. It is important to note that the SEIFA indexes represent the overall wellbeing of a geographical area, rather than that of individuals.

The ASGC is the primary classification system used by the ABS when calculating the indexes for areas. Area index scores are calculated at a census collection district (CCD) level and then aggregated into various larger geographic areas such as POA, SLA and LGA. This is done by taking the weighted average, using population counts from the 2006 census across all areas that comprise the larger geographic area. Because they are calculated at a CCD level they reflect CCD characteristics, not all people in each CCD are identical and the CCD index scores do not apply directly to individuals in each CCD. When larger geographical areas are considered the extremes are smoothed out, and the indexes are more stable and more likely to be representative of the individuals within the area <sup>68</sup>.

## **Appendix 1C**

Table 3

### *B31 DWELLING STRUCTURE*

Census Data Quality Statement

© Commonwealth of Australia 2007

---

Separate house

Semi-detached, row or terrace house, townhouse etc. with:

One storey

Two or more storey's

Flat, unit or apartment:

In a one or two storey block

In a three storey block

In a four or more storey block

Attached to a house

Other dwelling:

Caravan, cabin, houseboat

Improvised home, tent, sleepers out

House or flat attached to a shop, office, etc.

ABS 2006. 'BCP, POA' Table 31 Dwelling Structure. Accessed on 15/10/2008

### **Description of buildings**

Definitions of dwelling structure.

Separate house: This is a house which stands alone in its own grounds separated from other dwellings by at least half a metre. A separate house may have a flat attached to it,

such as a granny flat or converted garage (the flat is categorised under Flat, unit or apartment - see below). The number of storeys of separate houses is not recorded.

Also included in this category are occupied accommodation units in manufactured home estates which are identified as separate houses.

Semi-detached, row or terrace house, townhouse, etc.: These dwellings have their own private grounds and no other dwelling above or below them.

Flat, unit or apartment: This category includes all dwellings in blocks of flats, units or apartments. These dwellings do not have their own private grounds and usually share a common entrance foyer or stairwell. This category also includes flats attached to houses such as granny flats, and houses converted into two or more flats.

For the 2006 Census, there have been some changes to classification procedures for private apartments within non-private dwellings. This may result in changes to the counts of private dwellings in some areas.

Caravan, cabin, houseboat: This category includes all occupied caravans, cabins and houseboats regardless of location. It also includes occupied campervans, mobile houses and small boats. (Separate houses in caravan/residential parks or marinas occupied by managers are not included in this category).

Improvised home, tent, sleepers-out: This category includes sheds, tents, humpies and other improvised dwellings, occupied on Census Night. It also includes people sleeping on park benches or in other 'rough' accommodation (the traditional definition of homeless people).

House or flat attached to a shop, office, etc.: A house or flat attached to a shop, office, factory or any other non-residential structure is included in this category<sup>65</sup>.

## **Appendix 1D**

### *ICD-10 codes*

**Table 4 ICD-10 codes used in selection of data from the VAED.**

Disease category	ICD -10 codes
Circulatory system	I00-I79, I95, I97, I99
Endocrine	E00-07, E09-14, E20-35, E66, E84, E86-87.
Respiratory	J00-84, J96-98
Mental health/behaviour	F00-99
Chronic renal disease	N00-N39
Diseases of nervous system	G00-09, G10-13, G20-26, G30-32, G35-37, G40,G41,G43,G44,G45, G70-73, G80-83
Neoplasm	C00-96
Pregnancy	O00-16
Other disease	X30, X32, T67, L55-56, and R50.9.

## **Appendix 1E**

### *Pearson correlations*

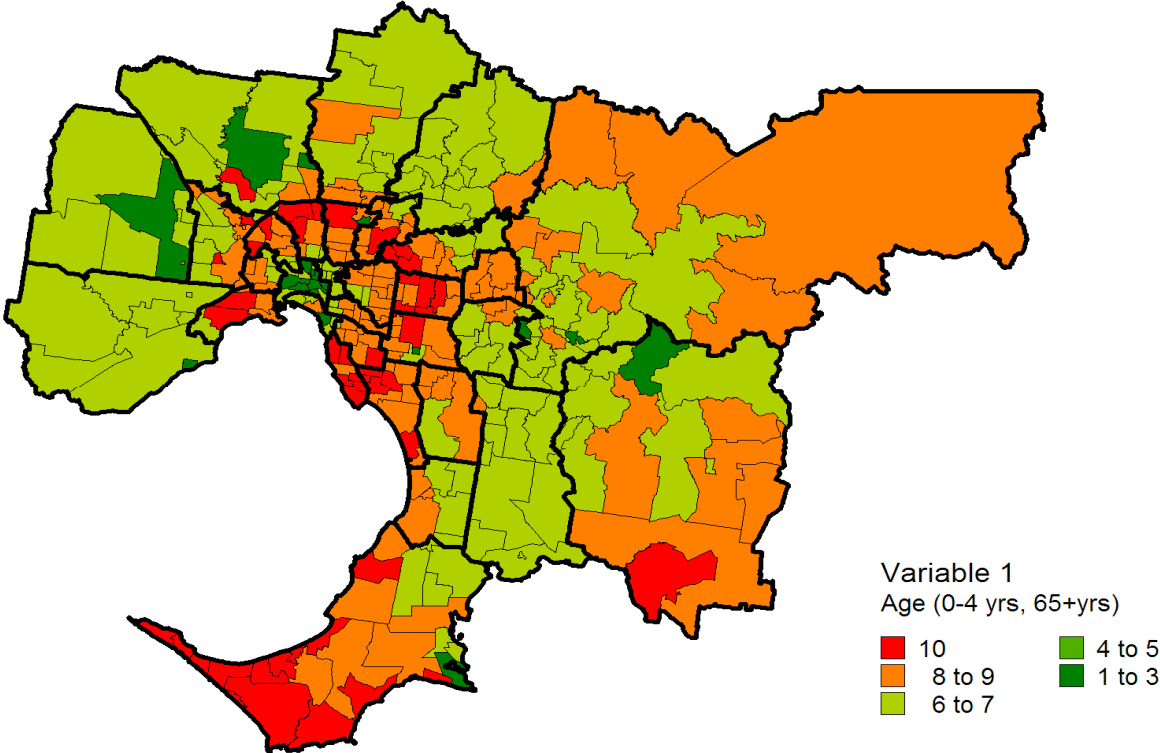
**Table 5 Pearson correlation from Regression analysis. (dependent variable AHO, n = 265)**

<b>Variable</b>	<b>Pearson correlation</b>	<b>Significance</b>
Age (65+,0-4)	0.195	0.001
Burden of Disease	-0.081	0.094
Aged care facilities	0.559	0.001
SES	-.151	0.007
Urban design	0.052	0.198
Single person households 65+years	0.275	0.001
Measure of disability	0.177	0.002
Population density (vulnerable age groups)	0.274	0.001
Ethnicity	0.446	0.001
UHI	0.282	0.001

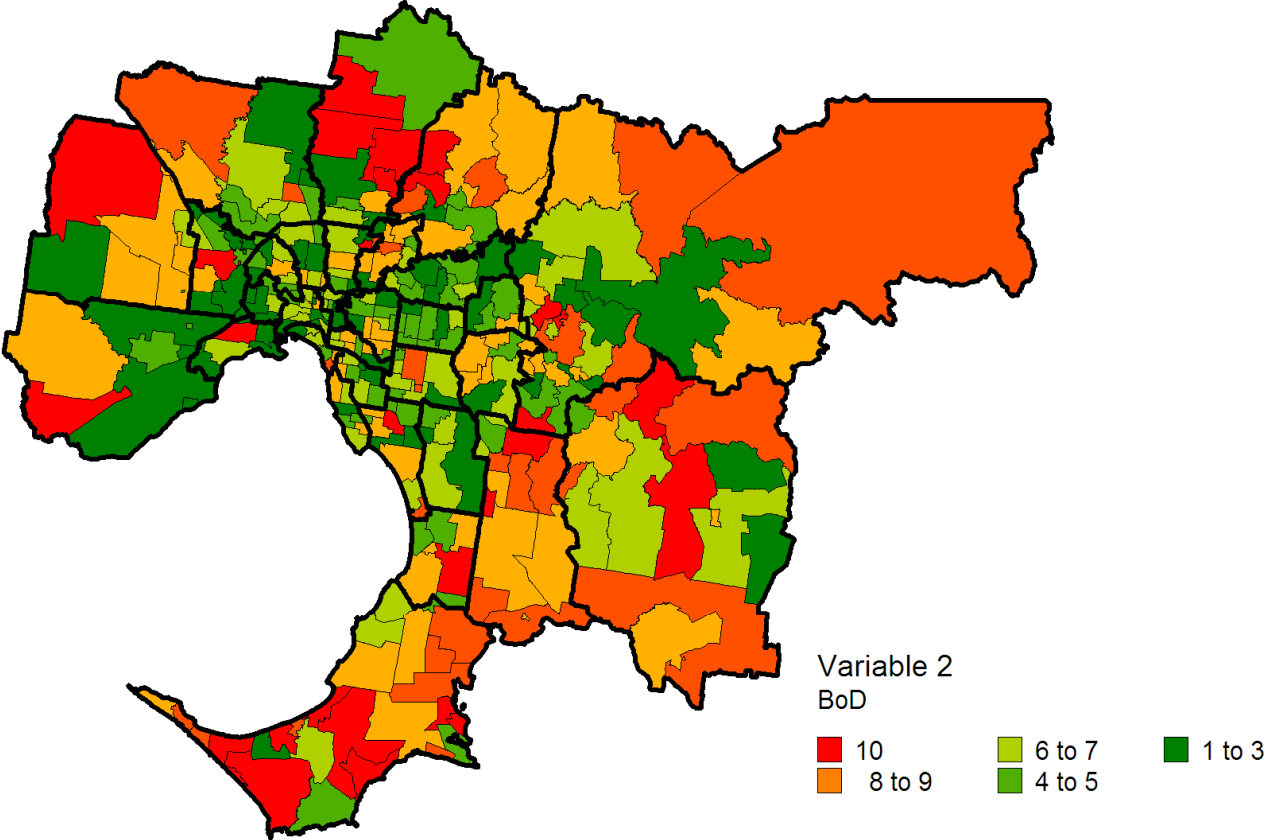
# Appendix 2

(Individual maps of each variable 1-10, for the Statistical district of Melbourne with Local Government Area boundaries)

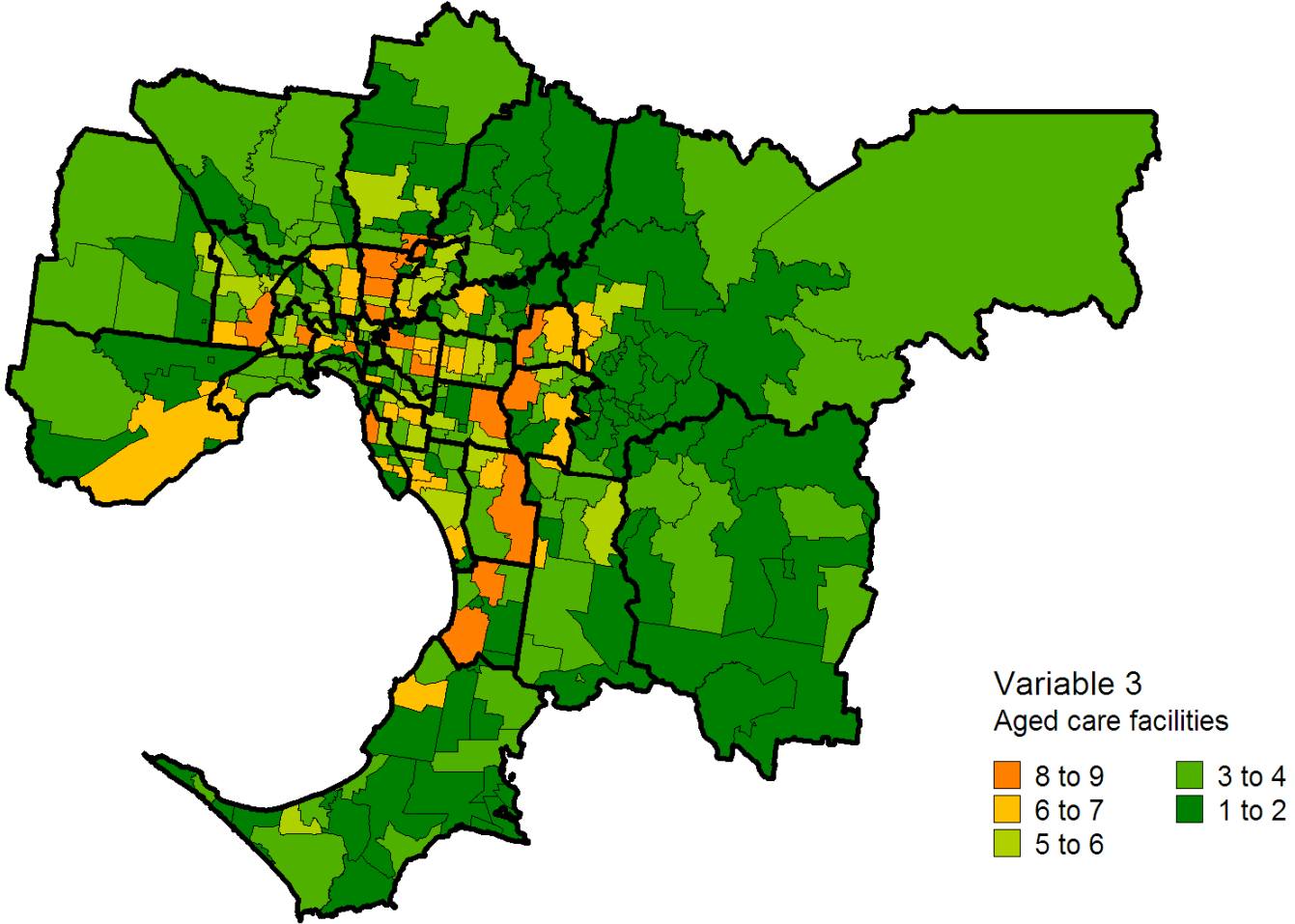
*Variable 1 Age*



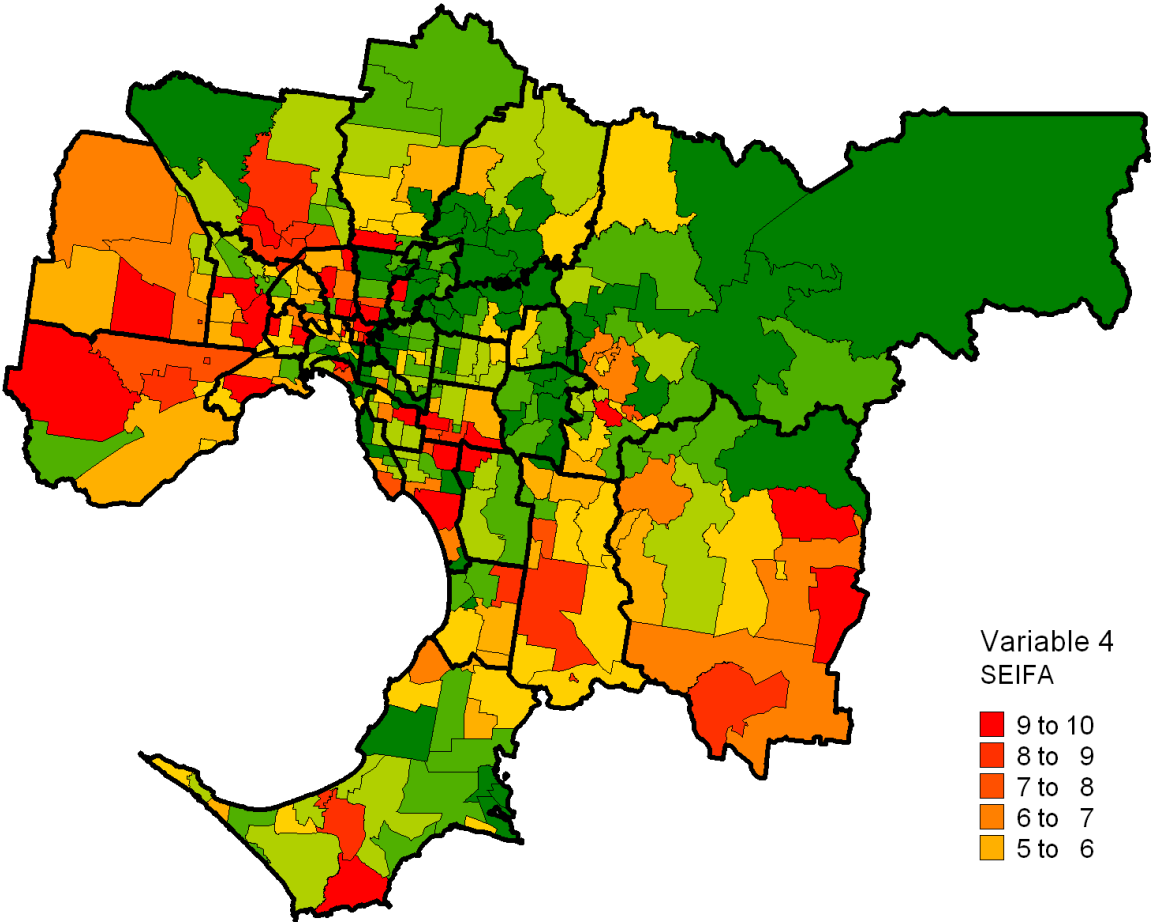
*Variable 2 Burden of disease (BoD)*



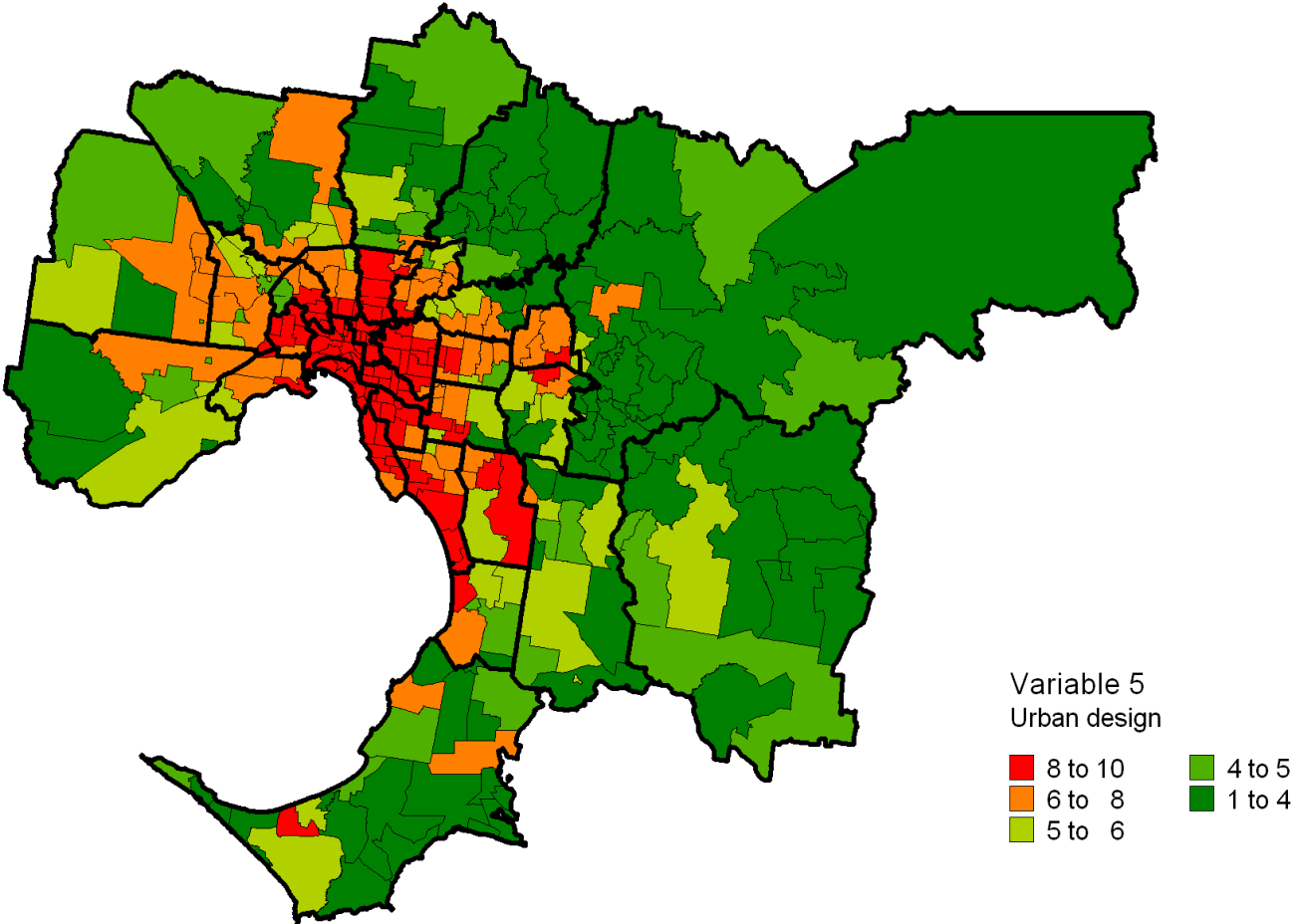
*Variable 3 Aged Care Facilities (ACF)*



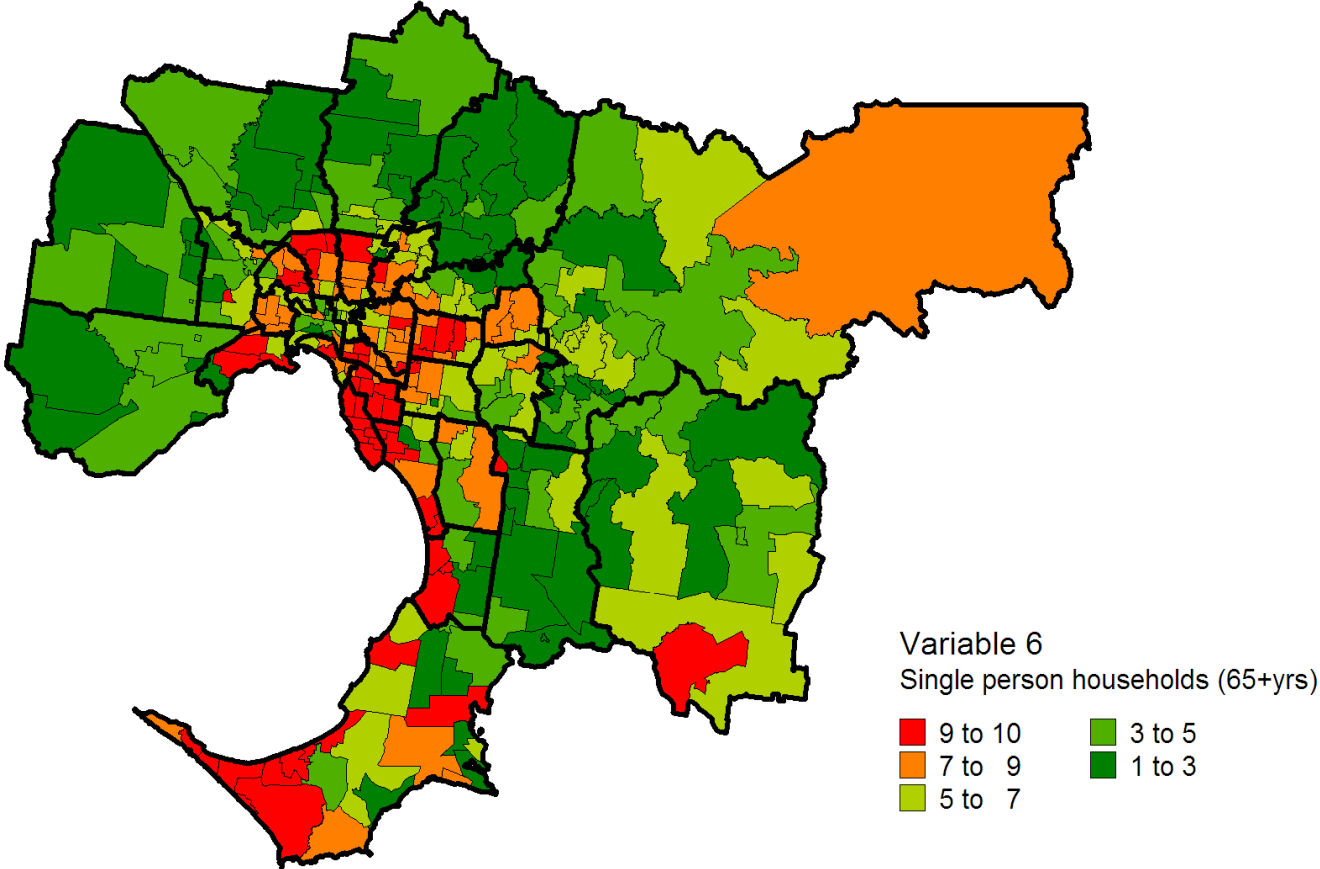
Variable 4 SEIFA



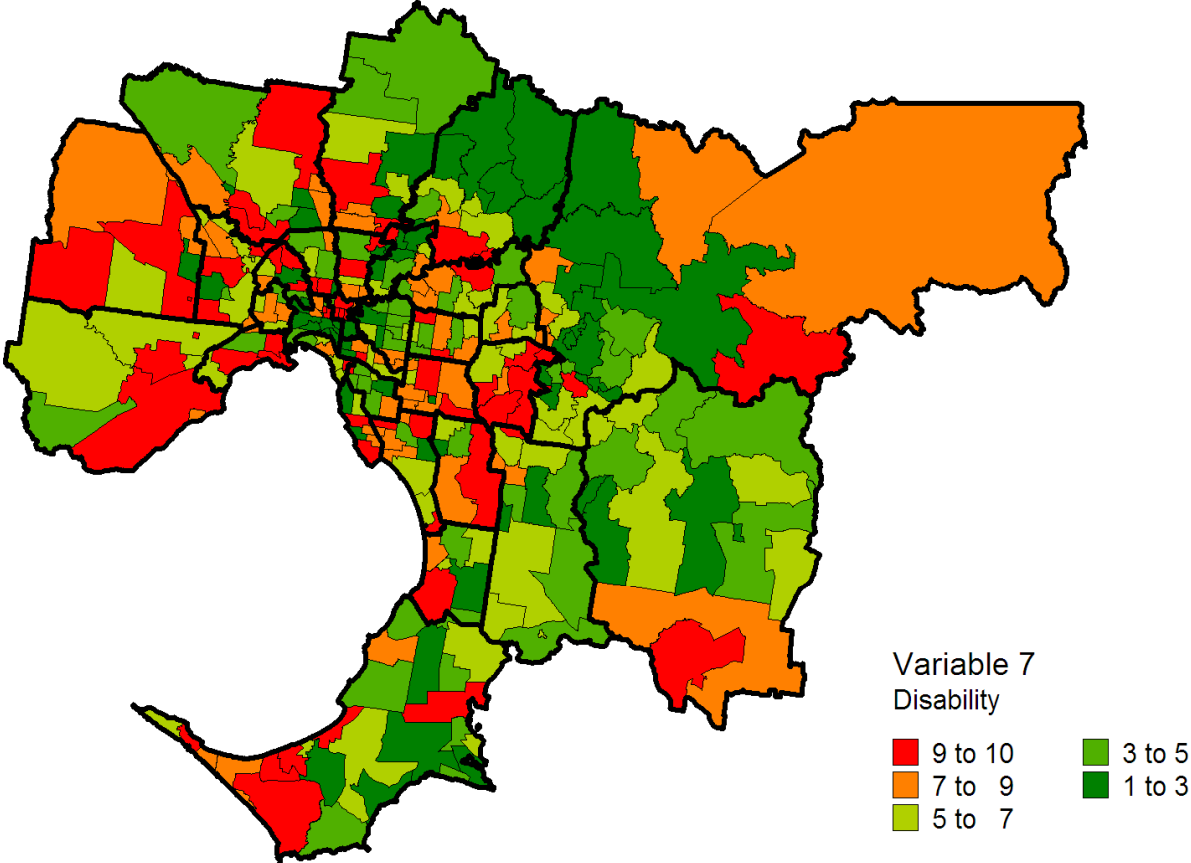
*Variable 5 Urban designs*



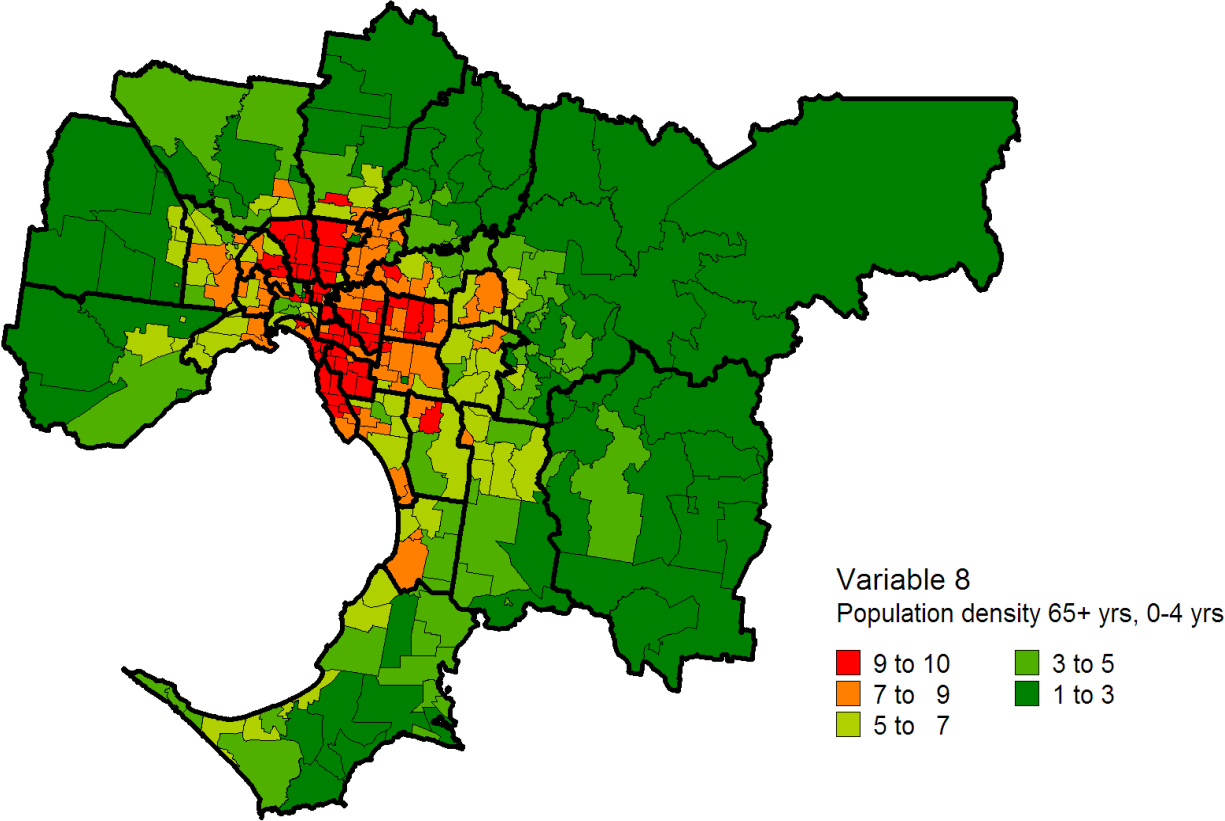
Variable 6 Single person households (aged 65 years and older)



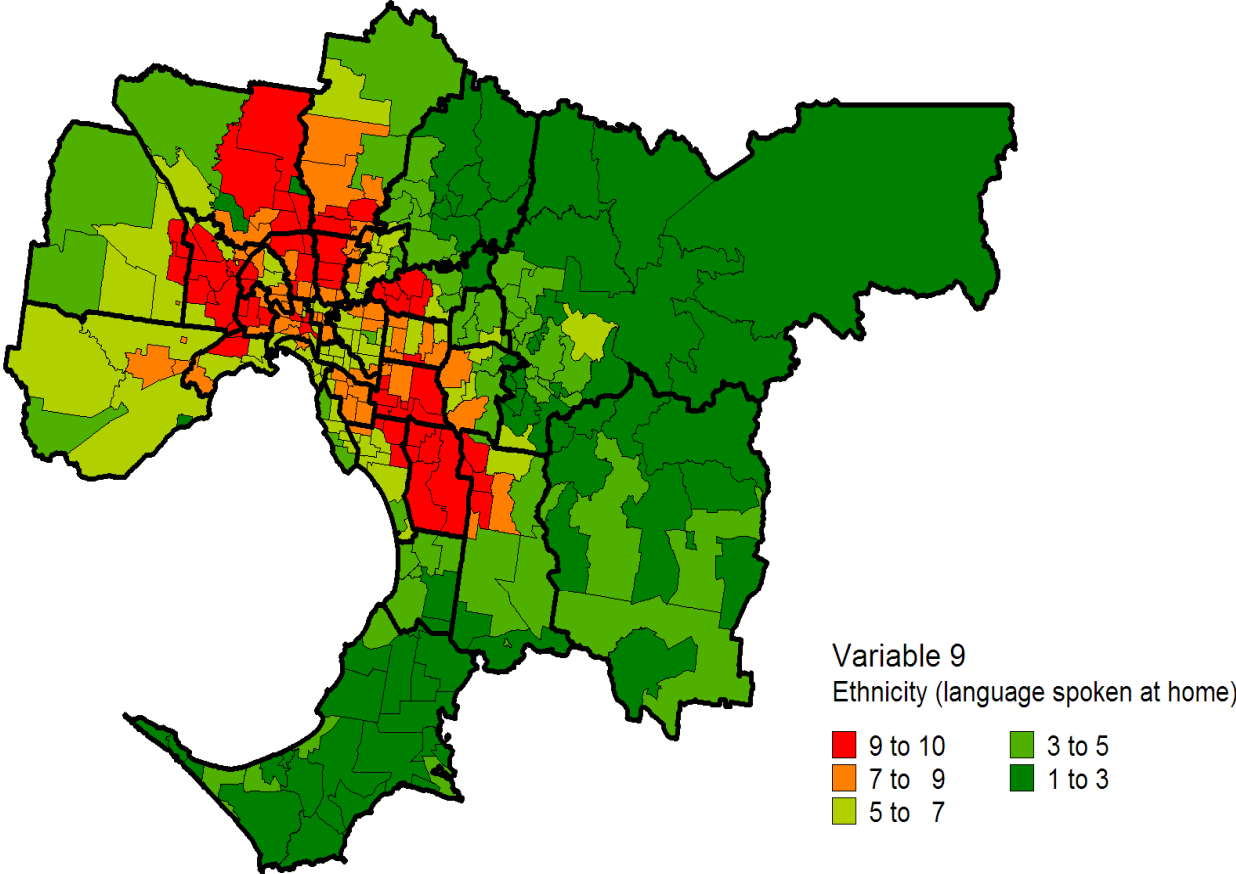
*Variable 7 Disability*



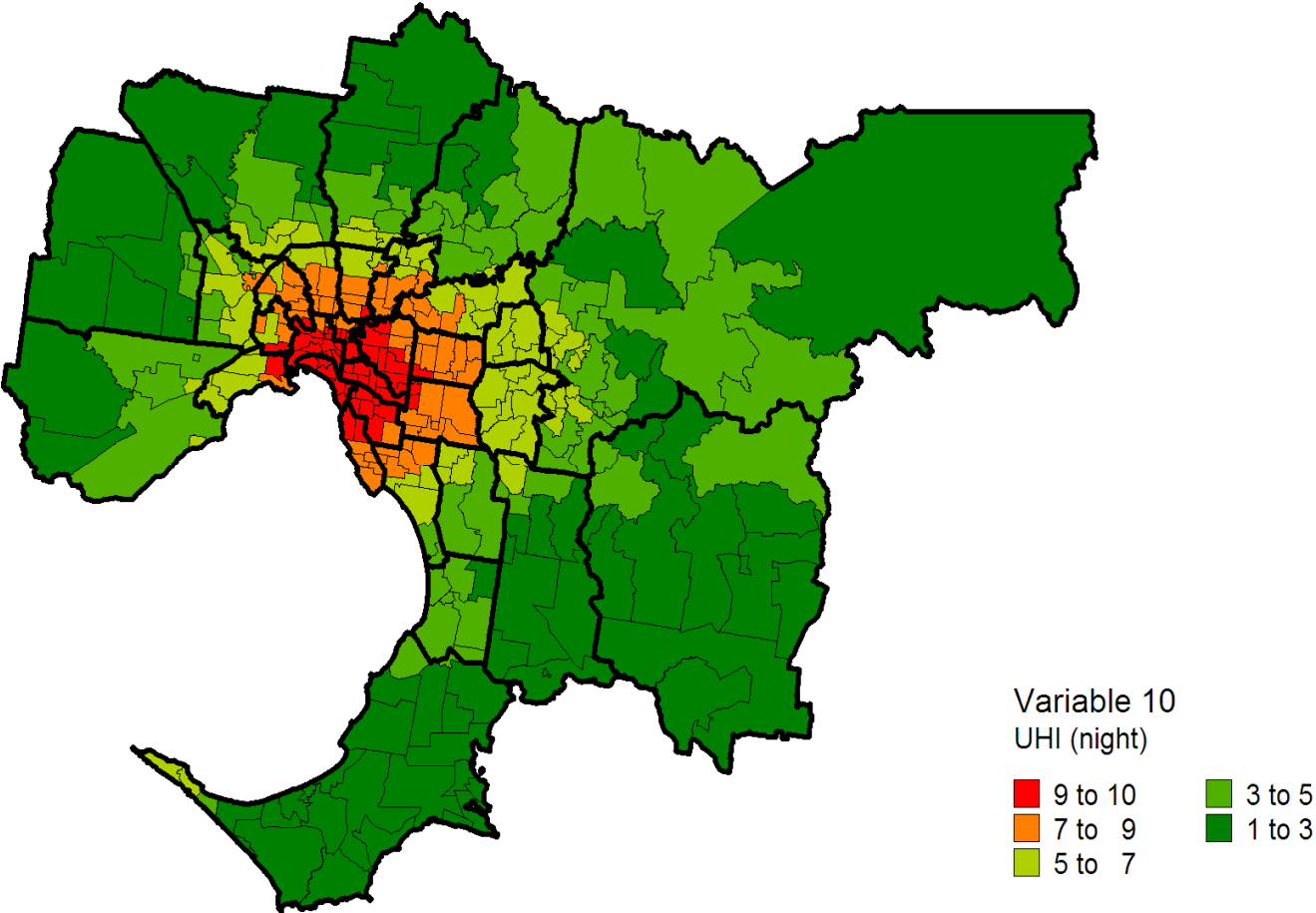
Variable 8 Population density (aged 65 years and older, 0 – 4 years)



Variable 9 Ethnicity

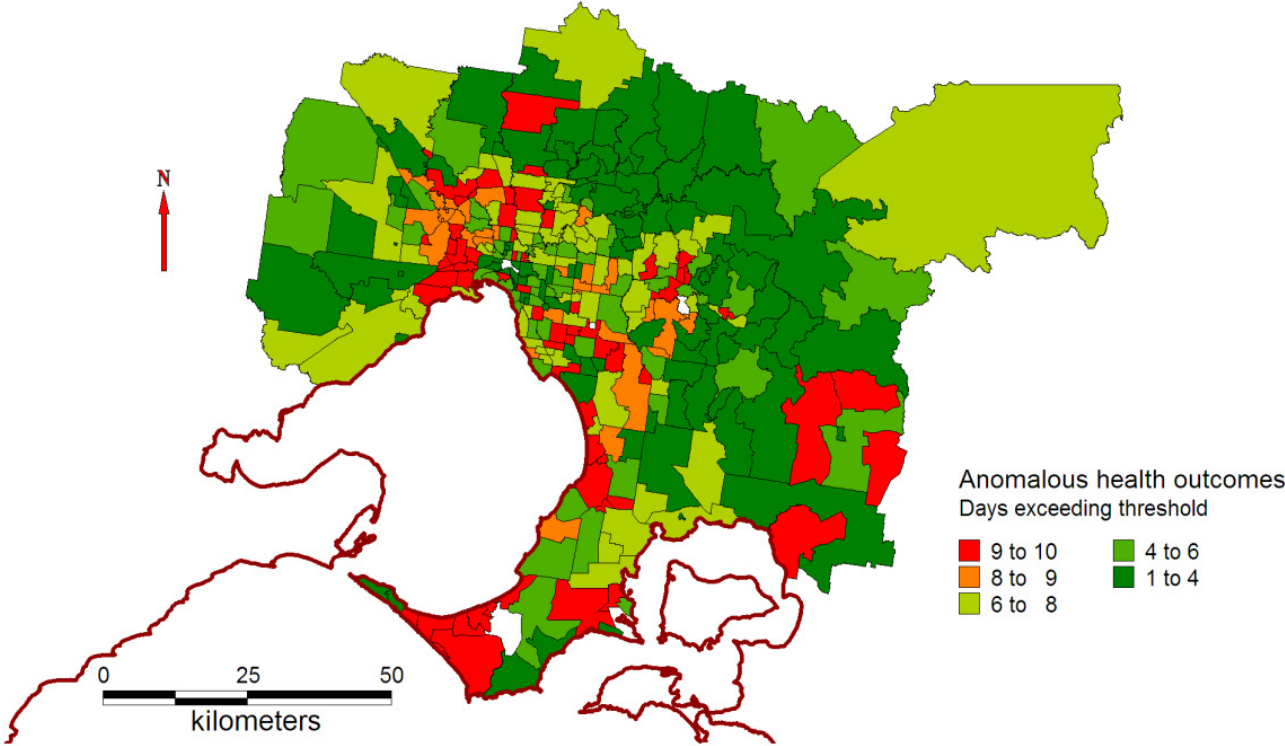


*Variable 10 Urban heat island*



# Appendix 3

*Anomalous health outcomes on days exceeding the threshold (mean T 29°C)*



*Change in AHO decile value between all other summer days and hot days.*

