Place in Health

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- Coffee N and Lockwood T, **Using Housing Values as a Socio-Economic Status Metric**, 6th Australasian Housing Researchers' Conference, Adelaide 8-10 February 2012.
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- Coffee N T, Lockwood T, Hugo G, Paquet C, Howard N, and Daniel M, **Property Value Wealth as a Socio-Economic Status Measure: An Opportunity for Health Research?** Population Health Congress 2012, Population Health in a Changing World, Adelaide, Australia, 10-12 September 2012.
- Coffee N T, Lockwood T, Paquet C, Howard N, and Daniel M, **Relative Property Value as a Socio-Economic Status Indicator**. International Medical Geography Symposium 2013, Michigan State University, East Lansing, United State of America, 7-12 July 2013.

Abstract

This research contributes to expanding the awareness and importance of *place* in health research. As a thesis by publication it features three peer reviewed published papers which provide methodological developments for the application of spatial techniques to health research. These papers constitute a response to the critique by a number of researchers on how spatial techniques are applied in some health research.

Place has been implicated in health research for centuries. Among the *place*-health literature there are two research streams that are the focus of this thesis; 1) the relationship between *place* and socioeconomic status (SES); and 2) the impact of the built environment on physical activity and chronic disease.

Place has an association with SES and SES has an accepted relationship with health, and therefore *place* may impact on health through its relationship with SES. An emerging research area used property values to represent wealth as an alternative or complementary SES measure. Two recent studies have used property value as an SES measure and reported a strong association with obesity and reported that property value was more predictive of fair/poor health status than area-level SES measures. This emerging research area is the focus of the first two papers which developed a property value SES measure that reflected *place* and wealth. The first paper provided the methodology to develop a residential property value measure (RLF) and the second paper tested the association between RLF and six chronic health outcomes, central obesity, hypertriglyceridemia, reduced high density lipoprotein (HDL), hypertension, impaired fasting glucose, and high low density lipoprotein (LDL) plus cumulative score of these chronic health outcomes. A statistically significant

association with the cumulative CMR score and all but one of the risk factors (high LDL) was found, and in all cases except high LDL, participants in the most advantaged and intermediate group had a lower relative risk (RR) for cardio-metabolic diseases.

The third paper focused upon the built environment and walkability and the methodology used to spatially represent walkability. Whilst this paper used the Australian adaptation of the walkability index used for the IPEN project (www.ipenproject.org), the outcome was not walking behaviour but the cumulative cardiometabolic risk score used in paper two. The third paper used predetermined administrative spatial units and road network buffers. This approach was chosen to provide further evidence that the choice of spatial unit matters in health research and that selecting an inappropriate spatial unit could mask or hide an association. There was no statistically significant association between walkability and the predetermined spatial units, but there was a modest statistically significant association between the road network buffers and lower RR of cardiometabolic risk.

Taken individually, the first two papers provide a spatially based measure for SES-health research which was statistically associated with chronic health outcomes and the third added to the literature on health associations with walkability and highlighted the need for appropriate spatial unit selection. Cumulatively, these papers add to the growing literature and demonstrated a more informed application of spatial methods to health research.

Disclosure

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

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To my family, my wife Jane and my sons Gareth and Owen, for continuing to encourage me and take an interest and for the special PhD aids for keeping focused and at work at the desk! My wife Jane contributed greatly to the finished thesis with encouragement along the way, support all the time and assistance with proof reading and final production of what has been many years in the making.

List of Abbreviations

ASD	Adelaide Statistical Division
ABS	Australian Bureau of Statistics
ASGC	Australian Standard Geographic Classification
CD	census collection district
CMR	cardiometabolic risk
CTVB	Council Tax Valuation Bands
DCDB	digital cadastre database
GEE	Generalised Estimating Equations
GDP	gross domestic product
GIS	geographic information system
HDL	high density lipoprotein
IPEN	the International Physical Activity and Environment Network
IDW	inverse distance weighted
LGA	local government areas
LOTS	land ownership and tenure system
LDL	low density lipoprotein
MAUP	modifiable area unit problem
NHMRC	National Health and Medical Research Council
NDVI	normalised difference vegetation index
NQLS	Neighbourhood Quality of Life Study
NWAHS	North West Adelaide Health Study
PC	personal computer
PLACE	Physical activity in localities and community environments

RLF	Relative Location Factor
RR	relative risk
RDB	Retail Database
SEIFA	Socio-Economic Index for Areas
SLA	statistical local areas
SA	South Australia
SSC	state derived suburb
SD	statistical divisions
SSD	statistical sub-division
SES	socio-economic status
UK	United Kingdom
USA	United States of America
WI	walkability index
W1	wave one NWAHS data
WHO	World Health Organisation

Chapter 1: Introduction

Place has been investigated in health research for centuries. Early works include the 1792 maps of human diseases produced by Finke (Barrett, 2000) and Booth's London Poverty maps from 1886–1891 (Orford et al., 2002). Despite these early examples of the importance of *place* to health, the analysis of health and *place* influences was relatively inactive until the 1990s (Diez-Roux, 2001, Earickson, 2000). It is evident in the literature reporting on neighbourhood effects on health that *place* is integral in health outcomes. The association between *place* and health is very broad and coverage of the many themes is beyond the scope of this thesis. However, two research streams form the focus of this thesis:

1) the social determinants of health and the relationship between socioeconomic status (SES) and *place; and*

2) the impact of the built environment and walk supportive places on chronic diseases.

The *Place*-SES-Health Association

SES research has progressed from its roots in the 19th century to a major area of research. This research has resulted in a large volume of published works and the association between SES and health is now accepted. The Whitehall study in the 1970s provided evidence of a gradient in SES and health and reported that as your occupation grade increased (as a proxy for SES) your risk of chronic heart disease reduced and this relationship held even when risk behaviours like smoking were included in the analysis (Marmot et al., 1978). Low SES is associated with poorer health and this relationship has been found throughout the developed world (Pickett and Pearl, 2001). *Place* was reintroduced into SES research in the 1980s and 1990s and has progressed from country comparisons through to states, counties, and cities to within city analyses. *Place* has an association with SES and SES has an accepted relationship with health, therefore one of the many ways *place* may impact on health is via SES. SES is typically measured as income, education and occupation and many studies have used these measures to describe SES and the association with chronic disease and health risk behaviours, including smoking and alcohol consumption. However, although the relationship between lower SES and poorer health is accepted, SES can be measured in many ways and there is no internationally recognised standard definition or measurement methodology. The majority of SES and health research use one or all of income, education and occupation as proxy measures for SES. However, in an attempt to encompass other important aspects of SES, some researchers have included family size (Bradley and Corwyn, 2002, Corvalán et al., 2005), overcrowding (Corvalán et al., 2005, Dragano et al., 2007), car ownership (Corvalán et al., 2005, Forastiere et al., 1997, Lewis et al., 1998, Sykes et al., 1999), housing factors such as tenure (Laaksonen et al., 2005, Lewis et al., 1998, Sykes et al., 1999) , housing type (Fuller-Thomson E, Hulchanski J D and Hwang S, 2000, Sabanayagam et al., 2007) and wealth measures such as assets, investments and residential property value (Auchincloss et al., 2007, Braveman P A and et al., 2005, Lindelow, 2006, Perera and Ekanayake, 2010, Pollack et al., 2007).

Property Value SES Measure

An emerging research area is the use of property values to represent SES as a measure complementary to income, education and occupation. Residential property value has been reported to account for between 21% (on average) to 50% (low SES households) of household net wealth in the US (Di, Yang and Liu, 2003). Wealth as an indicator of SES represents the influence of wealth accumulation, which is of particular interest for older or retired persons who have lower incomes and no occupation and are generally classified as low income, even though they may be asset rich (Allin, Masseria and Mossialos, 2009, Gornick, Sierminska and Smeeding, 2009, Robert and House, 1996). Traditional measures do not accurately report SES for this group, nor does income reflect wealth per se as the income question is generally only about current income and does not include accumulated wealth, which can be substantial (Adams et al., 2009b). Two recent studies have used property value as an SES measure and reported strong associations with obesity (Rehm et al., 2012) and that property value was more predictive of fair/poor health status than area-level SES measures, calculated either as single variables or as indices (Vernez Moudon et al., 2011). This emerging research area provided an opportunity to progress a new SES measure which reflected *place* and wealth and was the basis for two of the papers in this thesis which presented a methodology to develop a residential property value measure as a spatial SES indicator that could be used at the household level but represented the local residential real estate submarket (Coffee and Lockwood, 2012).

Health and Physical Activity

The other major stream of research focus for this thesis is the health benefits of being physically active and the importance of *place* effects. Being physically active is good for health and this association is well established. Many reviews have highlighted the positive relationship between good health and moderate level physical activity (see for example (Morris and Hardman, 1997, US Department of Health and Human Services, 1996). Spending on getting people active has been described as the “best buy in public health” (Morris, 1994) and many programs have been established over the past thirty years to get people more active, in particular walking. Walking is the most popular form of physical activity as it is available to most of the population, is low cost, does not require specialist equipment or infrastructure and can be undertaken at almost any age. In Australia the Commonwealth and State Government programs have included, Life Be In It (www.lifebeinit.org/), Exercise: Make It a Part of Your day, Take 30, Be Active, 10,000 Steps and in the USA include, the President's Challenge, Let's Move (https://www.presidentschallenge.org) and the Centre for Disease Control's Promoting Lifelong Physical Activity. These programs raised the awareness and were partially successful but did not get everyone walking or active. Consequently, researchers have looked for other influences on walking behaviour. Two main streams have emerged, individual and community level influences and built environmental influences on physical activity. The second stream forms the basis of the third paper in this thesis. The built environment as a research area deals principally with the places people live, work or recreate in and how this might support or impede walking. As was the case with SES-*place*-health research there is now evidence from many countries regarding the association between the built environment and walking.

Built Environment and Walkability

Researchers have investigated a range of factors that categorise elements of the built environment that are "walk supportive" and two of the persistent themes have been the connectivity and proximity (Frank, Andresen and Schmid, 2004, Frank et al., 2005) which collectively are usually described as walkability. Walkability has been used to investigate associations between time spent walking, walking for transport and the number of walking trips and physical activity. Study results have been mixed as some studies have reported increased levels of walking for transport but not for total walking time (Berrigan, Pickle and Dill, 2010, Cao, Handy and Mokhtarian, 2006, Cerin et al., 2007, Cervero, 1996, Cervero and Gorham, 1995, Cervero and Radisch, 1996, Craig et al., 2002, Frank et al., 2006, Huang et al., 2009, Owen et al., 2007, Sundquist et al., 2011, Van Dyck et al., 2010a), while other studies have not reported any association (Ewing, 2005, Forsyth et al., 2008, Learnihan et al., 2011, Lovasi et al., 2008, Oakes, Forsyth and Schmitz, 2007). For the purpose of this thesis, the walkability definition which underpins the 12 studies that are part of the International Physical Activity and Environment Network (IPEN) project was used. This definition of walkability includes dwelling density, intersection density, land use diversity and retail space footprint ratio to car parking area and was selected to provide comparability with the many IPEN publications. Constructing an objective index of walkability was the subject of earlier work by this author (Coffee, 2005, Leslie et al., 2007). That work is not replicated here, rather this methodology was used to construct a walkability index and test this with a selection of spatial units and health outcomes. The aim with this component of the research was to add to the call for more research which considered the relationship between the health outcome, exposure and the spatial unit and in particular the need to test associations using multiple spatial units (Brownson et al., 2009).

Modifiable Areal Unit Problem

Built environment measures are expressed spatially, yet as is the case with SES and health, many *place* and health researchers do not consider the choice of spatial unit used, its size (scale), or comment on the potential for the modifiable areal unit problem (MAUP) (Openshaw, 1984). Geographers have studied the MAUP for many years, yet few publications in the field of public and population health consider the MAUP when reporting their findings which include spatial analysis (Root, 2012). *Place* and health researchers would appear to select and analyse predetermined administrative spatial units without the level of scrutiny typically applied to their choice of variables, the reliability and validity of data capture techniques, and the specification of an appropriate statistical methodology.

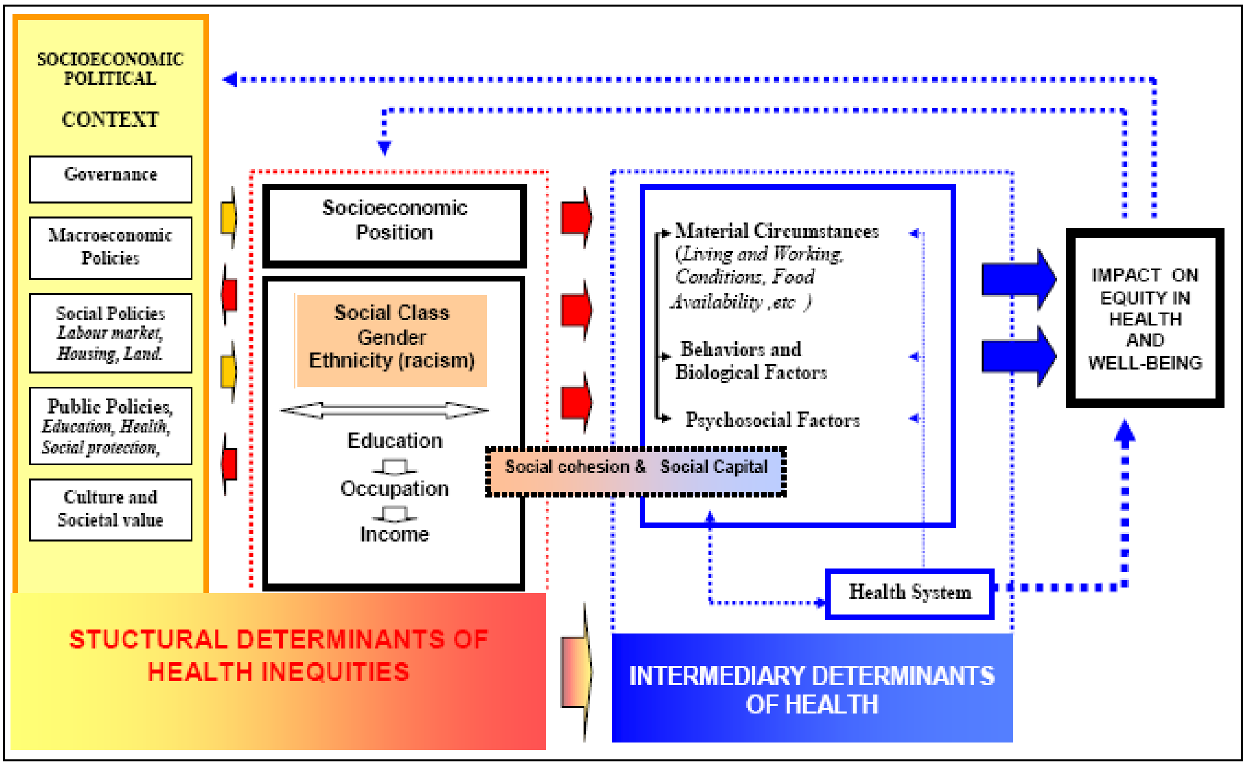
Place-Health Research

The two foci of health research in this thesis would appear at face value to be separate areas of research. However, they have significant overlaps in terms of their representation and use of *place*. *Place* in health is an important research question as the literature has provided evidence of the strong links between *place* (SES) and health and *place* (built environment) and walking outcomes. SES and walkability are not evenly distributed but vary spatially. Local area clustering of spatial association is often described as neighbourhood and is then used as an explanatory variable in health research. One of the key tenets of geography, Tobler's first law of geography (Tobler, 1970), states that everything is related to everything else, but near things are more related than distant things. This is a simple, understandable, yet elegant explanation of spatial proximity that could be used to inform the *place*-health research and is central to the work in this thesis. It may be a moot point that this law of geography is a universal truth, or that it would describe all spatial circumstances, but it provides an excellent starting point. *Place* is fundamental to the understanding of both SES and the built environment; neither construct exist independent of *place*. SES and the built environment are used to represent different views of *place*; SES representing social aggregated or population averages of position, and the built environment *place* morphology.

Conceptual Framework

As stated, the overarching influence on this work is Tobler's first law of geography, which states that everything is related to everything else, but near things are more related than distant things (Tobler, 1970). While this concept is still debated by geographers (Barnes, 2004, Goodchild, 2004, Miller, 2004, Sui, 2004, Tobler, 2004) it provides a clear explanation of spatial association. It may be a truism that Tobler's first law of geography applies across all spatial relationships. Despite the mixed views of the validity of Tobler's law (Barnes, 2004, Goodchild, 2004, Miller, 2004, Sui, 2004, Tobler, 2004), the underlying proximity relationship described by Tobler's law provides an excellent starting point. *Place* is fundamental to the understanding of both SES and the built environment and these constructs do not exist independent of *place*. Indeed, the influence of proximity is reflected in both the SES and the built environments as presented in this thesis. This spatial relationship is inherent in the concept of property value, as features that are nearby will influence property value far more than features that are distant. In the same way, the walkable built environment is best expressed using smaller spatial extents to capture greater homogeneity and walk interaction space which will diminish in influence with distance. However, local relationships do not occur in isolation to the wider socio-political environment and the interplay between Tobler's first law and the World Health Organisation's (WHO) conceptual frame work (Figure 1.1) on the influences on health and well-being were integral to the methodological developments provided in this thesis. While Tobler provided a strong rationale for considering *place* influences, the WHO provides a framework for considering how social position is influenced by a range of factors. The World Health Organisation Social Determinants Commission provided a conceptual framework to guide its research and policy development work which included both multi-factorial and multi-directional pathways between social position and political influences and the impacts on health and wellbeing (Figure 1.1).

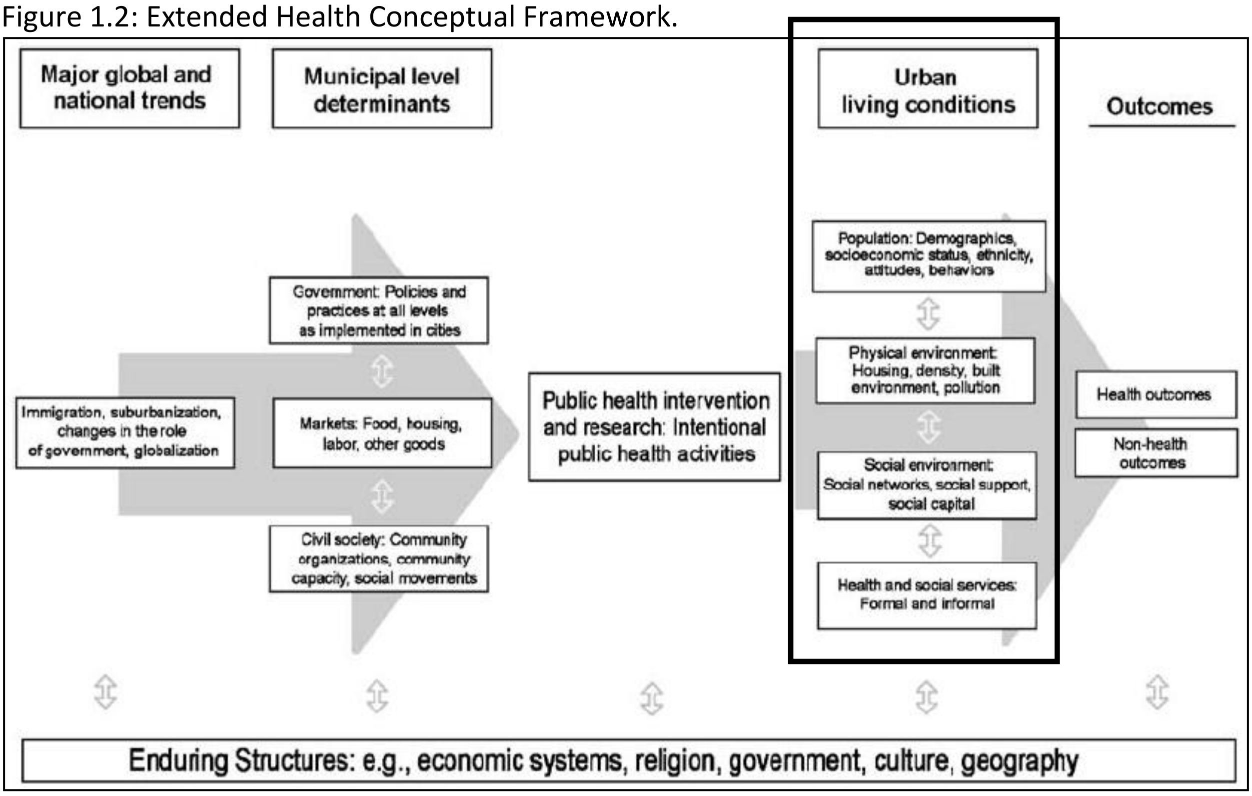
Figure 1.1: World Health Organisation Social Determinants of Health Conceptual Framework.



Source: A Conceptual Framework for Action on the Social Determinants of Health, Discussion paper for the Commission on Social Determinants of Health (DRAFT) April 2007. Solar, Orielle, and Alec Irwin. "A conceptual framework for action on the social determinants of health." (2007): 1-77.

While this framework provides a multidimensional framework, it is devoid of a *place* context. Given that *place* is increasingly being implicated in health research, a framework which does not recognise and include *place* in the pathways to health and well-being is deficient and missing a major potential influence. Galea, Freudenberg and Vlahov (2005) provided a framework that built upon the WHO framework, implicating global, national and local socioeconomic and political influences as well as the impact of location through the urban living conditions along a pathway to health outcomes (Figure 1.2).

Figure 1.2: Extended Health Conceptual Framework.



Source: (Galea, Freudenberg and Vlahov, 2005).

This framework links global and local factors with *Place* at several points along the pathway and specifically highlights several sets of factors within the urban living conditions (highlighted above) which are of particular relevance to this work. These include population, the physical environment, the social environment and health and social services, all of which can influence health through *place* via proximity or access (social and geographic).

Research needs to be guided and informed by a framework that embeds the outcomes within a sound theoretical basis. It is the aim of this thesis to look at *place* and health, but from a *place* perspective and as such the geographic relationship expressed via Tobler's first law is the major driving force. The multi-dimensioned health conceptual framework (Figure 1.2) provides for an understanding and appreciation of the multi-factorial pathway relating *place* to health, and this framework was used in this research to guide the conception of how the different dimensions of SES-*place*-health together influence health outcomes. The *place* method development in the three peer reviewed papers in this thesis were all guided by the multiplicity of macro and micro level influences that combine to impact upon health outcomes.

Research Aims

As a thesis by publication, this research contributes to expanding the awareness and importance of sound methodological development for *place* in health research. *Place* is used in this thesis to encompass the many spatial descriptors found in the literature, such as neighbourhood, community, and locality or the many statistical spatial unit names such as census tract, block face, enumeration district and census collection district. These and other spatial units are used throughout the literature and are often used as a proxy term for neighbourhood. The aim of this thesis is to increase the awareness of the importance of *place* to health research and in particular, the need for more rigour in the selection of the spatial unit used to represent *place*.

The key contribution that this thesis makes is in the advancement of *place* awareness, a contribution to the small but expanding body of research concerned with promoting *place* as a major area of research focus in its own right. More attention is required in the choice of spatial unit, beyond the use of administrative predetermined spatial units. While data constraints such as confidentiality often force the use of these predetermined spatial units, it still behoves the researcher to acknowledge the potential problems this might introduce, such as the modifiable areal unit problem (MAUP), ecological fallacy or the masking of *place* and health associations. Three peer reviewed papers are included in this thesis contributing to the *place* awareness issue. Each paper contributes to the methodological literature with the aim of continuing the debate and improving understanding of *place*. The choice for peer reviewed publications was to ensure the research component of this thesis was more widely available, than is often the case for a traditional research thesis.

The three publications that form the major component of this thesis are provided in chapters four, five and six. As it is not possible in journal articles to provide a detailed literature review due to word limits, chapter two expands the literature to provide the context for the three publications. Chapter three provides more a detailed description of the data and method development, supplementing the journal articles, setting the scene and developing the connection between the source data, spatial units and the health outcomes. Chapters four, five and six present the papers as published. Chapter seven includes a short discussion of the three papers and Chapter eight discusses limitations of the methods, future method development and future research directions. The final chapter, the conclusion, reiterates the importance of *place* understanding to health research and the need for more efforts to foster a greater appreciation of the potential for including *place* in health research that is tempered with an understanding of the potential issues.

Chapter 2: Literature Review

This thesis investigates the application of "*place*" in health research. The term "*place*" is used to denote location as expressed by the many spatial units or terms used to represent *place*, such as neighbourhood or community, in the literature. The aim of this thesis was to address two of the methodological challenges identified in the literature: 1) the definition and 2) operationalisation of *place* (Auchincloss et al., 2007, Brownson et al., 2009, Chaix et al., 2009, Diez-Roux, 2001, Gauvin et al., 2007, Leal and Chaix, 2011, Riva et al., 2009). Two methods that can assist health researchers report *place* effects on health outcomes are presented. This is necessary because of the widespread expression of *place* using predetermined administrative spatial units (Gauvin et al., 2007) and the reporting of results without consideration of potential biases or mention of one of the major issues associated with areal units, the MAUP (Openshaw, 1984). MAUP is associated with scale and configuration of spatial units such that statistical associations may change as the size of the spatial unit changes (scale) or as the study area is subdivided into different spatial configurations (zonation). Even though this problem was identified in the early 20th Century (Gehlke and Biehl, 1934) and described by a number of geographers (Flowerdew, 2011, Flowerdew, Manley and Sabel, 2008, Fotheringham and Wong, 1991, Openshaw, 1977, Openshaw, 1984), few health studies acknowledge, let alone account for the impact of the MAUP despite the increasing use of *place* in health research.

Health researchers stress the importance of reliable data, tests for various forms of data and collection reliability and in the choice of analysis models, but fail to apply this level of rigour to the design or choice of spatial units. Many studies list the spatial unit used and provide no more detailed or rationale on choice of unit, nor a description of the spatial unit or its origin (Leal and Chaix, 2011). It is this lack of rigour in the choice of *place* in health research that drives the methods proposed in this thesis.

Two long standing relationships expressed in the literature provide the subject of this work, first, the enduring socioeconomic status (SES) - health - *place* association and second, the important challenge of defining neighbourhoods or relevant geographic areas specific to research questions (Diez-Roux, 2001). This chapter is divided into four sections. The first section reviews the literature on SES and health and the increasing inclusion of *place* associations. The second section reviews the increasing interest in the built environment, walkability and the spatial units that have been used to test for associations with health outcomes. Section three addresses the issues identified in the literature and reports on the studies that have looked at solutions to the definition of *place*. The final section outlines the two *place* methodologies developed for this thesis. Both have been published in peer reviewed journals ensuring the work is widely available and can generate continuing discussion and development. Both of the methodologies proposed use cardiometabolic risk as the chronic health outcome, offer methods that can be tested and improved over time, progress a more informed use of *place* and are guided by the importance of MAUP in any spatial analysis.

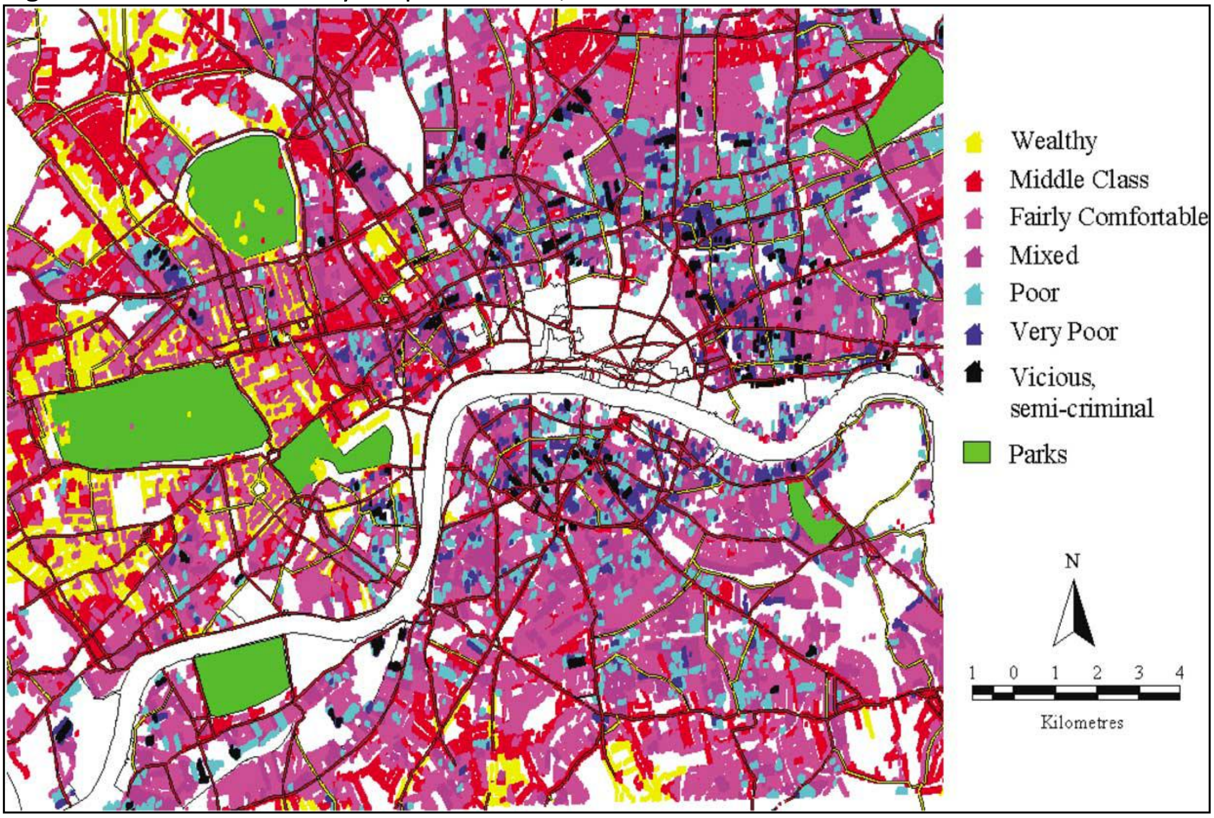
SES and Health

It is not the purpose of this chapter to reference the vast literature covering SES and health associations; the aim is to focus on some of the key studies that established the basis for SES and health research, research that led to the identification of the SES-health gradient, SES measurement and the growing interest in *place* associations, areal units and the concept of neighbourhood. This is provided as context for this thesis as the *place* associations are central to this thesis.

The association between *place*, social position and health has a long history. One of the more cited examples of the nexus between *place* and social position is the late 19th century work of Charles Booth who mapped in detail the social and economic conditions of the people of inner London. The results were published in 17 volumes between 1886 and 1903, with volumes 1-4 reporting on poverty, volumes 5-9 reporting on industrial conditions and volumes 10-17 on religious (social) influences. The impetus for this work was to improve the living conditions of the people in inner London, especially the high level of poverty, which was described by Booth as the “problem of problems” (Bales, 1996). The spatial extent of Booth’s work encompassed much of inner London, covering the area from Highgate in the north, Clapham in the south, Greenwich in the east and Hammersmith in the west with an estimated population of 4 million (Orford et al., 2002). Booth and his team did not collect data from house to house, but interviewed professionals who had expert knowledge of the types of people living in inner London (Figure 2.1)(Orford et al., 2002). Education was made compulsory in 1871 and school fees were required from all families, with the exception of the poorest families. The exemption of school fees was only permissible after an assessment by a School Board Visitor to ensure that the family was genuine and could not afford to pay the school fees or that they were not wasting their income (Orford et al., 2002). Booth used the School Board Visitors to collect the poverty data as they had expert knowledge on income levels across inner London as an outcome of assessing family incomes for school fees and validated the School Board Visitor data against the 1881 Census to ensure reliability (Orford et al., 2002). The poverty map plotted family income as reported by

School Board Visitors and was mapped on a building by building, street by street basis. The poverty map was very detailed and buildings were subdivided into different classes, with lower levels occupied by poorer families while more affluent families lived in the upper levels (Orford et al., 2002). Poverty was classified into seven groups with the most well off described as “Wealthy; upper middle and upper classes” through seven classes with the least well-off described as “Lowest class; vicious, semi-criminal” (Figure 2.1). In a modern context, Booth’s lowest class grouping of “semi-criminal and vicious” is now amusing but is not a description that would or could be used in modern socio-economic classification regimes. Orford and colleagues (2002) revisited Booth’s poverty map and created a new geographic information system (GIS) version (Figure 2.1) and compared this with a poverty classification based on the 1991 Census data which was accorded with the 19th Century classification as closely as possible. Remarkably, and despite almost 100 years since Booth’s work, Orford et al (2002) found that the distribution of poverty in London was not significantly different although they found slightly more people in the wealthier class and fewer in the lowest class. Booth’s work reflects the important contribution that social surveys and the use of geographic information made long before the computer version typically described as GIS. It is important in a study that is concerned with *place* research that such a significant work be given prominence to highlight the long provenance of *place* research and to stress that *place* research did not eventuate as a result of the personal computer (PC) and GIS software. Certainly, the rise of the PC and development of GIS software have enabled the focus of *place* in health research. That this work was seminal is evidenced by the number of citations (956) and references in the literature, use in lectures and presentations reporting on SES and the importance of *place*.

Figure 2.1: Booth's Poverty Map of London, 2002 GIS Version.



Source: Orford, S., Dorling, D., Mitchell, R., Shaw, M. & Smith, G. D. 2002.

Booth's work is remarkable in a number of areas, first in establishing a methodology for major social surveys, second for the use of poverty to represent social position (income is still the major indicator for social research), and third, and of more interest to this work, the use of detailed maps to communicate the results. This is one of the earliest examples of a major social application of geographic information and while social survey and socio-economic status (SES) continued to be studied this, coupling with maps, remained largely dormant for almost 100 years.

This work and some other notable early examples of SES research (the 1792 map of human diseases produced by Finke, the early 19th Century work by Louis-Rene Villerme on mortality in Paris, Rudolf Virchow's work on the Typhus epidemic in Upper Silesia in the mid-19th

Century and the work of John Snow and the Cholera outbreak in London in 1858 provided a base that established an area of research concerned with social inequality and poorer health.

A Scopus Sciverse search using the keywords "socioeconomic status" resulted in almost 69,000 documents (articles, reviews, books, articles in press) since 1939 and refining this search using "health" resulted in 53, 424 documents. Few health outcomes have not been associated with SES, as evident from a refined Scopus Sciverse search using key health and behaviour keywords (Figure 2.2):

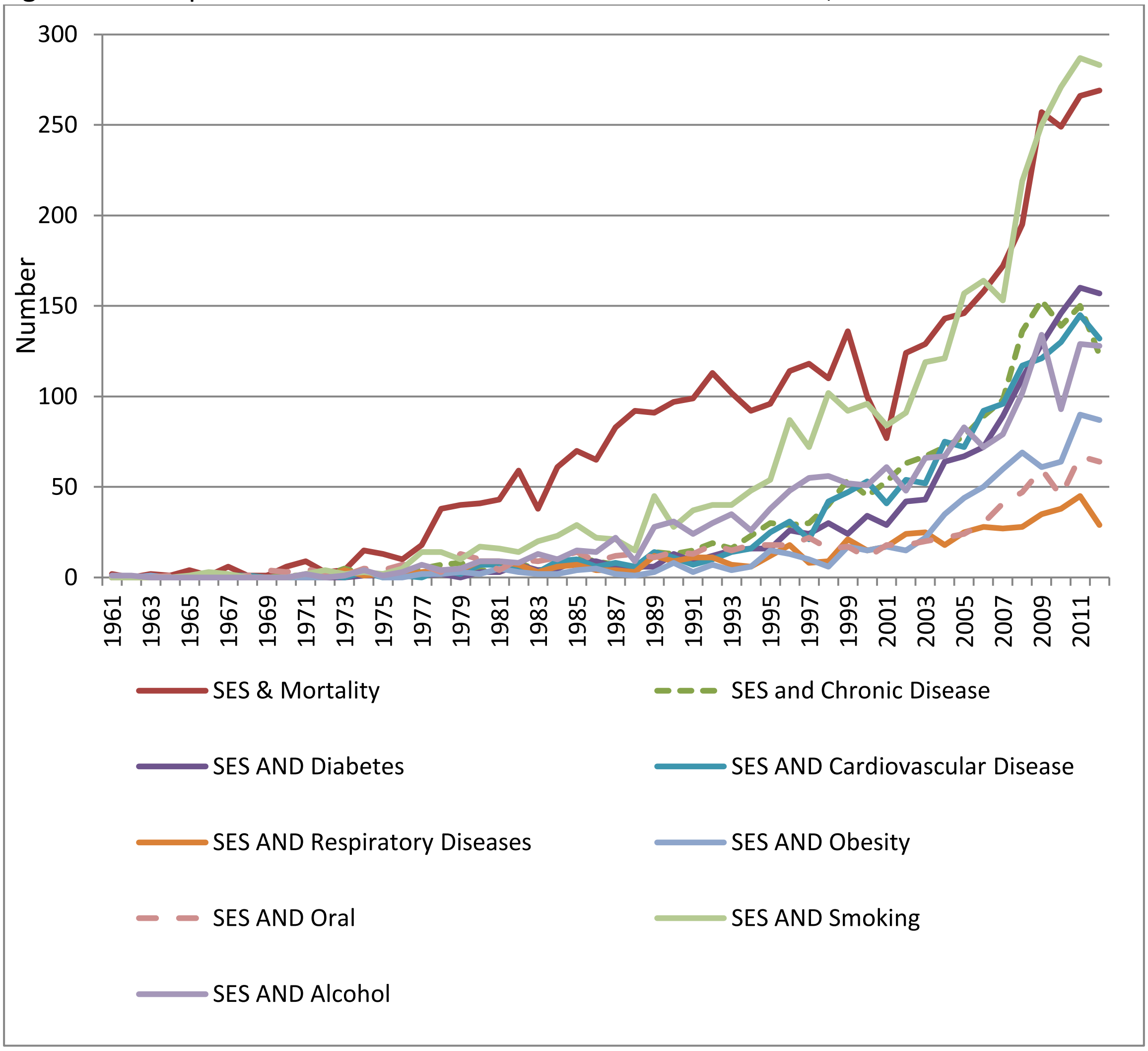
- SES & Mortality;
- SES and Chronic Disease;
- SES AND Diabetes;
- SES AND Cardiovascular Disease;
- SES AND Respiratory Diseases;
- SES AND Obesity;
- SES AND Oral Health;
- SES AND Smoking; and
- SES AND Alcohol Consumption.

Searches were conducted using Scopus, a multidisciplinary navigational tool covering the following subject areas: Chemistry, Physics, Mathematics, Engineering, Life and Health Sciences, Social Sciences, Psychology, Economics, Biological, Agricultural, Environmental and General Sciences. As at November 2012, Scopus accessed 19,500 journals, 400 trade publications, 360 book series and articles in press from 3,840 journals with approximately

49 million records dating back to 1823. The database is updated daily and adds an estimated 2 million records per annum (http://www.info.sciverse.com.ezlibproxy.unisa.edu.au/scopus/scopus-in-detail/facts accessed December 31 2012).

This search resulted in approximately 14,000 documents since 1961. While mortality and smoking are most prominently represented, this search displays a persistent pattern of research activity linking SES and health.

Figure 2.2: Scopus Sciverse Health and Behaviour Search Results, 1961-2013.



Some recent examples include, (Chaix et al., 2007, Chaix, Rosvall and Merlo, 2007, Korda et al., 2007, Næss et al., 2005, Ross et al., 2005) SES and mortality, (Blanc et al., 2006, Chen, Breithaupt and Muhajarine, 2000) SES and respiratory diseases, (Auchincloss et al., 2007, Auchincloss et al., 2009, Chaix et al., 2007, Chichlowska et al., 2009, Dragano et al., 2007, Loucks et al., 2007, Matricciani et al., 2013, Ngo et al., 2013) SES and chronic diseases, (Adams et al., 2009b, Clarke et al., 2010, Fonda et al., 2004, Rehm et al., 2012, Sabanayagam et al., 2007) SES and obesity levels, (Perera and Ekanayake, 2010) SES and oral health and (Adams et al., 2009b, Chuang et al., 2005, De Vries, 1995, Gilman, Abrams and Buka, 2003, Laaksonen et al., 2005), and behaviours such as SES and smoking (Curran et al., 1999, Parker and Harford, 1992), SES and alcohol consumption and even bystander cardiopulmonary resuscitation (Mitchell, Stubbs and Eisenberg, 2009).

Another key study, the "Whitehall Study" (Marmot et al., 1978) was originally established by Professor Donald Reid and Professor Geoffrey Rose in 1967 to investigate the power of risk factors and indicators of coronary heart disease (CHD) to predict mortality (Marmot, 2001) and included approximately 18,000 British civil servants and used employment grade as a proxy for social position. Men in the lower grades of the British civil service had nearly three times the 10 year risk of mortality from coronary heart disease compared with men in the higher grades (Bosma et al., 1997). The study was longitudinal over a seven year follow-up and across all employment grades and showed that men in the lowest employment grades were much more likely to die prematurely than men in the highest grades and that these SES inequalities were not accounted for by differences in well-known risk factors, such as smoking (Marmot et al., 1978). An unintended outcome from this study was the social gradient of health, such that as social position increased, health increased, an association that has been found in almost every developed nation since (Pickett and Pearl, 2001). Michael Marmot has reported on the social determinants of health in many studies since the 1978 Whitehall Study paper, including the Whitehall Study II in 1984 and continues to be one of the leading researchers in this field. The original Whitehall Study and the follow-up study resulted in a vast literature on the social determinants of health and were pivotal in the international interest in the determinants of health and continuing work on the importance of social position to health. The World Health Organisation 'Social Determinant's of Health: The Solid Facts' report authored by Wilkinson and Marmot (1998) was another major landmark report which resulted in the production of similar studies for developed as well as developing nations. This report has been updated (2nd Edition in 2006) and continues to provide the impetus for similar studies from around the globe (See for example):

- *Social Determinants of Indigenous Health*, 2007, Bronwyn Carson, Terry Dunbar, Richard D. Chenhall;
- *Social Determinants of Health in Countries in Conflict: A Perspective from the Eastern Mediterranean Region*, 2008 , WHO Regional Office for the Eastern Mediterranean Region;
- *Closing the Gap in a Generation: Health Equity Through Action on the Social Determinants of Health,* 2008, WHO Commission on Social Determinants of Health, World Health Organization;
- *Social Determinants Of Health: Canadian Perspectives*, 2009 edited by Dennis Raphael;
- *Equity, Social Determinants and Public Health Programs,* 2010, Erik Blas, Anand Sivasankara Kurup, World Health Organization;

- *Social Determinants of Health Among African-American Men,* 2012, Henrie M. Treadwell, Clare Xanthos, Kisha B. Holden et al; and
- The World Health Organization's Social Determinants Commission web page provides a link to publications and studies http://www.who.int/social_determinants/en/

There is a significant body of research linking SES and health, and the next section of this chapter will focus on how SES is classified, measured, collected, and how the measurement of SES differs in the many published studies.

Measuring SES.

As the strong association between SES and health has already been established, it is important to review the measures that are and have been used to represent SES. While the concept is intuitively understood by researchers (Galobardes et al., 2006), SES is not easily defined (Haghdoost, 2012) and it could be argued that a single definition would ignore the social and cultural components which underpin national or regional SES definitions (Bögenhold, 2001, Wilkinson and Pickett, 2007). The aim of this section is to highlight the SES measures that are used most frequently, and document some of the other measures used to represent SES.

SES is frequently implicated as a contributor to the disparate health observed among racial/ ethnic minorities, women and elderly populations (Shavers, 2007). It is a complex, multidimensional concept (Haghdoost, 2012) with the underlying meaning of SES taken as given without the need for a clear description (Galobardes et al., 2006). Consequently, SES is seemingly simple to describe in terms of a person's position on a social hierarchy that may influence their life course and health (Turrell et al., 1999) but an internationally applicable definition is far less straight forward.

Whilst there is no standard or universal definition of SES, there are three measures that are most frequently used to represent SES. Traditionally, SES has been measured using one or all of the “triad” of indicators, income, education and occupation (Bradley and Corwyn, 2002, Braveman et al., 2005, Braveman, Egerter and Williams, 2011, Laaksonen et al., 2005, Matthews, Schwartz and Cohen, 2011, Pickett and Pearl, 2001, Williams et al., 2010). Indeed, looking to the early 19^{th} Century studies, poverty (or lack of income) was generally implicated in relation to poorer health or higher mortality rates.

While many studies used income, education and occupation to express SES, other researchers have included housing tenure (Laaksonen et al., 2005, Lewis et al., 1998, Sykes et al., 1999), housing type (Fuller-Thomson E, Hulchanski J D and Hwang S, 2000, Sabanayagam et al., 2007), number of bedrooms (Chen, Breithaupt and Muhajarine, 2000, Ball et al., 2002, Sykes et al., 1999), overcrowding measures (Corvalán et al., 2005, Dragano et al., 2007), number of offspring (Bradley and Corwyn, 2002, Corvalán et al., 2005, Forastiere et al., 1997), car ownership (Corvalán et al., 2005, Forastiere et al., 1997, Lewis et al., 1998, Sykes et al., 1999), and asset or wealth measures (Auchincloss et al., 2007, Braveman et al., 2005, Lindelow, 2006, Perera and Ekanayake, 2010, Pollack et al., 2007). In addition, efforts have been directed towards developing indices, such as the United Kingdom Index of Deprivation (Department for Communities and Local Government, 2007, Payne and Abel, 2012) or the Australian Socio-Economic Index for Areas (SEIFA) (Australian Bureau of Statistics, 2006a, Australian Bureau of Statistics, 2001c, Australian Bureau of

Statistics, 1998, Australian Bureau of Statistics, 2006b), although these are only available for predetermined spatial geography at the time of the census. Table 2.1 contains a list of measures identified in the literature and draws on the indicators of socioeconomic position constructed by Galobardes and colleagues in 2006.

Table 2.1: Socioeconomic Status Measures.

Group	Indicators

Education	• Years of education completed
	• Level of education completed
	    ○ Primary
	    ○ Secondary
	    ○ Tertiary
	• Parental education (for childhood research)

Income	• Weekly, monthly or annually
	• Individual
	    ○ Actual income
	    ○ Income range
	• Household
	    ○ Actual income
	    ○ Income range
	• Family
	    ○ Actual income
	    ○ Income range
	• As deciles
	    ○ E.g., Lowest quartile
	• Poverty - Proportion below poverty level
	• Housing cost as proportion of income

Occupation	• Occupation
	    ○ Classification of occupation
	    ○ Longest held
	    ○ Parental
	    ○ First
	    ○ Household head

Housing	• Tenure
	    ○ Owned
	    ○ Purchasing
	    ○ Rented
	    ○ Social housing
	• Condition
	    ○ Size
	    ○ Number of bedrooms
	    ○ Overcrowding

	○ Physical condition ○ Age (year built) • Amenities ○ Availability of hot\cold water ○ Heating ○ Inside toilet ○ Common appliances (e.g.,) ▪ Refrigerator ▪ Washing machine ▪ telephone
Employment Status	• employed\unemployed • period unemployed • full time\part time\casual
Wealth	• combined assets and income ○ house value ○ car value ○ investments
Other	• Number of offspring
Composite Indices	• composite measures using all\some of above or additional indicators, such as race\ethnicity\gender • United Kingdom Index of deprivation • Australian Socio-Economic Index for Areas

NB: SES measures presented above may be individual, household or area level. Composite measures are only area level.

Wealth as an SES measure.

As is evident from Table 2.1, there are many indicators used to research SES and health associations. One area of increasing interest is the potential to use wealth as an SES proxy measure. The interest in wealth has been growing in the last 15 years with studies finding stronger associations between wealth and health (Duncan, 2002). In a study looking for an alternative to the traditional education and occupation, Duncan (2002) concluded that wealth and family income were the most powerful associations with mortality. Another study investigating mortality and wealth concluded that policies aimed at closing the health disparities gap in the US may be poorly conceived if they ignore the impact of wealth on premature adult mortality (Bond Huie et al., 2003). A distinction is made between income and wealth; while income may contribute to wealth, wealth is a longer term accumulation and includes interest earnings, stocks, mutual funds and real estate (Bond Huie et al., 2003).

A systematic review of the inclusion of wealth in health studies concluded that health studies should use wealth and that not using wealth could result in an underestimate of the impact of SES on health outcomes (Pollack et al., 2007). Although the systematic review did not find any studies that included property value or found any health association with home ownership, a small number of researchers have looked at property value as an SES indicator (Rehm et al., 2012, Vernez Moudon et al., 2011). The use of property values for SES-health research linked to location is a major component of this thesis, and will be covered in more detail later in this chapter.

The SES measures described above are usually collected either via a survey as self-report data or derived from population census collections. Both forms of data capture have strengths and weaknesses. Self-report data are collected at the level of the individual and are subject to incorrect, non-response issues and socially desirable responses but not ecological fallacy (Robinson, 1950). Area level data, collected via a national census can provide population level data, but it also has incorrect, non-response issues, socially desirable responses and is only released for predetermined spatial units. It is the choice of predetermined spatial units that creates the potential for modifiable area unit problem (MAUP) (Openshaw, 1984).

Both self-report and census data collection methods are subject to the potential issues associated with recall, incorrect responses, non-responses and socially desirable responses especially regarding questions on income and education (Barnett, 1998, Podsakoff et al., 2003, Steenkamp, de Jong and Baumgartner, 2010). Socially desirable responses result when respondents provide answers they believe will provide a better impression and these responses may introduce variations in scale scores or median values (such as income). These have been described as a major issue for survey based research (Steenkamp, de Jong and Baumgartner, 2010). This is of particular concern when these measures are being used to represent SES and the respondents have not correctly stated their income (Moore and Stinson, 2000, Robert and House, 1996, Shavers, 2007, Tourangeau and Yan, 2007).

As stated earlier, SES data are used at the individual level or at an areal unit level. While survey data would be used at the individual level most frequently, it could be used for areal level if the sample were representative and large enough. Census based collections are used at the areal unit level; individual level extrapolations of area-level relationships from census data could generate ecological fallacy (Robinson, 1950). The use of survey or census data could also be subject to the MAUP (Openshaw, 1984) and serious consideration is required for any application of data using areal units.

Table 2.1 provides a listing of commonly applied SES measures that includes composite measures, although this is not a comprehensive listing of composite measures. Many countries construct composite measures, generally calculated by the country Census Bureau, using census variables. Examples of official SES indices include:

- Australia: Socio-Economic Indexes for Areas (SEIFA)
    - Index of Relative Socio-economic Disadvantage

    - Index of Relative Socio-economic Advantage and Disadvantage
    - Index of Economic Resources
    - Index of Education and Occupation
- French Small-Area Index Of Socioeconomic Deprivation (Challier and Viel, 2001)
- New Zealand: (NZDep 2006 Index of Deprivation)
- South African Index of Multiple Deprivation for Children Census 2001
- Swedish Under Privileged Area score
- United Kingdom:
    - The English Indices of Deprivation 2007
    - Scottish Index of Multiple Deprivation 2009
    - Welsh Index of Multiple Deprivation 2008
    - Northern Ireland Multiple Deprivation Measures 2010

While the USA and Canada are notable omissions from this list, researchers from these countries have proposed various census based composite SES measures (Matthews, Schwartz and Cohen, 2011, Messer et al., 2006, Pampalon et al., 2009). Two aspects of SES composite measures are similar across countries, each is a proxy for SES and all are provided for predetermined administrative spatial units. This latter point is of particular concern because of the convenience factor. The availability of an SES measure for a given spatial unit will drive the choice of spatial unit, not a more considered choice based on the research question and the health outcome.

In an Australian context, the area-level SES measure most often used is the Australian Bureau of Statistics (ABS) SEIFA Indexes which have been calculated for the 1996, 2001 and 2006 Censuses (SEIFA for the 2011 Census will be released in 2013) (Australian Bureau of

Statistics, 2001c, Australian Bureau of Statistics, 1998, Australian Bureau of Statistics, 2006b). SEIFA is used in the majority of health-SES analyses due to the lack of SES measures in most administrative health data and the aggregation of data to larger spatial units to protect confidentiality (Glover, Rosman and Tennant, 2004). The practice of using SEIFA in Australian public health analysis has been described as an automatic practice and termed the SEIFA cul-de-sac (McCracken, 2001). This emphasises the earlier point that the choice of spatial unit is often driven by convenience and the availability by predetermined spatial units and the spatial unit is not considered by the researcher as a potential source of bias. It should be noted that despite the SEIFA bias, Australian SES and health researchers also use education, income and occupation and other SES measures. However, SEIFA is widely used because it provides a nationally comparable measure and is available for a relatively small spatial unit in urban areas. The ABS calculated SEIFA for the census collection district (CD), which was the smallest available spatial unit, containing approximately 160-200 households (Australian Bureau of Statistics, 2001b). Of particular note when using census derived SES indices, is that many of the spatial unit boundaries, calculation methodologies and input variables change from one census to the next. In fact, the ABS does not provide temporal comparability, and warns against comparisons of SEIFA from one census to the next (Australian Bureau of Statistics, 2006b).

Consequently, there are a number of issues associated with SES measures including collection quality, non-response bias and the spatial expression of data aggregated to provide outputs for census geographies that may not be suitable when attempting to understand *place* associations. Despite the many studies researching health and SES, the recognition of the importance of *place* is still a major challenge. Many studies rely on SES data presented as averages for predetermined aggregated spatial units, generally with an administrative nature and created without specific research design criteria. Ecological Fallacy (Robinson, 1950) and MAUP (Openshaw, 1984) may be introduced into the analysis as is the potential to mask SES variations within these spatial units.

Even though some authors provide international comparisons of SES (Ross et al., 2005, Wilson et al., 2010), many SES measures used are not directly comparable, and of even greater concern is the choice of spatial units. Whilst SES expressed as income, education and occupation may provide the basis for comparisons nationally and internationally, comparing neighbourhood level SES relying on the notion that the use of the term “neighbourhood” to describe the *place* association, assuming this provides comparability is often flawed and misleading. The use of SES and *place* in research is important, but it has to be built on an informed and common understanding and definition of both elements. Research using SES and *place* at any level (country, state, city etc) must be built upon a clear definition of SES and *place*. National Census agencies do provide the basis for much international SES comparison. However, the matching of SES measures still needs careful management and while this component of the place-SES-health nexus is important it is outside the scope of this work as providing an improved understanding of *place* is the raison d'être here. This literature review has highlighted a number of key issues:

1. long standing association between SES and health;
2. although not directly comparable, much of the SES and health research use income, education and occupation as a proxy for SES;
3. SES is reported at the individual level and area level;
4. there are issues associated with data capture for both individual and census collections;

5. composite SES indexes are provided for predetermined administrative spatial units;
6. many predetermined spatial units are designed for purposes other than geographic analysis. For example, the Australian Census Collection District (CD) is designed as the two week workload of a census collector. Despite this, the CD has become a standard unit for health analysis in Australia:
7. area based SES measures may be subject to both ecological fallacy and the modifiable areal unit problem.

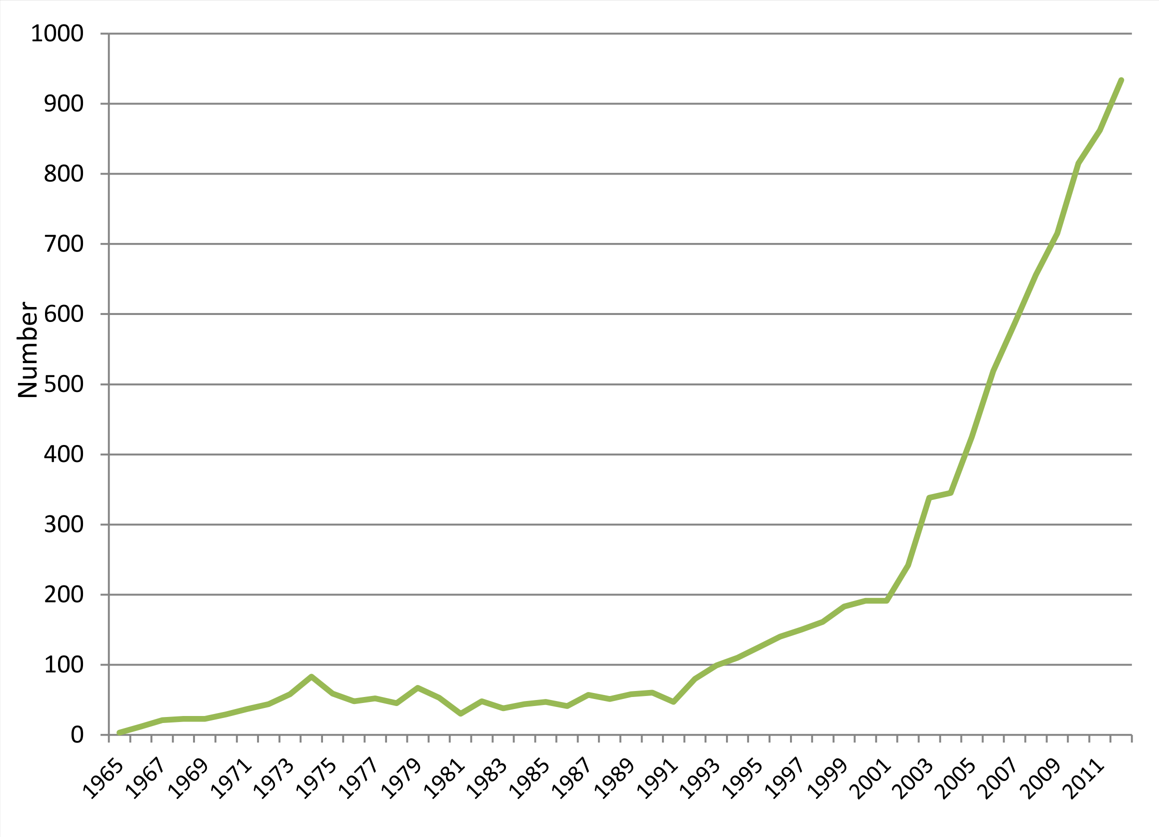
It is the use of areal units or "*place*" in health research and how appropriate spatial representations can be incorporated into place and health research which are of concern here. Thus far the measurement of SES has been examined, the next section will focus on how *place* is being applied in health research.

Place, SES and Health

With all of the attention focussed on SES and health and the differences evident across countries, the inclusion of *place* at a finer spatial scale is not surprising, although as reported earlier in this chapter, for many years *place* was not a major research theme.

A further literature search was conducted looking at the link between *place* and health. Figure 2.3 displays the results of a Scopus Sciverse search using the key words neighbourhood (the most common proxy term in the literature for *place*) and health. This search highlighted two key points, the modest interest in *place* research before the 1990s and the sharp increase in the literature reporting neighbourhood since the 1990s. The increase has been marked, there were approximately 50 studies in 1991, and by 2012 there were more than 900, an increase of almost 19 times.

Figure 2.3: Scopus Sciverse *Place* and Health Search Results, 1965-2012.



The marked increase in neighbourhood and health research after 1991 has been reported by several authors (Bernard et al., 2007, Coulton, Chan and Mikelbank, 2011, Gauvin et al., 2007, Haynes et al., 2007, Macintyre, Ellaway and Cummins, 2002, Ross, Tremblay and Graham, 2004, Spielman and Yoo, 2009). Of particular relevance for this thesis, Diez-Roux (2001) and Pickett and Pearl (2001) noted the increased inclusion of spatial post the 1990s and challenged researchers to consider whether the choice of spatial unit was appropriate for the study question and the causal pathways. This stemmed from an issue long recognised by geographers, the modifiable areal unit problem (Arbia and Petrarca, 2011, Flowerdew, 2011, Fotheringham and Rogerson, 2009, Openshaw, 1984, Sexton, 2008) but not recognised as an issue or limitation in many of the *place* and health studies.

To gain more insight into the level of recognition of the MAUP in the *place*-health literature, the earlier Scopus Sciverse search results for “neighborhood AND health” were searched using “modifiable areal unit problem”. Of the nearly 10,000 results from the initial search, only 56 referenced MAUP. As the interest in the association with neighbourhood increased after 1991, the search was limited to later than 1990. This did not change the result as all 56 were later than 1990 and in fact most were post 2005. A final search within the 933 “neighborhood and health” search results for 2012 using the same search term “modifiable areal unit problem” or “MAUP” resulted in only 14 documents.

The recognition that using predetermined administrative spatial units may introduce MAUP and the little attention this has received in the literature has been reported by a small number of authors (Chaix et al., 2009, Cockings and Martin, 2005, Gauvin et al., 2007, Haynes et al., 2007, Hayward, 2009, Parenteau and Sawada, 2011, Riva et al., 2008, Stafford, Duke-Williams and Shelton, 2008). However, there is a growing recognition of the importance of the impact the choice of spatial unit in health research (Chaix et al., 2009, Cummins et al., 2007, Diez-Roux, 2000, Diez-Roux, 2001, Feng et al., 2010, Foley, 2009, Gauvin et al., 2007, Macintyre, Ellaway and Cummins, 2002, Macintyre, Maciver and Sooman, 1993, Riva et al., 2008, Ross, Tremblay and Graham, 2004, University of California n.d.), but there are still studies (the many studies in 2012) that use spatial data without any acknowledgement of the MAUP (Berry et al., 2010b, Black and Macinko, 2010, Hoehner et al., 2011). Often this involves the use of “neighbourhood” without a clear definition, as described by (Galster, 2001),

> “Urban social scientists have treated ‘neighbourhood’ in much the same way as courts of law have treated pornography: as a term that

is hard to define precisely, but everyone knows it when they see it. Yet, even a cursory survey of definitions in the literature reveals some crucial differences in what the implicit 'it' is" (p. 2111).

Guo and Bhat (2007) also highlight the issue regarding the definition of a neighbourhood and the use of predetermined administrative spatial units as a neighbourhood surrogate,

> ''.. the spatial definition of neighborhood has received very little attention in the literature. Theoretical studies of neighborhood effects often use the term neighborhood rather loosely. …….On the other hand empirical studies of neighborhood effects across many disciplines typically used census tracts, zip code areas, or transport analysis zones as operational surrogates for neighborhoods'' (p. 31).

There are two fundamental issues here: 1) the lack of a clear definition for neighbourhood and; 2) the use of predetermined administrative spatial units as a proxy for neighbourhood. This reinforces the search results presented above which found few studies listing MAUP and the resultant lack of understanding the choice of spatial unit may have on the analysis due to MAUP. These issues raise the question as to which spatial unit is the most appropriate when analysis results may be different depending on the choice made (Coffee and Lockwood, 2012).

There are some notable exceptions to the above issues. Researchers who understand MAUP and the potential problems this may pose have critiqued the widespread use of predetermined administrative spatial units and offered both challenges to be more deliberate in the choice of spatial units and create more meaningful spatial areal units (Bodea et al., 2008, Chaix et al., 2009, Cockings and Martin, 2005, Daniel, Moore and Kestens, 2008, Flowerdew, Manley and Sabel, 2008, Foley, 2009, Haynes et al., 2007, Hayward, 2009, Riva et al., 2008, Riva et al., 2009, Sabel et al., 2012, Schuurman et al., 2007, Spielman and Yoo, 2009, Stafford, Duke-Williams and Shelton, 2008). However, in the context of the vast literature, there is still a gap between what is mostly understood in geographic research (although not always acted upon) and how this understanding can flow to health research through multidisciplinary team approaches.

Another *Place*-Health perspective was proposed by Macintyre, Ellaway, & Cummins, (2002) and further developed in Cummins et al (2007) that questioned the context-composition approach and suggested a more universal, relational approach to link *place* and health. This work reiterated the post 1990s resurgence of interest in researching the impact *place* may have on health outcomes and highlighted the way context and composition were framed in the *place*-health research as:

> "…………mutually exclusive and competing explanations for health inequality" (Cummins el al, (2007; p. 1826).

While recognising the value of the earlier empirical research and identifying potential gaps, Cummins et al., (2007) proposed a relational approach that called for the incorporation of the causal pathway and recognised the relationship between environmental characteristics and individual health. Whilst not explicitly focused on the MAUP or the use of predetermined administrative spatial units, the critique by Macintyre, Ellaway, & Cummins,

(2002) and the relational method described by Cummins e al., (2007) stressed the need to consider qualitative as well as quantitative approaches to understanding the way *place* may impact on health and the strength of association. While not directly linked with the focus of this thesis and the choice of spatial unit it does align in the need for more informed and theoretical basis for researching *place* and health relationships.

The literature review has highlighted several major issues and challenges to the use of *place* in health research. That SES is a significant predictor of health outcomes is beyond question, the vast literature outlined in this chapter is testament to this. The gradient of SES is also now well established as is the association between SES and *place* and *place* and health. What is still to be achieved is a more informed use of *place* in health. The rigour that most health researchers apply to the study methodology and data reliability should be applied to the choice of spatial unit. Researchers should be more explicit in clearly stating that the spatial unit was used because the data were only available at that spatial scale, and include this in the limitations section with a reference to the potential for MAUP. The next section continues the themes of SES and *place* research and introduces the use of wealth and the emergence of property as an additional or alternative spatial expression of SES.

Residential Property as an SES Measure

Traditional SES measures were described earlier in this chapter and reference was made to a recent area of research interest, the use of wealth as an SES measure. Wealth as an indicator of SES represents the influence of wealth accumulation. Residential property may well be the most valuable asset owned by most individuals and therefore it can provide the basis for a residential property wealth indicator reflecting SES. Overall, home equity was reported to account for 21% (on average) of US household net wealth, and 50% for low SES household net wealth (Di, Yang and Liu, 2003). Residential property is a major asset and this provides the basis of its use as a wealth SES indicator. In addition to its general population utility as a SES measure, it provides a better indicator for retired person's employment status and income may not represent the true SES situation (low income and not in the labour force) while they are possibly quite asset rich and may be classified as low income, even though they may be asset rich (Allin, Masseria and Mossialos, 2009, Gornick, Sierminska and Smeeding, 2009, Robert and House, 1996). Traditional measures do not accurately reflect SES for this group, nor does income reflect wealth per se as the income question is generally only about current income and does not include accumulated wealth, which can be substantial (Adams et al., 2009b). A small number of researchers have included a wealth measure of SES for SES-*place*-health research (Bond Huie et al., 2003, Braveman et al., 2005, Pollack et al., 2007, Rehm et al., 2012, Vernez Moudon et al., 2011). Wealth and property are important at the individual level and as a major component of an economy's gross domestic product (GDP) (Gibb and Hoesli, 2003) which reinforces the role of property ownership to society generally. An understanding of housing market structures was reported to be fundamental to understanding a society's wellbeing (Rothenberg et al., 1991).

Location is generally considered to be the "three (location, location, location)" most important contributors to residential property value as is the associated social geography (Bourassa, Hoesli and Peng, 2003). Residential property is typically immovable and this is the basis for making location a prime residential property value determinant (Galster, 1996). An understanding of the immovability of residential property value and how the value of more or less desirable residential property could be related to location is crucial in its use as an SES measure (Coffee and Lockwood, 2012).

Residential property location and the acknowledgement that a group of residential properties may be more or less valuable based on location is often described as a residential property market. While a method for determining the spatial boundaries of property submarkets is still undecided, it is generally accepted that residential property markets exist and can be comprised of submarkets (Watkins, 2001). It is critical that property submarkets should not be derived using *a priori* areas such as suburbs or postcodes, but derived from the data (Adair, Berry and McGreal, 1996) using both spatial and structural identifiers (Watkins, 2001). These data should represent the underlying residential property real estate market structure of the study area and not rely on selected residential property characteristics such as size, style, age, number of bedrooms etc (Bourassa et al., 1999, Bourassa, Hoesli and Peng, 2003, Maclennan and Tu, 1996).

As well as property characteristics and/or socio economic geography, a residential property market structure should also include an expression of price (market) to give it an economic entity status (Pryce, 2004). Identifying all of the attributes that contribute to the underlying market structure is one of the major issues, as the quantity of locational attributes is almost limitless (Orford, 1999). Locational attributes often serve as a 'proxy' for the numerous unobserved attributes affecting residential property value (Pavlov, 2000). Gallimore, Fletcher and Carter (1996) developed a methodology which isolated the effects of location to the error term of a hedonic regression model, simplifying the need to account individually for the many attributes, but still capturing their effect on value. This was achieved by describing price in terms of observable residential property characteristics, but remaining deliberately 'blind' to location and assuming the error term as a proxy for the deliberately omitted location variables. This methodology was applied in this thesis (papers one and two) to provide the means for determining the relative value of location to a study area mean and is termed the Relative Location Factor (RLF) (for more detail see Coffee and Lockwood, 2012). The resulting relative property value (RLF) represented the relationship between *place* (where you live) and SES as the important relationship when studying health outcomes.

The relative nature of the RLF provided the important link between the residential property value focus on 'where you live' rather than the 'absolute value of the residential property you live in' as being the important ingredient when developing an individual residential property level SES metric. The use of RLF allowed analysis to be potentially free of the MAUP (Openshaw, 1984), ecological fallacy (Robinson, 1950) and provided a better understanding of any local spatial variation occurring across space than tradition predetermined administrative spatial units. The use of residential property or housing value in health research is an emerging literature linking residential property value and SES and includes the use of Council Tax Valuation Bands (CTVB) in the United Kingdom (UK) (Fone et al., 2006) and property values in the USA (Rehm et al., 2012, Vernez Moudon et al., 2011).

The UK study (Fone et al., 2006) used 8 CTVB bands and reported associations between many health and lifestyle outcomes and SES expressed as property value classes (CTVB). Another study used residential property value to test the relationship between obesity and area level SES in Seattle (Vernez Moudon et al., 2011). The results from this Seattle study concluded that the residential property level measure was more predictive than area-level SES in identifying fair or poor health status (Vernez Moudon et al., 2011). Obesity was the outcome of a study which used the Seattle Obesity Study data and the assessed value of study participant's house as the SES measure. In this study, women in the bottom quartile of property values were 3.4 times more likely to be obese (Rehm et al., 2012). This study also concluded that property values may provide a novel and objective SES measure for future health studies. Australian studies have shown how the variation in socio economic indicators was correlated with the variation in median house price movement when aggregated to the same spatial unit (Jackson, Kupke and Rossini, 2007, Reed, 2001).

It is important to stress that the RLF methodology proposed in this thesis is a relative residential property wealth SES measure rather than an absolute property value. In this way, RLF overcomes the problem of two neighbours having significantly different absolute property values while both belonging to similar or the same SES sub group or two residential properties in different locations with the same absolute value but different RLF scores. This provided a more reliable indication of SES through an inherently better underlying sense of '*place*' and removed the potential for distortion due to specific residential property differences. The details of the methodology for creating RLF is contained in the peer reviewed paper (Chapter five) and an analysis which used the RLF SES measure and tested for an association with six chronic health outcomes and a cardiometabolic risk factors score (Chapter six).

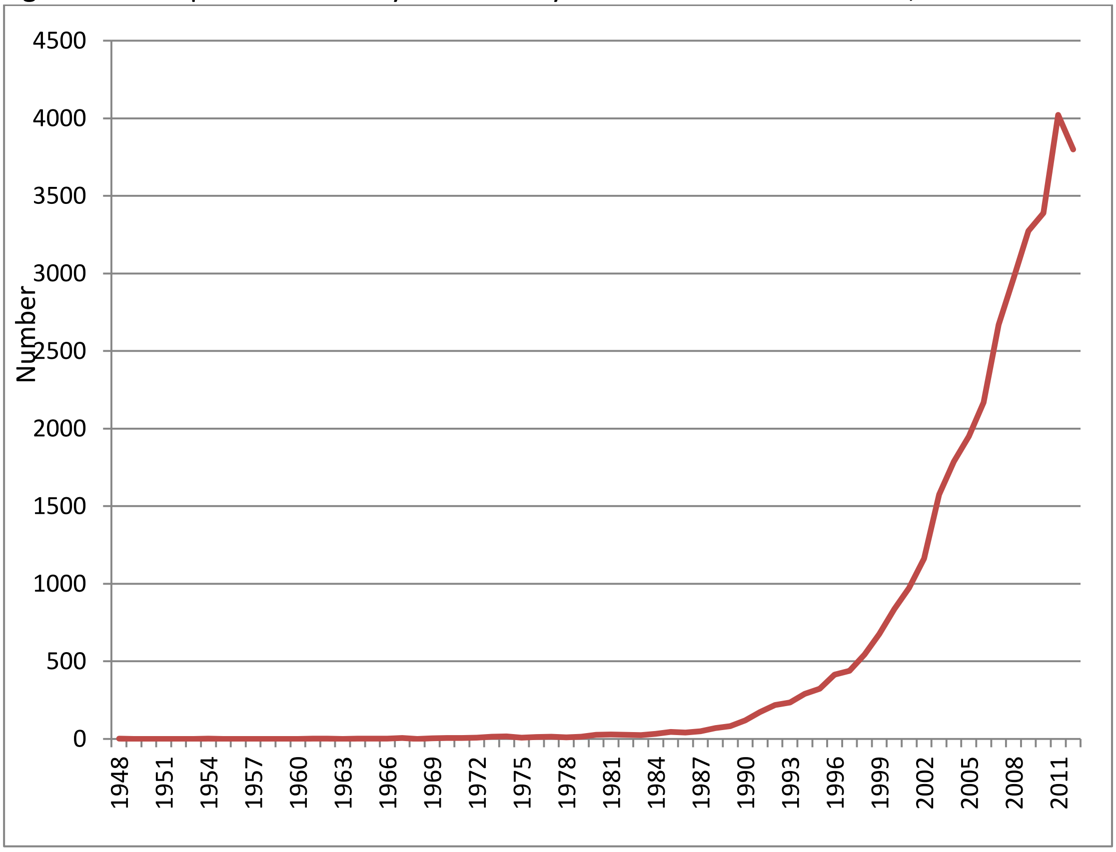
RLF was designed to provide an objective wealth SES measure that is spatial as well as add to an emerging area of research interest that could be used to promote an improved use of *place* for health researchers. The next section of the literature review continues with the theme of spatially informed health analyses and tackles the challenges proposed by Brownson et al.(2009 and Diez-Roux (2001) to select spatial units appropriate to the research question and the health outcome, and to consider testing across multiple spatial units.

Built Environment Walkability

As discussed, the use of spatial analysis and *place* association has increased since the 1990s and this has resulted in a recognition that *place* matters, and neighbourhood (notwithstanding the lack of a standard definition for neighbourhood) associations have been increasingly reported across a vast number of health outcomes and behaviours. Another key subject area for spatial associations in health is the influence that *place* may have on levels of physical activity. This stems from the many studies that have shown that moderate levels of physical activity can lower obesity and the risks of chronic diseases such as type 2 diabetes, cardiovascular disease, hypertension and cholesterol (Morris and Hardman, 1997, US Department of Health and Human Services, 1996). Since the seminal report from the US Surgeon General (US Department of Health and Human Services, 1996) the positive health benefits of physical activity in reducing the risk of chronic diseases have been well established (Andersen, 2007, Bauman, 2004, Brown, 2004, Hamer and Chida, 2008, Lee and Buchner, 2008a, Morris and Hardman, 1997).

As was the case with SES and health research, there is a plethora of physical activity and health literature. A Scopus search using “physical activity” and health resulted in 34,650 documents (Figure 2.4). This search was restricted to literature from the following subject areas and only articles, review and conference papers; medicine had the most (32,491), followed by the health professions (4,222), nursing (4,063), and social sciences (2787).

Figure 2.4: Scopus Sciverse Physical Activity and Health Search Results, 1948-2012.



Similar to the search results presented earlier, there has been an increase in the number of papers since the late 1980s. This is evident from the search results related to physical activity and health above, some examples are included to highlight the vast literature, (Alfonzo, 2005, Andersen, 2007, Bauman, 2004, Bauman et al., 2002, Berke et al., 2007, Berlin and Colditz, 1990, Biddle, Gorely and Stensel, 2004, Boone-Heinonen et al., 2009, Brown, 2004, Brownson et al., 2001, Bull and Bauman, 2011, Bull et al., 2010, Charreire et al., 2010, Cooper et al., 2005, Cooper et al., 2006, Diabetes Australia, 2010, Dishman, 2004, Dunn, Andersen and Jakicic, 1998, Ewing et al., 2003, Frank et al., 2007, Giles-Corti et al., 2005, Giles-Corti et al., 2009, Global Advocacy Council for Physical Activity, 2010, Hagstromer, Oja and Sjostrom, 2007, Hamer and Chida, 2008, Department of Health, 2005, Kesäniemi et al., 2010, Kokkinos, 2010, Kwasniewska et al., 2010, Larouche and Trudeau, 2010, Lee and Moudon, 2004, Lee and Buchner, 2008a, National Institute for Health and Clinical Excellence, 2010, Ogilvie et al., 2007, Physical Activity Guidelines Advisory Committee, 2008, Population Research and Outcome Studies Unit, 2007, Pucher et al., 2010, Ready et al., 1996, Rojas-Rueda et al., 2011, Rosenberger, Bergerson and Kline, 2009, Sallis, Bauman and Pratt, 1998, Simpson et al., 2003, Stamatakis, Hirani and Rennie, 2009, Thomas, 2007, Thompson Coon et al., 2011, Troiano et al., 2008, Vogel et al., 2009, Wendel-Vos et al., 2004).

As was the case with SES and health, the case for the “health benefits-physical activity” association is accepted. Moderate level physical activity has been identified as one of the best investments for individual and community health and plays a crucial role in the prevention and management of a range of chronic diseases (Bauman, 2004, Brown, 2004, Hamer and Chida, 2008, Lee and Buchner, 2008b, Morris and Hardman, 1997). At least 40 years of epidemiological research evidence from quality cohort studies supports the associations between physical activity and chronic disease outcomes (Bauman, Owen and Leslie, 2000). Morris and Hardman (1997) concludes that physical activity is the “best buy” for public health as exemplified by the numerous health benefits associated with walking, including, physical fitness, strength, bodyweight, metabolism, blood pressure, mental health and cardiovascular disease. The health benefits of physical activity or moderate level walking to reduced risk of chronic diseases have been the subject of numerous studies (Andersen, 2007, Bauman, 2004, Berlin and Colditz, 1990, Brown and Bell, 2007, Brown, 2004, Bull and Bauman, 2011, Bull et al., 2010, Hamer and Chida, 2008, Kesäniemi et al., 2010, Lee and Buchner, 2008a, Physical Activity Guidelines Advisory Committee, 2008, Zheng et al., 2009), with associations reported between age (Andersen et al., 2006, Biddle, Gorely and Stensel, 2004, Briganti et al., 2003, Vogel et al., 2009), gender (Boone-Heinonen et al., 2009, Manson et al., 1999, Ready et al., 1996) and SES (Adams et al., 2009b, Cerin, Leslie and Owen, 2009, Kamphuis et al., 2009). The most common form of adult physical activity, walking can be undertaken at most ages for transport, leisure or health (Kruger et al., 2008, Lakka and Laaksonen, 2007, Rafferty et al., 2002, Saelens, Sallis and Frank, 2003). Walking is a simple, universal and readily available form of physical activity (Lee and Buchner, 2008b, Morris and Hardman, 1997).

A systematic review of walking and health benefits reported that men who walked 5-10 kilometres per week had a 13% reduction in risk of coronary heart disease (CHD) than men who walked less and women who walked more than one hour per week had a 14% reduction than women not walking (even after adjusting for smoking, diet, use of postmenopausal hormones and parental history) (Lee and Buchner, 2008a). The current Canadian Physical Activity Guidelines (http://www.csep.ca/) report that a gross energy expenditure of approximately 4.2 MJ/week (1,000 kcal/week) was estimated to be associated with at least a 20% lower risk for premature all-cause mortality and that a consistently inverse relationship between physical activity and cardiovascular disease exists with a mean of 33% lower risk for the most active compared to the least active groups and this risk reduction was observed in both men and women and in Caucasian as well as non-Caucasian populations (Kesäniemi. et al., 2010).

While it is clear that walking is good for health, getting people walking is not straightforward. A survey in the US reported that 20% of adults had not walked in the past 30 days during the summer of 2002 (National Highway Traffic Safety Administration. and Statistics., 2002). A more recent study in Perth, Western Australia, reported similar results with 26% not walking (Health Promotion Evaluation Unit, 2009). A longitudinal analysis of walking trends in the US reported 26% of men and 40% of women walked for leisure in 1986 and the proportion had increased to 29% for men and 47% for women by 2000 (Simpson et al., 2003). This research highlighted the theme common to many of these studies that getting more people walking would improve health, decrease chronic disease incidence and reduce the cost of health provision. Why people walk (or don't walk) is a research focus investigated for both individual and population factors that influence walking. Many programs aimed at encouraging physical activity have been established over the past thirty years. In Australian these include:

- Life Be In It (http://www.lifebeinit.org/);
- A Healthy and Active Australia (http://www.healthyactive.gov.au/);
- Be Active (http://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/SA+Health+Internet/Healthy+living/Be+active/); and
- 10,000 Steps (http://www.10000steps.org.au/).

In the US health promotion programs include:

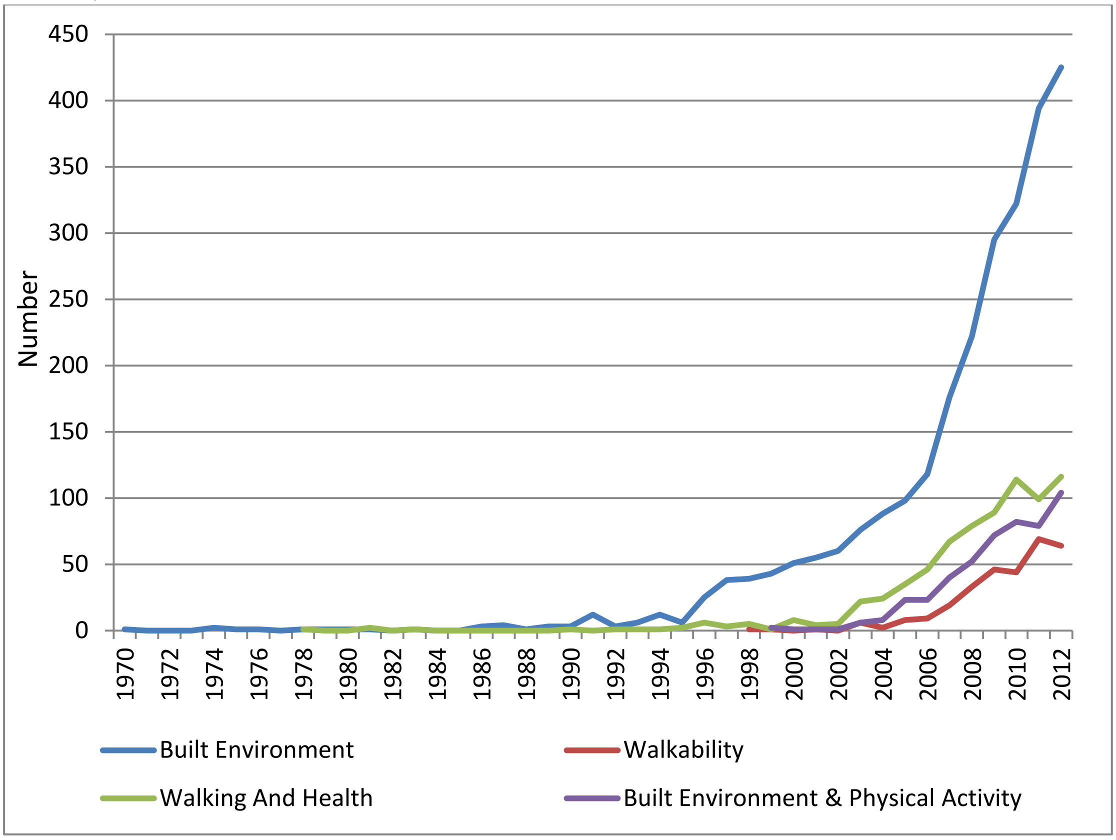
- the President's Challenge (https://www.presidentschallenge.org/);
- healthy people 2020 (http://www.healthypeople.gov);
- Let's Move (http://www.letsmove.gov/); and
- the CDC' Promoting Lifelong Physical Activity (http://stacks.cdc.gov/view/cdc/19147).

Current guidelines recommend 30 minutes of moderate level walking per day (American Heart Association, 2012, Department of Health and Ageing, 2009, SA Health, 2012). Consequently, as the goal of many state and national health agencies is to promote physical activity, particularly walking for the health benefits, Healthy People 2010 (US Department of Health and Human Services 2000) targeted a 50% increase in walking trips for adults for trips of less than 1 mile (Saelens, Sallis and Frank, 2003). Despite the national programs promoting healthy lifestyles, about one-half of the Australian adult population was insufficiently active for health gain and similar results are reported for other industrialised countries (Bauman, 2004, Bauman et al., 2002, Owen et al., 2007, Owen et al., 2004, Sallis, Bauman and Pratt, 1998, Sallis et al., 2009, Troped et al., 2001). As these programs had only partial success, research looked for other factors that could influence walking behaviour. Two main research themes emerged, individual and community level influences and the environmental influences of physical activity. The first theme of study is not directly pertinent to this research and is not included in this review. The second theme is the basis for this study and provides part of the rationale for creating an index of walkability.

The research into the impact of environmental influence (typically described as the built environment) and physical activity is the link with the work in this thesis as this area is principally interested in spatial aspects of the built environment. Built environment has become a major focus of research and continues to provide evidence from many countries of the association between the built environment and physical activity and walking (Adams et al., 2011, AIHW, 2011, Allender et al., 2009, Badland et al., 2009, Berke et al., 2007, Booth, Pinkston and Poston, 2005, Dygryn, Mitas and Stelzer, 2010, Frank et al., 2005, Gordon-Larsen et al., 2006, Handy et al., 2002, Lee and Moudon, 2006, Lee, Ewing and Sesso, 2009, Lovasi et al., 2008, Renalds, Smith and Hale, 2010). A search of the Scopus database using several search phrases illustrates the level of absolute interest in walkability research and the increase since the 1990s. Search phrases were, “built environment”, “walking and health”, “built environment and physical activity” and “walkability” (Figure 2.5).

While the absolute numbers might contain some double counting (it is almost certain that all the papers in the subset searches would also be in the overall built environment result due to the use of multiple keywords), the important aspect is the sharp increase since the 1990s. It is the recent interest in the built environment that has created the level of interest in using spatial data to represent aspects of the built environment. The vastly improved personal computer (PC), geographic information system (GIS) software and availability of spatial data provided a greater potential to create objective spatial expressions of the built environment. One interesting aspect of work on the built environment is its multidisciplinary nature, with transport planners, town planners, geographers, epidemiologists and public health researchers working independently and in multidisciplinary teams. The International Physical Activity and Environment Network (IPEN) is an excellent example of multidisciplinary research. IPEN is both multidisciplinary and transnational with 12 participating countries bringing together researchers from the disciplines listed above, for more detail see the IPEN website (http://www.ipenproject.org/index.html).

Figure 2.5: Scopus Sciverse Built Environment, Walking, Health and Walkability Search Results, 1970-2012.



Built environment research has investigated a range of factors that categorise walk supportive elements of the built environment (Forsyth et al., 2008, Handy, 1996a, Handy, 1996b, Handy et al., 2002, Sallis, Bauman and Pratt, 1998). The focus for this thesis is the concept of neighbourhood built environment walkability expressed using the themes of connectivity and proximity (Cervero and Kockelman, 1997, Frank, Andresen and Schmid, 2004, Frank et al., 2005, Krizek, 2003, Lee and Moudon, 2006). Walkability for the purpose of this study is operationalised as population or dwelling density, intersection density, land use diversity and retail space footprint ratio to car parking area (Adams et al., 2009a, Frank et al., 2010, Frank et al., 2009, Frank et al., 2005, Learnihan et al., 2011, Lee and Moudon, 2006, Leslie et al., 2007, Lovasi et al., 2008, Smith et al., 2008, Van Dyck et al., 2010a). This walkability construction methodology underpins the 12 studies that are part of the IPEN project and was purposely chosen for this thesis to provide comparability. Walkability has been used to investigate associations with walking and physical activity (Berrigan, Pickle and Dill, 2010, Berrigan and Troiano, 2002, Cerin et al., 2007, Cerin, Leslie and Owen, 2009, Craig et al., 2002, Frank et al., 2006, Learnihan et al., 2011, Lovasi et al., 2008, Owen et al., 2007, Sallis et al., 2009, Van Dyck et al., 2010c), and obesity and body mass index (BMI) (Berke et al., 2007, Booth, Pinkston and Poston, 2005, Brown et al., 2009, Frank et al., 2008, Grafova et al., 2008).

Results of the research investigating associations between the built environment and walking are mixed with some studies report greater levels of walking for transport (Berrigan, Pickle and Dill, 2010, Cao, Handy and Mokhtarian, 2006, Cerin et al., 2007, Cervero, 1996, Cervero and Kockelman, 1997, Craig et al., 2002, Frank et al., 2006, Huang et al., 2009, Owen et al., 2007, Sundquist et al., 2011, Van Dyck et al., 2010b), while others reported no association with total walking time (Ewing, 2005, Forsyth et al., 2008, Learnihan et al., 2011, Lovasi et al., 2008, Oakes, Forsyth and Schmitz, 2007).

The construction of an objective walkability index using GIS was the subject of previous work by this author, both as part of the physical activity in localities and community environments (PLACE) study (Leslie et al., 2007, Owen et al., 2007) and for a Masters Thesis in 2005 (Coffee, 2005). It is not the purpose in this work to repeat the earlier method development work. The aim here is to build on my earlier work with a view to validating the index and taking account of the work since 2005, particularly the selection of spatial units and testing with a health outcome.

Built environment measures are expressed spatially, yet as is the case with SES and health, the choice of spatial unit used or its size (scale) or the modifiable areal unit problem (MAUP) are frequently understated. Geographers have studied the MAUP for many years (Fotheringham, Brunsdon and Charlton, 2002, Fotheringham and Rogerson, 2009, Fotheringham and Wong, 1991, Openshaw, 1977, Openshaw, 1984, Parenteau and Sawada, 2011) and, despite the level of attention directed towards the issues and possible solutions, few publications in the field of public and population health consider the MAUP when reporting their findings from spatial analysis (Root, 2012). *Place* and health researchers would appear to select and analyse predetermined administrative spatial units without the level of scrutiny typically applied to their choice of variables, the reliability and validity of data capture techniques, and the specification of an appropriate statistical methodology. A recent example from Australia investigates whether the built environment can reduce health inequalities and walking for transport highlights this issue (Turrell et al., 2013). This study is in Brisbane, Queensland using the HABITAT data. The spatial unit selected was the census collector district (CD). This choice is described as the smallest administrative unit available from the ABS. The authors then justify this choice with the statement that:

> "In urban areas such as Brisbane, a CD contains an average of 200 private dwellings which are **deemed** to be relatively homogeneous in terms of their socioeconomic characteristics. CDs are embedded within a larger suburb, hence the area corresponding to, and immediately surrounding, a CD is likely to have meaning and significance for their residents: for this reason, we hereafter use the term 'neighbourhood' to refer to CDs" (p. 91) (author's emphasis).

However, the ABS designed the CD to contain the number of dwellings one collector could deliver and collect census forms from in the two week census collection phase of the five yearly national census collection cycle. The CD was a spatial unit designed around the workload of a collector, not socioeconomic homogeneity and does not warrant being "deemed" appropriate. It is the "deemed to be" statement that is of most concern as without testing or evidence of homogeneity the CD is now both homogenous and a neighbourhood. In addition Turrell et al.(2013) does not mention the MAUP or list the spatial unit choice as another limitation. It should be stressed that this is a 2013 publication and reflects contemporary practise. While the CD has become a defacto neighbourhood spatial unit in Australia, it was not designed for this purpose and its continued use provides legitimacy that is not warranted and should be subject to more scrutiny. These examples of inappropriate practice provide the underlying rationale for this thesis and highlight the need for methodological debate regarding the use of *place* in health. It is clear, or at least it should be, that the choice of spatial unit is just as important as the choice of the data, reliability of the data and the analysis methodology. It should not be dismissed with a simple statement that it is acceptable or that this was the only unit that the data were available for and consequently this spatial unit is deemed to be a neighbourhood for this study.

A few key review articles in the past five years have looked at *place* in health research and critiqued the issues highlighted in this chapter. Gauvin et al.(2007) recognised the increasing use of spatial units and described the challenge of delineating spatial units as,

"a conundrum – a vexing riddle that continues to elude a satisfactory solution" (p. S18).

This scoping study described the spatial units as either predetermined administrative boundaries or statistical boundaries and reported that most studies use one of these or a combination of both units. Aggregating the smaller territorial units (Canadian Units) was proposed, but it was recognised that this would not address the MAUP and that defining appropriate spatial units was still a challenge that was yet to be solved (Gauvin et al., 2007).

Using predetermined administrative spatial units has been described as " spatial units of convenience" within the context that research evidence for variations in health between areas was clear as was the potential for area context to help explain the variation (Riva et al., 2008). Riva et al.(2008) also raised the challenge of operationalising relevant spatial units and the associated problems of validity given that different scales or spatial units would be required for different contexts or health outcomes. Riva and colleagues (2008) classified the built environment into seven zones and tested how well the census tracts contained these different environment zones. Overall, the environment zones were not well contained in census tracts as almost half the zones straddled two or three tracts and a further 21 percent of zones were spread over four tracts (Riva et al., 2008). MAUP was also highlighted within the context of defining relevant geographic areas the associated problems of both scale and zonation and the potential for MAUP to mask area effects. Brownson et al., (2009) reviewed 50 public health and travel studies that used GIS to characterise the built environment and suggested that the development and evaluation of measurement properties is still in the early stages. GIS as a tool was described as the only way to create objective measures, but the review identified considerable variation of measures and spatial units. Spatial units included a range of administrative spatial units, Euclidian buffers and road network buffers. MAUP was also highlighted coupled with the issue of artificial spatial patterning associated with spatial units of differing sizes and aggregation levels (Brownson et al., 2009). Table 2.2 displays the spatial units used in the studies using GIS to create environmental measures.

Table2.2: Comparison of Spatial Unit Choice.

Administrative Units	**Description**
Cervero (1997)	Census tract
Ewing (2004)	Traffic analysis zones
Frank (1994)	Census tract
Kockelman (1997)	Traffic analysis zones & census tracts
McNally (1997)	Neighborhood
Rodriguez (2004)	Commute route
Ewing (2003)	County & Metropolitan Area
Ball (2007)	Neighborhood
Doyle (2006)	County
Hillsdon (2007)	Super Output Area (England)
Michael (2006)	Neighborhood
Burdette (2004)	Neighborhood
Ewing (2006)	County
Lopez (2004)	Metropolitan area
Ross (2007)	Census tract & metropolitan area
Rundle (2007)	Census tract
Euclidian Buffer (single buffer)	**Distance**
Boer (2007)	0.25 mile
Braza (2004)	0.5 mile

Gomez (2004)	0.5 mile
Gordon-Larsen (2006)	0.5 km
Nelson (2006)	3 km
Rutt (2005)	0.25 mile
Cohen (2006)	0.5 mile
Epstein (2006)	0.5 mile
Lee (2006)	1 km
Roemmich (2007)	0.5 mile
Euclidian Buffers (>1 buffer)	**Distance**
Cervero (2003)	1 & 5 mile
Berke (2007)	0.1, 0.5 & 1 km
Diez-Roux (2007)	0.5, 1, 2 & 5 mile
Sallis (1990)	1, 2, 3, 4 & 5 mile
Duncan (2005)	0.5 & 1 mile
Handy (2006)	400, 800 & 1600 metre
Jilcott (2007)	1 & 2 mile
McGinn (2007)	0.125, 0.5 & 1 mile
Wendel-Vos (2004)	0.3 & 0.5 mile
Network Buffer (single buffer)	**Distance**
Kerr (2006)	1 km
Tilt (2007)	0.4 mile
Lindsey (2006)	0.5 mile
Frank (2005)	1 km
Frank (2004)	1 km
Kligerman (2007)	0.5 mile
Network Buffers (>1 buffer)	**Distance**
Norman (2006)	0.5 & 1 mile
Measure to Distance	
Krizek (2006)	
Giles-Corti (2005)	
Hillsdon (2006)	
Combination administrative/buffer units	**Distance\Description**
Forsyth (2007)	0.2, 0.4, 0.8 & 1.6 km Euclid and network buffer
King (2005)	1.5 km network buffer and census block group
Krizek (2003)	150m grid

Source: Modified from Brownson et al., (2009).

To assist in understanding how the 48 studies included in the Brownson et al (2009) review represented *place*, a summary is provided in Table 2.3.

Table2.3: *Place* Spatial Unit Summary.

Type	Number	Percent
Administrative Units	16	33.33
Euclidian Buffer (single buffer)	10	20.83
Euclidian Buffers (>1 buffer)	9	18.75
Network Buffer (single buffer)	6	12.50
Network Buffers (>1 buffer)	1	2.08
Measure to Distance	3	6.25
Combination administrative/buffer units	3	6.25
Total	**48**	**100.00**

What is clear from Table 2.3 is that the use of *place* in health is still evolving with a third of the recent studies using predetermined administrative spatial units, a further 38% using Euclidian buffers, 15 percent using road network and only six percent using both administrative and buffer spatial units. Tables 2.2 and 2.3 provide further evidence of the central theme of this thesis that *place* is not being used to its full potential. *Place* is described as neighbourhood in several of these studies and others are using quite large spatial units (county and metropolitan) and while it is a useful context to study health at the county or metropolitan level, analysis at this scale masks the significant variation that occurs across these spatial units. Euclidian buffers were used for 38 percent of the studies and, while this is a step in the right direction, Euclidian buffers require more of a conceptual rationale to interpret the unit as meaningful and not reflective of inaccessible aspects of the environment. The number of studies reviewed that used network buffers (seven or 15 percent) reflects a recognition that administrative units and Euclidian buffers may not provide meaningful spatial units. The number directly measuring distance to features and testing across multiple spatial units is very low and this is indicative of the developmental nature of *place* in health research and the work still required to progress to a more informed *place*-health research agenda.

Most analysts when estimating associations include a number of possible covariates to ensure the outcomes are robust. Yet this level of scrutiny is not applied to the choice of spatial unit (*place*) or the potential for the variation in *place* to influence the outcome. Two key outcomes arise from Brownson et al (2009). First, that a definition or the most relevant geographic scale would vary depending on the built environment variable or outcomes being studied, and second, that it would be useful if more investigators evaluated and reported the results of built environment and health outcome analysis using multiple geographic scales such as varied buffer distances. These outcomes were echoed in an article from Chaix et al.(2009) who stated that,

> "Overall, these theoretical considerations suggest that complementary sets of neighbourhood boundaries, with distinct rationales, scales, and shapes, are needed to assess environmental exposures, depending on the study territory, the population, the specific individuals, the environmental factor, and the health outcome under study" (p. 1307).

Many of the existing spatial definitions were reviewed including:

- homogeneity to define a neighbourhood when it may not always be suitable;
- the use of ego-centred buffer representations, both Euclidian and network, and the need to vary the shape and size to allow for physical barriers and connections\disconnections; and
- street block units which typically group neighbours across the back fence and not neighbours that front the same block and therefore have more in common.

The challenge is to investigate outcomes across multiple spatial units as well as the need to look for manual and automated strategies for defining neighbourhood boundaries (Chaix et al., 2009). A systematic review of cardiometabolic risk factors and geographic environments, (Leal and Chaix, 2011) identified 131 studies, mostly post 2006 adding to and supporting the argument that *place* has increased as an area of research interest since 2001. This review had four aims, but it is the fourth aim that is most pertinent; to identify under-investigated research areas, evaluate methodologies and to propose an agenda for future research. Predetermined administrative spatial units were the spatial unit of choice for 73% of the studies in the Leal and Chaix (2011) review. This review was published in 2011, and most of the studies were post 2006 supporting the contention that spatial unit choice is not as rigorous as it should be. This is further supported by the fact that 74% of studies did not provide information on the spatial unit population size. The use of ego-centred buffers of varying sizes was reiterated in this review as was the need to measure activity space beyond the residential area and include work and recreation environments. One of the major outcomes of this review was an agenda for future research and while it is far ranging in scope and content, there were two recommendations in particular that are pertinent to this thesis. The recommendations from the Leal and Chaix (2011) systematic review are shown in Table 2.4, the two pertinent recommendations are highlighted in red.

Table 2.4: Research Agenda.

Outcomes

- Avoid studies relying on self-report CMRF outcomes.
- Take into account, in addition to body mass index, parameters of abdominal adiposity and visceral fat.
- Develop studies on diabetes, dyslipidemias and the metabolic syndrome.
- Prioritise studies with longitudinal assessment of the outcomes.

Environmental exposures

- **Define ego-centred geographic areas that approximate the actual space of activity of individuals in their local environment.**
- Take into account non-residential geographic environments (e.g., the geographic work, school or shopping environments) in addition to the residential environment.
- **Assess the spatial scale on which environmental factors affect the outcomes.**
- Distinguish between acute and chronic environmental exposures.
- Perform studies with a longitudinal assessment of environmental exposures.
- Develop and apply efficient protocols to characterise the food environment and social interactions that take place in the neighbourhood.
- Take into account the accessibility to healthcare services, a particularly neglected dimension in the reviewed studies.

Analytical design

- Apply multilevel or spatial regression techniques to assess the magnitude and scale of geographic variations in CMRFs.
- Rely on directed acyclic graphs to present research hypotheses in an explicit way and identify individual or neighbourhood variables that should be considered as confounders, modifiers, mediators or sources of selection bias.
- Take into account area-level confounding by adjusting environment-CMRF associations for area socioeconomic characteristics and other area characteristics (pay attention, however, to collider bias).
- Measure selective migration processes and take them into account during the analyses.
- Investigate and disentangle the individual-level mechanisms mediating associations between environmental variables and CMRFs.
- Develop questionnaires to measure the experience individuals have in their environment as possible contributors to the environment-CMRF associations of interest.

CMRF, cardiometabolic risk factor.

Source: (Leal and Chaix, 2011)

These reviews and the literature reviewed in this chapter, were consistent in identifying the difficulty associated with defining spatial units for health research and the need for more work to understand the relationship between predetermined administrative spatial units, buffer expressions of local environments, or other spatial interpolated expressions of *place*. (Diez-Roux, 2001) posed the challenge to consider how the choice of spatial unit might vary according to the health outcome being studied and the causal pathway. Brownson et al. (2009) noted that few researchers used or reported analyses of multiple geographic scales, and that further research into the use of predetermined spatial units or variable distance based road buffers is required, as did Chaix et al. (2009) and Leal and Chaix (2011). A recent Australian study found a strong association between road buffers spatial representations of walkability and more walking for transport, but not with two predetermined units (the Census Collection District (CD) and State Derived Suburb (SSC) (Learnihan et al., 2011). This study concluded that the scale and type of spatial unit was an important consideration when characterising walkability and larger predetermined spatial units were less likely to provide a meaningful statistical result. This leads to the conclusion that more method consideration and development is required to advance the use of *place* in research. While the preceding reviews have highlighted issues and critiqued method and studies, a small number of authors have looked at methodological developments that attempt to address the shortcomings described in this review, specifically the issues of the MAUP.

The problems with variation across studies and the variable nature of the spatial unit has been recognised by Siu et al.(2012) whose study team used high resolution raster data (80sqm) to construct their expression of the built environment. Other research teams have constructed spatial units using zone aggregation methods that were suggested more than 37 years ago as a possible solution to the MAUP (Openshaw, 1977). Whilst the concept of zone aggregation has a long heritage, the computer and GIS software now provide an environment which can effectively manage the large datasets required for this form of spatial aggregation. However, despite the work of Openshaw and others in the 1970s, 1980s and 1990s on the concept of zone design, very few examples are apparent in the *place* and health literature. Zone design methodology was based on the concept that the smaller census spatial unit could be aggregated to form larger more meaningful spatial units based on a grouping system that used socio-demographic variables to group similar population groups and these groups could be different depending on the research question and outcome measure (Martin, Nolan and Tranmer, 2001). One automated solution was offered by Openshaw and researchers at Leeds University during the 1990s, ZDES (http://www.geog.leeds.ac.uk/papers/96-6/) and although out of date, it generated interest in re-engineering the UK census spatial units (Martin, 1995, Martin, 1998, Martin, 2003, Martin, Nolan and Tranmer, 2001). Of particular interest, Openshaw and Alvinides (1996) proposed that the rise of GIS increased the potential for MAUP to be problematic, especially the aggregation problem. Prior to GIS, predetermined spatial units offered by the census bureaus were aggregated into a rigid hierarchy that was set at the time of the census collection. This hierarchy was fixed and controlled the possible aggregation combinations of the smallest spatial unit into progressively larger spatial units. GIS provides the potential to increase the number of possible aggregations, although as is evident from the literature, few researchers have applied spatial unit aggregation. However, a few health researchers have adopted zone design to overcome the shortcoming of using predetermined administrative boundaries (Cockings and Martin, 2005, Gregorio et al., 2005, Riva et al., 2009, Sabel et al., 2012)

Andrews et al., (2012) provided a far ranging review and critique of built environment-walkability research and posed some interesting and provocative challenges to health geographers. Underpinning Andrews et al., (2012) critique was the view that the current practice of built environment measures is inherently positivist, that *place* making or a focus on space is not considered, that "perceptions" data are less reliable than "objective" measures, that classification regimes that use labels such as overweight and obese may be inappropriateness and that the research focus is on the able bodied movers. While this article raises many excellent questions, the fundamental issue and subject of this thesis still stands. Before the issues and conceptual considerations raised by Andrews et al (2012) can be addressed, it is important that an improved understanding of *place* and *place* measurement be achieved. Until the many researchers engaging in *place*-health research move beyond the present use of *place* as a variable which is of less importance that the health data, the call for deeper and more informed *place* research will remain the domain of the few and not the many.

Conclusion

This review has investigated the use of *place* in health research and focussed on two specific areas of research, *place*-SES-Health and built environment (*place*) and health. The first section highlighted the widespread use of predetermined administrative spatial units coupled with low reporting of the MAUP or the limitations these units could have on the research outcomes. Many of these studies are very detailed when describing the health data, collection reliability and selecting statistical analytic models, but provide little detail of the spatial unit. The second section reviewed another area of *place* in health research, the built environment and health and despite the more overt spatial data for this area of research, highlighted similar problems with the recognition of spatial unit issues. The difficulty in defining appropriate spatial units and the widespread use of predetermined administrative spatial units is still widespread as is the low number of studies reporting the MAUP as a potential problem associated with the choice of spatial unit. Why is this lack of spatial "awareness" still all pervading? Whatever the reason, it is clear that more research reporting health outcomes coupled with more spatial rigour are required. This is *riason d'etre* of this thesis and underpins the three peer reviewed publications which specifically address spatial issues, but with a health outcome. It is hoped that these articles will pique the interest of other health researchers to consider the choice of spatial unit, perhaps analyse multiple units or look to new alternate spatial expressions that can better inform health relationships.

The publications that comprise this thesis are presented in chapters five, six and seven. All have been peer reviewed and comments from the peer review process were used to clarify and focus aspects of the method and analysis. Unfortunately, detail regarding the methodology is usually the casualty of this process and the three papers were all shortened to meet the journal requirements at the expense of the methodology. Therefore, to ensure that the detail of the data and methodology can be understood more fully, within this thesis, the next chapter contains details of the data sets used for these papers and the methodologies. It was not the intent to replicate information contained in the publications, but to provide background that would enhance the understanding of the method developments proposed as the major component of this thesis.

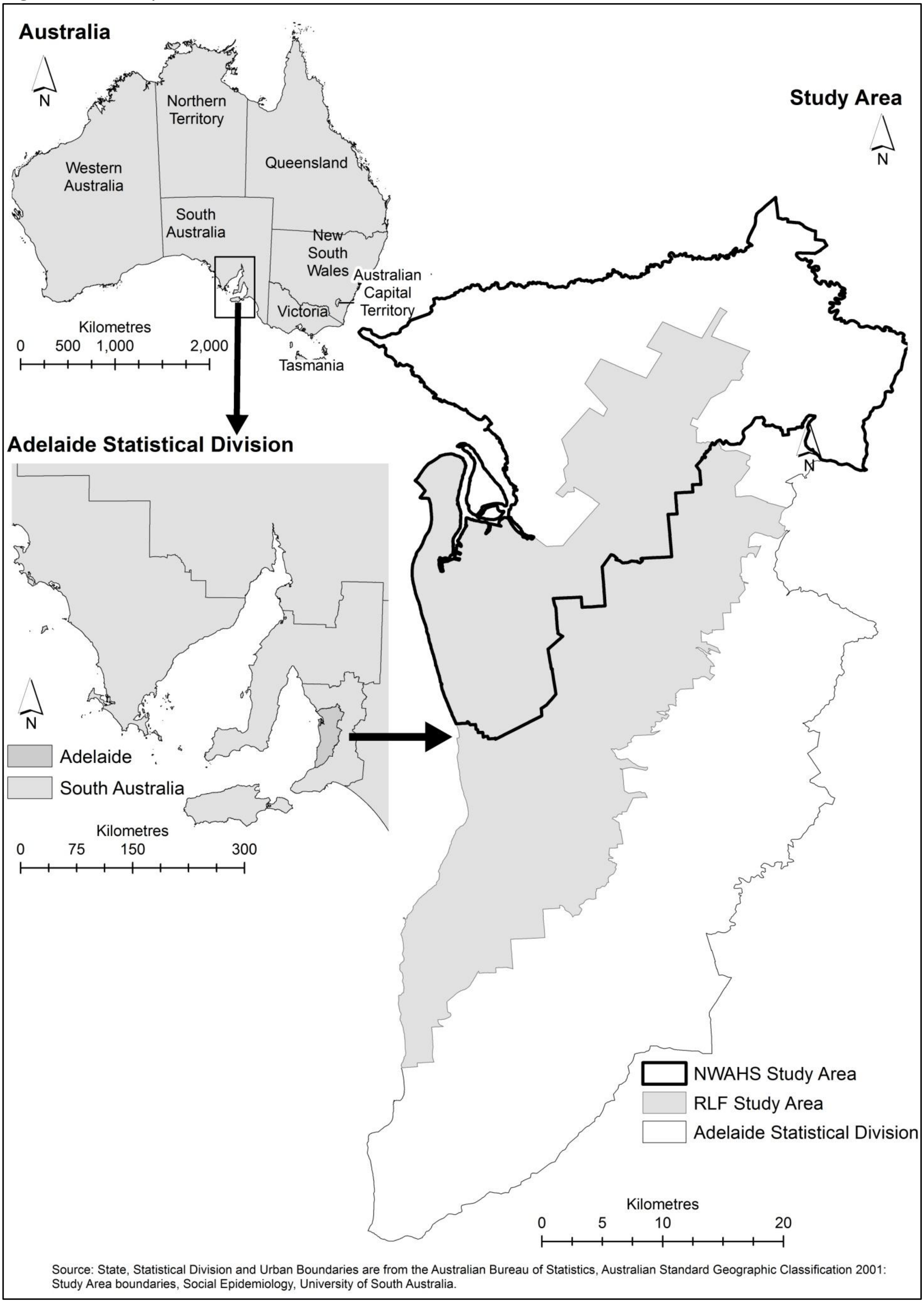
Chapter 3: Data

Introduction

Fundamental to the examination of this work were the central themes of *place* and health associations and the use of GIS to link disparate data to analyse spatial associations and the data used. All analyses in this thesis are within the Adelaide Statistical Division (ASD) (Figure 3.1) for 2001. Much of the detail regarding the data are included in the papers that form the core of this work, but some additional information is required. The purpose of this chapter is to provide the additional information that was not included in the three peer reviewed papers due to word limits, particularly the use of similar data for different outcome measures, between the three papers in this thesis. This thesis includes data or methodology developed as part of three National Medical and Research Council (NHMRC) funded projects, all of which researched the impact of *place* on health outcomes. These projects were:

- Physical Activity in Localities and Community Environments (PLACE) study was a NHMRC funded project (Project Grant (#213114), 2002-2004;
- Place and Metabolic Syndrome (PAMS) Project National Health and Medical Research Council (NHMRC) Project Grant (#631917) - Testing the behavioural and psychosocial mechanisms underlying geographic variation in metabolic syndrome (current); and
- Partnership Grant with SA Health (#570150) - Linking Place to Metabolic Syndrome via Behavioural and Psychosocial Antecedents: Levers for Public Health Intervention (current).

Figure 3.1: Study Area.



The data used for these NHMRC projects was a mix of built environment spatial measures, two surveys and clinic collected biomedical data. The PLACE project collected data from 2652 respondents across the Adelaide Metropolitan Area and the PAMS study used data collected from 4056 respondents from the North West Adelaide Health Study (NWAHS). Spatial measures included built environment and walkability which were calculated from road and centreline data, dwelling data, land use mix and retail land use data, residential property sales data and the South Australian Government digital cadastre and land use and tenure system data provided by the South Australian government. These survey collections and details of these data sets are provided in this chapter in conjunction with the data transformations used to take raw data and provide the measures needed to conduct the various analyses in this thesis.

Study Area

The ASD is approximately 80 kilometres north to south and 30 kilometres east to west and had a population of 1.1 million in 2001 (Australian Bureau of Statistics, 2003). While the ASD forms the outer boundary of the capital city and its immediate area of economic interaction, the research used subsets of this area for the three papers. The study area and the specific study extents for the three papers are displayed in Figure 3.1.

PLACE Study

Physical activity in localities and community environments (PLACE) study was a NHMRC funded project (Project Grant (#213114), which aimed to understand how environmental factors might operate to influence habitual physical activity (Du Toit, Cerin and Leslie, 2005). The PLACE study was undertaken between 2002 and 2004 in Adelaide, South Australia. Adelaide was chosen for this study because of the quality and availability of spatial data. This study is part of the International Physical Activity and the Environment Network (IPEN) project (http://www.ipenproject.org/) and used the Neighborhood Quality of Life Study (NQLS) (http://www.nqls.org/) from the USA as the template for the survey instrument. The built environmental walkability component for the PLACE study was an Australian adaptation of work in the US by Frank and colleagues (Frank, Engelke and Schmid, 2003, Frank, Andresen and Schmid, 2004, Frank et al., 2005) and used the two major walkability themes of proximity and connectivity. GIS was used to calculate proximity measures (dwelling density, land use mix and retail footprint) and connectivity (constructed as intersection density). The spatial unit for the PLACE study was the Australian Bureau of Statistics (ABS) 2001 Census Collection District (CD) (Australian Bureau of Statistics, 2001d). The CD was chosen as it was the smallest spatial unit provided by the ABS. These four components of walkability, net dwelling density, intersection with greater than 2 directions of travel potential density, land use mix and retail footprint were used to designate each CD in the ASD as walkable (4^{th} quartile) or non-walkable (1^{st} quartile). To account for SES, the ABS Socio-Economic Index for Areas (SEIFA) (Australian Bureau of Statistics, 2001c) was used to identify CDs into the following combinations:

- high SES-high walkable;
- low SES – high walkable;
- high SES – low walkable; and
- low SES – low walkable.

A total of 32 communities representing the combinations above were identified and these were used to select households using a simple random sampling methodology. The modified NQLS survey was mailed to the randomly selected households with a target of 2400 respondents, with 600 from the four SES-walkability combinations. A total of 2652 participants were recruited. For more detail on the PLACE project and the respondent recruitment, see, An Account of Spatially Based Survey Methods and Recruitment Outcomes (Du Toit, Cerin and Leslie, 2005).

PLACE Data

The detail of the data and methodology for walkability construction was provided in earlier work (Coffee, 2005, Leslie et al., 2007). This section provides a brief description of the data and method used to construct the original walkability index and then describe walkability in the context of the analysis provided in Chapter five in this thesis.

The data required to construct the walkability index included the 2001 South Australian road network, digital cadastre database (DCDB), land ownership and tenure system (LOTS), land use database and the 1998 Retail Database (RDB). All data sets were provided by the South Australian Government. The 2001 DCDB and LOTS data were fundamental data which underpin all of the main spatial data for South Australia and are used to derive the dwelling, land use and retail data.

Walkability required four input measures, intersections, dwellings, land use and a retail footprint. For the original PLACE study these were extracted for the CD only. For the later analysis, these measures were extracted for the CD, state suburb (SSC) and three road distance buffers (500m, 1000m and 1500m).

Intersections

Intersections were not (and are still not) provided as a standalone data set. Intersections were derived using a GIS method that placed a node (intersection) at every point where two arcs (lines) intersected. Once a node (intersection) has been created, the next step is to remove all the pseudo nodes. Pseudo nodes occurred as some roads have multiple arcs and each connection between two arcs resulted in a node placement (the process for removing pseudo nodes was provided in more detail in Coffee, 2005, pp92). The intersection density is calculated for intersection with greater than two directions of potential travel. Directions of travel are created by creating a 1 metre buffer around each intersection (after removing the pseudo nodes) and counting the unique arcs in each buffer. As the walkability index was designed to reflect walkability and dead-ends or cul-de-sacs do not provide travel routes (but origin or destinations), they are not included in the intersection count. The count is converted to density using the traditional method of count divided by area in hectares.

Dwelling Density

Dwelling counts were calculated using the relationship between the 2001 DCDB, which is the spatial representation of land parcels in South Australia and the 2001 LOTS data, which provides details of land use and improvements to the land parcels, including dwellings. A centroid is created for each DCDB parcel using the GIS minimum bounding rectangle method, and a dwelling count created from the LOTS data. The dwelling density is calculated as the dwelling count by the CD residential area in hectares.

Land Use Mix

Land use data was derived from the 2001 DCDB and LOTS data. The 2001 DCDB provides the spatial referent and via linkage with the 2001 LOTS data the detailed land use can be extracted. Land use is provided via a very detailed four digit code, but for the purposes of these analyses, land use was grouped into five groups, residential, commercial, industrial, recreation and other.

The land use mix measure was designed to reflect diversity on the basis that with different land uses there would be a greater variety of destinations for walking trips. As a measure of diversity, the method used an equation that was borrowed from ecology that was designed to report on species diversity and described as entropy. In brief, the area of each land use group was summed and then the percentage of each group was calculated. The following equation is used to calculate the entropy index.

$$\frac{\sum_k \left(p_k \ln p_k\right)}{\ln N}$$

In this equation, k was the category of land use and N was the number of land use categories and p was the percent of each land use in each CD. The results can range from 0 (homogenous, all one type of land use) and 1 (even spread across all the land use groups).

Retail Footprint

The 1999 Retail Database was provided by Planning SA (now the Department of Planning, Transport and Infrastructure) included all retail activity identified using the detailed land use codes from the 1999 LOTS data or parcels zoned for retail activity by local government. Any retail location was included if the gross retail area was greater than 240 square metres or a cluster of three of more shops. Once identified as a potential retail land use, field teams visit all locations and record the gross retail area and activity. The field teams add any retail locations they find in the field that was not identified from the administrative data.

The retail footprint was designed to provide a ratio of total retail parcel area and gross retail floor space. The rationale underpinning this measure is that a small ratio provides a large area for car parking which was not walk friendly, whereas a ratio close to one describes an area with minimal space for parking and therefore was walk friendly.

Walkability Index

When the four components were calculated for each CD, the values were classified as deciles and reclassed as their decile value (1 to 10). The decile values were summed, which resulted in a potential walkability index of between 4 and 40, with 4 representing the least walk supportive CD and 40 and most walk supportive CD. It was only the walkability index methodology that was used from the PLACE study for the research reported in Chapter five in this thesis.

Walkability Index Revisited 2012

For the PLACE study, the walkability index was calculated for one spatial unit, the CD with the purpose of identifying those CDs for the survey data collection to ensure both the built environment and SES were accounted for when the analysis was undertaken. In the paper included in this thesis, the walkability index was a replication of this methodology. This was done to enable comparison with the body of work resulting from the IPEN project, which has used this method and or similar data forms in 12 countries (Australia, Belgium, Brazil, Colombia, Czech Republic, Denmark, Hong Kong, Mexico, New Zealand, Spain, UK and US). The paper in this thesis tested multiple spatial units and associations with a six factor cardiometabolic risk score (where 0 = no risk and 6 = all risk factors).

North West Adelaide Health Study

The North West Adelaide Health Study (NWAHS) was used for all the research in this thesis and provided the biomedical health data for testing the health associations with *place* either via walkability or SES. As the NWAHS data were fundamental to this work an overview is important to establish both the basis of this thesis and to understand the original intent of the NWAHS. For a more detailed account of NWAHS, see the web page (http://www.nwadelaidehealthstudy.org/) or Grant et al.,(2006).

The NWAHS was established to provide data for population-based chronic disease research in the northern and western portions of the Adelaide Statistical Division. The extent of the NWAHS is provided in Figure 3.1. The study was longitudinal and has three waves of data collected over the 2000 to 2010 period. The analysis in this thesis used the first wave of data (W1) collected from 2000 to 2003 with 4056 participants. Participants were recruited into the NWAHS via random selection from the Adelaide White Pages Telephone Directory (Grant et al., 2006). All participants were aged 18 or older and data collection included self-report socio-demographic and health data, clinical and biomedical data, and prescription medication which were linked with the Australian Pharmaceutical Benefits Scheme using the Medicare number. During the questionnaire component of the data collection, participants provided their residential address and this information was confirmed when they attended the clinic for the biomedical data collection. Of the 4056 originally recruited into the NWAHS, valid address data were supplied by 4041 and these were used to create a georeference point to enable spatial linkage with Census and built environment data. Written consent was provided by all NWAHS participants for the use of their address data, self report and biomedical data, and ethics approval was granted by the Human Research Ethics Committees of the University of South Australia, the North West Adelaide Health Service, and the South Australian Department of Health.

While the NWAHS study collected data on many chronic health issues, this research was only concerned with the set of risk factors that are referred to as metabolic syndrome, which includes:

- hypertension (systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥ 85 mmHg or treated for hypertension with medication);
- abdominal adiposity (waist circumference ≥ 94 cm in men and ≥ 80 cm in women);
- reduced high density lipoprotein (HDL) cholesterol (< 1.03 mmol/L in men and < 1.29 mmol/L in women);
- raised triglycerides level (≥ 1.7 mmol/L or treated for lipid abnormality with medication); and
- raised fasting plasma glucose (≥ 5.6 mmol/L or previously diagnosed diabetes).

These risk factors were selected to reflect a condition that is often referred to as “metabolic syndrome”, and were defined from internationally established clinical cut-offs by the International Diabetes Federation (IDF) (Alberti, Zimmet and Shaw, 2006). The National Cholesterol Education Program (NCEP) ATP-III (Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults, 2001) identified increased low density lipoprotein (LDL) cholesterol levels (≥ 4.1 mmol/L) as a risk marker and this was added as a sixth marker. Each of the six risk markers were scored as zero (below the cut-off) or one (above the cut-off). The six risk factor scores were then summed to create a single cardiometabolic risk (CMR) score with a range from 0 (no risk markers) to 6 (all risk markers). No weighting was applied to any of the six factors as each was considered to contribute to overall risk equally. These risk factors and CMR were used in this thesis as the chronic health risk which was tested for *place* association via walkability and RLF.

Relative Location Factor

For detailed data and methodology see Chapter four. This section will provide a précis of the method and data used to create the RLF. As was the case with much of the work described in this chapter, the DCDB and LOTS data were fundamental to this work. Three data sets were used for creating RLF, residential sales data, DCDB and LOTS. All data were supplied by the South Australian Government. This highlights the importance of these data for spatially based research and the adaption of administrative data for research that are critical to our understanding of the impact of *place* on health, but were never intended for such use. The process for creating RLF is provided below.

To avoid variation in the selling price due to exogenous market variations only residential house sales data for the period between and including May to October 2001 were used. Additionally only sales that were considered as legitimate market transactions by the Valuer General were included.

After cleaning the data for missing sale price, missing address or land-use the sale price, dwelling age, dwelling size, land area, dwelling style and dwelling condition were extracted (n=6800). The sales were only extracted for the urban area within the ASD (Figure 3.1) as different factors influence urban and non-urban (semi-rural or rural) residential property markets.

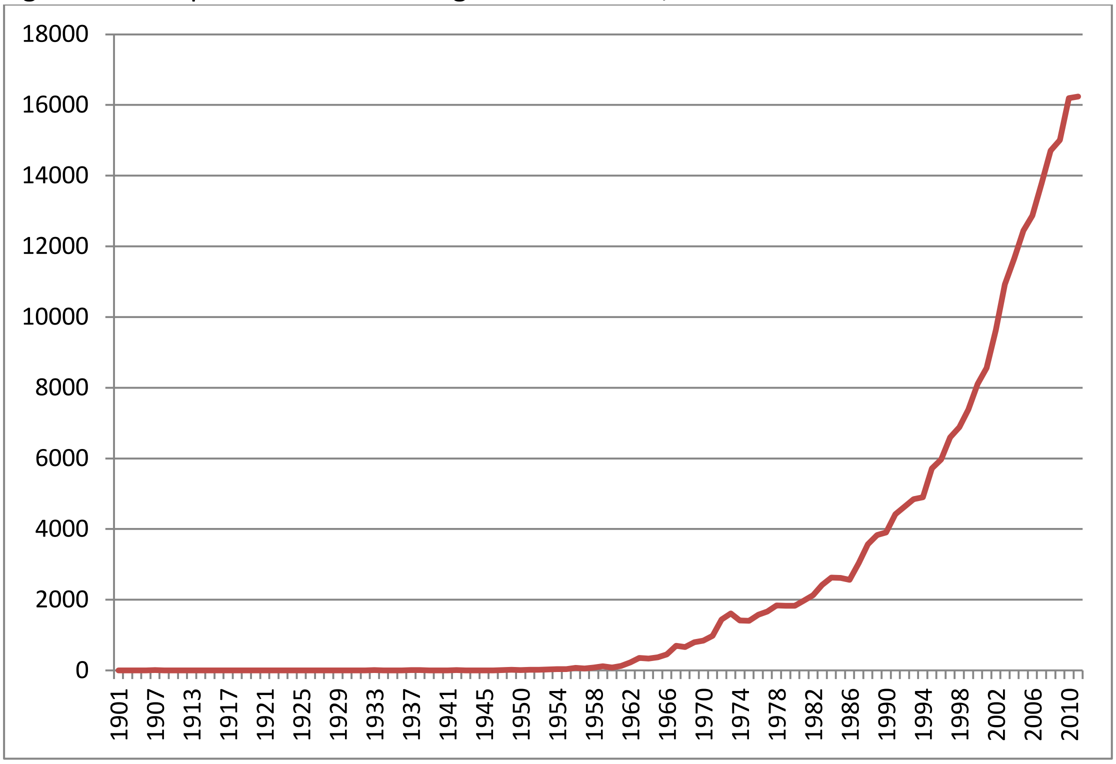
Using the residential property sales transaction data and the residential property characteristics listed above, a global hedonic regression model that was deliberately blind to location was run to predict the selling price of each residential property. The model error was then inferred as the influence of location on the sale price. The difference between the predicted and actual sale price was calculated and expressed as a ratio (a value of one accorded to the mean ratio, a value less than one was interpreted as location lowering the residential property values and a value greater than one was interpreted as location positively influencing residential property values).

The next step used geographic information system (GIS) kriging to interpolate a continuous raster surface (the relative location factor, RLF) from the 6800 predicted to actual price ratios represented spatially as a single point for each sale ratio. The RLF raster surface resolution was set at 25 metres to more closely approximate the individual residential property level. Once the RLF has been interpolated for the study area the value can be extracted to any point using the ESRI, ArcMap Version 10.1 point extraction tool. For this research, RLF was extracted for each of the NWAHS participants that resided in the urban portion of the study area at wave 1 (2001).

Scopus Sciverse Search

The use of Scopus to search for relevant articles in chapter two displayed a significant increase in search results for both SES-*place*-health and the built environment-walkability research areas since the 1990s. Was this is an artefact of the electronic database and the start of electronic records? Scopus states that they added many older references as well as adding approximately two million records per annum. To test whether the 1990 upturn was an artefact of the electronic record keeping, a search was run for smoking, an area of research interest that has a long history (Figure 3.2). The smoking search results included documents from as far back as 1825 and resulted in a small number of documents for almost all years through to 1950 when the numbers started to increase from less than 10 to almost 100 by 1960 and approximately 1000 by 1970. This search result would suggest that Scopus search results span a period that does not reflect just the start of the electronic record keeping and therefore the search results provided in this literature review do reflect an actual upswing in research interest from the 1990s. Figure 3.2 displays the results from 1901 and as is evident the increase in documents is much earlier (approximately 1960) and reflects the research interest in smoking and not the start of electronic recording.

Figure 3.2: Scopus Sciverse Smoking Search Results, 1901-2012.



Conclusion

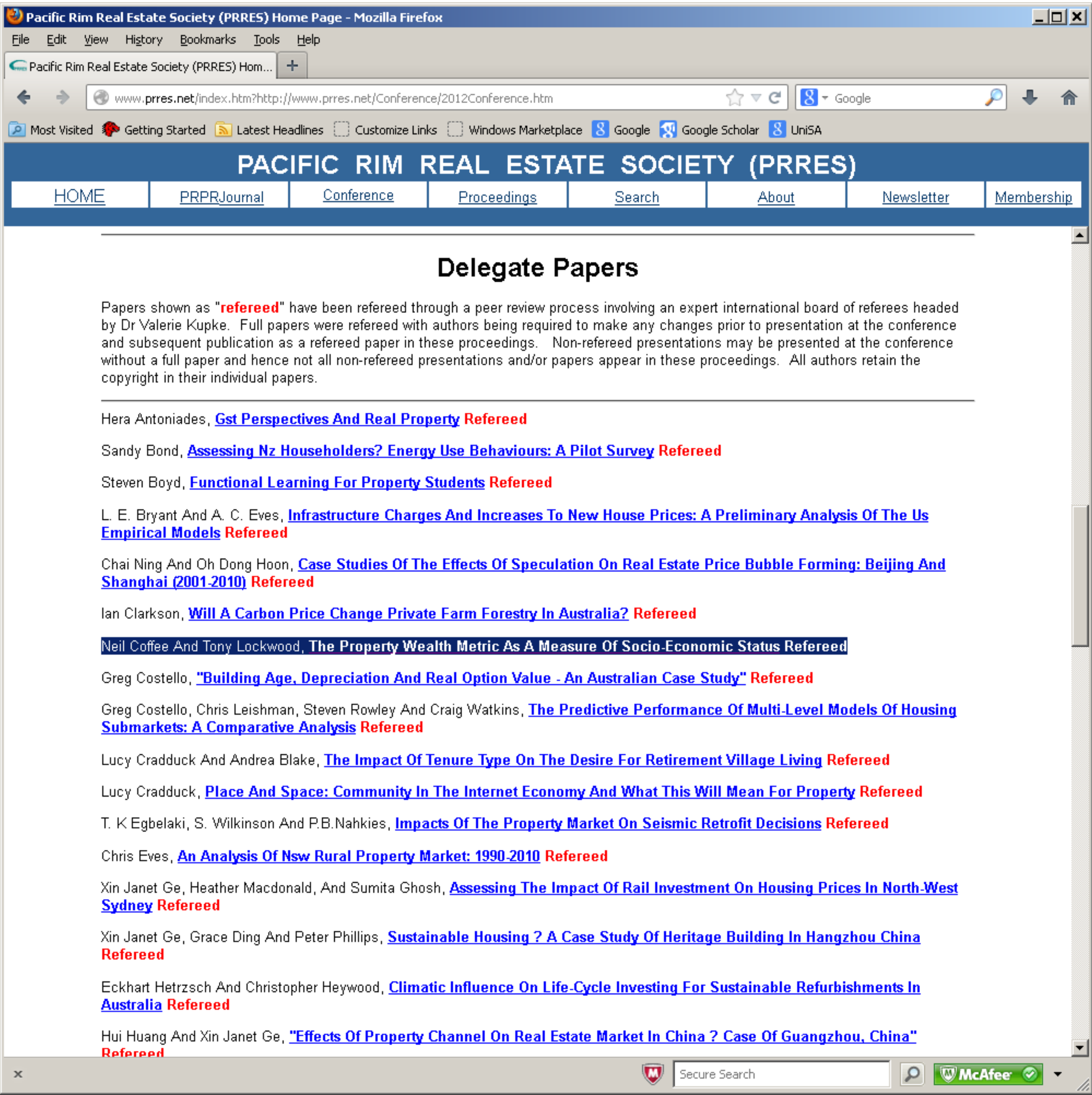
This section has presented a précis of the data sets and methods used for the three papers presented in this thesis. This section does duplicate some of the content of the three papers, but to provide additional background and as a supplement to the data description and methods section in the papers. Due to the word limits imposed by the journals, the detail or number of words that can be devoted to data and methods has to be limited. It is understandable the results are critical, but the brevity required by some journals does not allow for a detailed data and methods section and this can impact on the understanding and ability for other researchers to duplicate the methodology. While this section does not provide a step by step process for all the data or methods, it does provide a more complete understanding when read in conjunction with the published papers.

Chapter 4: Paper 1: The Property Wealth Metric As A Measure Of Socio-Economic Status

Proceeding of the Pacific Rim Real Estate Society 18th Annual Conference, January 15th-18th 2012, Adelaide, Australia Property: Nexus of Place & Space.

http://www.prres.net/index.htm?http://www.prres.net/Conference/2012Conference.htm

Neil Coffee[1] and Tony Lockwood[2]



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Hera Antoniades, Gst Perspectives And Real Property Refereed

Sandy Bond, Assessing Nz Householders? Energy Use Behaviours: A Pilot Survey Refereed

Steven Boyd, Functional Learning For Property Students Refereed

L. E. Bryant And A. C. Eves, Infrastructure Charges And Increases To New House Prices: A Preliminary Analysis Of The Us Empirical Models Refereed

Chai Ning And Oh Dong Hoon, Case Studies Of The Effects Of Speculation On Real Estate Price Bubble Forming: Beijing And Shanghai (2001-2010) Refereed

Ian Clarkson, Will A Carbon Price Change Private Farm Forestry In Australia? Refereed

Neil Coffee And Tony Lockwood, The Property Wealth Metric As A Measure Of Socio-Economic Status Refereed

Greg Costello, "Building Age, Depreciation And Real Option Value - An Australian Case Study" Refereed

Greg Costello, Chris Leishman, Steven Rowley And Craig Watkins, The Predictive Performance Of Multi-Level Models Of Housing Submarkets: A Comparative Analysis Refereed

Lucy Cradduck And Andrea Blake, The Impact Of Tenure Type On The Desire For Retirement Village Living Refereed

Lucy Cradduck, Place And Space: Community In The Internet Economy And What This Will Mean For Property Refereed

T. K Egbelaki, S. Wilkinson And P.B.Nahkies, Impacts Of The Property Market On Seismic Retrofit Decisions Refereed

Chris Eves, An Analysis Of Nsw Rural Property Market: 1990-2010 Refereed

Xin Janet Ge, Heather Macdonald, And Sumita Ghosh, Assessing The Impact Of Rail Investment On Housing Prices In North-West Sydney Refereed

Xin Janet Ge, Grace Ding And Peter Phillips, Sustainable Housing ? A Case Study Of Heritage Building In Hangzhou China Refereed

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Hui Huang And Xin Janet Ge, "Effects Of Property Channel On Real Estate Market In China ? Case Of Guangzhou, China" Refereed

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Statement of Authorship

Title: The Property Wealth Metric As A Measure Of Socio-Economic Status

Journal: Proceeding of the Pacific Rim Real Estate Society 18th Annual Conference, January 15th-18th 2012, Adelaide, Australia Property: Nexus of Place & Space.

Neil Coffee (Candidate): Conceived and designed the study; data capture, spatial and statistical analysis and interpretation; literature review, writing the manuscript; and important critical review of the intellectual content.

....Date...5/9/13...........

Tony Lockwood: Contribution to the design of the project; data capture, spatial and statistical analysis and interpretation; writing the manuscript; and important critical review of the intellectual content. I give consent for Neil Coffee to present this paper for examination toward the Doctor of Philosophy.

....Date...30/8/13...........

Abstract:

Neighbourhood socio-economic status (SES) is linked with poor health outcomes (Auchincloss et al., 2007; Adams et al., 2009; Chichlowska et al., 2009; Kavanagh et al., 2010; Williams et al., 2010). One of the more common Australian data sources for analysing social disadvantage is the Australian Bureau of Statistics (ABS) Socio-Economic Indicators for Areas (SEIFA) index of Advantage\Disadvantage (Australian Bureau of Statistics, 2006). As SEIFA is aggregated to predetermined spatial units the index masks variation and impacts on epidemiological studies at the local level. This research investigated the potential to use the South Australian Fiscal Cadastre as a surrogate socio economic indicator in the investigation of community health at the property level to supplement the more traditionally used SEIFA index. A Relative Location Factor metric (RLF) is developed by comparing the relative locational merit of each property to the global average for the study area and comparing this with the 2006 SEIFA index of disadvantage-advantage. This paper presents the results from this first step. Further research will examine the relationship between RLF, health survey data, the underlying census socio-economic characteristics and SEIFA.

Introduction:

The relationship between poor health and socio-economic status (SES) has a long history and early work, such as Booth's 1898-99 maps of poverty in London highlighted the links. However, despite the many studies researching health and SES, the lack of an understanding about the spatial distribution of SES is still a major challenge in the implementation of informed public health policy. The traditional approach relies on socio economic data which is typically presented as some sort of average within an arbitrarily aggregated spatial unit to preserve confidentiality. This introduces Ecological Fallacy (Robinson, 1950) and Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984) into the analysis as well as masking any variation within these spatial units potentially hindering the successful intervention of any resulting public health policy. These issues raise the question as to which spatial unit is the most appropriate when analysis results may be different depending on the choice made.

The objective of this paper is to use a derived relative location factor (RLF) based on property value as a proxy for SES at an individual property level and make initial comparisons with the more traditionally used Australian Bureau of Statistics (ABS) Socio-Economic Index for Areas (SEIFA) index. Property may well be the most valuable asset owned by many individuals and as such it can provide the basis for a property based wealth indicator reflecting SES. The derivation of the RLF uses a hedonic global ordinary least squares (OLS) regression model constructed using property characteristics as independent variables that describe the dwelling and not its location. The deliberate omitted variable bias may then be attributed to location and expressed as a RLF value surface which can be assigned to each property. This allows analysis to be potentially free of the MAUP and provide a better understanding of any local spatial variation that may be occurring within the traditionally presented spatial units thus enhancing public health policy.

The literature has established the link between public health and SES and there is an emerging literature on the relationship between property values and SES (Vernez Moudon et al., 2011). The scope of this paper is to establish a RLF surface and compare it to the traditional SEIFA index of advantage-disadvantage and identify some of the differences and discuss how the RLF could contribute to enhanced public health outcomes. This is the first step in understanding the contribution that RLF can make to SES and health research. The limitations of this study were the property data availability and its ability to represent the current market at a particular point in time. The strength of the RLF is that it can be easily constructed at any point in time and could therefore provide an understanding of changing SES between the quinquennial Australian Census of Population and Housing.

Background

The relationship between socio economic status (SES), social disadvantage and poorer health outcomes is well documented and has a long history with Louis-Rene Villerme (Julia and Valleron, 2011), Rudolf Virchow's (Waitzkin, 2006), Charles Booth (Orford et al, 2002) and John Snow (Newsom, 2006) in the 19th Century, and numerous studies since, see for example (Kawachi, 2003; Marmot and Wilkinson, 2006; Cabrera et al., 2007; Chaix et al., 2007; Aldabe et al., 2010; Brownell et al., 2010; Kavanagh et al., 2010; Kestens and Daniel, 2010; McDonough et al., 2010; Wilson et al., 2010). In Australian studies, socio-economic status is usually analysed using the five yearly ABS Census and the SEIFA index (Australian Bureau of Statistics, 2006). The latest Census was recently collected (2011), but presently the most up-to-date census is 2006. Due to the confidentiality provisions associated with the ABS, data are not released that would enable the identification of any individual or household. To protect confidentiality when releasing data, the ABS randomise cell values of less than three (to either 0 or 3) and aggregate data outputs to predetermined spatial units. The ABS spatial units are set prior to each census and released as the Australian Standard Geographic Classification [3](ASGC) (Australian Bureau of Statistics, 2006). The 2006 ASGC provides spatial units which cover all of Australia without overlap or omission starting with the smallest unit, the collection district (CD), through to statistical local areas (SLA), local government areas (LGA), statistical sub-division (SSD), statistical divisions (SD), state (SA) and nation. The smallest spatial unit, the CD, is typically 160-200 households (Australian Bureau of Statistics, 2006) and while this provides a small unit in urban areas, it can be very large in rural or remote areas. Consequently, data aggregated to provide outputs for the

[3] 2011 will be the final version of the ASGC as the ABS has redesigned the spatial geography of Australia and the new source document will be the Australian Statistical Geography Standard (ASGS).

census geographies may not be suitable when attempting to understand local variations within these larger spatial units. This paper presents the results from the first step which examined the construction of a relative location factor (RLF) based on property values as a potential enhancement to the more traditional SES indicators of social disadvantage by providing a breakdown of the local variation to the property level. Further research will examine the relationship between RLF, health survey data, the underlying census socio-economic characteristics and SEIFA.

The objective of this study was to take the established nexus between property value and SES and show how the potential property market structure may help explain local variations beyond that possible using aggregated SES data. A similar study used a similar measure to test the relationship between obesity, a property specific wealth metric and area level SES in Seattle (Vernez Moudon et al., 2011). The results from the Seattle study concluded that the property level measure was more predictive than area-level SES in identifying fair or poor health status (Vernez Moudon et al., 2011). Australian studies have shown how the variation in socio economic indicators is correlated with the variation in median house price movement when aggregated to the same spatial unit (Reed, 2001; Jackson et al., 2007).

Location is generally recognised as a most important determinant of property value. As Bourassa et al.(2003) stated, the three most important contributors to property value "location, location, location" is not just a tired dictum; location does matter and therefore its associated geography does matter. Social geography can not only describe the composition of a geography (Shevky and Bell, 1955) but perhaps more importantly can show the associated spatial variation of that geography across a study area.

The property may well be the most valuable asset owned by many individuals. As it accounts for a significant proportion of an economy's GDP (Gibb and Hoesli, 2003) the importance to society generally can be appreciated. Therefore to manage the development and affordability of this asset and its association with health, through informed government policy requires insight to the housing market structure and the spatial variation associated with it. The importance of this understanding was expressed by Rothenberg et al. (1991) as being "to understand that which fundamentally influences the wellbeing of most citizens".

One of the most important attributes of housing as a traded commodity is its immovability. This provides the basis of making location a prime value determinant (Galster, 1996). Therefore as well as an economic equilibrium expressed in terms of supply and demand, property can also be expressed in terms of a spatial equilibrium as proximity to various places of interest as influencing price (Thrall, 2002).

The question as to how best represent the changing nature of the residential value surface becomes of interest in understanding the property market's perception of where the more desirable and less desirable locations may be as this may be related to an interpretation of property location as an indication of SES. The existence of the housing market composed of a number of interrelated sub markets has long been acknowledged, but discussion is still prevalent in the literature as to the best methodology to determine these sub markets (Watkins, 2001).

The issues that emerge from the literature involve the recognition that submarkets are best defined simultaneously in terms of both spatial and structural identifiers (Watkins 2001) and should be derived from the data itself rather than on the basis of some a priori definition such as suburbs or postcodes (Adair et al., 1996). The data should reflect the underlying residential real estate structure of the study area and not rely on selected property characteristics alone (Maclennan and Tu, 1996; Bourassa et al., 1999; Bourassa et al., 2003). However, it is insufficient to identify the underlying structure and geography only, as submarket definition requires expression in terms of the marketplace in order to give it an economic entity status (Pryce, 2004). To identify all attributes contributing to the underlying market structure is not a trivial exercise as the quantity of locational attributes alone are almost limitless (Orford, 1999). As locational attributes often serve as a 'proxy' for the numerous unobserved attributes (Pavlov, 2000) a methodology described by Gallimore et al. (1996) isolating the effects of location to the error term of an hedonic model describing price in terms of observable property characteristics and remaining deliberately 'blind' to location may be an appropriate methodology in determining a residential location factor (RLF).

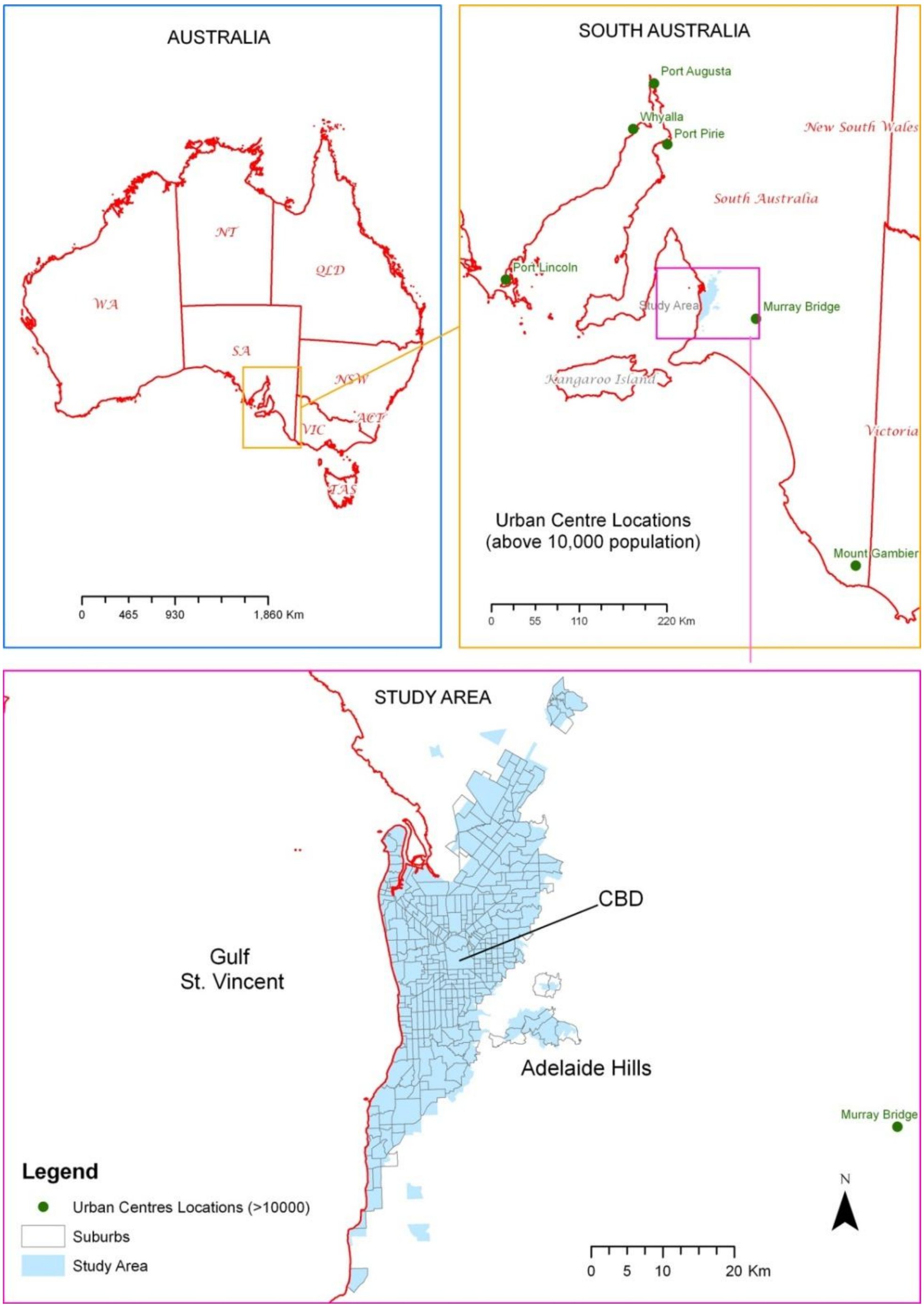
The methodology in this study was divided into two stages. The first stage was to express property values in terms of a household specific wealth indicator providing another view of SES that could complement the more traditionally employed ABS SEIFA index. It is not the intention to replace or compete with such a long established index, but rather to contribute by expressing the importance of property wealth as a complementary SES metric. SEIFA is calculated using a combination of census social and demographic variables collected every five years and as such does not directly include property wealth as part of the index. This research suggests one way of achieving this may be to construct a continuous raster surface depicting the residential market structure at an individual property level. Following Gallimore et al.(1996) this was achieved through constructing a global hedonic ordinary least squares model that was deliberately “blind” to location. There is an assumption that the error term is due to the value attributes describing location and used as the input to construct a Residential Location Surface (RLF) as the ratio of Sale Price to the estimated Value from the “blind” model. The second stage was to compare the traditionally used ABS SEIFA index of advantage-disadvantage at the CD level and compare this to the RLF aggregated to the CD level. It was not necessarily expected that the two should be closely aligned across the whole study area as the SEIFA index was constructed as a relative index between a particular CD and the whole of the state whereas the RLF is a metropolitan specific model. In part this may be where the RLF can contribute to a better understanding of locations of social advantage-disadvantage as it is derived by study area specific data and expressed at the property level thereby capturing local variations not possible with more global metrics.

This is very much an exploratory study that may ultimately lead to a better understanding between location and SES.

Study Area:

The study area for this research was the urban area of the Adelaide Metropolitan Area as displayed in Figure 1. Adelaide is used for this study as there were excellent detailed spatial data for property, property sales and a comprehensive longitudinal health survey available for further analyses.

Figure 1: Study Area



Data:

In adopting the global hedonic OLS model approach, the data used were taken from the 2006 Sales History data of the South Australian Valuer General. The data used in this study are summarised in Table 1.

TABLE 1: Ordinary Least Squares Model Input Data.

VARIABLE	TYPE	DESCRIPTION
Sale Price (SP)	continuous	Sale Price in dollars obtained from the South Australian Government
Dwelling size (DS)	continuous	Equivalent main area in square metres (source: South Australian Valuer General).
Dwelling age (DA)	continuous	Age in years obtained (source: South Australian Valuer General)
Dwelling land area (LA)	continuous	Area in square metres taken from the digital cadastre (source: South Australian Valuer General)
Dwelling style(DT)	Dummy	If "South Australian Housing Trust style" or "poor conventional" dummy = 1 else 0 (source: South Australian Valuer General)
Dwelling quality(DQ)	Dummy	If high quality based on housing style i.e. "high quality contempory"; or "high quality conventional" or "high quality ranch" or "mansion" or "architectural design" dummy = 1else 0 (source: South Australian Valuer General)

The raw data described above were cleaned as follows:

- all sales not representing market value were removed;
- no adjustments were made for time as the market was deemed stable over this time period;
- there was no screening of sales data on the basis of 'outliers' to make the resulting model as unbiased as possible from a valuation perspective; and
- only sales that were part of the study area were included.

This resulted in a sales data set of 6,800 sales.

Methodology:

The methodology adopted used the improved property market sale transactions to establish an interpolated continual raster surface of relative location factors (RLF) at a given point in time. This was achieved through the analysis of completed property transactions captured when the transfer of ownership is registered with the relevant government authority, in the case of Australian jurisdictions, the Registrar General, which is a State Government responsibility. In this study sale transactions occurring between May and October 2006 were captured and used as evidence of market value as at 30th June 2006. The methodology was carried out in two stages. Stage 1 involves creating a RLF value for each residential dwelling in the study area. Stage 2 compares this to traditionally used SES indicators to establish the efficacy of using the RLF as a surrogate SES indicator.

Stage 1:

Only independent variables describing the property (i.e. dwelling characteristics) and assuming the error associated with predicting the sale price is due to omitted variables, in this case "location" were used to predict the **sale price** (shown in Equation 1). A raw RLF (rRLF) was derived from the sales sample by dividing the **sale price** by the **predicted value** as shown in Equation 2.

$$SP_i = B_0 + B_1DS_i + B_2DA_i + B_3LA_i + B_4DT_i + B_5DQ_i + error \qquad \text{Equation 1}$$

$$rRLF_i = SP_i \,/\, (B_0 + B_1DS_i + B_2DA_i + B_3LA_i + B_4DT_i + B_5DQ_i) \qquad \text{Equation 2}$$

where:

SP_i = the sale price of the i^{th} property
$rRLF_i$ = the estimated location factor for the i^{th} property
LF_i = the derived location factor for the i^{th} property from the value surface

B_0 to B_5 = the parameter estimates
DS_i = the dwelling size for the i^{th} property·
DA_i = the dwelling age for the i^{th} property·
LA_i = the Land Area for the i^{th} property·
DT_i = dummy variable for poor style for the i^{th} property
DQ_i = dummy variable for the high quality style for the i^{th} property

This led to an interpretation that an rRLF greater than 1.0 means, that compared with the average, there was money paid for the dwelling over and above the dwelling itself, namely location. Conversely, a RLF of less than 1.0 would indicate that less was paid for the property than indicated by the dwelling alone and relative to the average of a rRLF of 1.0 is a less desirable location. The next part of stage one was to establish if the derived rRLF was randomly distributed across the geographic study area or was there a spatial pattern that leads to the conclusion that location (represented through the rRLF) had spatial significance. A global Moran's I statistic was calculated to summarize the pattern of the rRLF across the study area to determine if the distribution could have been formed randomly.

A non-deterministic interpolated surface was then formed from the rRLF using ordinary kriging as it was deemed that a smoother surface more accurately represents a relative location factor. This surface of interpolated rRLF factors (from equation 2) produces the RLF surface from which individual RLF scores can be assigned to individual properties. A 25 metre cell size was adopted in the production of the RLF as this would more closely approximate a true RLF value at the individual property level.

Stage 2:

This stage of the methodology created an individual dwelling point representation of the RLF surface and a CD average RLF value. The RLF surface values were extracted to the 2006 individual dwelling points using the ArcMap toolbox, Spatial Analyst Tools, Extraction, Extract values to Points tool. The result provided a property level expression of the RLF surface generated in stage 1 and the means for highlighting the within CD variation of the RLF.

The CD RLF was generated using the ArcMap toolbox, Spatial Analyst Tools , Zonal, Zonal Statistics as Table and the resulting table joined to the CD spatial layer using the CD Code. This function uses a CD layer to calculate the minimum, maximum, average, standard deviation and variance of the RLF surface for each CD. The ABS SEIFA scores were presented as deciles, therefore to provide a standard basis for comparison, RLF decile values were calculated for the CD RLF layer. The resulting layers and values are presented in the results section below.

Results:

Stage 1:

The global OLS regression model specified in Equation 1 was calibrated using the above described sales data set containing 6,800 sales and presented in Table 2 below.

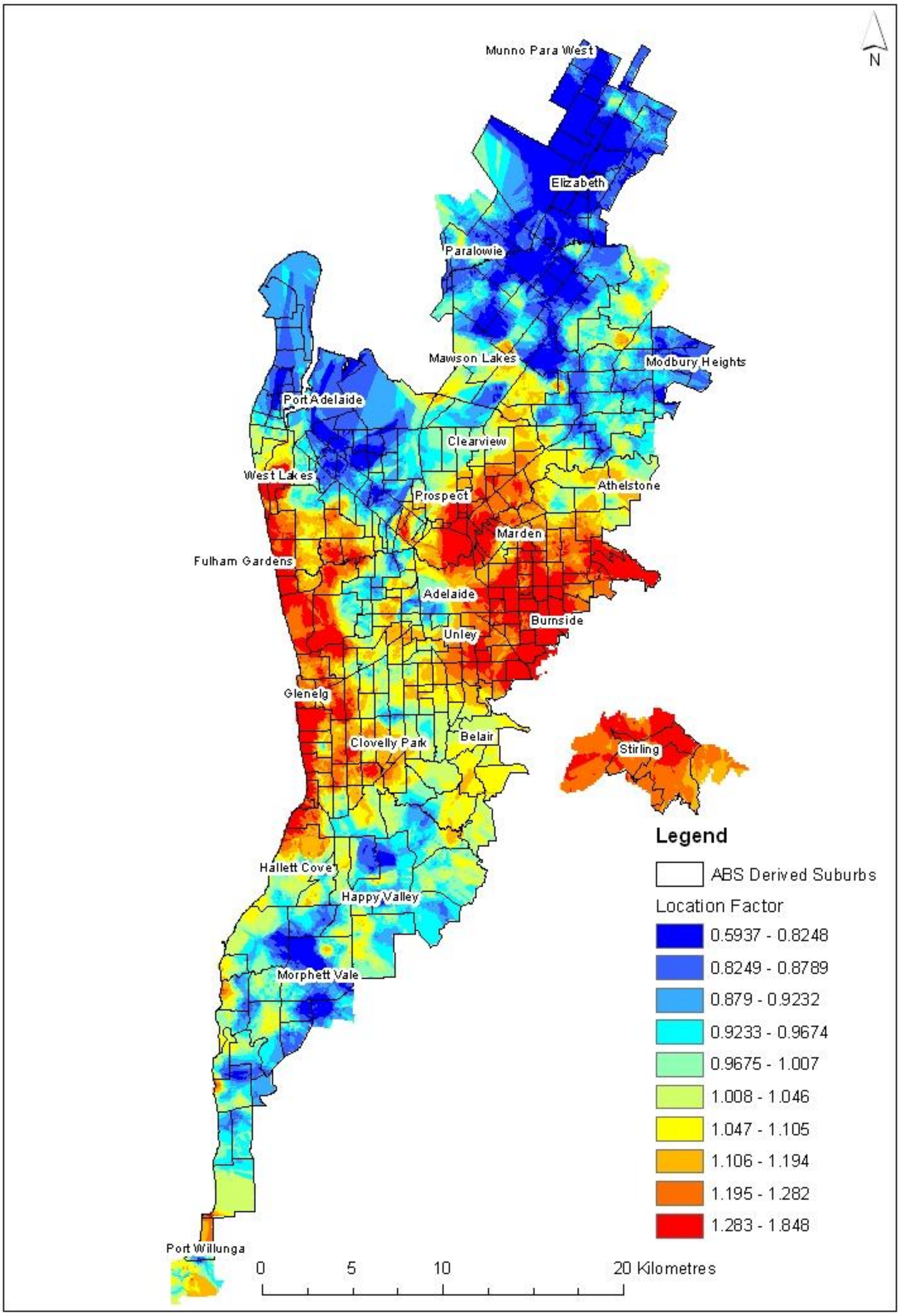
TABLE 2: Ordinary Least Squares Model Variables.

Variable	Coefficient	t stat	Prob
Intercept	-83466	-16.83	0
DS	2095	81.06	0
DT	-43568	-11.98	0
DQ	80546	14.59	0
LA	1.34	0.267	0.79
DA	2261	47.61	0

An adjusted R squared statistic of 0.59 was obtained. This was an expected result as bias in the form of the deliberately omitted location variables can be seen.

The global Moran's Index of 0.23 with a Z-score of 194.9 (p-value of 0.000000) was obtained indicating a less than 1% likelihood that the clustered pattern of the derived rRLF could be a result of random chance. The interpolated raster surface was then generated giving the RLF as shown in Figure 2.

Figure 2: Relative Location Factor Surface.

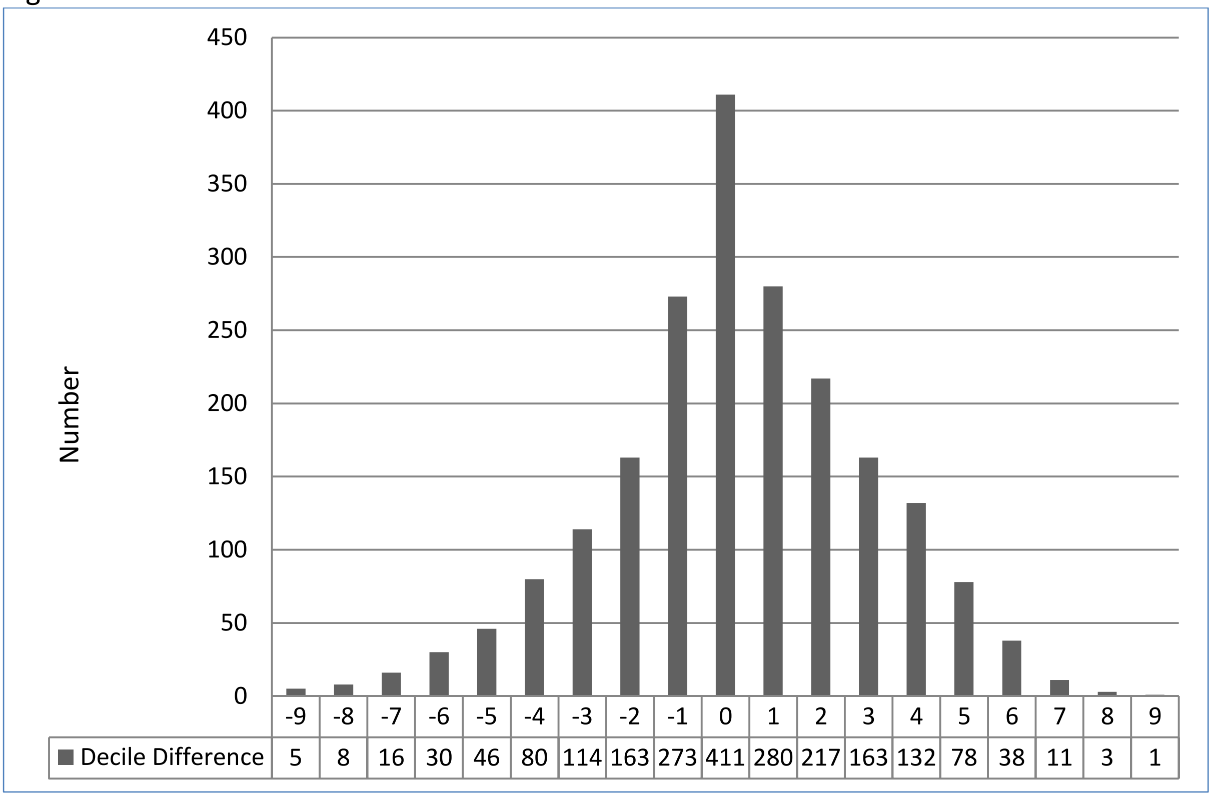


Stage 2:

As stated earlier, the results were not expected to provide an exact correlation with SEIFA, but a metric that could be used to supplement SEIFA, highlight the within CD (or other spatial unit) variation and provide a measure that could be matched to individuals at the property level. The correlation coefficient for the SEIFA state based decile ranking and the RLF decile ranking was 0.55. This is clearly indicative of a relationship without providing a measure that is an exact match and therefore of limited value above using SEIFA.

The difference in decile values is displayed in Figure 3. The difference was calculated as the RLF decile minus the SEIFA decile and a positive result indicates cases where the RLF is greater than the SEIFA decile a negative occurs, when the RLF is less than the SEIFA decile.

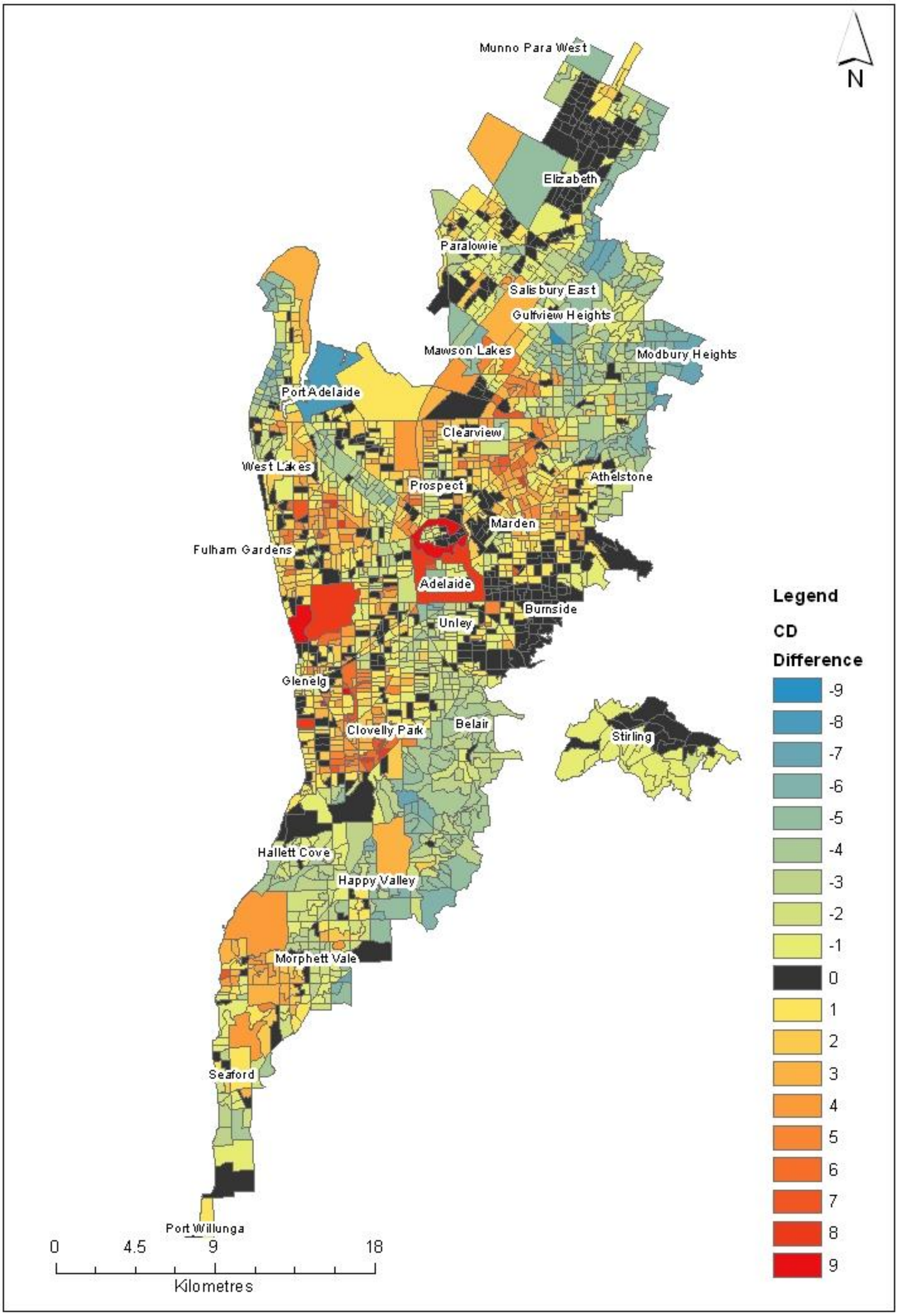
Figure 3: Difference Between RLF Decile and ABS SEIFA Decile.



The difference between the SEIFA decile values appeared normally distributed with 47 percent between +-1 decile difference and 65 percent between +-2 deciles different. While the distribution does indicate a relationship is present between the two measures it is not such that the RLF would not have any utility above and beyond using SEIFA. It is important to report a relationship at the aggregate level as this supports the utility of the property level RLF and the added value this will provide for research at a more detailed level.

In addition to the decile difference as displayed in Figure 3, the difference was mapped to visually identify any spatial associations (see Figure 4). Spatially, the differences did not appear visually clustered and occurred across the study area in areas that include high, low and all decile levels in between. It is important to note that the RLF and SEIFA both identify the extremes of disadvantage (Elizabeth area, lowest RLF and lowest SEIFA) and advantage (Burnside, highest RLF and SEIFA).

Figure 4: Spatial Distribution of RLF Decile and SEIFA Decile Difference.

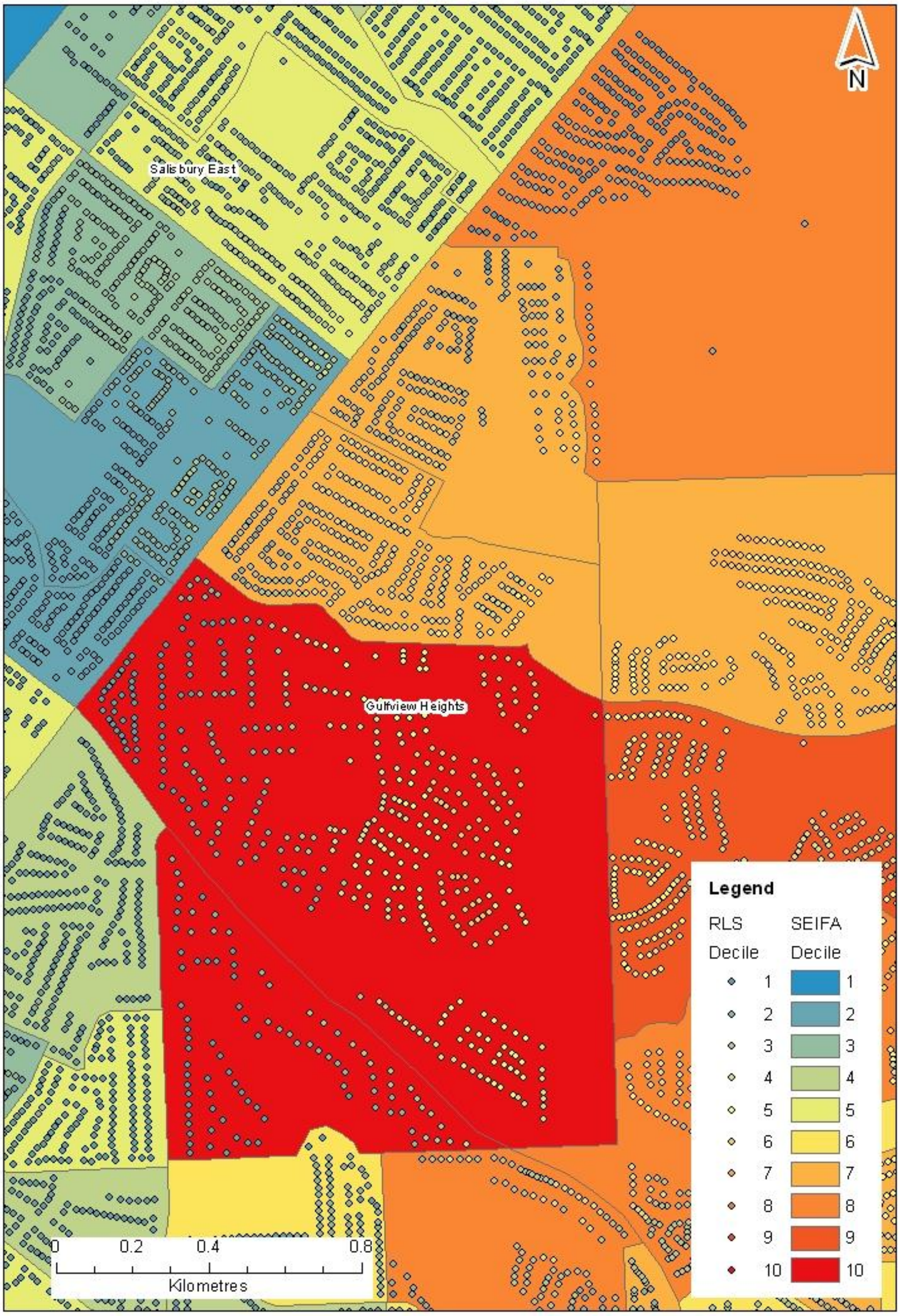


Discussion:

Building upon the work of Vernez Moudon et al. (2011) these results provide enough to suggest that the RLF as constructed provides an additional SES measure for research into health and SES. One of the aims of this research was to provide a property level SES measure that would work with the more traditionally calculated area level measure but enable the within area variation to be included. The property level RLF decile value is overlain on the CD SEIFA decile value to illustrate the variation that occurs within spatial units (Figure 5). Figure 5 is zoomed to the Gulfview Heights and Salisbury East area approximately 15 kilometres to the North of Adelaide City. This area was selected because the property based RLF decile values display a gradient moving across the area from the west to the east, with lower SES (as indicated by the RLF) in the west to higher values in the east, compared with the CD based SEIFA decile value which would indicate an area of advantage. In this example, any association with poor SES would not be identified using the aggregate SEIFA measure. Figure 5 highlights a number of areas of difference to pursue this line of research and with the inclusion of census variables and individual level health data will provide the basis to test if the area level data returns a statistically valid relationship with the RLF and whether the property based RLF provides a stronger relationship that enables within area SES variance to be included.

Given that much of the earlier work used to report on the health and SES relationship were based on aggregate spatial units and yet still reported a clear relationship suggests that a property based measure will provide a more locally based expression of SES. It should be noted that the methodology utilised in this research, through the use of surfacing methodology takes into account the influence of neighbouring when used to create the sales value surface. This was a factor which Vernez Moudon et al.(2011) identified as a strength of their work in the Seattle paper.

Figure 5: Property Level RLF and CD level SEIFA.



Conclusion:

The association between poorer health and SES has a long association and in Australian research the ABS SEIFA measures are used via predetermined geographies to model social and health relationships with SES. The ABS is bound by strict confidentiality conditions and does not release unit record data or any data that could potentially identify an individual. Consequently, all analysis using SEIFA is built upon models which incorporate SES based upon an aggregated spatial unit and therefore represent an averaged outcome. This is increasingly evident in the health and place research and is managed using multi-level statistical models to allow both individual data and aggregate to be analysed. In an attempt to improve the SES, health and place research, the objective of this research was to derive a supplementary SES indicator that could be used at the household level.

This was achieved by deriving a RLF and running initial comparisons with the traditionally used SEIFA index. Future research will look at the benefits that might be gained in using the RLF in conjunction with SES indicators. The initial indication is that RLF could potentially enhance the traditional SES indicators through making comparisons that fall into two broad groups. Firstly, the comparison between RLF and aggregate spatial units such as the CD may highlight locations where the CD SEIFA scores were not supported based upon the RLF value variation. This poses the question as to appropriateness of the SEIFA index when compared to a more locally derived metric. Perhaps the RLF identifies the local differences that could be masked using SEIFA and a broader national average. Secondly, and perhaps more importantly, RLF provides within group variation which cannot be identified by SEIFA. This helps address the MAUP issue, assists in the accuracy of resulting research and consequent intervention policy. As the RLF is a dwelling measure and is expressed at each property the variation and association relationships may result in the identification of areas of similarity for research that are more meaningful and more closely reflect the true social structure of the study area.

Future research will investigate the link between RLF, census and individual measures of SES indicators with the SEIFA index to establish if the more locally derived indicators are more closely aligned with the RLF. Future research will investigate the potential to more appropriately identify spatial SES boundaries. The limitation of the RLF is the inability to recognise the underlying elements of the social structure which can be seen through interpretation in conjunction with SES indicators.

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Chapter 5: Paper 2: Relative Residential Property Value as a Socioeconomic Status Indicator for Health Research.

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Relative residential property value as a socio-economic status indicator for health research

Neil T Coffee[1,2*], Tony Lockwood[3], Graeme Hugo[2], Catherine Paquet[1,4], Natasha J Howard[1] and Mark Daniel[1,5]

Abstract

Background: Residential property is reported as the most valuable asset people will own and therefore provides the potential to be used as a socio-economic status (SES) measure. Location is generally recognised as the most important determinant of residential property value.

Extending the well-established relationship between poor health and socio-economic disadvantage and the role of residential property in the overall wealth of individuals, this study tested the predictive value of the Relative Location Factor (RLF), a SES measure designed to reflect the relationship between location and residential property value, and six cardiometabolic disease risk factors, central obesity, hypertriglyceridemia, reduced high density lipoprotein (HDL), hypertension, impaired fasting glucose, and high low density lipoprotein (LDL). These risk factors were also summed and expressed as a cumulative cardiometabolic risk (CMR) score.

Methods: RLF was calculated using a global hedonic regression model from residential property sales transaction data based upon several residential property characteristics, but deliberately blind to location, to predict the selling price of the property. The predicted selling price was divided by the actual selling price and the results interpolated across the study area and classified as tertiles. The measures used to calculate CMR were collected via clinic visits from a population-based cohort study. Models with individual risk factors and the cumulative cardiometabolic risk (CMR) score as dependent variables were respectively tested using log binomial and Poisson generalised linear models.

Results: A statistically significant relationship was found between RLF, the cumulative CMR score and all but one of the risk factors. In all cases, participants in the most advantaged and intermediate group had a lower risk for cardio-metabolic diseases. For the CMR score the RR for the most advantaged was 19% lower (RR = 0.81; CI 0.76-0.86; p <0.0001) and the middle group was 9% lower (RR = 0.91; CI 0.86-0.95; p <0.0001) than the least advantaged group.

Conclusions: This paper advances the understanding of the nexus between place, health and SES by providing an objective spatially informed SES measure for testing health outcomes and reported a robust association between RLF and several health measures.

Keywords: Socio-economic status, Cardiometabolic risk, Geographic information system, Residential property value, Relative location factor

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Neil Coffee (Candidate): Conceived and designed the study; data capture, spatial and statistical analysis and interpretation; writing the manuscript; and important critical review of the intellectual content.

....Date....5/9/13..........

Tony Lockwood: Contribution to design of the project; data capture, spatial and statistical analysis and interpretation; writing the manuscript; and important critical review of the intellectual content. I give consent for Neil Coffee to present this paper for examination toward the Doctor of Philosophy.

....Date..........................30/8/13

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........Date....5 Sept 2013........

Abstract

Background

Residential property is reported as the most valuable asset people will own and therefore provides the potential to be used as a socio-economic status (SES) measure. Location is generally recognised as the most important determinant of residential property value. Extending the well-established relationship between poor health and socio-economic disadvantage and the role of residential property in the overall wealth of individuals, this study tested the predictive value of the Relative Location Factor (RLF), a SES measure designed to reflect the relationship between location and residential property value, and six cardiometabolic disease risk factors, central obesity, hypertriglyceridemia, reduced high density lipoprotein (HDL), hypertension, impaired fasting glucose, and high low density lipoprotein (LDL). These risk factors were also summed and expressed as a cumulative cardiometabolic risk (CMR) score.

Methods

RLF was calculated using a global hedonic regression model from residential property sales transaction data based upon several residential property characteristics, but deliberately blind to location, to predict the selling price of the property. The predicted selling price was divided by the actual selling price and the results interpolated across the study area and classified as tertiles. The measures used to calculate CMR were collected via clinic visits from a population-based cohort study. Models with individual risk factors and the cumulative cardiometabolic risk (CMR) score as dependent variables were respectively tested using log binomial and Poisson generalised linear models.

Results

A statistically significant relationship was found between RLF, the cumulative CMR score and all but one of the risk factors. In all cases, participants in the most advantaged and intermediate group had a lower risk for cardio-metabolic diseases. For the CMR score the RR for the most advantaged was 19% lower (RR=0.81; CI 0.76-0.86; p <0.0001) and the middle group was 9% lower (RR=0.91; CI 0.86-0.95; p <0.0001) than the least advantaged group.

Conclusions

This paper advances the understanding of the nexus between place, health and SES by providing an objective spatially informed SES measure for testing health outcomes and reported a robust association between RLF and several health measures.

Keywords

Socioeconomic status; cardiometabolic risk; geographic information system; residential property value; relative location factor

Background

Residential Property as an SES Measure

Residential property may well be the most valuable asset owned by many individuals and can provide the basis for a residential property wealth indicator reflecting socio-economic status (SES). Di and colleagues (2003)[1] reported that home equity accounted for 21% of household net wealth in the United States of America (USA). For low SES households the percentage of household wealth represented by residential property was substantial, accounting for approximately 50% of household net wealth. Property represents a significant proportion of an economy's gross domestic product (GDP) [2] . Rothenberg and colleagues (1991)[3] stressed that a society's wellbeing is dependent on a fundamental understanding of housing market structures.

Location is generally recognised as the most important determinant of residential property value. As Bourassa et al (2003)[4] stated, the three most important contributors to residential property value, "location, location, location" is not just a tired dictum; location does matter and therefore its associated geography also matters. Social geography can not only describe the composition of geography [5] but, perhaps more importantly illustrate the associated spatial variation.

One of the most important attributes of residential property as a traded commodity is its immovability or location specific capital. This provides the basis of making location a prime residential property value determinant [6] which can extend the often described economic equilibrium expressed in terms of supply and demand to include a spatial equilibrium where proximity to various places of interest and location influences price [7].

The question of how best to model residential property value is important in understanding how the locations of more or less desirable residential property could be applied as a meaningful indication of local area SES. The locational aspect of residential property and the acknowledgement that a group of residential properties may be described as more or less valuable are often described as a residential property market. While the notion of a residential property market composed of a number of interrelated sub markets is a cornerstone of real estate transactions, the literature is still undecided on the best methodology to determine the spatial boundaries of such sub markets [8]. The themes expressed in the literature converge in the recognition that submarkets are best defined using spatial and structural identifiers [8]. It is also acknowledged that submarkets should be derived from data rather than on the basis of some *a priori* definition such as suburbs or postcodes [9]. Such data should reflect the underlying residential property real estate market structure of the area under study and not rely on residential property characteristics such as size, style, age, number of bedrooms [4, 10, 11].

Residential property market structure cannot be identified by property characteristics and socio-economic geography alone. The identification of a residential property market structure also requires the expression of price (market) to give it an economic entity status [12]. Identifying all of the attributes contributing to the underlying market structure is a challenge, as the list of locational attributes alone is extensive [13]. Locational attributes often serve as a 'proxy' for the numerous unobserved attributes affecting residential property value [14]. A methodology described by Gallimore et al, (1996)[15] isolating the effects of location to the error term of an hedonic regression model simplifies the need to account individually for such numerous attributes while still capturing their effect on value. This is achieved by describing price in terms of observable residential property characteristics only, remaining deliberately 'blind' to locational characteristics and interpreting the error term as a proxy for location. This provides a methodology for determining the relative value of location to the study area mean by interpreting the relationship between residential property value and SES as the nexus between 'where you live' (place) rather than the 'absolute value of the residential property you live in' and SES as being an important relationship when studying health outcomes. This is what the Relative Location Factor (RLF) [16] was designed to reflect. Of importance for this study is that the resulting interpolated continuous RLF surface can be assigned to any residential property. This allows analyses to be potentially free of the modifiable area unit problem (MAUP) [17] and provide a better understanding of any local spatial variation that may be occurring within the traditionally presented spatial units. MAUP is an issue associated with scale and configuration of spatial units such that statistical associations may change as the size of the spatial unit changes (scale) or as the study area is subdivided into different spatial configurations (zonation). Even though this issue has been described by geographers for a number of years [18-22], few health studies acknowledge, let alone account for, MAUP despite the burgeoning use of place in health research.

Health and Socioeconomic Status

SES has long been established as one, if not the most, important population health risk factor [23] with pioneering work in the 19th Century by Louis-Rene Villerme [24], Rudolf Virchow [25], and Charles Booth [26]. Charles Booth's 1898-99 maps of poverty in London highlighted the link between poor health and poverty and incorporated a spatial dimension.

Since this early work there are few health outcomes that have not been associated with SES. Studies have investigated SES and mortality [27-31], respiratory diseases [32, 33], chronic diseases [28, 34-38], obesity levels [39-43], oral health [44] and health-related behaviours such as smoking [40, 45-48], and alcohol consumption [49, 50]. This association is often reported as a gradient, with social position strongly influencing health outcomes such that across many disease or behaviours the effects are more prevalent as SES decreases [51]. These numerous studies provide a significant literature that has repeatedly associated low SES with poorer health.

SES is a complex, multidimensional concept that is typically represented using one or all of the "triad" of indicators, education, income and occupation. Beyond the many studies that use these three SES measures, other researchers have represented SES in terms of housing tenure [48, 52, 53], housing type [43, 54], number of bedrooms [33, 53, 55], overcrowding measures [38, 56], number of offspring [56-58], car ownership [52, 53, 56, 58], and asset or wealth measures [34, 44, 59-61].

In addition, efforts have been directed towards developing integrated SES indices, such as the United Kingdom Index of Deprivation [62, 63] or the Australian Socio-Economic Index for Areas (SEIFA) [64-67]. Such measures are however, constructed for predetermined spatial geographies at the time of the census. Of particular note when using Census derived SES indices, is that many of the spatial unit boundaries change from one census to the next, methodologies and input variables change, and there is limited temporal comparability. In the case of the Australian SEIFA index, the Australian Bureau of Statistics specifically warns against comparisons of SEIFA from one census to the next [64].

SES measures are collected either via survey or derived from area level data from population surveys such as census collections. Both forms of data capture have strengths and weaknesses. Survey data are subject to limitations associated with recall, incorrect responses, non-responses and socially desirable responses [68-70], especially with questions on income and education. Area level data, collected via a national census can provide population level data, but are similarly subject to the above limitations in addition to being susceptible to the MAUP [17].

The potential limitations associated with SES measures makes them unsuitable for understanding local variations within spatial units. Despite the many studies researching health and SES, the lack of an understanding about the spatial distribution of SES is still a major challenge. Many studies rely on SES data presented as an average for a predetermined aggregated spatial unit. MAUP [17] may be introduced into the analysis as is the potential to mask any SES variations within these spatial units. This raises the question as to which spatial unit is the most appropriate when analysis results may be different depending on the choice made.

One area of research investigating SES measures that are less prone to MAUP is the use of residential property or housing value. In health research this is an emerging literature linking residential property value and SES, including the use of Council Tax Valuation Bands (CTVB) in the United Kingdom (UK) [71] and property values in the USA [42, 72]. The UK study [71] used the eight band CTVB and reported associations between many health and lifestyle outcomes and SES expressed as property value classes. A study in the USA used residential property value to test the relationship between obesity and area level SES in Seattle [72]. Results from the Seattle study indicated that the residential property level measure was more predictive than area-level SES in identifying fair or poor health status [72]. Another USA study reported an association between property value and obesity, such that women were 3.4 times more likely to be obese if they lived in the bottom quartile than the top quartile [42]. Australian studies have shown how the variation in socio economic indicators was correlated with the variation in median house price movement when aggregated to the same spatial unit [73, 74]. RLF [16] adds to this emerging area of research and provides a relative location wealth SES measure for social and health researchers.

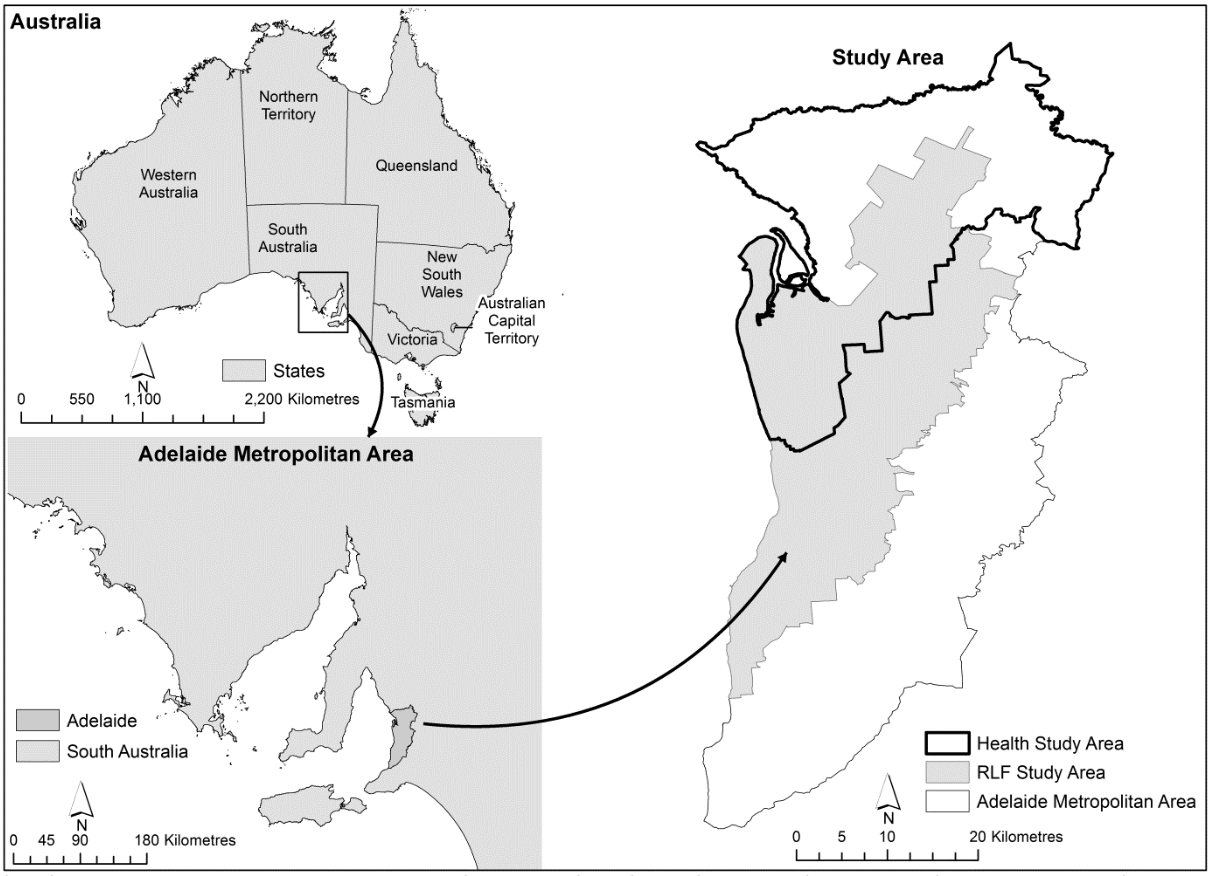
Based on the long standing relationship between poor health and SES and the significance of residential property in the overall wealth of an individual, this study tested the predictive value of RLF as a measure of SES to six clinical measures of chronic disease risk and a cumulative risk score.

Methodology

Study Area

The study area for calculating RLF was the Adelaide Metropolitan Area which stretches approximately 80 kilometres north-south and 30 kilometres east-west (Figure 1) and had a population in 2001 of 1.07 million [75]. The study area for the health data was the North Western and Northern Adelaide Metropolitan Area, stretching approximately 60 kilometres north-south and 30 kilometres east-west with a 2001 population of 410341, 38% of Adelaide's metropolitan population [75].

Figure 1: Study Area.



Source: State, Metropolitan and Urban Boundaries are from the Australian Bureau of Statistics, Australian Standard Geographic Classification 2001: Study Area boundaries, Social Epidemiology, University of South Australia.

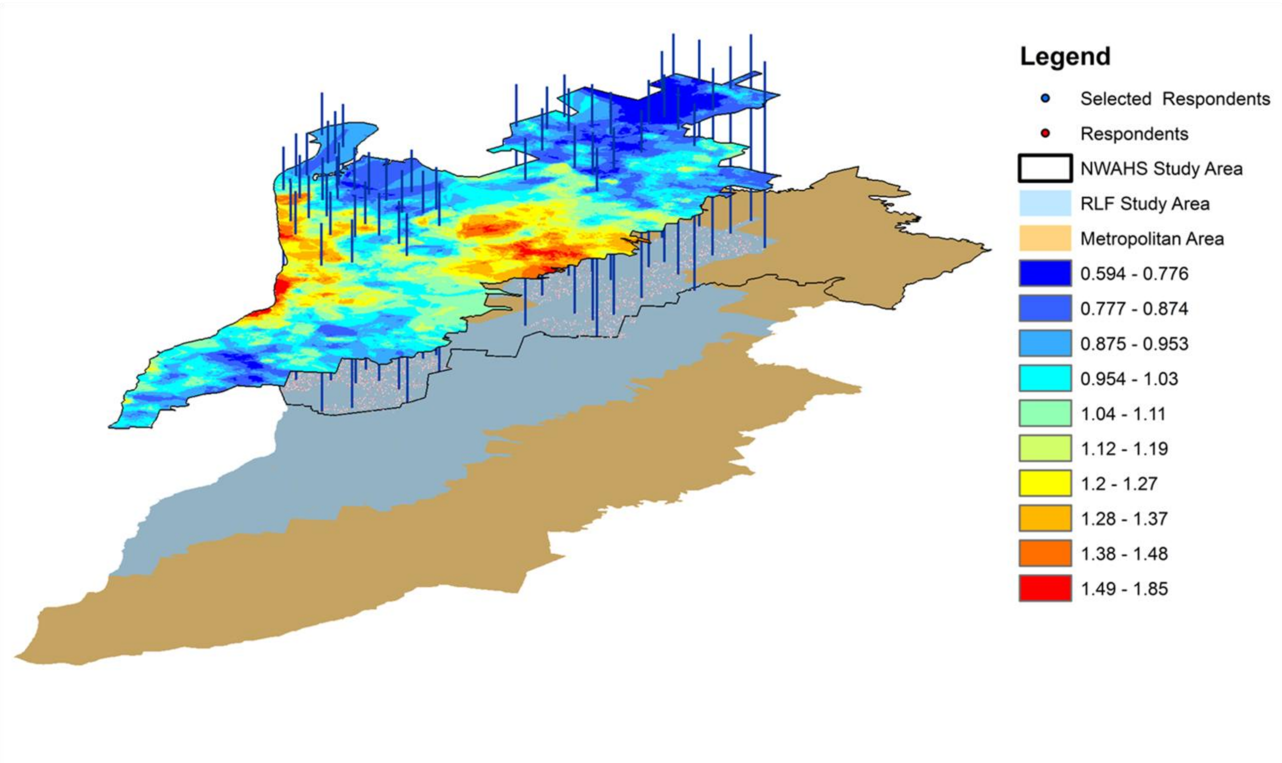
Participants

This study utilised data from the North West Adelaide Health Study (NWAHS) which was established to provide a longitudinal population-based biomedical cohort for investigating a number of chronic conditions and health-related risk factors over three waves of data collected between 2000 and 2010. This report involves a cross-sectional analysis that used the first wave (W1) of NWAHS data collected between 2000 to 2003 with 4056 adults who were 18 years of age or older. All participants were randomly selected via from the Adelaide White Pages Telephone Directory [76]. Data collection included self-report socio-demographic data, clinical and biomedical data, and prescription medication usage via linkage with the Australian Pharmaceutical Benefits Scheme. Participants provided their residential address during the self-report data collection and this information was validated during the clinic visit. Of 4056 participants recruited for W1, 4041 supplied valid addresses. All NWAHS participants provided written consent to use their health and residential address data. Geographic information system (GIS) software was used to geocode the participants' address for spatial analysis. Ethics approval was granted by the Human Research Ethics Committees of the University of South Australia, the North West Adelaide Health Service, and the South Australian Department of Health.

Relative Location Factor

The method to derive the RLF was described in detail in an earlier paper [16] and had three main steps. Step one specified a global hedonic regression model using residential property sales transaction data based upon several residential property characteristics, but deliberately blind to location, to predict the selling price of the residential property. This enabled the model error to be inferred as a proxy for the omitted variable bias of any attributes describing the influence of market value due to location. Such error was expressed as the ratio of the predicted price to actual price. Only Sales Transaction data in the study area that had been assessed as representing market value by the South Australian Valuer General were used in this stage (n=6800). Sale transactions between May and October 2001 were used to ensure market comparability. In step 2, the RLF was created using a geographic information system (GIS) to interpolate a continuous raster surface representing the individual residential property predicted to actual price ratios (a value of one accorded to the mean ratio, a value less than one was interpreted as location lowering the residential property values and a value greater than one was interpreted as location positively influencing residential property values). Step 3 used GIS to extract the value from the RLF surface to the geocoded respondent's location (Figure 2). The RLF resolution was set at 25 metres to more closely approximate the individual residential property level. RLF was only calculated for urban areas as different factors influence urban and non-urban (semi-rural or rural) residential property markets (Figure 1). RLF was grouped in tertiles using the ESRI Fisher-Jenks natural breaks algorithm [77]. This method for classifying RLF was used to provide groupings that were more meaningful and represented groups where the between group variation was maximised and the within group variation was minimised.

Figure 2: Linking RLF to Respondent Location.



Measures

Cardiometabolic Risk Factors and Score

In this study, the health measures analysed were six clinical risk factors and a cumulative cardiometabolic risk score. This was calculated as the sum of the six clinical risk factors. The risk factors were selected to reflect components of the metabolic syndrome and were based on internationally established clinical cut-offs for expressing metabolic syndrome and cardiometabolic risk generally. The risk markers were defined by the International Diabetes Federation (IDF) [78] and included:

- hypertension (systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥ 85 mmHg or treated for hypertension with medication);
- abdominal adiposity (waist circumference ≥ 94 cm in men and ≥ 80 cm in women);
- reduced high density lipoprotein (HDL) cholesterol (< 1.03 mmol/L in men and < 1.29 mmol/L in women);
- raised triglycerides level (≥ 1.7 mmol/L or treated for lipid abnormality with medication); and
- raised fasting plasma glucose (≥ 5.6 mmol/L or previously diagnosed diabetes).

A sixth marker, increased low density lipoprotein (LDL) cholesterol levels (≥ 4.1 mmol/L), was included based on a cut-off from the National Cholesterol Education Program (NCEP) ATP-III [79]. Each risk marker was scored as either zero (below the cut-off) or one (above the cut-off). CMR was calculated by summing the six risk markers and the value ranged from 0 (no risk markers) to 6 (all risk markers). Each elevated clinical risk factor was assumed to contribute equally to total cardiometabolic risk, therefore no weighting was applied.

Covariates

Covariates included participant reported age, gender and education. The NWAHS participant's age and gender were collected during the phone recruitment process and level of education was collected from the self-report questionnaire. Age was modelled in 10 year increments and education was dichotomised as with or without a university education.

Statistical analysis

Models for each risk factor as the dependent variable were tested using log binomial generalized linear models. The CMR score as the dependent variable was tested using Poisson regression. Parameter estimates were exponentiated to provide relative risk (RR). All analyses included participants' gender, age and education. The analyses were conducted in SAS (version 9.2; SAS Institute Inc, Cary, North Carolina). Statistical significance was set at alpha = 0.05.

Results

Sample characteristics

Of the 4041 participants with a geocoded address, 3915 had a complete cardio-metabolic risk profile. This number was reduced by a further 330 participants who lived in semi-urban fringe or rural locations as RLF was not calculated in these locations. The final sample after removing the non-urban NWAHS participants was 3585. Characteristics of the sample are presented in Table 1.

Table 1: Descriptive Characteristics of the Individual Survey Sample (n=3585)

Characteristic		**N (%)**
Gender: Male		1731 (48.2)
Female		1862 (51.8)
Education: No university degree		3155 (87.8)
University graduate		438 (12.2)
Relative Location Factor (Mean (SD))	Tertile 1	0.76 (0.084)
	Tertile 2	0.95 (0.046)
	Tertile 3	1.21 (0.146)
Central Obesity	Yes	2332 (65.0)
	No	1253 (35.0)
Hypertriglyceridemia (or medication)	Yes	1221 (34.1)
	No	2364 (65.9)
Reduced HDL	Yes	1054 (29.4)
	No	2531 (70.6)
Hypertension	Yes	1897 (52.9)
	No	1688 (47.1)
Diabetes Risk	Yes	798 (22.3)
	No	2787 (77.7)
High LDL	Yes	629 (17.8)
	No	2898 (82.8)
Cardiometabolic risk score (Mean (SD))		2.2 (1.5)

Table 2 displays the results from the analysis testing for associations between RLF, the six risk factors and the cardiometabolic risk (CMR) score. Five of the six risk factors were significantly associated with RLF. Participants in the most advantaged tertile had a lower risk of having central obesity, hypertriglyceridemia, reduced HDL, hypertension, and impaired fasting glucose compared with the most disadvantaged tertile. Higher LDL was not statistically significantly associated with RLF. RLF was a strong predictor of the likelihood of poorer cardiometabolic health in the lowest SES grouping. The CMR score was also statistically significantly associated with RLF. Participants in the most advantaged and middle RLF tertile respectively had a 19% and 9% lower CMR score than participants in the most disadvantaged RLF tertile. All covariates were statistically significant in most of the models, with the exceptions of the LDL model where only age was statistically significant and the HDL model where only gender was statistically significant.

Table 2: Parameter Estimates for Associations between RLF and Cardiometabolic Risk Factors and Cardiometabolic Risk Score (n=3585).

Tertiles (Natural Breaks)		**RR**	**95 % CI**		**P**
Central Obesity***	RLF: 3 v 1	0.89	0.83	0.95	0.0004
	RLF: 2 v 1	0.93	0.89	0.98	0.0033
Hypertriglyceridemia***	RLF: 3 v 1	0.79	0.70	0.90	0.0005
	RLF: 2 v 1	0.90	0.82	0.98	0.0173
Reduced HDL#	RLF: 3 v 1	0.79	0.67	0.92	0.0025
	RLF: 2 v 1	0.87	0.78	0.97	0.0159
Hypertension***	RLF: 3 v 1	0.94	0.88	1.01	0.0824
	RLF: 2 v 1	0.90	0.85	0.95	<.0001
Diabetes Risk***	RLF: 3 v 1	0.52	0.43	0.64	<.0001
	RLF: 2 v 1	0.79	0.70	0.89	<.0001
High LDL^	RLF: 3 v 1	0.95	0.77	1.17	0.6277
	RLF: 2 v 1	1.05	0.90	1.23	0.5399
CMR Score***	RLF: 3 v 1	0.81	0.76	0.86	<.0001
	RLF: 2 v 1	0.91	0.86	0.95	<.0001

*** Gender, Age and Bachelor Education Significant
# Gender Significant
^ Age Significant

Discussion

Six cardiometabolic risks and a cumulative CMR score were modelled to test the predictive power of RLF. In all but one of the risk factors and for the cumulative cardiometabolic risk, RLF was statistically significantly associated with the likelihood of poorer health in the most disadvantaged group relative to the middle and most advantaged groups. The CMR score of a participant living in the most advantaged tertile was 19% lower than a participant in the most disadvantaged tertile and 9% lower for the middle group compared to the most disadvantaged group.

The RLF methodology outlined in this paper and provided in more detail in an earlier paper [16] provides an alternative, or complementary, objective SES measure for place and health research. While SES is a many dimensioned and complex concept, RLF is a measure of relative residential property value, which as reported by Di and colleagues [1] represented between 21-50% of an individual's wealth. The relative nature of RLF provided the important link between 'where you live' and residential property wealth as the important ingredients when developing an individual residential property SES measure. It is important when deriving a relative measure such as the RLF to have it relate to a larger area such as Metropolitan Adelaide, so that people's choice of places to live includes as many competitive properties as possible. This makes the "relative" component of the measure more realistic in terms of the importance of location.

The utility of the RLF construction methodology is reflected through its ability to be generated at any time, subject to the availability of analysed residential property price transaction data together with the corresponding residential property characteristics data at the time of sale. This makes the methodology suitable for many jurisdictions both nationally and internationally and also may allow linking with other relevant data within a GIS environment. Study areas and time frames can be varied, the latter adding to the veracity of longitudinal studies.

A specific aim of this study was to add to the discussion within the growing literature that recognises residential property wealth as a SES measure. This paper has expressed residential property wealth as a function of relative location value rather than the absolute value of the property itself and found a significant link with cardiometabolic risk. This overcomes the problem of two neighbours having significantly different absolute property values while both belonging, in the SES sense, to similar, if not the same, SES sub group, removing the potential for distortion due to specific residential property differences. Conversely, two residential properties in different locations may have the same absolute value but attract different RLF scores providing a more reliable indication of SES through an inherently better underlying sense of 'place'. RLF was an objective SES measure and as a relative location factor for residential property value overcomes the potential challenges of MAUP and enabled the local SES variation to be captured. This study adds to the small but growing number of studies investigating the use of residential property value for SES and the application of GIS methods to link disparate data using location [42, 71, 72].

This is the first study in our knowledge to use residential property sales data to interpolate a continuous relative value surface and apply this as a SES measure to evaluate associations with cardiometabolic health risks. As noted above, the majority of analyses linking SES with health rely on predetermined aggregate spatial units.

RLF provides an objective SES measure that emphasises 'relative location value' rather than the 'residential property value' lived in. This approach can contribute to the overall advancement in the use of GIS regarding place and health research by expressing the importance of residential property wealth as a complementary SES metric.

Conclusion

RLF was statistically significantly associated with a lower CMR score and a lower risk of being centrally obese, having hypertriglyceridemia, reduced HDL, hypertension or being at risk of diabetes. These results add to the long standing association between SES and poorer health conditions, supported a gradient of poorer health with declining SES, and provided an objectively-derived residential property wealth based measure that could be applied with any study using individual participant address data. While many studies have concentrated on the health association with SES, few studies have looked beyond education, income and occupation. These are important indicators, but an objective measure that reflects both residential property wealth and location provides the basis for overcoming MAUP.

One of the enduring issues with many place and health studies is the lack of rigour associated with the choice or appropriateness of spatial boundaries. Such studies tend to focus on the rigour in selecting health data, accounting for bias and ensuring appropriate statistical methodologies. While these are all vitally important aspects of any study, the expression of place requires a similar level of attention and should be subject to similar levels of scrutiny.

RLF is a very flexible measure and can be interpolated for any jurisdiction that has location based residential property sales data with associated residential property characteristics. These sales transaction data are recorded in most jurisdictions as part of the land administration systems. Unlike statistical agency measures, RLF can be calculated quarterly, half-yearly, annually or for any period supported by residential property sales transaction data. In addition, it is not limited to census collection years and can be used to measure SES change over time as well as over space. This paper advances the understanding of the nexus between place, health and SES by providing an objective spatially informed measure for testing health outcomes and reported a robust association between RLF and cardiometabolic risk.

List of abbreviations

CMR cardiometabolic risk

CTVB Council Tax Valuation Bands

GDP gross domestic product

GIS Geographic information system

HDL high density lipoprotein

LDL low density lipoprotein

MAUP modifiable area unit problem

NWAHS North West Adelaide Health Study

RLF Relative Location Factor

RR relative risk

SEIFA Socio-Economic Index for Areas

SES; socio-economic status

UK United Kingdom

USA United States of America

W1 wave one data collection

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

NC and TL Conception of the project; data capture, spatial and statistical analysis and interpretation; writing the manuscript; and important critical review of the intellectual content. CP and NH: Data capture, health data definition, statistical analysis and critical review of the intellectual content. GH and MD: important critical review of the intellectual content and final approval of the version to be published. All authors read and approved the final manuscript.

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Chapter 6: Paper 3: Is Walkability associated with a lower cardiometabolic risk?

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Abstract

As built environment walkability has been associated with more walking and walking improves health, then people living in more walkable areas should have a lower risk of cardiometabolic (CMR) diseases. This study tested the hypothesis that higher walkability was associated with a lower CMR for two administrative spatial units and three road buffers. Data were from North West Adelaide Health Study, first wave of data collected between 2000 and 2003. CMR was expressed as a cumulative sum of six clinical risk markers, selected to reflect “metabolic syndrome”. Walkability was operationalised as dwelling density, intersection density, land-use mix and retail footprint. Walkability was associated with lower CMR for road buffer representations of the built environment but not for the administrative spatial units. This may indicate a limitation in the use of administrative spatial units for analyses of walkability and health outcomes.

Keywords

Built environment, Walkability, cardiometabolic risk, GIS, spatial scale.

Introduction

The health benefits of physical activity in reducing the risk of chronic diseases are well established (US Department of Health and Human Services, 1996, Andersen, 2007, Bauman, 2004, Brown, 2004). Walking is a simple, universal and readily available form of physical activity. Enabling more people to walk could improve health, decrease chronic disease incidence and reduce health care costs (Morris and Hardman, 1997, Lee and Buchner, 2008, Hamer and Chida, 2008). Research into the factors influencing walking has considered individual behaviour, population level factors and the impact of the built environment. The focus on the built environment has enabled a more cross disciplinary approach linking objective built environment data with walking and health outcomes (Adams et al., 2009, Berke et al., 2007, Booth et al., 2005, Frank et al., 2003, Lee and Moudon, 2006, Lovasi et al., 2008, Handy et al., 2002).

Various elements of the built environment are now widely viewed as “walk-supportive” (Forsyth et al., 2008, Handy et al., 2002, Handy et al., 2008, Handy, 1996, Sallis et al., 1998). These include population density, street network pattern, land use mix, retail access, and accessibility to a range of facilities such as food shops and public open space (Frank et al., 2003, Lee and Moudon, 2006). Associations such as these led to a definition of walkability built upon the themes of connectivity and proximity (Frank et al., 2003, Frank et al., 2005, Lee and Moudon, 2004, Cervero and Kockelman, 1997), operationalised as population or dwelling density, intersection density, land use mix and retail space footprint (Adams et al., 2009, Frank et al., 2003, Lee and Moudon, 2006, Lovasi et al., 2008, Frank et al., 2005, Frank et al., 2010, Leslie et al., 2007). This and similar definitions of walkability have been used to investigate associations with walking and physical activity (Learnihan et al., 2011, Berrigan et al., 2010, Berrigan and Troiano, 2002, Cerin et al., 2007, Craig et al., 2002, Owen et al., 2007), obesity and body mass index (BMI) (Berke et al., 2007, Booth et al., 2005, Brown et al., 2009). As walkability has been associated in many studies to correlate with higher walking levels, and as walking improves health outcomes, it should follow that people living in locations with higher measured walkability should have a lower risk of cardiovascular and metabolic diseases. Few studies have sought to evaluate whether cardiometabolic risk is related to walkability. Most published studies have investigated walkability and obesity. Of the few to have looked beyond obesity, the classes of outcomes studied include: blood pressure (Li et al., 2009, Mujahid et al., 2008) O2 max and maximal aerobic power (Larouche and Trudeau, 2010); and biochemical markers, percent body fat, blood pressure, and metabolic syndrome (Dengel et al., 2009).

Built environment measures are typically expressed spatially, however much of the place and health research does not consider the choice of spatial unit used or its size (scale), or comment on the modifiable areal unit problem (MAUP). Geographers have studied the MAUP for many years (Openshaw, 1977, Openshaw, 1984, Fotheringham and Wong, 1991, Parenteau and Sawada, 2011) and, despite the level of attention directed towards the issues and possible solutions, few publications in the field of public and population health consider the MAUP in reporting their findings from spatial analysis (Root, 2012). Place and health researchers would appear to select and analyse predetermined administrative spatial units without the level of scrutiny typically applied to their choice of variables, the reliability and validity of data capture techniques, and the specification of an appropriate statistical methodology. The choice of spatial unit is a key issue and more work is required to understand the relationship between predetermined administrative spatial units, buffer expressions of local environments, or other interpolated expressions of place. Diez-Roux (Diez-Roux, 2001) posed the challenge in 2001 to consider how the choice of spatial unit might vary according to the health outcome being studied and the causal pathway. Brownson (Brownson et al., 2009) has noted that too few researchers have used or reported analyses of multiple geographic scales, and that further research into the use of predetermined spatial units or variable distance based road buffers is required. A recent Australian study found a strong association between road buffers and more walking for transport, but not with the Census Collection District (CD) or State Derived Suburb (SSC) (Learnihan et al., 2011). This study concluded that the scale and type of spatial unit is an important consideration when characterising walkability and that larger predetermined spatial units are less likely to provide a meaningful statistical result (Learnihan et al., 2011). Research explicitly addressing issues of geographic scale and the use of predetermined spatial units has the potential to uncover associations that may otherwise be masked.

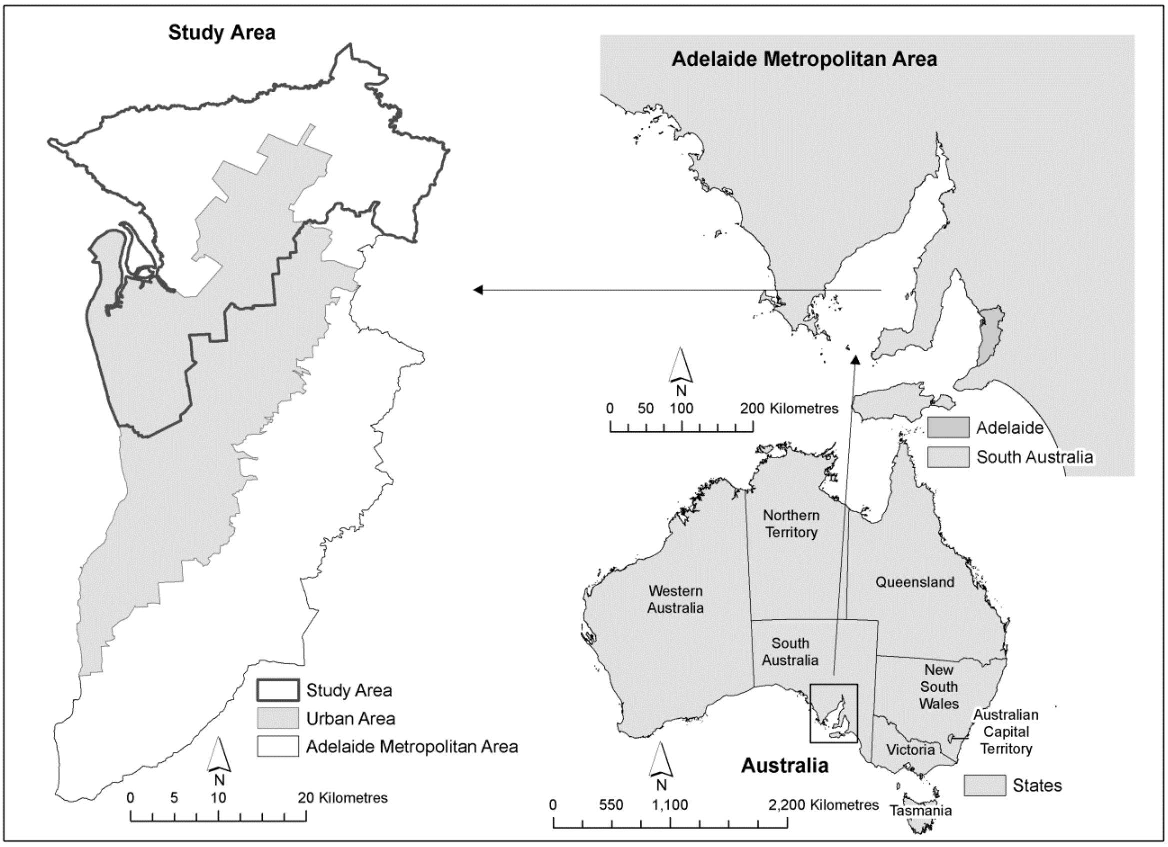
This study tested the hypothesis that higher built environment walkability is associated with a lower risk of cardiometabolic diseases and tested this hypothesis for two existing predetermined administrative spatial units and three road distance buffers.

Methods

Study Area

The study area comprised the North Western and Northern Adelaide metropolitan area, stretching approximately 60 kilometres north-south and 38 kilometres east-west and is part of the capital city of South Australia (Figure 1). The population of study area in 2001 was 410341, 38% of Adelaide's metropolitan population (Australian Bureau of Statistics, 2003).

Figure 1: Study Area



Source: State, Metropolitan and Urban Boundaries are from the Australian Bureau of Statistics, Australian Standard Geographic Classification 2001: Study Area boundary, Social Epidemiology, University of South Australia.

Walkability is typically a measure applied to urban locations and not semi-urban and rural locations, as these areas are typically characterised by very large parcels, fewer roads, minimal land use diversity and few retail centres. For this research, walkability was calculated for urban areas (population density > 200 persons per hectare) (Australian Bureau of Statistics, 2001) within the study area (Figure 1).

Study Cohort

The North West Adelaide Health Study (NWAHS) was established to provide a longitudinal population-based biomedical cohort for investigating the prevalence of a number of chronic conditions and health-related risk factors over three waves of data collected between 2000 and 2010. This cross sectional analysis used the first wave of data collected over the period 2000 to 2003 with 4056 participants. All participants were over 18 years of age and recruited via random selection from the Adelaide White Pages Telephone Directory (Grant et al., 2006). The data collection included self-report socio-demographic and health data, clinical and biomedical data, and prescription medication via linkage with the Australian Pharmaceutical Benefits Scheme. Participants provided their residential address during the self-report data collection and this information was validated during the clinic visit. Valid address data supplied by 4041 of the wave one participants were used to create a georeference point to enable spatial linkage with Census and built environment data. Written consent was provided by all NWAHS participants to allow geocoding, and ethics approval was granted by the Human Research Ethics Committees of the University of South Australia, the North West Adelaide Health Service, and the South Australian Department of Health.

Measures

Cardiometabolic Risk Score

The cardiometabolic risk measure applied in this study was a cumulative sum of six clinical risk markers. The risk markers were selected to reflect the clustering of components often termed "metabolic syndrome" and defined using established clinical cut-offs. These included, hypertension (systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥ 85 mmHg or treated for hypertension with medication), abdominal adiposity (waist circumference ≥ 94 cm in men and ≥ 80 cm in women), reduced high density lipoprotein (HDL) cholesterol (< 1.03 mmol/L in men and < 1.29 mmol/L in women), raised triglycerides level (≥ 1.7 mmol/L or treated for lipid abnormality with medication), and raised fasting plasma glucose (≥ 5.6 mmol/L or previously diagnosed diabetes). These cut-offs were defined by the International Diabetes Federation (IDF) (Alberti et al., 2006). The final marker, reduced low density lipoprotein (LDL) cholesterol levels (≥ 4.1 mmol/L), was included to reflect guidelines from the National Cholesterol Education Program (NCEP) ATP-III (Expert Panel on Detection Evaluation and Treatment of High Blood Cholesterol in Adults, 2001) even though it is not a component of the IDF consensus worldwide definition of metabolic syndrome. Each risk marker was scored as zero for below or one for above the cut-off. The count of elevated markers was summed to create the cumulative risk score. No weighting was applied to the risk score on the assumption that each elevated clinical risk factor contributes equally to total cardiometabolic risk.

Walkability index

The objective walkability index was calculated using the geographic information systems (GIS) methodology established by Frank and colleagues (Frank et al., 2003) and adapted for Australian data by Leslie and colleagues (Leslie et al., 2007), and Coffee (Coffee, 2005). The walkability index had four components, intersection density (connectivity), dwelling density, land use mix and net retail area (proximity) (Frank et al., 2005, Leslie et al., 2007, Coffee, 2005).

Data

The data used to construct the Walkability measure were the 2001 South Australian Digital Cadastral Database (DCDB), Land Ownership and Tenure System (LOTS) database, the 2001 Dwelling Count, 2001 Generalised Land Use and the 1998 Retail Data Base provided by the Land Services Group, South Australian Government, Department of Planning, Transport and Infrastructure (DPTI), and StreetPro© road data provided by Pitney Bowes Business Insight. The key spatial data for this research were the DCDB and LOTS as these data provided a detailed parcel based record of all land ownership in the study area with attributes pertaining to land area and land use among many others. DPTI used these data to derive a dwelling count for all residential land use and a primary land use classification for each parcel. These data form the basis for the dwelling density and land use mix components of the walkability index and were used to derive dwelling numbers, buffer land area and land use mix for each spatial unit in this analysis. The data processing was important as these data have been validated by DPTI and can be used in the walkability index with confidence.

Dwelling density

Dwelling density was calculated as the count of dwellings by the total residential area (Km^2) for each spatial unit.

Intersection density

Road networks do not usually include intersection data, therefore a data building and validation process was required. This involved converting the StreetPro© roads to a spatial network layer which created a node (intersection) at every point where two roads intersected. The potential directions of travel were calculated for each intersection and density was the count of greater than two direction intersections by the total area (Km^2) for each spatial unit.

Land use mix

Land use mix is an indication of the heterogeneity (or diversity) of land use for each spatial unit. Measures of diversity are often applied in ecological research to quantify species diversity and have been increasingly applied in walkability analyses (Lee and Moudon, 2006, Frank et al., 2005, Owen et al., 2007, Brown et al., 2009, Dygryn et al., 2010, Frank et al., 2004, Frank et al., 2006). This measure, termed entropy uses the following formula, where k

is the category of land use, *N* is the number of land use categories and *p* is the percent of each land use in the spatial unit:

$$\frac{\sum_k (p_k \ln p_k)}{\ln N}$$

The entropy equation results in a score of 0 to1, with 0 representing homogeneity (all land uses are of a single type), and 1 representing heterogeneity (the developed area is evenly distributed among all land use categories). For this research, three land use types were used to calculate land use mix, residential, commercial and recreation.

Net retail area

Net retail area was conceptualised to reflect the extent that a shopping centre promotes walking behaviour (Cervero and Kockelman, 1997, Frank et al., 2006, Gebel et al., 2009), using car parking as a proxy measure. A shopping centre with large car parking area is designed to attract car based shoppers while a centre with small or minimal car parking is more walk orientated. On this basis, net retail area was calculated as the gross retail space divided by the total parcel area for the shopping centre. Low values indicate larger parking areas and less walk friendly retail access.

Walkability index score

The four walkability components were classified into deciles and the values summed for each of the five spatial units (described below) to create the walkability index (WI) with values ranging from 4-40 ((Berke et al., 2007, Frank et al., 2003, Frank et al., 2005, Leslie et al., 2007, Owen et al., 2007, Coffee, 2005, Dygryn et al., 2010)). Lower values indicated less walkable built environments.

Spatial Units

Many of the studies applying walkability use either existing predetermined spatial units (Lovasi et al., 2008, Cervero and Kockelman, 1997, Brown et al., 2009, Frank et al., 2006, Gebel et al., 2009, Frank et al., 2009, Ewing, 2005) or buffers (Adams et al., 2009, Berke et al., 2007, Lee and Moudon, 2006, Frank et al., 2004, Sallis et al., 2010, Troped et al., 2010); few have used both (Learnihan et al., 2011, Boer et al., 2007). To progress understanding into the consideration of spatial scale, the WI was calculated for two ABS Australian Standard Geographic Classification (ASGC) (Australian Bureau of Statistics, 2001) administrative units, the Collection District (CD) and the State Derived Suburb (SSC), and three road distance buffers (500m, 1000m and 1600m). The road distance buffers reflect walk times of approximately 5-7 minutes (500m), 10-12 minutes (1000m) and 15-18 minutes (1600m) at a normal walking pace (Morris and Hardman, 1997). The variability between the spatial units is presented in Figure 2 and Table 1, with increasing mean size from the CD (0.32km^2) through to the largest unit, the 1600m road buffer (5.7 km^2).

Figure 2: Geographic Scale Variation Across the Study Spatial Units, NWAHS, 2001

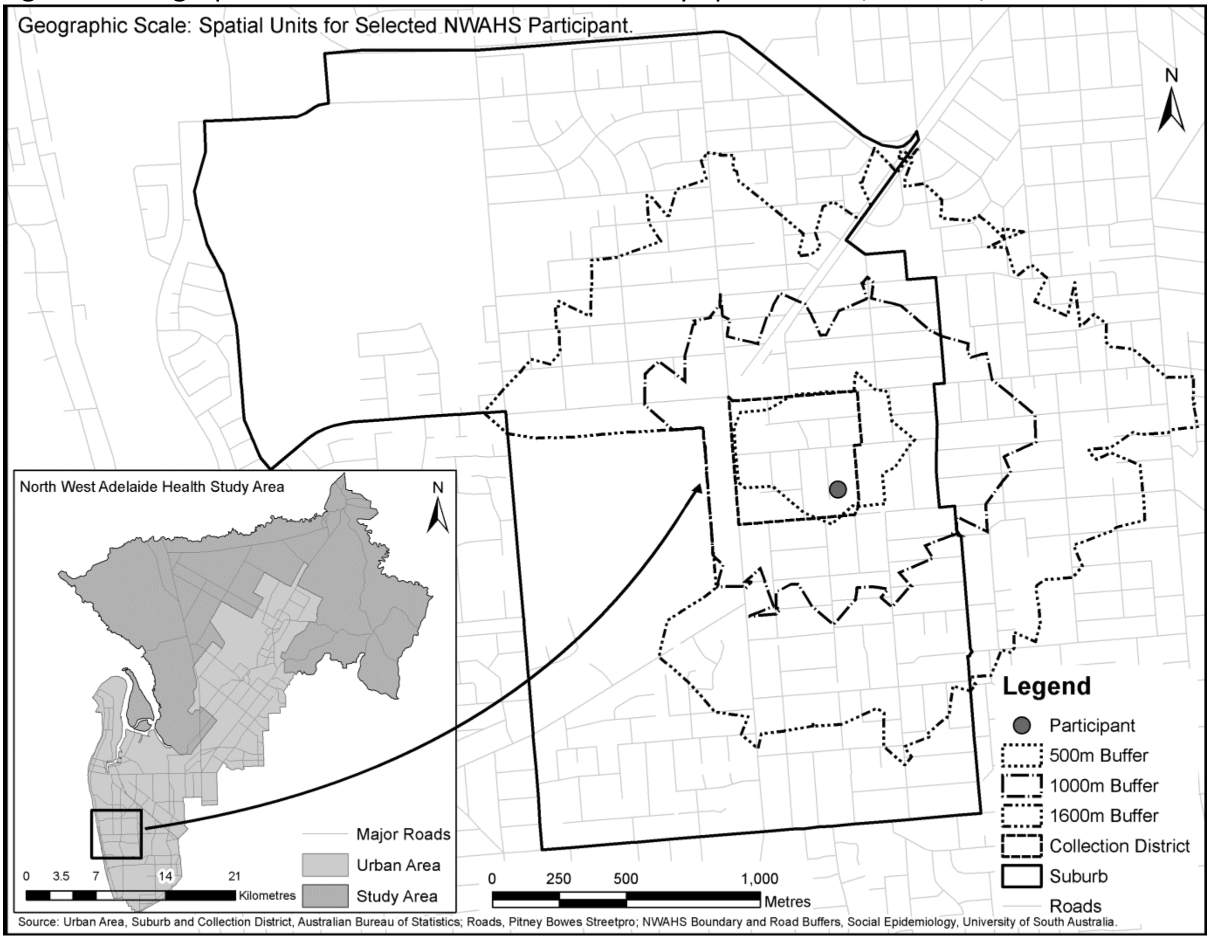


Table 1: Descriptive Statistics for Spatial Units, According to Buffer Area or Unit.

Spatial Unit	N	Mean (km^2)	Standard Deviation (km^2)	Median (km^2)	Minimum (km^2)	Maximum (km^2)	1st Quartile (km^2)	3rd Quartile (km^2)
500 metre*	3593	0.96	1.85	0.58	0.10	19.15	0.49	0.78
1000 metre*	3593	2.60	2.64	1.90	0.45	20.99	1.60	2.32
1600 metre*	3593	5.73	3.98	4.47	1.17	34.06	3.78	5.53
Collection District	739	0.32	0.58	0.24	0.05	12.59	0.17	0.33
Derived Suburb	124	2.54	4.60	1.47	0.25	47.78	1.01	2.67

* Road buffer area calculated as sum of all land parcels intersected by the buffer.

Covariates

Covariates included age, gender, education, household income and area-level median household income. The NWAHS participant's age and gender were confirmed when recruited, the highest level of education, and broad classes of gross household income were collected for each participant via self-report questionnaire. Age and education were dichotomised as either aged less than or equal to 55 or greater than 55 years of age (to include the increased cardiac risk for older persons) and being a university graduate (bachelor degree or higher) or not. Three household income groups were used: less than $20000 AUD per annum; $20000 to $60000 AUD; and greater than $60000 AUD. Area-level median household income was calculated from the ABS 2001 Population and Housing Census for the SSC.

Statistical analysis

Models with the cumulative cardiometabolic risk (CMR) score as the dependent variable were tested using Poisson regression. Regression estimates from these models were exponentiated to express results as relative risks. All analyses included WI, participants' gender, age, income, education and the SSC median household income. Each model was run for the five spatial units. The spatial clustering of observations according to SSC was accounted for through the use of Generalised Estimating Equations (GEE) estimation. SSCs were formed by aggregating CDs (37) and were selected as the preferred aggregate census spatial unit for clustering as the SSC contained a sufficient number of participants per spatial unit and provided larger between-unit variability. All analyses were conducted in SAS (version 9.2; SAS Institute Inc, Cary, North Carolina). Statistical significance was set at alpha = 0.05.

Results

Sample characteristics

Of the 4041 NWAHS participants with a geocoded address only 3915 had a complete cardiometabolic risk profile. Of these, 322 lived in urban fringe or rural locations and WI was not calculated in these locations. The final sample after removing the non-urban NWAHS participants was 3593. The characteristics of the sample are presented in Table 2.

Table 2: Descriptive Characteristics of the Sample (n=3593)

Characteristic	**N (%)**
Gender: Male	1731 (48.2)
Female	1862 (51.8)
Age: < 55	2147 (59.8)
>= 55	1446 (40.2)
Education: No university degree	3155 (87.8)
University graduate	438 (12.2)
Income: 0-19,999 AUD	1148 (31.9)
20,000-59,999 AUD	1705 (47.5)
>60,000 AUD	740 (20.6)
Cardiometabolic risk score (Mean (SD))	2.2 (1.5)
Suburb Weekly Household Income (Mean (SD))	651 (149.3)
Walkability Score 500m (Mean (SD))	20.5 (7.0)
Walkability Score 1000m (Mean (SD))	22.0 (6.6)
Walkability Score 1600m (Mean (SD))	22.6 (6.1)
Walkability Score CD (Mean (SD))	21.1 (5.7)
Walkability Score Suburb (Mean (SD))	24.4 (4.4)

Walkability index and cardiometabolic risk score

Table 3 contains results from the analysis testing associations between CMR and the WI for each of the five spatial units. A statistically significant, modest relationship existed for the 500m, 1000m and 1600m road buffers, but not for either of the two predetermined ABS aggregate spatial units, the CD or SSC.

Specifically, younger individuals, females, participants with a bachelor's degree or higher education, and those who lived in suburbs with higher median household incomes, had a lower CMR score. The magnitude of the relative risk of WI on CMR strengthened slightly as the road buffer size increased (0.97 to 0.94). All covariates were statistically significant except for individual high-low household income (data not shown specifically). More walkable built environments were associated with lower CMR scores.

Table 3: Parameter Estimates for Associations between Cardiometabolic Risk Score and Spatial Unit Walkability Score (n=3593)*

Walkability Score	RR	95 % CI		P
500m Road Buffer	0.97	0.94	1.00	0.04
1000m Road Buffer	0.94	0.91	0.98	0.002
1600m Road Buffer	0.94	0.90	0.97	<0.001
Collection District	0.98	0.94	1.03	0.47
Derived Suburb	0.97	0.91	1.04	0.37

*Adjusted for individual gender, age (<55 or >=55), education (no university or university degree), weekly income (0-19,999; 20,000-59,999, >60,000) and suburb weekly median household income.

Discussion

Lower CMR score was associated with higher WI for road buffer representations of the built environment with a three percent reduction in relative risk for the 500m road buffer, and six percent for the 1000m and 1600m road buffers. No statistical relationship was found for either predetermined administrative spatial unit. These results indicate that the choice of spatial unit used and its scale influence the nature of relationships estimated between the built environment and clinical risk factors.

A number of studies have investigated physical activity and positive health outcomes, including lower CVD (Bauman, 2004, Hamer and Chida, 2008, Boone-Heinonen et al., 2009, Rodriguez et al., 2009) or positive associations between walking and walkability scores (Lovasi et al., 2008, Frank et al., 2005, Gebel et al., 2009, Rodriguez et al., 2008), few have specifically evaluated CMR scores in relation to walkability. A recent published review of cardiometabolic risk factors and environmental characteristics reported on 113 studies, most of these investigated weight-related outcomes with only three studies investigating metabolic syndrome (Leal and Chaix, 2011). In expressing the environment, most studies used SES, 37 studies used built environment characteristics and 45 studies used objective GIS environment measures (Leal and Chaix, 2011).This review exemplifies the interest of health researchers in the built environment and health, expressed primarily in terms of body weight and area-level SES. Overall, its findings suggest the need for research to move beyond evaluating the relationships between the built environment and walking, to chronic disease risk factors and outcomes that relate to walkability as well as more specific characteristics of the built environment.

In the present study, a lower CMR score was associated with higher walkability for road buffer representations of the built environment with a three percent reduction in relative risk for the 500m road buffer, and a six percent reduction for the 1000m and 1600m road buffers. No meaningful statistical relationship was found for either of the predetermined administrative spatial units. These results are similar to the findings from an earlier

Australian study that found strong associations between walking for transport and road buffers, but no relationship with administrative units such as the collection district (CD) or suburb (SSC) (Learnihan et al., 2011).

Whilst the relative risk observed for road network buffers was modest in the current study, such results demonstrate differences in cardiometabolic disease associated with a variation in how the built environment was expressed. Road buffers were selected to reflect the immediate walking environment of the NWAHS participants. Centered on participants' home addresses, road buffers represented the most likely walking paths in all directions for durations of 5, 10 and 15 minutes, based on a modest walking pace (Morris and Hardman, 1997). Simply stated, the road buffer method builds from the participant's address point and radiates along the road network in all directions. Conversely, for a predetermined administrative spatial unit the georeference point for a participant may fall anywhere within the spatial unit, including its edge. As a result, the spatial extent associated with any given participant may reflect all, part, or none of their area of walking interaction.

Additionally, the predetermined administrative spatial units may turn out to be either too small (as was the collection district (CD), in this study), or too large (as was the suburb (SSC), in this study). Such limitations arise because administrative spatial units were not designed for geospatial analysis. In Australia, the CD was designed by the ABS as the workload of a single census collector for the two week period every five yearly census collection cycle (and CDs may change every census). The SSC is a geopolitical boundary (the older SSCs were historical) which varies considerably in size, does not purposely encompass a community of interest for analysis, but may provide a convenient subdivision of areas for address purposes.

Use of predetermined administrative spatial units remains widespread in health research: Leal and Chaix (Leal and Chaix, 2011) recently reported that approximately three quarters of studies identified in their review (2011) used pre-determined administrative spatial units. The selection of spatial unit is a critical decision for place and health research and clearly has an impact on study outcomes. This analysis would not have uncovered an association had the choice of spatial unit had been limited to the CD or the SSC, each of these are often used in Australian place and health research.

These results support the call by Diez-Roux (Diez-Roux, 2001) to define relevant geographic areas that reflect realistic pathways between the health outcome and the geographic area. These results align with Brownson's (Brownson et al., 2009) call for research on the use of predetermined spatial units versus road distance buffers as an important issue still to be addressed by health researchers. This study thus contributes to understanding the health in relation to the built environment and geographic scale. It is amongst the first of studies to explicitly evaluate the associations between the built environment characterised as a cumulative walkability score and clinically measured cardiometabolic risk markers.

Limitations

The cross-sectional design of this study does not allow for causal inference. The definition of walkability used in this research was chosen to provide compatibility with a number of existing studies. Future work will expand the definition of walkability used in this study to include other built environment characteristics as well as accessibility to selected facilities to ensure that future research considers many other attributes of the built environment identified in the literature (Brownson et al., 2009, Leal and Chaix, 2011). A further limitation is the potential for self-selection of individuals more likely to walk into more walkable areas, resulting in a lower CMR score. This possibility will be evaluated in future analyses of multiple waves of longitudinal data from the NWAHS.

Conclusion

Many studies have concentrated on the health benefits of walking, or on the factors that define walkable neighbourhoods and whether this results in more walking. Few studies have applied the logic that if walkability corresponds to more walking, then walkability should be associated with a lower risk of cardiometabolic diseases. This paper advances the understanding of the nexus between the health benefit of walking and the categorisation and spatial scale of walkability by testing the association between clinically measured cardiometabolic risk and an objective GIS derived index of walkability. More walkable areas were modestly associated with lower CMR scores. The strength of this association was slightly greater for larger walking distances. Importantly, this study demonstrates how spatial scale in terms of the use of predefined administrative units versus user-specified network buffers shapes the results of place and health analyses.

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Chapter 7: Discussion

Place in health research, despite its long history, has only recently re-emerged as a focus for health research and therefore is still evolving. However, while the inclusion of *place* is growing, only a relatively small number of researchers are advocating the need for method and application developments to better understand the use of spatial boundaries and improve spatial modelling (Cummins et al., 2007, Diez-Roux, 2000, Diez-Roux, 2001, Feng et al., 2010, Gauvin et al., 2007, Macintyre, Ellaway and Cummins, 2002, Macintyre, Maciver and Sooman, 1993, Riva et al., 2008, Ross, Tremblay and Graham, 2004). The MAUP remains an issue for any research using *place* but is largely ignored in a large proportion of *place*-health research articles with only a small group of *place* and health researchers highlighting the spatial issues (Berry et al., 2010a, Black and Macinko, 2010, Chaix et al., 2009, Cockings and Martin, 2005, Foley, 2009, Gauvin et al., 2007, Haynes et al., 2007, Hayward, 2009, Hoehner et al., 2011, Parenteau and Sawada, 2011, Riva et al., 2008, Spielman and Yoo, 2009, Stafford, Duke-Williams and Shelton, 2008). The three papers which are the core of this thesis provide the potential to progress the use of spatial methods for health analysis. Collectively, these papers address the use of *place* in health research and provide a basis for a continuing debate on the conceptualisation and methodological applications of *place* for health researchers. Individually, these papers provide a spatial methodology for calculating and applying a property based wealth SES measure and supporting evidence on the importance of matching the *place* measure to the research question and health outcome.

Place-SES-Health Research

Chapter two established the strong link between *place* and health, and reinforced the need for a more informed use of *place*. Historically, there were some important and detailed studies in the 19th Century that studied poverty (SES) and *place* (Barrett, 2000, Orford et al.,

2002) and used detailed maps to display the results. Despite this historical application of *place* to health, this practice has been dormant for much of the 20^{th} Century. While the use of *place* for research is becoming more frequent and the spatial tools available to the present researcher more advanced, the 19^{th} century work was still more detailed than some modern health applications. Perhaps this stems in part from the specialisation of skills that is now the norm relative to the more rounded researcher of yesteryear and the creation of subject specific silos has resulted in advances in specific theory and modelling techniques at the loss of a multi-discipline skill base (Public Policy Group, 2011, University of California n.d.). In addition, it may be argued that the increased privacy legislation in many developed nations has limited the production and release of detailed small area population and health outcomes data. The increased use of GIS and geocoding can enable participant re-identification (Foley, 2009) and this can hamper access to health data for small spatial units and is often the reason for the supply of health data for larger spatial units. This is one of several methods the Australian Bureau of Statistics and the Australian Institute of Health and Welfare use to ensure they meet their respective legislated confidentiality provisions and will not release data at a spatial unit that might enable the identification of an individual. As larger spatial units are the only means for some data supply and data are limited in this fashion, this leads to the question of why the use of aggregated data associated with larger spatial units is not included in the study limitations with an indication of how this can impact upon research outcomes.

The increasing use of *Place* as a research variable in both the SES and built environment walkability literature since the 1990s was highlighted in Chapter two. The literature review identified four main issues:

- since the 1990s more studies have included *place* ,although the methods are relatively under-developed (focused on the use of GIS to make maps, create variables for statistical analysis and not for spatial analysis)*;*
- there is a need for a more theoretical and conceptual understanding of the causal pathways between *place* and health;
- many of the studies used predetermined administrative spatial units; and
- the implications of the above points, especially the use of predetermined administrative spatial units or the potential for the MAUP, are under-reported in the limitations.

The search of articles in chapter two resulted in approximately 10,000 results which included *place* (via several search terms) but, of these, only 54 included some reference to the MAUP in the title, abstract or keywords. It could be argued that a detailed read of each paper would be required to form this conclusion. This may be a valid point, but a number of *place* and health researchers have highlighted these very issues and called for more development work and a closer match between the choice of spatial unit and the health outcome under investigation (Brownson et al., 2009, Chaix et al., 2009, Cummins et at., 2007, Diez-Roux, 2001, Leal and Chaix, 2011, Riva et al., 2008). The call to improve the use of *place* recognition in the literature, coupled with this author's personal experience in working with several health research teams created the impetus for the methodological developments presented in the three articles that form the substance of this thesis.

Social disadvantage has a long history and its association with health is accepted and included in an extensive literature as was reported in chapter two and two of the papers prepared for this thesis (chapters four and five). SES is typically represented using measures of income, occupation and education either individually or collectively (aggregated to a spatial unit or population sub-group). These measures have been used in many studies across an array of spatial units, such as countries, states, provinces, counties, metropolitan areas, local government areas, cities, suburbs, postcodes and a range of census output units. What is remarkable given the substantial literature and acceptance of *place*-SES-health associations is the lack of a standard definition for both the SES measures and the spatial units employed. This should be cause for some caution as without a clear definition, comparability from one jurisdiction to another must be managed carefully to ensure comparisons are valid. While the validity of SES measures will often be addressed specifically, the same cannot be reported for the spatial units. As reported in the literature review the spatial unit is often poorly described or included briefly in the method without any justification. The Leal and Chaix, (2011) systematic review reported 75% of researchers did not include the total population or characteristics of the spatial units used in their respective studies.

GIS in Health Research

GIS has been associated with the increased use of *place* in health research and the increased use of *place* coincided with the release of Windows based user friendly GIS software such as Arcview and MapInfo in the 1990s. GIS provided a platform for adding *place* via the use of predetermined spatial units, the release of census data and the potential geocoding of survey respondents. While GIS provided an easy access point for including *place* it did not explicitly warn the user about the potential issues associated with areal units or the need for a deeper understanding of the use of *place* in research. This is not just an issue for GIS, but can be associated with any software that provides a “point” and “click” solution, such as spreadsheets, databases and statistical software like SPSS or SAS. These software packages remove the need for expert knowledge and can be used with very little instruction. The potential for misuse is then increased as the software does not have a “validity” filter and will process the input data and produce an outcome. The loss of expert status is both good and bad. Certainly it is beneficial to provide improved tools that are easier to use and readily available, but this creates a situation where the tools can be used with little understanding of the limitations.

The increasing use of GIS and the greater application of spatial methods to health analysis are at the centre of this thesis. It is important to include *place* in research as understanding the variations in health across space are fundamental to better service delivery and policy development. While policy and service levels can be described at the level of the country, state or city, the actual impact will be evident at the local scale and this is why *place* is a critical component in any understanding of health outcomes. The statements used to market GIS by the vendors express this sentiment, “everything is somewhere” (MapInfo© Corporation) and “geography matters” (ESRI©). Indeed, people, facilities, services, land uses etc are all distributed in space and the pattern of this distribution is a critical component of any understanding that attempts to report on population associations. To geographers, place is central to understanding of both the physical and human environments and as stated by Tobler (1970) and referred to as Tobler’s law, everything interacts, but those things that are closer interact more. This “law” provides the basis for understanding the interaction between *place* and health (as is the case in this thesis) and describes the influence of distance through a range of mechanisms, such as maximum effect distances or via distance decay. Consequently, the inclusion of spatial association (*place)* should involve an informed choice of spatial unit and a clear understanding of potential issues that may result from the choice, especially if the spatial unit is used solely because the data were only released for that particular spatial unit. It is these situations where the limitations should include the potential for MAUP and a clear statement of possible effect bias as a result. The three articles in this thesis contribute to highlighting these issues by stressing the impact of MAUP in *place*-health research and calling for more scrutiny of *place* spatial unit choice at least to the same level applied when selecting the health outcome variable and the statistical modelling.

The Contribution of RLF

This thesis presents two papers which provide a new, objective, spatially based wealth measure for health and social research. Wealth has been suggested by a number of health researchers (Auchincloss et al., 2007, Bond Huie et al., 2003, Braveman et al., 2005, Duncan, 2002, Pollack et al., 2007, Rehm et al., 2012, Vernez Moudon et al., 2011) as an important indicator over and above income, occupation and education because of the potential to highlight wealth accumulation and not just the status at the survey time point. Income, for example, will reflect a value at a given time, whereas wealth includes accumulation and can therefore express social position with more certainty than a single point in time that can be distorted by a short lived event or poor question construction (Allin, Masseria and Mossialos, 2009, Bond Huie et al., 2003, Brown and Nepal, 2010). RLF as a wealth SES measure is both objective and spatially based and thereby provides a means of moving beyond self-report income, education and occupation or area level aggregate outcomes. The relative location factor (RLF) was designed to represent the importance of where you live as the significant determinant of relative wealth and social position and the detailed methodology was presented in chapter four and the application with health outcomes in chapter five.

The RLF method was novel in a number of ways:

- used comparable residential property sales to express property value;
- can be calculated at any time and for differing spatial extents (subject to data availability);
- used a hedonic model built from a small number of property characteristics but blind to location to provide the metropolitan “average” for a given set of characteristics;
- calculated the difference between the model predicted price and the actual sale price;
- was a relative indicator of property value (relative in this case to the metropolitan average);
- used GIS to interpolate a continuous surface of the ratio of actual to predicted sale prices;
- the interpolated surface at any point represents the influence of neighbouring properties;
- the relative nature of the measure overcomes the problems of neighbouring properties with vastly different values being classified as different when they would most likely belong in the same SES class;
- the interpolated RLF can be associated with any residential property using GIS; and
- RLF better expressed residential property value across space by removing the variation that is present when using actual property values.

RLF was conceptualised to provide a wealth SES measure either to complement or as an alternative to income, occupation and education. In addition RLF is explicitly about location, and, as is so often stated, the three most important components of property value are location, location, location (Bourassa, Hoesli and Peng, 2003). In this way RLF could be used as a variable for population health research and provide a variable that reflected both *place* and SES. The first paper provided detailed methodology as well as a comparison with the Australian SEIFA index. Even though RLF was designed to reflect a spatial SES measure free from the MAUP, it can be aggregated to administrative spatial units which would then introduce the potential for the MAUP and would require the potential limitation this could introduce to be included. Using GIS zonation methodology, the 2001 RLF average value for the ABS CD was calculated, classified into deciles and compared with the 2001 SEIFA index of advantage and disadvantage decile values. As was reported in the first paper (chapter four) the correlation was 0.61, which provided evidence that RLF reflected SES as measured with the ABS SEIFA, although the result was not strong enough to suggest that there is no utility to the use of RLF over and above using SEIFA. It must be stressed that this analysis was undertaken to provide an indication of how well it correlated with SEIFA because of the widespread use of SEIFA in Australia. The utility of RLF goes beyond a correlation with SEIFA which can only be used at the area level; RLF was developed as an individual SES measure that could be applied at the household level and free of the MAUP. RLF builds on the emerging use of property values and health research (Rehm et al., 2012, Vernez Moudon et al., 2011) and offers another method for calculating property wealth. While RLF is a different methodological approach to the research cited above it should be considered within this small developing area and assessed further. As is the case with any method development it should be tested in other jurisdictions and with other outcomes data. In this way the use of wealth, expressed through property value can develop and provide an informed spatial SES measure that can reduce the impact of MAUP.

RLF and Health Analysis

While the first paper presented the method for calculating RLF (chapter four) , the second paper (chapter five) built upon and applied RLF in an analysis of six health risk factors associated with metabolic syndrome. This second paper was an important step in taking the method to analysing health outcomes and presenting this to the *place* and health research community for critique and comment. This second paper was the start of a dialogue which aims to continue the development of spatial measure that can highlight social disadvantage and promote *place* awareness.

The six health factors in paper two were, central obesity, hypertriglyceridemia, reduced high density lipoprotein (HDL), hypertension, impaired fasting glucose, high low density lipoprotein (LDL) plus a cumulative risk score of these factors. Importantly, RLF was significantly associated with all but one of the health risk factors. This is important as it provided a statistically significant association between many health outcomes and SES expressed using RLF even after controlling for age, gender and education. Although not reported in the paper, income was also tested in this model and it did not change the outcomes. The inclusion of income in the models but not reporting it in the paper was a deliberate strategy to highlight RLF without confusing the analysis with the traditional SES measures. The use of detailed spatially based property wealth measures is relatively new and to date there are only two other studies, to the author’s knowledge, that apply property at the individual level (Rehm et al., 2012, Vernez Moudon et al., 2011). While RLF and the two studies use different methods, all three have reported strong associations between property wealth SES indicators and poorer health. The work presented in this thesis adds to the ongoing development, provided further proof of the utility of property wealth measures in health, supported the use of GIS to create objective spatially based measures and created a new SES measure that can be calculated for any nation, city or jurisdiction where residential property sales are recorded. RLF can provide a simple SES measure that can be used to test for associations across multiple locations with certainty that the SES measure was comparable, removes the difficulty of matching spatial units and the MAUP (the health data would also need to be comparable). While RLF has been used in this work to research health outcomes, it would be equally applicable to any research interested in SES associations.

The Importance of Spatial Unit Choice

The literature reviewed in this thesis highlighted a growing use of spatial methods for health analysis and a growing awareness for a more considered use of spatial methods and spatial units (Brownson et al., 2009, Chaix, Leal and Evans, 2010, Diez-Roux, 2011, Diez-Roux, 2001, Diez-Roux and Mair, 2010, Leal and Chaix, 2011). In particular, two key challenges were reported in the literature, 1) testing associations across more than one spatial unit and 2) the selection of spatial units informed by the research question. Brownson et al.(2009) stated that GIS was still underdeveloped in health research and highlighted the need for researcher to test for associations using more than one spatial unit. The Brownson et al. (2009) paper was highlighting the MAUP and the potential for an inappropriate choice of spatial unit to mask any statistically significant relationship. As described by Gehlke and Biehl, (1934) (cited (Openshaw, 1984) modifying the aggregation of spatial units could change the correlation coefficients from a strong negative result to a strong positive result or no association at all. This was termed the MAUP and has been reported as an issue for many years, and while some researchers report the potential for MAUP in the limitations sections, many do not acknowledge the MAUP or discuss the limitations imposed from the use of predetermined administrative spatial units. Some researchers have recognised this potential limitation and suggested that health researchers consider testing for associations across several spatial units (Brownson et al., 2009, Leal and Chaix, 2011). Consequently, the third paper tested the association between built environment walkability and health across five spatial units.

Walkability is part of a major international project which is comparing walkability across 12 countries; the International Physical Environment Network (IPEN) project (www.ipenproject.org). A measure of walkability has been developed within this network that has been analysed for associations with walking behaviour and reported more walkable environments are positively associated with higher levels of walking for transport (Cerin et al., 2013, Cerin et al., 2007, Cerin, Leslie and Owen, 2009, Leslie et al., 2007, Network, 2004, Owen et al., 2007, Sugiyama et al., 2009, Van Dyck et al., 2010a).

The third paper investigated walkability using the IPEN definition calculated for the Wave 1 NWAHS data and the six health risk factors cumulative score (for consistency with the health measures used in the second paper) and tested for associations with walkability for a combination of predetermined administrative spatial units and network buffer distances. Built environment walkability and cardiometabolic risk were used in the paper based on the logic that walkability has been associated with more walking and more walking is good for health, therefore more walking in more walkable areas should be associated with lower risk of cardiometabolic disease. Much of the work on walkability has used predetermined spatial units or buffer distance spatial extents (Adams et al., 2009a, Adams et al., 2011, Arvidsson et al., 2012, Badland et al., 2009, Cerin, Leslie and Owen, 2009, Frank et al., 2012, Frank et al., 2010, Frank et al., 2005, Leslie et al., 2007, Owen et al., 2007, Van Dyck et al., 2010a). The analysis in the third paper tested for associations using two ABS spatial units and three network buffers 500m, 1000m and 1600m. The two ABS units were selected as they represent the smallest administrative spatial units available in Australia and the CD was the spatial unit for the Australian PLACE study (Leslie et al., 2007, Owen et al., 2007). The three network distance buffers were selected to represent the walk interaction space around the NWAHS participants. As the analysis was testing for cardiometabolic risk and walkability, the spatial units should reflect a walkable distance and this was the basis for the three buffers. Network buffers were used as the road network is the most accessible and likely pathway for walking as opposed to Euclidian buffers which may encompass areas not accessible or over-estimate the walk interaction space.

The results from this study reported that the two predetermined units did not result in any statistically significant association and if these units were the only spatial units analysed it would conclude that there was no association between CMR and walkability. The spatial unit choice would provide a result that did not support walkability. Yet, the three network buffers were statistically significant, even though the relative risk reduction was modest. What does this mean for *place*-health analysis? The choice of spatial unit is important and highlights the potential for associations to remain undiscovered if the spatial unit is inappropriate. The analysis in the third paper reinforced the results of another Australian study which concluded that walkability was not associated with either the ABS CD or SSC, but was associated with network buffers (Learnihan et al., 2011). The call for more testing of spatial units is supported by the results of this paper as is the need to link the spatial unit to research question.

It was the intent of all the papers in this thesis to contribute to the development of *place* in health and add to the ongoing call for a more informed use of *place*. This thesis has highlighted the importance of informed choices when selecting the *place* components for health research and the potential for the MAUP. That *Place* is a fundamental component of health research should be beyond debate, to ignore the *place* impact is to ignore the fundamental factor that **<u>ALL</u>** things are distributed across space and the distribution may or may not be even. While the practice of analysing health and populations without *place* has been widespread, especially in the middle to latter part of the last century, it is now included in most contemporary health research. However, while the inclusion of *place* is to be encouraged this thesis has highlighted that the full importance of *place* in research is yet to be understood. This thesis included three papers which aimed to advance the use of *place* and improve the level of understanding through the development and application of a new spatial method for including *place*-SES and the importance of testing for *place*-health associations across multiple spatial units. The publication of the two *place*-health papers in health peer-reviewed journals was a strategy to engage with other researchers with similar aims and to highlight the requirement for more *place* in health methodological discussion. Together, this thesis and the published papers provide a cogent case for increasing the rigour of *place* choice for health research. The aim was not to curtail or criticise existing researchers, but to highlight an area where more effort and understanding and more inter-disciplinary work is required. The MAUP is not easy to solve; it is now almost 80 years since one of the first papers to call attention to the MAUP was published (Gehlke and Biehl, 1934), yet MAUP is still largely unsolved and still remains a issue for any research using spatial units and while census collections retain a predetermined spatial unit hierarchy as the basis of their collection it is likely that the MAUP will remain unsolved.

Chapter 8: Limitations and Future Research.

This thesis has sought to contribute to the better use of spatial methods in health research through a more informed use of *place*. While each of the three papers included method and limitations sections, the need for brevity and word limits prevented a detailed reporting on limitations and possible method enhancements. This chapter will build from the papers and focus on methodological and analytical limitations and the potential for method enhancements.

Causality and Self-Selection

One area of limitation which is reported in the two papers (chapters five and six) was the inability to infer causality when using cross-sectional data. While this is a major issue with all cross sectional data, its impact was less significant for these papers which were fundamentally concerned with highlighting the importance of sound geographic methods. One means of overcoming this limitation is longitudinal analysis and it is intended to take advantage of the longitudinal nature of the NWAHS data and investigate whether the associations reported with CMR and the two spatial constructs, RLF and walkability, are significant over time. This will add to both the validity of the association between CMR and SES (as expressed using RLF) and walkability.

Self selection, or the issue of whether people move to areas which support their behaviour choice, such as moving to areas that are more walkable to pursue more walking, is also an issue for the *place*-health association. However, this is a harder problem to account for and within the context of these papers is a limitation of the analysis, but not the spatial methods, an important distinction. A possible solution to the issue of self-selection is to use the longitudinal nature of the data and look to the mobility data included in the NWAHS wave 2 (2004-2005) and wave 3 (2008-1010) data. These data will be used to test for associations between participants who have not moved (duration at current address) and movers (duration at new address), CMR and both the *place* constructs (RLF and walkability). In this way, the limitation for both causality and self-selection may be partly accounted for. It may not be possible to manage the self-selection problem, but at least the additional analyses will provide more insight into the issue of exposure (the time spent living in the present and past address) and the *place* constructs included in this thesis. While further analyses are planned to investigate longitudinal associations, another area of potential limitation, and one which is more pertinent to this thesis, is the actual place constructs.

RLF Data

RLF requires residential property sales transaction data with both location and property characteristics. Therefore, the availability of data and the quality of data attributes is a possible limitation when constructing RLF in other jurisdictions. While the data for South Australia provides both location and characteristics, this may be limited in other jurisdictions. In Australia, all states collect similar data and therefore RLF can be calculated for national through to local comparisons. For international comparisons, many developed nations collect similar data, but the comparability would have to be managed on a case by case basis. As similar research is underway in the USA (Rehm et al., 2012, Vernez Moudon et al., 2011) potential international comparisons and collaboration are being pursued as it is only through international collaborations that the multi-jurisdictional nature of RLF can be tested.

Quality is an issue with any data and the use of administrative data collections is often problematic when the data are being used for purposes that are beyond the scope of the collection rationale. For South Australia, sale transaction data are collected as an integral part of the land management system which maintains the legal title for land ownership. This process includes details of the legal property boundaries as well as attributes for property tax purposes. Consequently, the collection was established to manage the land property and property taxation system and was established and is managed by property and valuation specialists.

The sales data, which forms the basis of RLF, captures information at the time of sale and therefore is current. These data were validated using GIS to check the property characteristics and sale price as recorded against the annual extraction of the South Australian Property Cadastre. The property cadastre contains the data used to manage the property taxation system and includes the annually updated assessed capital value (land and improvements) and a range of property attributes. An anomaly between the two data sets triggers a follow-up to ensure the sales data are correct. The Valuer General's Department assess all sales to ensure they are true market transactions. Property transactions that do not match a market price are flagged and for the purpose of creating RLF all non-market transactions were removed.

Two limitations of the sales transactions data that may impact upon RLF are: 1) the number of sales and; 2) the temporal component. RLF requires as many sales as possible, as with any measure a higher number of cases are always desirable. As sales occur almost every day of the year, it is important to balance the number of sales with a time period where sale price is comparable. Major fluctuations in the sales market can significantly alter the sale price and this can be managed by limiting the date range for valid sales or by adjusting the sale price to a common base dollar reference time point. It is the role of any analyst when calculating measures, such as RLF from administrative data to ensure they understand how the data were collected, the data classifications applied and the basis of the stored data attributes. RLF was constructed with these limitations, however, all steps were taken to ensure price comparability for the time period selected and all non-market transactions were removed. Other data cleaning, such as missing values, invalid data etc were also included and form a part of any data management process. RLF is very much a work in progress and provides a rich and fertile area for further development. There are a number of areas which require further development. These include the impact of scale, model development and the GIS interpolation method and these are discussed in the next sections.

RLF Scale

Fundamental in the scale issue is the spatial extent used to determine the global mean for a given set of input variables. It is clear that a 'one size fits all' approach is not appropriate for RLF. While RLF as applied in this thesis was based on the Adelaide urban metropolitan area and this was guided by the NWAHS data and therefore RLF was relative to this spatial extent. RLF when applied to a given study area is manageable, but how will RLF work for other spatial scales? Such as:

- the nation;
- state;
- metropolitan areas;
- capital city or all capitals cities;

- major regional centre(s); and
- urban versus rural.

One of the principles guiding the work in this thesis was the desire to optimise the link between the study area and research objective. But how effective is a relative property value for a property in a small regional town if the mean is based on sales generated for the whole state? This is an area of research that overlaps with the model development as one of the possible solutions is to use geographically weighted regression (GWR), but this violates the present “blind to location” model rule. Future model developments will include testing for scale issues across varying spatial extents and the use of alternative models such as GWR.

RLF Dwelling Type

The type of dwelling is another area of developmental effort. The existing RLF model is based upon detached single dwellings. While this is the prominent dwelling type in this region (70% of dwelling type; (Australian Bureau of Statistics, 2001a), other dwelling types are present and newer models will look to include dwelling type as an input variable. At this point it is not known whether this will alter the outcomes significantly, but the impact needs to be assessed and the model modified accordingly. Jurisdictions where single detached dwellings are not the predominant dwelling type will require modifications to the model or the inclusion of dwelling type as one of the input variables. In addition, the number of sales across the various dwelling types will be assessed to ensure the number is sufficient for modelling. If the number is too small the time of sale period will have to be increased and the prices adjusted to reflect the same dollar value. Prevailing economic conditions are a key component to avoid major fluctuations that will change sale prices; this would include major economic fluctuations such as the 2009 global financial crisis and similar events. As with any model, the outcomes are only as good as the input data and the quality of the assumptions applied and it is the role of the modeller to ensure that these aspects have been given due consideration and that all model parameter choices are clearly articulated.

RLF GIS Interpolation

The next major component of the RLF model that requires some development is the GIS spatial interpolation method that was used to create the ratio of predicted to actual sale price for the study area extent. GIS provides several surface interpolators and each has strengths and weaknesses. The interpolators are grouped as deterministic, geostatistical and interpolators with barriers (these are not relevant to this method at this point). Deterministic interpolators include inverse distance weighted (IDW), polynomial and radial bass functions. Geostatistical include kriging and co-kriging while barrier interpolators include kernel smoothing and diffusion. The various interpolators provide exact and inexact data point matching and various levels of surface smoothing. Two of the more commonly applied interpolators are IDW and kriging. IDW is an exact deterministic interpolator that requires few settings, is quick and easy to generate but does not provide any error prediction and can produce “bull’s eyes” around data points (ESRI©, n.d.). Kriging is a very flexible interpolator which produces exact or smoothed surfaces. The surface result requires parameters values and these are guided by a range of statistics presented as graphs of spatial auto- and cross-correlation, predicted surfaces, prediction standard errors, probability and quantiles (ESRI©, n.d). Kriging requires more understanding and parameter settings than IDW, but provides error prediction statistics which can be assessed and through iteration the surface error can be minimised. As stated in the method paper, RLF applied the kriging methodology. While kriging has been applied to model RLF, more work will be undertaken to investigate the other interpolation methods described above. As with all interpolating methods, assumptions are included on the distance decay effect. Further development will look at both the interpolation method as well as the effect of varying the distance decay values. These elements of the RLF methodology will be part of the spatial enhancements and ensure that the locational aspects are modelled to ensure a good local fit that attempts to minimise local error and not overall error. This is an important distinction because modellers will often attempt to minimise overall model error, but at the expense of local error. RLF is designed to be used as a household SES relative measure and this aspect is critical to its utility.

Walkability

The walkability index (WI) was described in detail in earlier work by this author (Coffee, 2005) including future developments. However, in the interest of providing a thesis that is self-contained, this section will include reference to some of this earlier work. The WI used in the third paper (chapter six) was purposely constructed to be comparable with the results of the PLACE study and a number of later studies linked with the IPEN project. This was deliberate for comparison purposes and did not address the limitations and possible enhancements contained in the earlier WI development (Coffee, 2005). The earlier WI (Frank et al., 2005) was developed to be a simple, objective index that could be constructed in many country settings. To this end it achieved this objective and has been used in studies in 12 countries. Despite this, there are a number of additional built environment features included in a number of other studies that warrant consideration. The limitations listed in Coffee (2005), are still valid and include refinement of the concept of land use mix, traffic flows, road hierarchy data, more detail on recreation facilities, more refined retail data, the presence of features such as street footpaths (including quality), street lights, street furniture (benches), street signs, a greenness indicator such as the normalised difference vegetation index (NDVI), crime and safety data and accessibility measures (distance and count) to a range of services and facilities (unhealthful food, healthy food, schools, medical services, recreation facilities etc).

The refinement of walkability that encompasses the additional factors listed above may provide a more rigorous depiction of the built environment and provide the potential to investigate in more detail which aspects of the built environment are strongly associated with chronic health or physical activity outcomes. This is a research area that is worthy of research effort and with the availability of more spatially referenced data could provide a sound basis for creating a WI which is based upon only those variables that were strongly correlated or alternatively, modifying WI to include only those variables that were selected based on the health or physical activity outcome being tested.

While it is desirable to expand the concept of walkability and add more detailed measures, it must be recognised that this will limit the potential for comparisons across multiple jurisdictions. This is why a simple spatially based WI is desirable and, notwithstanding the limitations and possible inclusions listed above, the WI utilised in this research and across the IPEN studies provides a comparable index and has been associated with more transport walking in a number of studies across a number of countries (Badland et al., 2009, Frank et al., 2010, Frank et al., 2005, Kruger et al., 2008, Leslie et al., 2007, Matthews, Schwartz and Cohen, 2011, Owen et al., 2007, Sallis et al., 2009, Sundquist et al., 2011, Tourangeau and Yan, 2007, Van Dyck et al., 2010b, Van Dyck et al., 2010c). Consequently, while the development of detailed measures for built environment research is an important area for future research, the need for a simple WI that is readily measured and can be created in multiple jurisdictions is also a worthy outcome. It is important to conduct research with the highest quality of data available and construct the most robust indicators as possible, but for comparability there is still a place for an indicator that is simple, objective which represents elements of the built environment for cross-city and country comparisons. In this way, the limitations listed above need to be considered and analysed for association with either health or physical activity. But, in the search for more meaningful indicators there is always a place for simple, objective measures.

Walkability Spatial Unit Choice

One of the major limitations included in Coffee (2005) and in Coffee et al (2013; chapter six) was the problem associated with using the predetermined administrative spatial units. In the same way as a number of authors (Brownson et al., 2009, Leal and Chaix, 2011) have called on researchers to include different spatial units in their analysis, the same applies to the construction of built environment measures. This would require researchers to consider both the health or physical activity outcome, WI (the Frank et al, (2005) based measure) and additional more detailed walkability indices, including accessibility (distance and count) and level and quality of services and facilities and the spatial expression of these outcomes and measures. In this way the process of working towards a set of characteristics that are significantly associated with health and physical activity can progress. It should be the aim of researchers in this field to address both the requirement for more considered use of *place* as well as built environment measures that provide meaningful and comparable indices.

Conclusion

This section has described a series of limitations associated with the methodology, data, analysis and spatial units. In addition to the limitations there were a series of method enhancements and potential directions for collaboration. The intent of the work undertaken as part of this thesis was to provide a research agenda for future development of *place* within the health analysis framework. To date work has commenced on the longitudinal analysis using RLF and the six health outcomes and the investigation into the GIS spatial methodology. When completed, the results will be published and provide a continuation of the work started in this thesis. In addition to this, the publication of the method and results may promote the use of these methods in other research teams with comparable property and health data.

Chapter 9: Conclusion

Place is important: geographers understand that and health researchers are rediscovering the importance of *place*. Where you live matters, it can influence and shape your health. The re-emergence of *place* in health research since the mid-1990s is gaining momentum and it is the role of geographers to assist in a more informed use of *place*. While *place* is a simple concept at face value, the house you live in, the street you live on or the neighbourhood you live in, suburb, county, city, state etc, like all constructs *place* requires a clearly articulated definition and this will usually be contextually specific. It is not enough to uncritically describe *place* as neighbourhood, census tract or census collection district and proceed to analysis. How was the spatial extent of neighbourhood designed? Was it designed or is it an historic administrative boundary? How large is the neighbourhood? How many people live in the neighbourhood? Does it have any meaning for the research question? How does it fit within the theoretical framework? What about contextual factors? *Place* is far more complex than just adding a label. These are complex issues that need to be understood by any researcher who includes *place* in their research.

This thesis highlighted a number of issues evident in the *place*-health literature, the lack of rigour with *place* choice and the low report rates of the MAUP in particular. MAUP has a long history and while a few techniques have been presented as potential solutions to the MAUP, it is as much a problem today as it was 80 years ago. While it may not be possible to provide a solution to the MAUP due to the limitation of data supplied for predetermined administrative spatial units, it should be included as a possible limitation and potential bias of results. Too few researchers acknowledge the MAUP or issues with scale and too few adequately address the 'why' and 'how' of their *place* spatial unit choice. The underlying theme of this thesis has been to highlight the potential for MAUP in *place*-health research and to continue the debate around method development and informed *place* use.

Two of the peer reviewed papers in this thesis provide a *place* based wealth SES measure that can be used in any location with property sales transaction data. This measure (RLF) was tested using six cardiometabolic risk factors and a cumulative risk score. RLF was strongly statistically significantly associated with five of the risk factors and the cumulative score of risk factors. While this was based on cross sectional data which limits it causality, it provides a sound basis for a continuing research effort.

The third paper addressed another key area of *place*-health research, the impact of the built environment. Built environment was expressed in this paper using a walkability index based on a definition that is widely accepted and applied in the literature. A major departure from many of the studies using walkability was the outcome; this paper used a CMR score for consistency with the earlier research in this thesis and not physical activity. The major contribution from this paper was not just a modest statistical association between walkability and CMR, but the advancement of the linkage between the research measure (walkability) and the operationalisation of *place* (spatial units). This paper tested the health outcome for five spatial units, two predetermined administrative units and three network buffer walk interaction spatial extents. The results questioned the use of predetermined administrative spatial units, as both were not significantly associated with the health outcome, a finding which was also reported by Learnihan et al., (2011).

This thesis has contributed to the *place*-health dialogue and provides support for progressing *place*-health research. The overarching message from this thesis is not one of criticism for the use of *place* in health research, but a call for a more informed and critical use of *place*. *Place* offers a rich and fertile area of research and one that is in its infancy, despite the long history. What is required is a continuing debate and discussion on the definition of spatial units and spatial analysis methodology. In this way, the impact of *place* on health can be advanced through a more informed and robust application in health research. The work that forms the core of this thesis is focussed on the application to health research, but much of this work is valid for social science and would be applicable across a range of research areas concerned with analysing SES or how the built environment influences behaviour. This thesis provides a contribution to this ongoing process.

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