Influence of space and time concepts on physical activity intensity in Singapore

DISSERTATION

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Abstract

Understanding why some people exercise more than others is a complex social and psychological challenge. Having knowledge about the general prevalence of the population engaging in physical activity is fundamental, however, in order to support interventions aimed at increasing the level of physical activity at the community or neighbourhood level, it becomes necessary to have a better understanding of the relationships between social determinants of health, physical activity and where people live. The rhetoric question is whether characteristics of the built environment in communities influence the extent of which people will engage in physical activity such as walking for utilitarian or for leisure purposes. Therefore, the research aimed to determine the influence of space and time concepts on physical activity intensity in Singapore. Manhattan distances to five different domains of walkability (food, community interaction, sports facilities, park connectors and public transportation) and two measures of social economic status (Populations living in public housing and resident working persons aged 15 years and above requiring public transportation to work) were postulated to be predictors for walkability in Singapore. For the first time, WHO Global Physical Activity Questionnaire standardised population measures and classification of physical activity intensity (based on metabolic equivalents) were used, instead of Body Mass Index values, as outcomes to validate the Walkability Index. Multinomial logistic regression analysis was conducted to determine both men and women's risk of low and moderate physical activity levels relative to high physical activity levels as a test of the performance of the Walkability Index, including age as a covariate. Results showed that for both men and women in the National Health Survey 2007, increasing the Walkability Index of the neighbourhood which they were living within would increase the likelihood of them having high physical activity levels (p=0.000). This effect was found to be greater for men than for women.

Key words: GIS, spatial analysis, physical activity, Walkability Index, GPAQ, Singapore

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List of abbreviations

DGP	Development Guiding Plans
GCP	Ground Control Point
GIS	Geographic Information System
GPAQ	Global Physical Activity Questionnaire
GWR	Geographically Weighted Regression
HDB	Housing Development Board
HPB	Health Promotion Board
LRT	Light Railway Transportation
MET	Metabolic Equivalent
MRT	Mass Rapid Transportation
NEA	National Environment Agency
NHSS07	National Health Survey 2007
OLS	Ordinary Least Squares
OR	Odds Ratio
SBS	Singapore Bus Service
SSC	Singapore Sports Council
URA	Urban Redevelopment Authority
WDP	Walkable Destination Points
WHO	World Health Organization

Disclaimer

The results presented in this thesis are based on my own research at the Faculty of Earth and Life Sciences of the Vrije Universiteit Amsterdam.

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Chapter 1 Introduction

1.1 Obesity and physical activity in Singapore

Singapore is a small island country with a land area of about 710 square kilometres and a population density of about 6800 people per square kilometres in 2008 (SingStats, Singapore Census of Population, 2000). Although the prevalence of obesity among adults aged 18 – 69 increased from 5.1% in 1992 to only 6.9% in 2004. 25.6% of adults were still found to be overweight (MOH, 2004). Obesity is a major public health challenge because of its increasing prevalence worldwide and the adverse health consequences associated with it, such as diabetes, heart disease and cancers.

It is commonly acknowledged that physical inactivity is among the main risks factors contributing to obesity (WHO, 2002). Regular physical activity such as walking is also well recognised as an important lifestyle behavior for the development and maintenance of individual and population health and well being. According to the National Health Survey in 2004, among Singapore residents aged 18 to 69 years, nearly one-quarter (24.9%) exercised regularly, 27.0% exercised occasionally, and close to half (48.1%) did not exercise at all. Among those who did not participate in any leisure physical activity, a higher proportion of females (54.8%) than males (41.4%) were physically inactive. The prevalence of physical inactivity was similar among the three ethnic groups, with the highest prevalence in Indians (49.2%), and slightly lower prevalence in Chinese (48.1%) and Malays (47.6%). Physical inactivity increased with age, with the prevalence rising from 29.7% among adults aged between 18 and 29 years to 64.2% among adults aged between 60 and 69 years (MOH, 2004).

1.2 Role of GIS in health promotion

The last decade had seen an explosion of research in the applications of geographic information systems (GIS) and spatial analysis in enabling better decision making in health care policy planning and health service interventions (see appendices 1 to 6). GIS and related spatial analysis methods provided a set of tools for describing and understanding the changing spatial organization of health care, for examining its relationship to health outcomes and access, and for exploring how the delivery of health care could be improved (Mclafferty, 2003). In a number of countries (Benigeri, 2007) (Foley, 2002) (Higgs, 2001) (Noor, 2004), existing literature had been drawn to highlight the gap between academic health-based applications of GIS and their everyday use within the national health care system.

The World Health Organization (WHO) defined health promotion as the process of enabling people to increase control over and to improve their health (WHO, 2002). However, it had also been argued that if an environment is one that discourages healthy behaviours or encourages unhealthy behaviours, it is unreasonable to expect large proportions of the population to make behaviour changes for the better (McGinn, 2007) (McGinn, 2007). What then is the role of GIS in health promotion?

GIS as a health information system had been described as a combination of the geography of diseases and the geography of health systems (Boulos, 2001). The former covered the exploration, description and modeling of the spatiotemporal incidence of disease and related environmental phenomena, the detection and analysis of disease clusters and patterns, causality analysis and the generation of new disease hypotheses. The latter dealt with the planning, management and delivery of suitable health services, ensuring among other things adequate patient access, after determining health care needs of the target community and service catchment areas. Prevention of unhealthy behaviours and increasing health promotion activities form part of these services.

1.3 Space and time concepts

The geographical approach towards the examination of diseases or spatial health research primarily focuses on the mapping of diseases and the correlation of spatial distributions by comparing two or more variables (Scholten, 1994). In the case of this research, the ultimate interest is to understand the influence of space and time on the individual's accessibility and utilization of services that can directly or indirectly to encourage physical activity.

Geographic accessibility is an important concept and has been often considered as a measure of distance to health care services or in this case, features that encourages walking. However, these measures typically do not account for differences in individual mobility, spatial habits, and subjective meanings of distance, as well as differences in travel environment. Activity space, defined as "the local areas within which people move or travel in the course of their daily activities" (Sherman, 2005, pg 2) is a measure of individual spatial behaviour that theoretically accounts for these individual and environmental differences and offers an alternative approach to studying geographic accessibility.

Activity space can also account for what we call relative distance, or individual tolerances for travel and distance to care. Both absolute distance and travel time can have different subjective meanings. Age, race, social economic status, and health status and destination types sought all contribute to different distance tolerances. Mode of transportation is also clearly important in seeking opportunities to exercise. Where some tolerate an hour of walking to the nearest public transport to get to work, others may find 10 minutes to be a disincentive.

Distance is related to access and utilization; the farther the distance required to travel, the less likely an individual is to use a service, all else being equal. Distance decay – or the attenuation of a pattern or process with distance – is a well-studied geographical phenomenon. Access is influenced by the shape and area of an individual's activity space, the spatial distribution of opportunities, and by the spatial structures that constrain and direct movement through space (Kwan, 2003).

Understanding why some people exercise more than others is a complex social and psychological challenge. Having knowledge about the general prevalence of the population engaging in physical activity is fundamental (see appendices 7, 8 and 9), however, in order to support interventions aimed at increasing the level of physical activity at the community or neighbourhood level, it becomes necessary to have a better understanding of the relationships between social determinants of health, physical activity and where people live. The rhetoric question is whether characteristics of the built environment in communities influence the extent of which people will engage in physical activity such as walking for utilitarian or for leisure purposes.

1.4 Physical activity and the Walkability Index

The *Walkability Index* or the 'walkability' of a community had been conceptualised as the extent to which characteristics of the built environment and land use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work (Leslie, 2007). Associations of neighbourhood physical environments with adults' walking for transport and walking for recreation had been extensively studied (McGinn, 2007) (McGinn, 2007) (Pikora, 2002) (Jago, 2006) (Li, 2008) (Owen, 2007).

1.5 Role of the Singapore Health Promotion Board

In Singapore, the Singapore Health Promotion Board (HPB) assumes the role of the main driver for national health promotion and disease prevention programmes. Its goal is to increase the quality and years of healthy life and prevent illness, disability and premature death for Singaporeans. In 2008, this research project was established as part of an overall programme to investigate the use of geographic information system (GIS) and spatial analysis techniques in enhancing health promotion research on physical activity and walkability in Singapore.

1.6 Aims and Objectives

1.6.1 Main research question

The main research question of this Master's thesis dissertation is: "How do space and time concepts influence physical activity intensity in Singapore?"

1.6.2 Sub-research questions

There are four sub-questions to this research:

- How have geographic information systems been applied in health promotion research from 1998 to 2009?
- What are the variables that can be measured to determine the conduciveness of a neighbourhood for physical activity?
- Does geographical accessibility and diversity to public transportation, food, community centres, sports and recreational facilities influence physical activity intensities of the adult population in Singapore?
- How might the Walkability Index be used to identify opportunities to increase adult physical activity intensity at the neighbourhood level?

1.7 Methodology and Structure

Chapter 2 provides the background literature review of the strengths and limitations of GIS use in health promotion, with a focus on highlighting research that investigated the influence of the built environment to health outcomes, such as adiposity, body mass index and physical activity intensity. In particular, highlighting noteworthy research relating to the development and use of a Walkability Index in physical activity research.

The reader should have a broad understanding of the accumulated knowledge on how GIS have been applied in health promotion (sub-question 1) based on the desk review of the published literature available on popular citation databases such as PubMed, Web of Science and other specific relevant GIS journals spanning the last decade, from 1998 to 2009. The literature review will utilize variation of terms as GIS, health planning, health promotion, physical activity, walkability, obesity and health care, with a focus on gathering an evidence on the variables that can be measured to determine the conduciveness of a neighbourhood for physical activity (sub-question 2) and the various models of building a walkability index for adults (sub-question 4) based on geographical accessibility and diversity modalities (sub-question 3).

At the end of Chapter 2, after determining the factors that seems to be relevant to determine the conduciveness of a neighbourhood for physical activity based on the literature, a theoretical optimal analysis design model will be suggested for the next steps. Depending on the data availability and other potential predictors for missing factors that can be obtained within a realistic time frame of this research, the model will be modified accordingly.

One of the main challenges of this project will be to establish a GIS geodatabase to integrate spatial and non spatial attribute information. **Chapter 3** will provide a detailed overview of the identification and preparation of the data sets used in the research. As there was no existing GIS infrastructure in place, all digital data layers will have to be generated for the themes on administrative boundaries, public transportation, food, community centres, sports and recreational facilities. Base maps for Singapore will have to be identified and since only a paper version of the Master Plans can be obtained, georeferencing techniques will be conducted. Where appropriate, open sources will be considered for other data sets.

Chapter 4 will introduce and explain the methods of spatial analysis used in this study. Undying spatial relationships of physical activity intensities will first be determined so as to identify statistically significant clusters of hot and cold spots. Subsequently, accessibility and diversity will be defined for the analysis of time and space on physical activity intensity. Associations to elements of the built environment will be explored using techniques of linear regression and geographically weighted regression.

To address the association of geographical accessibility and diversity to public transportation, food, community centres, sports and recreational facilities influence physical activity intensities of the adult population in Singapore (sub-question 3), the research will need to determine a standard indicator for physical activity intensity at a population level and preferably with a complete data set that has been collected in recent years. In particular, efforts will be made to consider the available data in the National Health Survey 2007 which adopted the WHO Global Physical Activity Questionnaire (GPAQ) tool. Since the raw data set of GPAQ has not been used in a GIS analysis environment, it will be necessary to clean up and codify the classifications of physical activity intensities for subsequent selection with the data set.

In order to address how the Walkability Index might be used to identify opportunities to increase adult physical activity intensity at the neighbourhood level (sub-question 4), this Chapter will also outline the steps and methods to build and validate such an Index. Depending on the results from sub-question 3, the inclusion of accessibility and diversity measures will be finalised. In addition, the proposed Walkability Index will also included measures of social economic status that are postulated to be predictors for walkability.

As a test of the performance of the Walkability Index, a multinomial logistic regression analysis to determine both men and women's risk of low and moderate physical activity levels relative to high physical activity levels, including age as a covariate will be conducted.

Results from the spatial analysis done in Chapter 4 will be presented in **Chapter 5**. In addition, various output maps of the Hot Spot Analysis (Getis-Ord Gi) on all respondents identifying spatial clusters of high and low physical activity intensities and the map of the Walkability Index for Adults (resident population aged 15 years old and over) in Singapore would be available.

The discussion **Chapter 6** towards the end will make a number of recommendations for future research.

Finally the article will conclude with **Chapter 7** and outline key lessons learnt that could be useful for similar research in other cities or countries.

Chapter 2 Literature Review

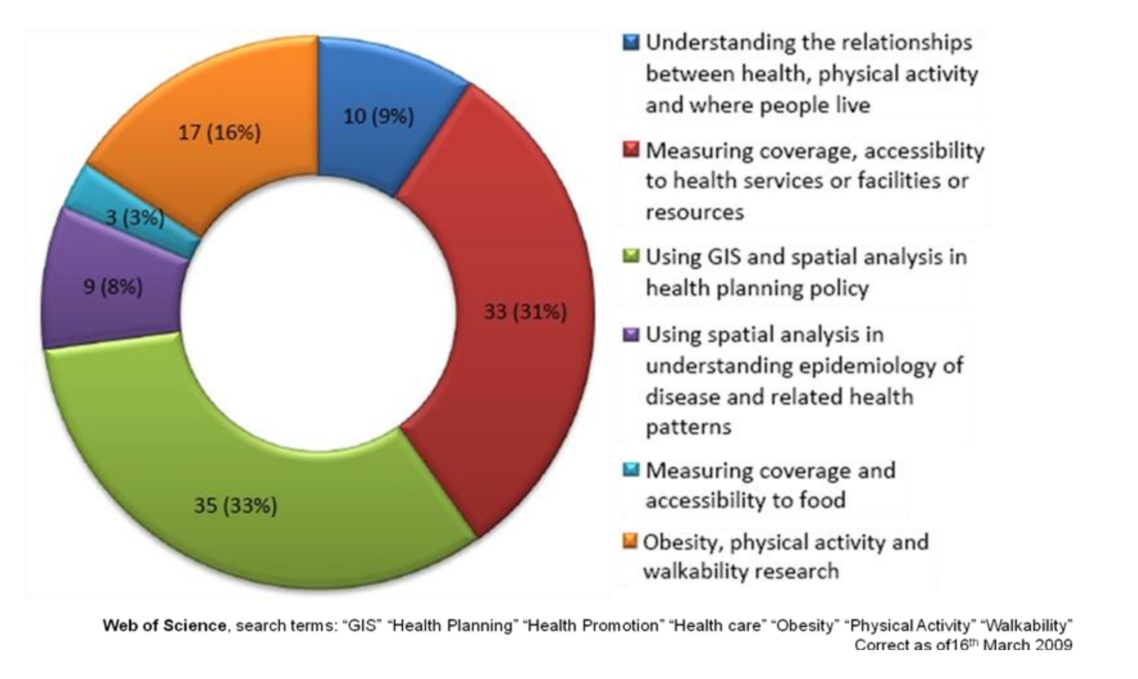
2.1 GIS research in Singapore

As of March 2009, there were only 26 published original researches related GIS and spatial analytical techniques in Singapore from 1994 to 2009. The domains of research were related to environment science (11 studies), urban planning (8 studies), engineering (4 studies), education (1 study) and tourism (1 study). Only 1 study was related to public health. That particular study in 2008 described the geographic epidemiology of pre-hospital cardiac arrest in Singapore using GIS technology and assessed the potential for deployment of a public access defibrillation (PAD) program. The research was able to demonstrate the utility of GIS with a national cardiac arrest database and suggested implications for implementing targeted cardio pulmonary resuscitation (CPR) training, and ambulance deployment (Ong, 2008).

2.2 GIS research internationally

In order to better understand how geographical information systems and science have been applied in overall health promotion research, a desk review of the published literature was conducted on popular citation databases such as PubMed, Web of Science and other specific relevant GIS journals. Internationally, the GIS research in health and health promotion is much broader and spans across different aspects. Figure 1 annotated the respective statistics and variety of topics considered relevant in this review, which was based on a preliminary literature search, utilizing variation of terms as GIS, health planning, health promotion, physical activity, walkability, obesity and health care, 107 references were selected for this research. The selection criteria were 1) published online literature from 1998 to 2009, 2) research relevant to direct and indirect use of spatial analysis on information relating to health promotion.

Fig 1: GIS Research in Health Promotion Internationally (1998-2009)



2.3 Health information systems

When comparing GIS research relating to health information systems, a number of studies cited that the main advantages of a GIS were its visual impact (Bullen, 1996) (Kaneko, 2003), including creating maps that conveyed information regarding the location and magnitude of health issues (Mujeeb, 2000). Another advantage of GIS was in the ability to monitor geographic access of resources and services, including various applications of spatially referenced inventory of service providers (Boulos, 2001) (Abdisalan, 2009). There were however, concerns that because of the possibilities offered by GIS in processing and cross matching geographic data, there was a potential for GIS to be more threatening to privacy than many other information technologies due to the possible combination of powerful data integration and analysis capabilities with data that were local in nature (Christina, 2003). One study commented that differences in geocoding methods and materials may introduce errors of commission and omission into geocoded data (Gerard, 2006).

2.4 Access to healthcare

When comparing GIS research relating to access to healthcare, a number of studies employed different techniques of determining accessibility of health services such as palliative care (Cinnamon J, 2008), primary care (Wang, 2005) (Lovett, 2002), CT scanning (Seymour , 2006) and facilities such as hospitals (Scott, 1998) (Wood, 2004) (Timothy, 2007), catheterization facilities (Patel, 2007) and mammography clinics (Hyndman, 2000). GIS techniques could also be well adapted to study access for different sections of the population, such as the elderly (Costa, 2007). The relationship between social disadvantage and health status was well documented, as well as the fact that health facilities were not usually located where they were most needed (Hyndman, 2000).

2.5 Diet and obesity

Substantive evidence had shown that in most countries, a few major risk factors accounted for much of the morbidity and mortality. For non-communicable diseases, the most important risks included high blood pressure, high concentrations of cholesterol in the blood, inadequate intake of fruit and vegetables, overweight or obesity, physical inactivity and tobacco use. Five of these risk factors were closely related to diet and physical activity (WHO, 2002).

Unhealthy diets and physical inactivity are thus among the leading causes of the major non-communicable diseases, including cardiovascular disease, type 2 diabetes and certain types of cancer, and contribute substantially to the global burden of disease, death and disability.
It is widely acknowledged that diet-related chronic diseases including obesity are a major health problem facing both the developed and developing countries. Much of the exploration of the environmental determinants of food intake had been driven by the proposition that poor access to healthy food or better access to unhealthy food in less advantaged neighbourhoods was a cause for the strong social gradient for diet-related diseases such as obesity, diabetes and coronary heart disease (WHO, 2002).

Research to date also indicated an association between area-level disadvantage and access to healthy food in the US, though this relationship between access to fast food and disadvantage had also been demonstrated in the UK, US and Australia (Cummins, 2006). More lately, differential locational access to fast-food retailing between neighbourhoods of varying socioeconomic status had also been suggested as a contextual explanation for the social distribution of diet-related mortality and morbidity (Pearce, 2009).

In recent years, the use of advance GIS methodologies significantly improved the ability for researchers and policy makers to assess accessibility to healthy and unhealthy foods (Burns, 2007), associations between neighbourhood access to fast-food outlets with individual diet-related health outcomes (Pearce, 2009) and associations between the availability of a range of food stores close to home and children's consumption of fruit and vegetables (Timperio, 2008).

Increasingly, the concept of food desserts referred as areas of relative exclusion where people experience physical and economic barriers to accessing healthy food became a point of great interest and provided relevance to better understand the geographic accessibility to healthy food in relation to social deprivation indices by incorporating GIS-based techniques for evaluating accessibility (Apparicio, 2007) (Larsen, 2008).

Evidence also suggested that the neighbourhood social and physical environments were considered significant factors contributing to children's inactive lifestyles, poor eating habits, and high levels of childhood obesity. Understanding of the neighbourhood environmental profile is needed to facilitate community-based research and the development and implementation of community prevention and intervention programs. The use of GIS may also provide tools to compare levels of dependence and covariance between social determinants of health and risk of increased obesity.

2.5 Physical activity and Walkability Index

The Walkability Index or the 'walkability' of a community had been conceptualised as the extent to which characteristics of the built environment and land use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work (Leslie, 2007). Associations of neighbourhood physical environments with adults' walking for transport and walking for recreation had been extensively studied.

There are various types of variables that can be measured to determine the conduciveness of a neighbourhood for physical activity. For example, associations of street connectivity, population density, land use mix, proximity to retail and commercial destinations, access to open and/or green spaces, crime levels, perceived safety, housing age, access to public transportation, traffic speed, traffic volume, among other subjective and objective measures of neighbourhoods. (McGinn, 2007) (McGinn, 2007) (Pikora, 2002) (Jago, 2006) (Li, 2008) (Owen, 2007).

The uses of geographic information systems (GIS) and spatial analysis techniques to manipulate multiple data sources to generate objective measures of walkability, including street connectivity and safety so as to measure neighbourhood walkability had been described elsewhere (Smith, 2008) (Zhu, 2008).

The elements of the built environment could also be used to construct Walkability Indices that would be useful for visualization and to support interventions aimed at increasing the level of physical activity by walking for transport or health in respective country contexts. For example, a 2009 study in Bogotá found that whereas road facility designs, like street density, connectivity, and proximity to “Ciclovia” (local term for cycling) lanes, were associated with physical activity, other attributes of the built environment, like density and land-use mixtures, were not. Subsequently, the research was able to make the case for extending the network of dedicated cycling lanes on Sundays and holidays to many areas of the city, including newly suburbanizing ones (Cervero, 2009).

Other important aspects of the built environment are the presence and mix of destinations that may encourage or discourage physical activity. A previous study examined the association between the proximity and mix of neighbourhood destinations and physical activity and found that proximity and mix of destinations appears strongly associated with walking for transport, but not walking for recreation or vigorous activity. Increasing the diversity of destinations may contribute to adults doing more transport-related walking and achieving recommended levels of physical activity (McCormack, 2008).

When considering social economic status drivers on walkability, a recent study in 2008 concluded that the strongest and most consistent predictors among walkability indicators were: proportion of population walking to work and housing age (Smith, 2008) and that the availability of destinations together with an interconnected street network makes walking a more competitive and attractive mode of travel to other options. While not directly measured to date, the cost, availability, location, and design of parking facilities at destinations is also a critical predictor of travel choice, and impacts the relative travel time required by the car (Leslie, 2007).

However, in general, past research in this field had been limited to basic understanding and construct of different walkability indices in a small number of selected local neighbourhoods in country specific settings (predominately in the United States, Canada, United Kingdom, and Australia). Walkability research was often challenged by the usually limited availability of spatial data for example, land use mix and necessary key health data such as Body Mass Index (BMI) or other measures of physical acitvity intensity in many countries. All previous research reviewed also only utilised BMI scores as an indicator of level of physical activity to validate the Walkability Index.

There seemed to be also limited research on child versus adult walkability. In the literature review, only 1 out of 13 researches on the Walkability Index in the last 10 years focused solely on child walkability with the rest on adult walkability. That particular study had focussed on school neighbourhoods, especially on walkability and safety around elementary schools.

Measures for the neighbourhood level walkability included the estimate of potential walkers (based on the percentage of students living within a half mile from school); pedestrian facilities (sidewalk completeness and traffic-signal density); residential density; street connectivity (street density and intersection density); and land-use mix. Neighbourhood level safety was captured by crime rates and traffic dangers such as traffic volumes, percentages of high-speed streets, and crash rates (Zhu, 2008).

2.6 Next steps

The process and results of the literature review served to understand the potential of GIS use in enhancing research in health promotion, in particular obesity issues in Singapore. Although it was recognized from the beginning that both the lack of physical activity and poor nutrition choices plays equally important roles in promoting obesity among adults and children in Singapore, in the timeframe of this research we would only concentrate on spatial analysis of the physical activity data and the construction of the Walkability Index for the next steps.

Intuitively, it was believed there were underlying spatial or geographical relationships between the neighbourhood environment and propensity for physical activity or inactivity. The next steps of the research aimed to confirm such intuitive relationships which had not been quantitatively evaluated via exploratory spatial analysis techniques. Exploratory spatial data analysis is an approach consisting of a variety of statistical techniques intended to describe and visualise spatial distributions, identify atypical locations or spatial outliers, discover patterns of spatial association (clusters or hot spots), and suggest hypotheses of a Walkability Index that relates to physical activity intensities.

Based on previous studies as highlighted in this chapter, it is important to consider features that promote physical activity, diversity and land use mix, social economic status predictors such as proportion of population walking to work and housing age, availability of destinations together with an interconnected street network taking into account both distance and time cost.

This research acknowledged that the methodologies on the Walkability Index were partly inspired by previous walkability research conducted in Australia and the United States to better understand how built environment factors can also influence participation in physical activity in Singapore (Smith, 2008) (Leslie, 2007). In these studies, walkable neighbourhoods were those designed to include the 3Ds: population density, pedestrian-friendly design, and a diversity of destinations.

Unfortunately, it was realised very early in this research that complete spatial data on land use mix and road network or street connectivity were not obtainable from the relevant authorities. As such, the analysis did not allow consideration of important factors pertaining to availability and diversity of retail or other land use mix, street network connectivity and design, accessibility by travel time, population and dwelling density, influence of key built environment such as availability and quality of pedestrian paths, covered walkways, green parks and places of worship. It would have been very interesting to test their applicability in a small compact urban city environment such as Singapore.

Alternative predictors had to be considered. The use of the proportion of residents who walk to work and the median age of neighbourhood housing as predictors for land use diversity had been demonstrated to be consistent in Salt Lake County, Utah, in the United States (Smith, 2008). The former measure was available from Census 2000 and thus adopted for testing in the Singapore built environment. In addition, a novel measure based on the proportion of population living in HDB dwellings was included for testing as a predictor for population density in the Singapore context. HDB dwellings are high rise public housing that has a high density of residents.

Although street connectivity was another well established variable of a Walkability Index which was not included due to the limited timeframe of this research. It was hypothesised that the availability of road intersections and pedestrian crossings within each DGP will not vary to a large extent given the fact that Singapore has an extensively connected road network infrastructure. This aspect could be considered for future research.

Nevertheless, in constructing the Walkability Index for adults, 5 distinct domains driving physical activity were postulated: public transport, sports facilities, food, park connectors and community centres. The features of each domain were selected based on the ease of availability of data and its relevance to influence choice of physical activity.

Although social economic status (SES) predictors such as proportion of population walking to work and housing age were relevant to previous studies in other countries, it was decided that 2 census measures of SES: Populations living in public housing and Resident working persons aged 15 years and above requiring public transportation to work, could be more accurate predictors for walkability in the unique built environment of Singapore.

At this stage, the work remained exploratory with a purpose to illustrate possibilities of the means rather than the end products. The GIS approach may enable decision and policy makers to identify community accessibility to facilities that promote physical activity and to determine quantitatively their influences on health outcomes. We anticipated that the use of GIS in this research would be a valuable interactive tool in examining which aspects of an area of residence influence different risks of physical inactivity by social groups and the effect of social determinants of health on physical activity intensity.

The next Chapter provides details on how base maps and data sets were identified and prepared.

Chapter 3 Identifying and Preparing Data

3.1 Singapore Master Plan 2008

There are two key plans in Singapore – the Concept Plan and the Master Plan, which both provide a comprehensive, forward looking and integrated planning framework for sustainable development in the country (Singapore Land Authority). The Master Plan is the statutory land use plan which guides Singapore's development in the medium term over the next 10 to 15 years. It is reviewed every five years and translates the broad long-term strategies of the Concept Plan into detailed plans to guide development. The Master Plan shows the permissible land use and density for developments in Singapore. For this research, the Master Plan that was updated in 2008 was used.

The 1:50,000 Master Plan 2008 paper map was obtained from the Urban Redevelopment Authority (URA) and scanned at high resolution (1200 dpi) in order to obtain a Tagged Image File Format (abbreviated TIFF) image file. Georeferencing is the process of assigning map coordinates and spatial locations to all elements of a map.

Field data collection was carried out on the 14^{th} April 2009 to establish location data of 8 ground control points (GCPs) all over the Singapore Island. A handheld Garmin GPS 60 was used with map datum Kertau 1984 and the latitude/longitude geographic coordinate system. For the purpose of georeferencing, the Singapore base map layer (Master Plan 2008) was imported into ARCGIS 9.3 and 7 GCPs were finally selected for georeferencing of the Master Plan 2008 to obtain an optimal RMS of 1.48800 using 2^{nd} order polynomial transformation and auto adjust.

All data layers in the GIS were projected using the projected coordinate system WGS_1984_UTM_Zone_48N as an appropriate GIS environment for spatial analysis involving ground distances in Singapore. Unit of measure was in meters. Where necessary, latitude and longitude coordinate data were converted to UTM coordinates using an open source tool (Dutch).

3.2 Administrative Boundaries

The Urban Redevelopment Authority (URA), the national land-use planning agency, is responsible for dividing Singapore into 55 planning areas and developing a Development Guiding Plans (DGP) for each of these areas. From 2003, five additional regional plans were established. The significance of the DGP was two-fold in this research. One, the administrative boundaries used by the Census 2000 reflected the boundaries of the 55 DGPs;

therefore they are important for the purposes of cross-linking census data to DGPs and the NHSS07 for spatial analyses. Two, the DGPs boundaries will be used to define the neighbourhoods for the Walkability Index model. The boundaries of the 55 DGPs and 5 regions were thus manually digitized in the GIS established for this research.

3.3 Singapore National Health Survey 2007

The National Health Survey was conducted to measure the prevalence of major non-communicable diseases such as diabetes mellitus and cardiovascular risk factors in Singaporeans. The survey was the fourth national survey to be conducted as part of the Ministry of Health's ongoing surveillance of non-communicable diseases and its risk factors in Singapore; the previous surveys being conducted in 1992, 1998 and 2004 respectively. The survey findings were used by the Ministry to monitor the health of the population, track progress towards national health targets and for planning and evaluation of health promotion programmes and health care services.

A request was made on the 23rd April 2009 by the Health Promotion Board (Adult Health Division) to the Ministry of Health (Epidemiology & Disease Control Division) for non aggregated de-identified Main Variables Data pertaining to physical activity, nutrition and social demographic profile of the National Health Survey 2007 (NHSS07). De-identified Data is data with records of individual persons but with all particulars concerning the identity of a person or any other particulars in relation to a person removed such that any individual person cannot be identified.

3.4 Government hawker centres and markets

One of the most important food source in Singapore is the hawker centre. A hawker centre or food centre is the name given to open-air complexes housing many stalls that sell a variety of inexpensive food. They are typically found near public housing estates or transport hubs (such as bus interchanges or train stations).

On 1 April 2004, the management of HDB markets/hawker centres was consolidated under the National Environmental Agency (NEA) and under the purview of the Hawkers Department. Today, there are more than 15,000 stalls in 115 government markets / hawker centres (National Environment Agency). Locations of 115 markets/hawker centres were geocoded in this data set. This information was updated as of 15th December 2008. It is important to note that all hawker centres in Singapore are centrally registered in this database.

3.5 Park connector network

National Parks Board (NParks) is responsible for providing and enhancing the greenery of the Garden City. NParks manages 10% of Singapore's total land area which comprises over 50 major parks and 4 nature reserves. An island-wide Park Connector Network is also being developed to link major parks and residential areas. These are dedicated pathways for walking, running, roller-blading and cycling. All existing 30 park connector polylines had been geocoded based on the source code available on the website of NParks. The open source KMZ file available on the Internet (Singeo) was therefore used for the research.

The "KML 2 SHP Converter for points, lines and polygons - Version 2.3" Arc Script was used for the conversion of all necessary KML/KMZ files to ESRI ARCGIS 9.3 compatible shape files for points and polylines. (ESRI)

3.6 Sport facilities

The Singapore Sports Council (SSC) is Singapore's lead agency tasked with developing sports in Singapore. 88 sports facilities had been geocoded in this data set based on address information available on the website of SSC (Singapore Sports Council) as of 23rd April 2009:

- Fields (n=6)
- Gymnasiums (n=15)
- Sports Halls (n=15)
- Stadiums (n=19)
- Swimming Complexes (n=23)
- Squash, Tennis and Netball Centres (n=10)

3.7 Community clubs and centres

The People's Association brings people together to take ownership of and contribute to community well-being and maintains a network of grassroots organisations, five Community Development Councils, the National Youth Council, National Community Leadership Institute, Outward Bound Singapore and Water-Venture.

In Singapore, the community clubs and centres form the central venues for residents to come together for social, educational, and physical activity. This is a unique central feature that defines a neighbourhood. All 105 community clubs and centres had been geocoded in this data set (People's Association). This information was updated as of 19th June 2009.

3.8 Public transportation

Singaporeans enjoy a varied range of public transport alternatives that provide services covering the entire island at reasonable fares. This includes the Mass Rapid Transit (MRT) system, Light Rail Transit (LRT) system, buses and taxis. An open source KMZ (Singeo) of the existing 65 MRT stations was first imported into Google Earth and their locations were each manually checked for correctness. The subsequent KMZ exported file was converted to ESRI Shape files in ARCGIS.

In addition, 41 bus interchanges and terminals (SBS Transit) were also geocoded in the GIS based on address information available from the Singapore Bus Services Transit.

Chapter 4 Methods

4.1 Introduction

One of the main challenges of this project was to establish a GIS geodatabase to integrate spatial and non spatial attribute information. As there was no existing GIS infrastructure in place, all digital data layers had to be generated. The GIS software used throughout this research was ESRI ARCGIS 9.3 version as the majority of data sets were geocoded in vector file formats and the software was available as a student license at the time of this research. The range of spatial analysis toolsets was found to be sufficient for the purposes of this research. Multinomial logistic regression analysis was conducted using SPSS Statistics 17.0 version software. A number of selected open source resources and tools were also used for extraction and conversion, in order for some data sets to be imported in a form suitable for analysis in the GIS software.

4.2 Measuring physical activity levels

Surveillance of population levels of physical activity using a standardized protocol is an important and necessary part of a public health response to current concerns regarding lack of physical activity in many populations (WHO). Surveillance of physical activity in populations is most often undertaken using questionnaires, as these are relatively inexpensive and easy to administer compared to objective measurement techniques. However, until recently very few countries regularly collected robust data on physical activity to monitor trends over time. This was at least partly due to the lack of consensus on what instrument should be used.

4.3 WHO Global Physical Activity Questionnaire

The Global Physical Activity Questionnaire is developed by WHO for physical activity surveillance in countries. The tool recommends collecting information on physical activity participation in three settings (or domains) as well as sedentary behaviour, comprising 16 questions (P1-P16). The domains are activity at work; travel to and from places and recreational activities. METs (Metabolic Equivalents) are commonly used to express the intensity of physical activities, and are also used for the analysis of GPAQ data (WHO).

MET is the ratio of a person's working metabolic rate relative to the resting metabolic rate. One MET is defined as the energy cost of sitting quietly, and is equivalent to a caloric consumption of 1 kcal/kg/hour. For the analysis of GPAQ data, existing guidelines have been adopted: It is estimated that, compared to sitting quietly, a person's caloric consumption is four times as high when being moderately active, and eight times as high when being vigorously active.

This research was unique in that it adopted fully the WHO GPAQ tool for national level data collection and represented an innovative approach to analyse the geographical distribution (including global and local effects of location) of a population's physical activity by using a combination of a continuous indicator such as MET – minutes per week or time spent in physical activity and spatial statistical analytical tools. An overview of the WHO GPAQ classification of physical activity intensities and corresponding select by attribute expressions used in the GIS can be referred in Table 1.

Table 1: WHO GPAQ definitions of different physical activity level classifications

Classifications	*GPAQ definitions*
High physical activity	A person reaching any of the following criteria is classified in this category: - Vigorous-intensity activity on at least 3 days achieving a minimum of at least 1,500 MET-minutes/week OR - 7 or more days of any combination of walking, moderate- or vigorous intensity activities achieving a minimum of at least 3,000 MET-minutes per week.
Moderate physical activity	A person not meeting the criteria for the "high" category, but meeting any of the following criteria is classified in this category: - 3 or more days of vigorous-intensity activity of at least 20 minutes per day OR - 5 or more days of moderate-intensity activity or walking of at least 30 minutes per day OR - 5 or more days of any combination of walking, moderate- or vigorous intensity activities achieving a minimum of at least 600 MET-minutes per week.
Low physical activity	A person not meeting any of the above mentioned criteria falls in this category.
No vigorous activity	A person who reported no work-, transport-, or Recreation related physical activity.
No work, transport or leisure activity	A person who did no vigorous physical activity.

4.4 GPAQ in Singapore

The NHSS07 collected data pertaining to physical activity levels in accordance to the WHO GPAQ tool with slight adaptations. In order to prepare this data set for the GIS analysis, the physical activity data was cleaned and re-coded in accordance to WHO GPAQ Analysis Guide (WHO). Due to more recent modifications to the WHO GPAQ version 2, it was important to note the minor differences between NHSS07 and GPAQ: Q2004 (*How long is your typical day?*) was still included in the former but not the latter; Q2005 (*In a usual week, on how many days do you walk for at least 10 minutes continuously to get to and from places?*) was modified in the former to exclude bicycle as mode of transport; Q2100a (*What is your main reason for not doing any leisure physical activity?*) was unique to former but not considered in the latter.

The NHSS07 raw data sets were received on the 8th June 2009 with 7279 unique survey identification (IDs) including address postal codes only of all respondents. The first task was to geocode all respondents of the NHSS07. Geocoding is the process of converting addresses (like "13 Ang Mo Kio Ave 9, 569764, Singapore, Singapore") into geographic coordinates (like latitude 1.384308°and longitude 103.838798°). Since there was no existing GIS infrastructure in HPB, there was neither access to the Singapore postal code boundaries nor a validated GIS address geocoding database, therefore the Google Earth Geocoding API was explored as a possible open source alternative to achieve postal code geocoding.

Google Earth is a freely downloadable software that makes available satellite imagery, most of which is approximately one to three years old, and other rich geographical content for exploration (Google). The Google Maps API includes a geocoding service that can be accessed directly via an HTTP request or by using a GClientGeocoder object. The Google Maps API also provides a client geocoder for geocoding addresses dynamically from user input (Google). In the case of Google Earth coverage for Singapore, the Map API service was found to be accurate at the address level 8, which was considered sufficient for the purposes of this research.

Subsequently, an open source utility tool (Schneide) was used to batch geocode all postal codes of the NHSS07 into latitude and longitude coordinates, and then converted into UTM coordinates. There were 587 postal codes that were discarded as they were not recognized by the Google Map API and returned multiple addresses for a single postal code. The remaining n=6692 of the NHSS07 were geocoded into the GIS database created for this research project.

4.5 Defining Walkable Destination Points

For this research, six data sets were used to define Walkable Destination Points (Table 2) based on their relevance to walking behaviour and additional information were calculated to define three distinct measures of diversity of Walkable Destination Points (Table 3).

Table 2: Data sets used to define Walkable Destination Points

Destination types	*Relevance to walking behaviour*	*Specific datasets used*
Food sources	Adult Singaporeans dined at hawker centres an average of 7 times per week and almost half (49.3%) of adult Singaporeans have their meals at hawker centres 6 times or more a week (HPB S. H., 2004). This information suggests that hawker centres are important sources of food for Singaporeans and people who live near a hawker centre will tend to walk for their meals outside of home. (See appendix 7 for further details)	National Environment Agency database of all markets and hawker centres in Singapore (n=115)
Park Connectors	Proximity to park connectors promote walking for leisure and brisk walking activities	NParks database of all park connectors in Singapore (n=30)

Sports Facilities	Proximity to sports facilities (fields, gymnasiums, sports halls, stadiums, swimming complexes, squash, tennis and netball centres) promote walking for these associated sports activities	National Sports Council database of government managed sports facilities in Singapore (n=88)
Community Clubs and Centres	People who live near to community centres and clubs tend to have more opportunities to be informed and engaged in community level activities. These are places where residents gather to obtain information about upcoming local events, thereby promoting more reasons to walk in the neighbourhood	Peoples 'Association database of all community clubs and centres (n=105)
Public transportation	Proximity to public transportation means such as MRT stations and bus terminals and bus interchanges promote walking for transport for work or to multiple and diverse retail/food opportunities.	Singapore Bus Services database of all MRT stations (n=65) and Bus terminals and interchanges (n=41)

Table 3: Additional information obtained to define diversity of Walkable Destination Points

Diversity	*Definition*	*Additional information calculated*
Immediate proximity	Distance to nearest distinct Walkable Destination Points.	Near module ran separately to respective Walkable Destination Point datasets (see table 2)
Diversity provided by the immediate surroundings	Total number of Walkable Destination Points within a walkable distance of less than 1000 meters	Generate Near Table module ran with all Walkable Destination Point datasets simultaneously and use summarized statistics to obtain total count of Walking Destination Points
Access to variety in terms different types of physical activity choices and a range of reasons to be there	Mean distance to nearest feature (of each 6 different Walkable Destination Points type). *This does not take into account the variety within each Walkable Destination Points type.*	Mean of nearest distances to each Walkable Destination Points obtained from Near module

4.5 Use of spatial statistics

4.5.1 Introduction

An important difference between spatial and traditional (non-spatial) statistics is that spatial statistics integrate space and spatial relationships directly into their mathematics (area, distance, length, etc). Consequently, many of the tools used in spatial statistics require one to select a conceptualization of spatial relationships prior to analysis. In this research, the conceptualization for a fixed distance band that reflected maximum spatial autocorrelation was used. The Manhattan distance method was used rather than Euclidean distance in the spatial analysis as the former was generally more appropriate when travel was restricted to a street network in cases where actual street network travel costs were not available, which was the case in this research (Mitchell, 2005). This consideration also suited the transportation and street environment for Singapore as a compact urban city.

4.5.2 Walkable Destination Points

In order to quantitatively measure the influence of distance to and diversity of essential services defined by Walkable Destination Points associated with the physical activity intensity, the concept of activity space was of high relevance as to how and why individuals in a population exercise differently and to different intensities. Activity space had been previously defined as the local areas within which people move or travel in the course of their daily activities; it is a measure of where people go on a routine basis (Sherman, 2005).

This research proposed and defined “Walkable Destination Points” as *locations within the activity space of an individual that directly promote physical activities (such as gyms, sports facilities and parks) or that provides an intermediary pathway to other intended non-specific activities (such as walking for transport and for food or walking to a community centre to attend art classes) within a reasonable walking distance.*

4.5.3 Spatial effects and use of Geographically Weighted Regression

The consideration of spatial effects in applied research involves a series of logical steps in the analysis. Spatial effects is a catchall term referring to both spatial dependence and spatial heterogeneity. Spatial dependence (or autocorrelation) means that features near each other tend to be more similar than features that are farther away (variables do not exhibit random normal distribution). This creates an over-count type of bias for traditional (non-spatial) regression methods. Spatial dependence and spatial heterogeneity are usually not easily discernable in an empirical sense. They compete as meaningful but mutually exclusive interpretations of the spatial distribution of real world phenomena. In the spatial statistical and econometric literature, however, substantially more attention has been given to testing for spatial autocorrelation as compared to spatial heterogeneity because the extent of heterogeneity can be assessed using standard statistical tools. Currently, several statistics measuring the extent of spatial autocorrelation are available, and their asymptotics and small sample behavior are well documented (Florax, 2003).

In this research, Moran’s *I* and *G* statistic of Getis and Ord are used to determine spatial autocorrelation. These tests could indicate whether the distribution of physical activity intensities is dependent on the spatial distribution of the Walkable Destination Points. If nearby features are more like each other than they are like more distant features, there is said to be positive spatial autocorrelation. In a random pattern, there is no spatial autocorrelation

Once spatial effects are discovered, there is obviously a need to specify a spatial regression model accounting for such spatial effects and to use an appropriately spatially adapted estimator. A common approach makes use of spatial filtering of the existing variables in such a way that one can, in the end, resort to the use of ordinary least squares. This was however not adopted as the available ARCGIS 9.3 was not yet capable of running spatial filtering procedures and this research regarded that geography is important, and often the processes most important to the model are non-stationary; these processes behave differently in different parts of the study area. This characteristic of spatial data can be referred to as regional variation or spatial drift (Mitchell, 2005)

Therefore, the alternative approach that focuses primarily on the specification of spatial heterogeneity by means of geographically weighted regression (GWR) was adopted. GWR provides a local model of the variable or process by fitting a regression equation to every feature in the dataset and can create a coefficient surface for every explanatory variable in the regression model (Mitchell, 2005). Another value of GWR is the added possibility of examining the test residuals to detect misspecification of the model which may have been overlooked or simply due to analysing data at the wrong scale for the process or that the model is, in fact, missing key independent variables.

4.5.4 Calculating the Walkability Index

The central feature of respondents that lie completely within each DGP was selected by location and weighted to the 2007 Singapore resident population in order to account for the geographical density distribution of resident populations within each DGP zone. This weight was provided by the MOH in the NHSS07 dataset. Distances to the nearest feature of each Walkable Destination Points type was then calculated from the weighted central feature. Where there existed more than 1 NHSS07 respondent on the same central feature location, the mean distance was taken.

A “Near” table of distances to nearest feature of each WDP type was computed for the weighted central feature within each DGP zone using ARCGIS. Based on the maximum distance to a nearest feature of each WDP type in the whole data set, ten equal scale distance intervals were created from zero distance to this maximum distance. For example, if the maximum distance to the nearest community centre within the “Near” table is 1000m. The score for a central weight feature (in a particular DGP zone) to the nearest community centre would be 10 – the highest, if the actual distance of their nearest community centre fall within the first scale distance interval (0 to 100m); vice versa, a score of 1 – the lowest, if the actual distance fall within the last scale distance interval (901 to 1000m).

The walkability index was thus calculated using the WDP data sets described in Table 4. The 1–10 score for each measure (distance to nearest food source, community clubs and centres, sports facilities, park connectors, MRT stations, bus terminals and interchanges, diversity of WDP, proportions of population living in HDB and proportions of population taking public transport to work) was summed for each DGP zone resulting in a possible score of 9–90. Where no data is available, a score of 0 was given. The final Walkability Index scores were further classified into 5 smart quantiles or natural breaks (Jenks). These were mapped using ARCGIS to visually identify areas in Singapore that were conducive or not to walking activities. The 1st smart quantile identified the least conducive to residents in the areas walking for leisure, exercise or recreation, to access services, or to travel to work and the 5th quantile indentified the most conducive areas.

Smart quantiles are used to delineate classes based on natural groupings of data values. Breakpoints are identified by looking for groupings and patterns inherent in the data. The features are divided into classes whose boundaries are set where there are relatively large variations in the data values, so groups with similar values are placed in the same class. This is a compromise method between Equal Interval and Quantile, with unequal-sized intervals such as Quantile that generally get a bit wider at the extremes, but not so much as with the Quantile method, so there is also a decreasing number of values in the extreme classes. This option tries to find a balance between highlighting changes in the middle values and the extreme values. It is useful for datasets such as rainfall, which may have more than 50 percent of the records equal to zero. (ESRI)

Table 4: Measures used to define Walkability Index

GIS derived measures	*Relevance to walking behaviour*	*Social economic status measures*	*Relevance to walking behaviour*
Distance to nearest food source*	Adult Singaporeans dined at hawker centres an average of 7 times per week and almost half (49.3%) of adult Singaporeans have their meals at hawker centres 6 times or more a week (HPB S. H., 2004).	Populations living in public housing	A high proportion of population living in HDB is proposed as a novel predictor for population density
Distance to community clubs and centres*	People who live near to community centres and clubs tend to have more opportunities to be informed and engaged in community level activities. These are places where residents gather to obtain information about upcoming local events, thereby promoting more reasons to walk in the neighbourhood	Resident working persons aged 15 years and above requiring public transportation to work	A high proportion of working adults requiring public modes of transportation (public bus only; MRT only; public bus and MRT only) work is a consistent predictor for walkability. This may be because of good accessibility to public modes of transport (Smith KR, 2008)

Distance to sports facilities*	Proximity to sports facilities (fields, gymnasiums, sports halls, stadiums, swimming complexes, squash, tennis and netball centres) promote walking for these associated sports activities
Distance to park connectors*	Proximity to park connectors promote walking for leisure and brisk walking activities
Distance to MRT stations*	Proximity to public transportation means such as MRT stations promote walking for transport for work or to multiple and diverse retail/food opportunities.
Distance to bus terminals and interchanges*	Proximity to public transportation means such as bus terminals and interchanges promote walking for transport for work or to multiple and diverse retail/food opportunities.
Total number of Walkable Destination Points within a distance of less than 1000 meters *	More number of Walkable Destination Points within walking distance suggests availability of physical activity choices and a range of reasons to be there, thereby promoting walking

* Measured from central feature of NHSS07 respondents within each DGP zone

The final consideration was the validation of the Walkability Index. Past research on validation of such an Index usually involves some form of extensive field testing of the performance of the Index. For example, a study comparing residents' perceptions of walkability attributes in objectively different neighbourhoods at the extremes of walkability, could determine if residents of high and low walkable neighbourhoods could reliably perceive the differences between them (Leslie, 2007). And in the context of Singapore, the existence of food sources other than government owned markets and hawker centres, for example, could be investigated. This consideration should be run through for all measures selected for each domains of the Walkability Index.

In any case, this research proposed a novel methodology of utilizing WHO GPAQ physical activity intensity classifications (see Table 1 and Appendix 8) as outcomes so as to conduct a simple multinomial logistic regression analysis to determine both men and women's risk of low and moderate physical activity levels relative to high physical activity levels as a test of the performance of the Walkability Index, including age as a covariate. A similar method had been used previously in research done on walkability but using only body mass index data and not GPAQ data for validation (Smith, 2008).

Chapter 5 Results

5.1 Underlying spatial relationships

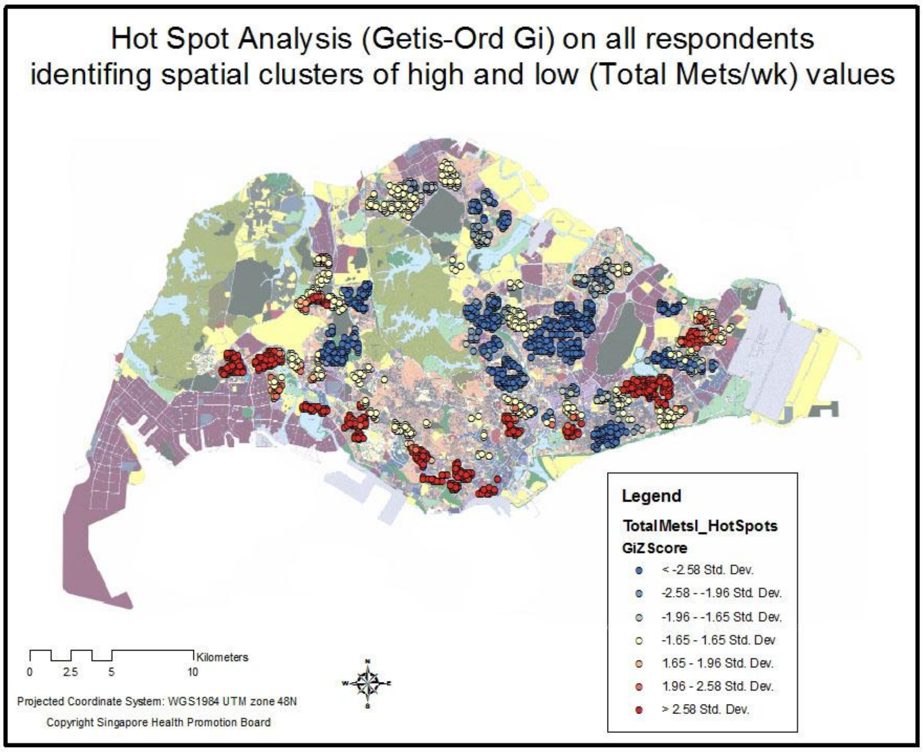
A multi-distance spatial cluster analysis was done to determine the distance band at which maximum spatial correlation occurs (1564.18m). Results of Moran's I test for spatial autocorrelation in Table 5 confirmed that there is less than 1% likelihood that the clustered pattern of physical activity intensity in Singapore could be the result of random chance (p=0.0000 at CI=95%).

Table 5: Results on spatial clustering of (Total Mets per week) values

Spatial statistics	***Multi-distance spatial cluster analysis (Ripley's K Function)***	***Spatial autocorrelation (Morans I)***	***Hotspot analysis (Getis-Ord Gi)***
Results	Input feature = Total Mets per week Input field = Total Mets Weighted by Sample_Wt field For distance 782.09, L(d) = 1423.77, Diff = 641.68 For distance 1564.18, L(d) = 2299.82, Diff = 735.65* For distance 2346.26, L(d) = 3024.24, Diff = 677.97 For distance 3128.35, L(d) = 3657.71, Diff = 529.36 For distance 3910.44, L(d) = 4219.59, Diff = 309.15 For distance 4692.53, L(d) = 4754.68, Diff = 62.16 For distance 5474.61, L(d) = 5257.62, Diff = -217.00 For distance 6256.70, L(d) = 5799.98, Diff = -456.72 For distance 7038.79, L(d) = 6379.52, Diff = -659.27 For distance 7820.88, L(d) = 6953.78, Diff = -867.10 *Maximum spatial correlation occurs	Input feature = Total Mets per week Input field = Total Mets Set fixed distance band at 1564.18 Manhattan Distance method Global Moran's I Summary Moran's Index: 0.121401 Expected Index: -0.000149 Variance: 0.000002 Z Score: 82.145622 p-value: 0.000000	See Fig 2

Figure 2 showed that there were statistically significant hot spot clusters in the south-western, south and south-eastern regions of Singapore with statistically significant cold spot clusters of respondents in western, central and north eastern regions of Singapore. A feature with a high value was interesting, but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature would have a high value and be surrounded by other features with high values as well. Our first preliminarily conclusion was that there existed underlying spatial relationships or geographical influences on the intensity of physical activity within and between different neighbourhoods defined by the Development Guiding Plans (DGP) in Singapore.

Fig 2: Hot Spot Analysis (Getis-Ord Gi) on all respondents identifying spatial clusters of high and low (Total Mets per week) values (MOH, 2004)



5.2 Association of Walkable Destination Points to physical activity intensities

Next step, was to determine the association of geographical accessibility and diversity to public transportation, food, community centres, sports and recreational facilities to physical activity intensities of the adult population in Singapore utilising techniques of geographically weighted regression (GWR).

Results of the GWR done at the national level (i.e. global) in Table 6 indicated the relative positive correlation of distances to Walkable Destination Points with Total Mets per week. Significant spatial autocorrelation of the residuals was also confirmed, which indicated a missing key explanatory variable.

Table 6: Results of Geographically Weighted Regression at national level evaluating distances to Walkable Destination Points only

Dependent variable	*Total Mets per week*						
Kernel type	*Fixed*						
Bandwidth method	*AICc*						
Explanatory variable	*Bandwidth*	*Residual Squares*	*Effective Number*	*Sigma*	*AICc*	*R^2*	*R^2 Adjusted*
Dist_CC	732.16	113735491211.07	217.27	4191.19	130750.86	0.183	0.156
Dist_MRT	805.38	114310629639.67	179.42	4189.54	130723.45	0.179	0.156
Dist_PC	805.38	114838163947.33	173.71	4197.36	130743.69	0.175	0.153
Dist_Sport	885.92	115665680299.24	152.66	4205.67	130757.07	0.169	0.150
Dist_Bus	974.51	115920904222.55	138.62	4205.80	130751.63	0.167	0.150
Dist_Food	1297.07	118678952756.06	98.74	4242.65	130840.29	0.148	0.135

Subsequently, the GWR was run at regional levels in order to minimise the effect of global spatial autocorrelation and to determine extent of non-stationarity. In the latter case, results from Table 7 showed that distances to Walkable Destination Points had strong explanatory power in the central region but was almost insignificant in all other regions.

Table 7: Results of Geographically Weighted Regression at regional levels evaluating distances to Walkable Destination Points only

Dependent variable	*Total Mets per week*						
Explanatory variable	Dist_MRT; Dist_Sport; Dist_Food; Dist_CC; Dist_Bus; Dist_PC						
Kernel type	*Fixed*						
Bandwidth method	*AICc*						
Regions	*Bandwidth*	*Residual Squares*	*Effective Number*	*Sigma*	*AICc*	*R^2*	*R^2 Adjusted*
West	3397.00	29260241654.81	22.11	4198.55	32854.19	0.130	0.119
Central	3700.70	24923294697.34	28.94	4158.74	28691.11	0.273	0.259
East	4563.80	30451181930.68	13.26	4897.17	25454.93	0.060	0.051
North East	5525.46	20637814513.17	12.01	3912.81	26370.83	0.032	0.024
North	6018.38	14791862375.32	9.58	4087.29	17434.55	0.026	0.017

Table 8: Results of Global Moran's I summary on residuals of GWR ran on central region

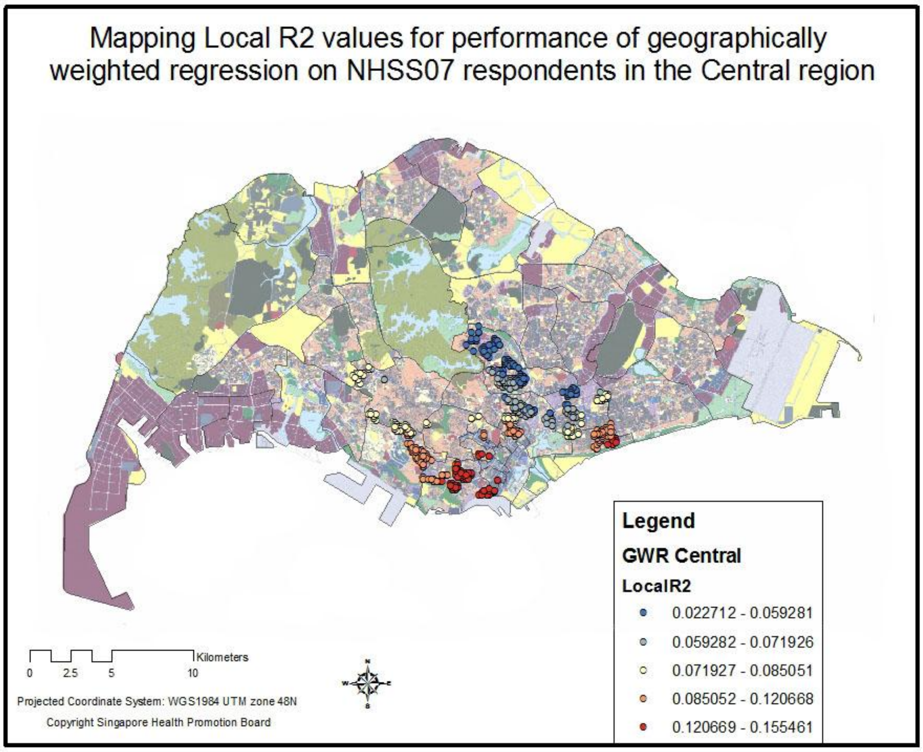
Global Moran's I Summary	
Moran's Index	0.142905
Expected Index	-0.000681
Variance	0.000287
Z Score	8.479268
p-value	0.000000

According to Table 7, the accountability by distance only to Walkable Destination Points, on the variance of physical activity intensity (Total Mets per week), was more pronounced in the central region of Singapore (R^2=0.273) versus the rest of the other regions (0.06 > R^2 < 0.13).

Table 8 showed that there was still statistically significant spatial autocorrelation within the central region. Over and under predictions for a well specified regression model will ideally be randomly distributed. Clustering of over and/or under predictions was evidence that the model was still missing at least one key explanatory variable.

The mapping of Local R^2 values in Figure 3 indicated the performance of geographically weighted regression (very low values indicate the local model was performing poorly) on NHSS07 respondents in the Central region. Mapping the Local R^2 values to see where GWR predicted well and where it predicted poorly provided clues about important variables that may be missing from the regression model.

Fig 3: Mapping Local R2 values for performance of geographically weighted regression on NHSS07 respondents in the Central region



At this stage, from the results from Table 7, it could be concluded that the use of GWR elucidated the fact that the NHSS07 dataset had statistically significant global variables (distances to WDPs) that contributed at least 27.3% of the variance in physical activity intensity, in addition, these variables also that exhibited strong regional variation which may inform local policy.

Based on the findings from Table 8 and Fig 3, the next step was to investigate the diversity of Walkable Destination Points as a probably missing key explanatory variable.

Table 9: Results of Geographically Weighted Regression at national level evaluating diversity of Walkable Destination Points only

Dependent variable	*Total Mets per week*						
Kernel type	*Fixed*						
Bandwidth method	*AICc*						
Explanatory variable	*Bandwidth*	*Residual Squares*	*Effective Num ber*	*Sigma*	*AICc*	*R^2*	*R^2Adjusted*
Distance to nearest WDP	550.09	110941655498.02	329.81	4175.84	130766.31	0.203	0.162
Count of WDP within 1000m	885.92	115426322275.71	159.74	4203.59	130754.43	0.171	0.151
Mean distance to nearest WDPs	1297.07	118859425416.39	96.50	4245.15	130850.08	0.146	0.134

Results of the geographically weighted regression done at national levels (global), from Table 9 indicated the respective contribution of the three measures of diversity of Walkable Destination Points to the variance in Total Mets per week values. Subsequently, the GWR was also run at regional levels in order to minimise and determine the effect of global spatial autocorrelation and to determine extent of non-stationarity.

Table 10: Results of Geographically Weighted Regression at regional levels evaluating diversity of Walkable Destination Points only

Dependent variable	*Total Mets per week*						
Explanatory variable	Near_Dist; Count_1000; Mean_alPOI						
Kernel type	*Fixed*						
Bandwidth method	*AICc*						
Regions	*Bandwidth*	*Residual Squares*	*Effective Num ber*	*Sigma*	*AICc*	*R^2*	*R^2Adjusted*
West	2320.20	29340997026.60	23.59	4206.22	32859.63	0.128	0.116
Central	2780.39	25625733089.67	25.21	4211.49	28725.14	0.253	0.240
East	1759.54	30253459166.66	20.32	4894.87	25454.63	0.066	0.052
North East	1600.53	20423754928.28	24.59	3910.75	26374.08	0.042	0.025
North	111940.23	14977315053.10	4.01	4099.96	17436.49	0.014	0.011

Similarly to Table 7, Table 10 showed that the accountability by diversity of Walkable Destination Points, on the variance of physical activity intensity (Total Mets per week), was more pronounced in the central region of Singapore (R^2=0.253) versus the rest of the other regions (0.014 > R^2 < 0.128).

At this stage, there was no clear explanation for the strong regional variation based on the distance and diversity variables. In any case, since the GWR model predicted well in the central region only, the subsequent spatial analyses were focused in this region so as to, at least, determine proof of concept of the research methodologies.

Table 11: Results of Geographically Weighted Regression in central region evaluating both diversity and distances of Walkable Destination Points

Dependent variable	*Total Mets per week*						
Kernel type	*Fixed*						
Bandwidth method	*AICc*						
Explanatory variable	*Bandwidth*	*Residual Squares*	*Effective Number*	*Sigma*	*AICc*	*R^2*	*R^2Adjusted*
Count_1000; Dist_Food	1071.96	22814621497.59	56.83	4018.00	28606.65	**0.335**	0.309
Count_1000; Dist_MRT	1071.96	22943087942.52	53.29	4024.25	28609.76	0.331	0.307
Count_1000; Dist_CC	1071.96	23049344881.62	54.48	4035.26	28618.58	0.328	0.302
Count_1000; Dist_PC	1071.96	23152604038.80	51.65	4040.24	28620.65	0.325	0.301
Count_1000; Dist_Sport	1071.96	23282016368.67	53.35	4053.96	28631.17	0.321	0.296
Count_1000; Dist_Bus	1297.07	23759804464.05	42.32	4079.49	28642.57	0.307	0.287
Count_1000; Mean_alPOI	1899.04	25000202564.38	28.19	4164.07	28693.30	0.271	0.257

Results from Table 11 confirmed that, in general, a combination of global variables relating to diversity and distances improved the GWR model with the highest R^2 values, contributing 33.5% of the variance in physical activity intensity, attributed by diversity measured by number of Walkable Destination Points within 1000 meters and distance to nearest food source (government owned markets and hawker centres).

The use of GIS can be extended to compare levels of dependence and covariance between social determinants of health and conduciveness of the neighbourhood environment to encourage increased physical activity by walking. To improve on the GWR model, additional information was obtained to define social economic status (SES) measures of the neighbourhoods (DGP zones) of the NHSS07 respondents (See Table 12 for definitions). The GIS then enabled the integration of spatial (distances to and diversity of WDP) and non-spatial (SES) attributes into the GWR model.

Table 12: Additional information obtained to define social economic status (SES) measures

SES measures	*Definition*	*Additional information obtained*
Populations living in public housing	Resident population in HDB dwellings (1 and 2 room flats, 3 room flats, 4 room flats, 5 room and executive flats)	Census 2000 Table 3 (SingStats, Singapore Census of Population, 2000)
Population with low literacy	Resident population aged 15 years and over who did not speak, read or write any language	Census 2000 Table 10 (SingStats, Singapore Census of Population, 2000)
Low total household income	Resident households whose monthly household income from work is below SGD$1000	Census 2000 Table 21 (SingStats, Singapore Census of Population, 2000)

Table 13: Results of Geographically Weighted Regression in central region weighted by social economic status (SES) measures

Dependent variable	*Total Mets per week*					
Explanatory variable	*Count_1000 and Dist_Food*					
Kernel type	*Fixed*					
Bandwidth method	*AICc*					
SES weights	***Unweighted***			***Weighted***		
	AICc	*R2*	*R2Adjusted*	*AICc*	*R2*	*R2Adjusted*
Populations living in public housing	28606.65	0.335	0.309	28391.23	0.342	0.315
Population with low literacy	28606.65	0.335	0.309	25323.26	0.346	0.317
Low total household income	28606.65	0.335	0.309	26303.77	0.343	0.317

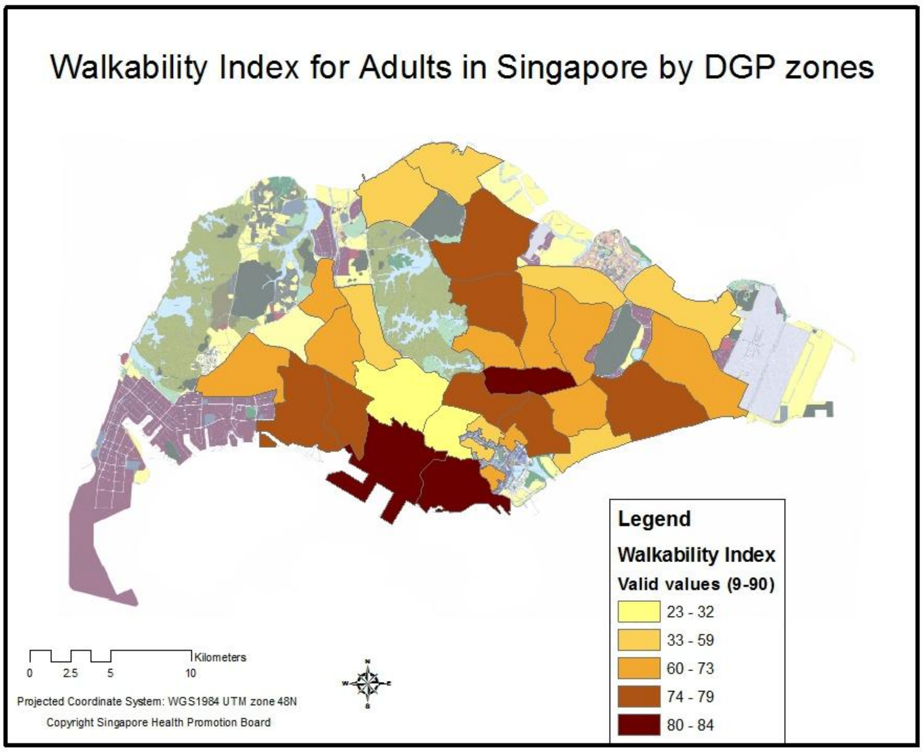
Comparing the AICc values of differently weighted models (see results from Table 13), indicated that the GWR modelling in the central region, utilising the best fitted explanatory variables (Count_1000 and Dist_Food), were all generally improved when weighted separately by 3 different social economic status measures as defined in Table 12. These results preliminarily concluded that the influence of distance to and diversity of Walkable

Destination Points were also predominately greater in populations with relatively lower social economic status neighbourhoods (DGP zones).

5.3 Map of Walkability Index for Adults

The Walkability Index scores were classified into 5 smart quantiles or natural breaks (Jenks). These were mapped using ARCGIS to visually identify areas in Singapore that were conducive or not to walking activities (See Figure 4). The 1st smart quantile identified the areas least conducive to residents walking for leisure, exercise or recreation, to access services, or to travel to work (Bukit Timah, Tanglin and Tengah) and the 5th smart quantile indentified the most conducive areas (Queenstown, Bukit Merah and Toa Payoh).

Fig 4: Map of Walkability Index for Adults (resident population aged 15 years old and over) in Singapore by DGP zones



5.4 Validation of the Walkability Index

A multinomial logistic regression analysis to determine both men and women's risk of low and moderate physical activity levels relative to high physical activity levels as a test of the performance of the Walkability Index, including age as a covariate was conducted as a form of validation. In general, an odds ratio < 1 indicates that the risk of the outcome falling in the comparison group relative to the risk of the outcome falling in the referent group decreases as the variable increases and an odds ratio > 1 indicates that the risk of the outcome falling in the comparison group relative to the risk of the outcome falling in the referent group increases as the variable increases (UCLA). Table 14 and 15 below showed that for both men and women in the NHSS07, increasing the Walkability Index of the neighbourhood which they were living within would increase the likelihood of them having high physical activity levels. This effect was found to be greater for men than for women.

The findings on age were unexpected. The analysis showed that the relative risk for having low physical activity levels increases when the age of men increases but decreases when the age of women increases. The goodness-of-fit for both models were statistically significant at 95% confidence interval.

Table 14: Men's risk of low and moderate physical activity levels, relative to high physical activity levels (multinomial logistic regression analysis), n=3215

	Low (n=587) versus high activity (n=1304)			***Moderate (n=1324) versus high activity (n=1304)***		
Measures	***B***	***OR (95% CI)***	***p***	***B***	***OR (95% CI)***	***p***
Intercept	1.967			1.017		
Walkability Index	-0.051	0.951 (0.942,0.960)	0.000	-0.022	0.979 (0.971, 0.987)	0.000
Age	0.017	1.017 (1.010, 1.024)	0.000	0.012	1.012 (1.007, 1.018)	0.000
Goodness-of-Fit	***Chi-Square***	***p***				
Pearson	1997.565	0.000				
Deviance	2258.628	0.000				

Table 15: Women's risk of low and moderate physical activity levels, relative to high physical activity levels (multinomial logistic regression analysis), n=3344

	Low (n=562) versus high activity (n=1367)			***Moderate (n=1415) versus high activity (n=1367)***		
Measures	***B***	***OR (95% CI)***	***p***	***B***	***OR (95% CI)***	***p***
Intercept	1.838			2.332		
Walkability Index	-0.036	0.965 (0.956,0.974)	0.000	-0.022	0.978 (0.970, 0.986)	0.000
Age	-0.005	0.995 (0.988, 1.003)	0.000	-0.017	0.983 (0.978, 0.989)	0.000
Goodness-of-Fit	***Chi-Square***	***p***				
Pearson	1986.477	0.000				
Deviance	2218.335	0.000				

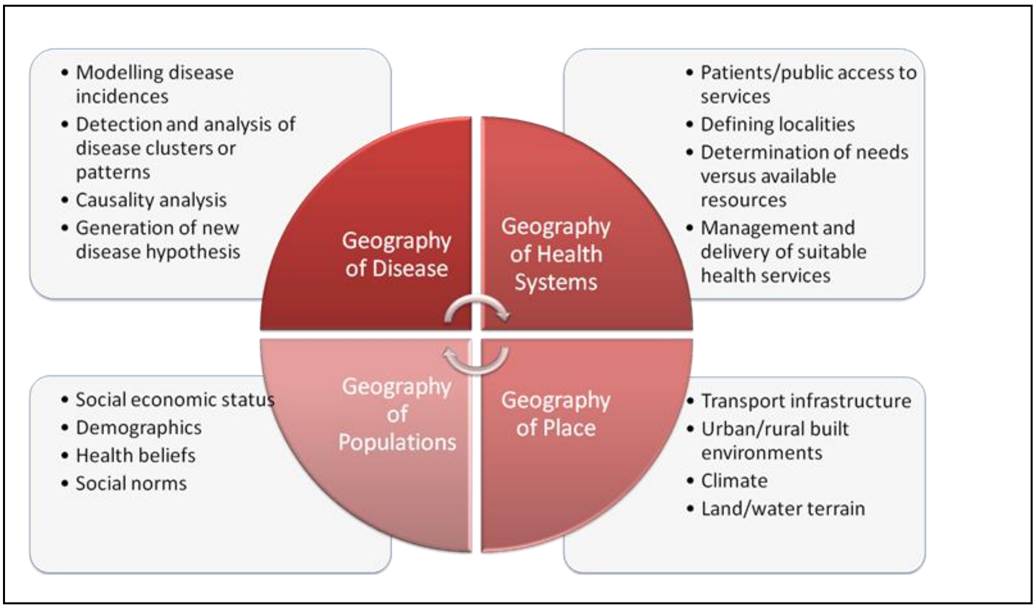
Chapter 6 Discussion

6.1 Discussion

This research was unique in that it adopted fully the WHO GPAQ tool for national level data collection and represented an innovative approach to analyse the geographical distribution (including global and local effects of location) of a population's physical activity by using a combination of a continuous indicator such as MET – minutes per week or time spent in physical activity and spatial statistical analytical tools. The data collected in 2007 was made available to this research.

In terms of a theoretical framework for the use of GIS in enhancing health promotion research, this research considered the unique ability of GIS to seamlessly integrate and conduct spatial statistical analysis on data from multiple sources as its main strength. GIS provided powerful tools for combining disparate data in a visual format to illustrate complex relationships that affect access to Walkable Destination Points. Figure 5 shows that the 4 "Gs" of GIS research in health that encompasses the geography of disease, geography of health systems, geography of populations and the geography of place. The former two had been described previously elsewhere (Boulos, 2001) and this research considered the influences of latter two as the "missing pieces" to making the case for a comprehensive GIS investment.

Fig 5: The 4 "Gs" of spatial health domains



The research project developed the first model of a Walkability Index for adults in Singapore. This study reinforced the fact that GIS data have the potential to be used to construct measures of environmental attributes and to develop indices of walkability for cities, regions or local communities (Leslie, 2007). A detailed systematic investigation of the contribution of each component measure to the Walkability Index would be very useful to inform where opportunities for interventions might be present. For example, the comparison of disparities between the components allow policy makers to detect neighbourhoods that have good access to food sources but perhaps poor access to other WDPs that promote physical activity or a lack of access to public transportation. Conversely, places that have good access to all domains of physical activity might be targeted for increased residential re-development and increased density of dwellings. Overall, the physical environment attributes that make up the walkability index are potentially important candidate factors for future environmental and policy initiatives designed to increase physical activity (Owen, 2007).

Further work in the validation of the Walkability Index should consider comparing perceived and objectively measured access to variables making up the Index. In a study that looked at comparing access to recreational facilities as predictors of physical activity in adolescent girls, the authors commented that the modes of transportation that people use, for example, play a role in determining what people observe in their surroundings. Someone who primarily walks and/or uses public transportation may be limited to a smaller geographic area, but have a better idea of what is on the ground within that space. In contrast, someone who primarily travels by private car is exposed to a larger geographic area but may not perceive the same level of detail as someone who walks. In addition, people’s own preferences may influence their perceptions (Scott, 2007).

In constructing the Walkability Index for adults, 5 distinct domains driving physical activity were postulated: public transport, sports facilities, food, park connectors and community centres. The features of each domain were selected based on the ease of availability of data and its relevance to influence choice of physical activity. This research was not set out to extensively quantify the association of each domain or features of each domain to physical activity intensity, thus, future work focusing on this aspect would be very interesting for research and policy development. In that regard, this research was also unable to consider previously researched variables of the built environment in other countries as those data types in Singapore were not obtainable within the timeframe of this research: these are street/road network, pedestrian path network, green parks, net retail area, and land use mix. Their applicability in a small compact urban city environment such as Singapore needed to be tested. Ultimately, all of the measures adopted in this research so far were physical objective measures, it would be critical to evaluate the influence of subjective perceptions of the built environment on adult physical activity intensity or choice of activity.

The proposed Walkability Index included two measures of SES that were postulated to be predictors for walkability. A future research should try to obtain land use data so as to determine the extent of correlation of these social indicators with residential density. The availability of land use data, in particular the plot ratio for residential land site would be a fairly accurate estimation of actual dwelling density. The plot ratio of a site is defined as the ratio of the gross floor area of a building(s) to its site area. This information would also helpful to develop a population weighted centroid according to actual residential land use sites within each DGP zone. The accuracy of the Walkability Index can be improved by further extensive modelling on accessibility by catchment areas of population to facilities or WDPs.

6.2 Limitations and assumptions

Overall, all the results were unfortunately hampered by several limitations. The unavailability of spatial data on land use and road network did not allow consideration of important factors pertaining to availability and diversity of retail or other land use mix, street network connectivity and design, accessibility by travel time, population and dwelling density, influence of key built environment such as availability and quality of pedestrian paths, covered walkways, green parks and places of worship.

The research was also unable to make the case for the influence of environmental factors such as air quality and climate due to lack of data. In particular, in hot and humid cities, such as Singapore, it was believed people would most likely avoid walking regardless how pedestrian-friendly or walkable was the neighbourhood. In this case, the availability of covered walkways or air-conditioned underpasses could be significant in encouraging physical activity outdoors.

The spatial analysis and regression models assumed that the associations between the built environment and physical activity seeking behaviour were linear in nature, this is a convenient generalisation undertaken by the research. Intuitively, it was also believed the conceptualisation of spatial relationships between people and WDPs need to be confirmed by further investigations. A population survey on the perception of distance decay might be required to support hypotheses of the choice of conceptualisations such as inverse distance, inverse distance squared, K nearest neighbours, distance band, zone of indifference and Delaunay triangulation options that should be used in our spatial analysis and modelling.

This study adopted a number of open source or freely downloadable tools in order to prepare the geodatabase and GIS layers. No attempts were made to determine the accuracy on the conversion of Lat/Long coordinate to UTM and KMZ files to shape files. The dependence on

Google Earth geocoding accuracy was a limitation as it was not possible for us to access its accuracy without the availability of true postal code boundaries and an address/street geocoding database in Singapore.

One of the main challenges in linking social data to physical (built environmental) data is determining how to represent people in space: mapping a person is different from mapping a stationary object, as people are not fixed to a single location. This research subsequently only considered potential spatial access to WDPs by Manhattan distance from residential locations and did not consider actual utilisations of these WDPs for physical activity. The regressions models were also simplified and restricted by assumptions on the population distribution in Singapore. Further spatial accessibility techniques such as the one and two standard deviational ellipse (SDE1, SDE2) measures, road network buffer (RNB) measures, standard travel time polygon (STT) and relative travel time polygon (RTT) measures and Two-Step Floating Catchment Analysis (FCA) could be conducted to compare population distribution and their accessibility to WDPs in the day on weekdays versus weekends, on residential locations versus workplace locations.

Further research focusing on individual activity space that would be important to determine actual attributes of the built environment influencing healthy and physical activity seeking behaviour could be recommended. Because activity space is comprised of directional and temporal components of spatial movement in addition to distance, activity space supplies more information than a distance-only measure by demonstrating point patterns and degree of eccentricity, and is suggestive of how boundaries and transportation networks influence activity patterns (Sherman, 2005).

Finally, because the analysis was cross-sectional, it was possible that those who value healthy weight and physical activity tend to be living in more walkable neighbourhoods (Smith, 2008). Critics of walkability research often argued that individuals self select neighbourhoods that reflect their underlying preferences for activity; thus, an association between environment and activity may be a reflection of that underlying individual preference. Consequently, neighbourhood selection might act to moderate the relationship between walkability and walking behaviour (Owen, 2007). Future research need to take into account the underlying preferences of the population so as to better isolate the impact of the built environment on walking and other health related outcomes.

Chapter 7 Conclusions

7.1 Conclusions

The last decade had seen an explosion of research in the applications of geographic information systems (GIS) and spatial analysis in enabling better decision making in health care policy planning and health service interventions (see appendices 1 to 6).

With regards to GIS application in health promotion research from 1998 to 2009, this research identified at least six distinct domains of knowledge generation, annotated here together with the percentage of respective literature as included in the desk review. These are 1) understanding the relationships between health, physical activity and where people live [9%]; 2) measuring coverage, accessibility to health services or facilities or resources [31%]; 3) using GIS and spatial analysis in health planning policy [33%]; 4) using spatial analysis in understanding epidemiology of disease and related health patterns [8%]; 5) measuring coverage and accessibility to food [3%] and 6) obesity, physical activity and walkability research [16%].

The research provided evidence to show that there is less than 1% likelihood that the clustered pattern of physical activity intensity in Singapore could be the result of random chance (p=0.0000 at CI=95%). There are statistically significant hot spot clusters in the south-western, south and south-eastern regions of Singapore with statistically significant cold spot clusters of respondents in western, central and north eastern regions of Singapore.

This research also proposed and defined “Walkable Destination Points” (WDP) as locations within the activity space of an individual that directly promote physical activities (such as gyms, sports facilities and parks) or that provides an intermediary pathway to other intended non-specific activities (such as walking for transport and for food or walking to a community centre to attend art classes) within a reasonable walking distance.

Five data sets were used to define WDP, these are distinct domains driving physical activity: public transport, sports facilities, food, park connectors and community centres. The features of each domain were selected based on the ease of availability of data and its relevance to influence choice of physical activity.

Even though this research was not set out to specifically quantify the association of each domain or features of each domain to physical activity intensity, the application of geographically weighted regression (GWR) did established the phenomena that the NHSS07 dataset had statistically significant global variables (based on Manhattan distances to WDPs)

that contributed at least 27.3% of the variance in physical activity intensity, in addition, these variables also that exhibited strong regional variation which may inform local policy.
In the central region of Singapore, a combination of global variables relating to diversity and distances improved the GWR model with the highest R^2 values, contributing 33.5% of the variance in physical activity intensity, attributed by diversity measured by number of WDPs within 1000 meters and distance to nearest food source (government owned markets and hawker centres) only.

The research also demonstrated how the use of GIS can be extended to compare levels of dependence and covariance between social determinants of health and conduciveness of the neighbourhood environment to encourage increased physical activity by walking. To improve on the GWR model, additional information was thus obtained to define social economic status (SES) measures of the neighbourhoods (DGP zones) of the NHSS07 respondents. GIS then enabled the integration of spatial (distances to and diversity of WDP) and non-spatial (SES) attributes into the GWR model.

Subsequently, preliminary results suggested that the influence of distance to and diversity of Walkable Destination Points were also predominately greater in populations with relatively lower social economic status neighbourhoods (DGP zones). In this analysis, three SES measures were adopted: resident population in HDB dwellings, resident populations aged 15 years and over who did not speak, read or write any language and resident populations whose monthly household income from work is below SGD$1000 dollars.

However, clustering of over and/or under predictions was evident that the model was still missing at least one key explanatory variable. This could a reason for non-conclusive results obtained in other regions of Singapore. Thus, future work focusing on this aspect would be very beneficial for research and policy development.

The research successfully developed the first model of a Walkability Index for adults in Singapore. The Walkability Index score of 30 out of 55 neighbourhoods were classified into 5 smart quantiles or natural breaks (Jenks). These were mapped to visually identify areas in Singapore that were conducive or not to walking activities (See Figure 4). The 1st smart quantile identified the areas least conducive to residents walking for leisure, exercise or recreation, to access services, or to travel to work (Bukit Timah, Tanglin and Tengah) and the 5th smart quantile indentified the most conducive areas (Queenstown, Bukit Merah and Toa Payoh).

Finally, validation of the Walkability Index showed that for both men and women in the National Health Survey 2007, increasing the Walkability Index of the neighbourhood which they were living within would increase the likelihood of them having high physical activity levels (p=0.000). This effect was found to be greater for men than for women.

It is believed that this type of GIS based research would be applicable to other cities. On the other hand, in dissimilar social, economic and physical contexts, the relative association of different characteristics of the built environment variables may vary to a large extent. For example, in some cities, the subjective perception of crime and neighbourhood safety could be a key determinant for increasing walkability and physical activity.

In conclusion, these preliminary research findings collectively support and call for further investment into spatial health research that considers how residential neighbourhoods' built and social environment characteristics can promote active, healthy lifestyles. The unique combination of spatial and non-spatial data sources; coupled with standards provided by the WHO GPAQ tool to define physical activity levels in a population; basic census SES information; and the objective GIS derived measures of distance and walkability, all together was able to provide different and useful dimensions to physical activity research.

Appendices

Appendix 1 - Comparing GIS research relating to health information systems

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(Bullen, 1996)	To show how Geographical Information Systems (GIS) can be used to identify local areas for primary health care planning.	UK	In order to reflect perceptual, functional and formal divisions of geographical space within West Sussex, a GIS-based strategy was adopted to integrate different layers of geographical data in order to define localities for health service planning	The GIS-based approach allowed the generation of several alternative regionalization, using different approaches (visualization and statistical) and designed to meet slightly different criteria. One of the main advantages of a GIS is its visual impact.
(Olvingson, 2003)	To analyze ethical conflicts that arise when sharing geographically referenced health data in public health programs and how this affects the design of information systems.	Sweden	This investigation used case study methods to explore ethical obstacles originating in the shared use of geographic health information in public health programs and how this affected the design of information systems.	The possibilities offered by GISs in processing and cross matching geographic data caused concern. GISs had the potential to be more threatening to privacy than many other information technologies due to the possible combination of powerful data integration and analysis capabilities with data that were local in nature
(Rushton, 2006)	To review geocoding practice in relation to major purposes and discusses methods to improve the accuracy of geocoded cancer data.	US	This study provided a good reference to questions on geocoding quality and recommendations relating to geocoding purposes	Differences in geocoding methods and materials may introduce errors of commission and omission into geocoded data. A common source of error came from the practice of using digital boundary files of dubious quality to place addresses into areas of interest.
(Mujeeb, 2000)	To explore the use of simple GIS based mapping of health information. The intent was to analyze hepatitis C data from a large public sector facility in Karachi	Pakistan	GIS created maps that conveyed information regarding the location and magnitude of health problems.	Decision making and planning processes could be aided by using GIS to spatially view available data; to identify patterns not evident in other more traditional data presentation formats; to plan and implement interventions in a cost effective manner

(Boulos, 2001)	This methodological review described how health geometrics can improve our understanding of the important relationships between location and health, and thus assist us in public health tasks like disease prevention and also in better health care service planning	UK	Not specifically described	Not specifically described
(Kaneko, 2003)	To visualise the locations of community health needs and to develop a community health needs assessment geographic information system (GIS) for rational decision-making in public health services.	Japan	To integrate different types of geographical data and handle data of different sized areas on the same platform. The geographical database for the assessment of community health needs consisted of 3400 items from seven data sources with information on demography, life and environment.	GIS visual localisation made it easy to illustrate and analyse the geographical distributions of community health needs at the local level. The community health needs assessment GIS presented geographical evidence suggesting how the current provision of services and programmes can meet objectively assessed community needs. Geographical needs assessments based on objective information on the area concerned made it possible to visually indicate the areas where services did not meet current needs.
(Noor, 2009)	To update the spatial audit of public health facilities in Kenya against high resolution population density maps projected to 2008	Kenya	To georeference and map the equity of expanded service provision since 2003, a GIS was updated with the spatial audit of public health facilities in Kenya against high resolution population density maps projected to 2008.	Monitoring geographic access, the applications of a spatially referenced inventory of service providers were manifold because they could be linked to other georeferenced datasets.

Appendix 2 - Comparing GIS research relating to access to healthcare

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(Cinnamon, 2008)	This study presented a description of those areas of BC that are within one hour travel-time to services and the proportion of the population that existing services are reaching.	Canada	To determine the current spatial accessibility of palliative care services in BC using a proven vector GIS catchment method. This method was appropriate for studying access to health services in geographically diverse regions such as BC because it was based on road network travel-time from home to location of care.	GIS methods allowed for evidence-based planning that can promote universally accessible health care services. GIS methods could be used to model health service catchments, thereby highlighting the populations that had access to care. Identification of communities that were greater than one hour from services was provided to shed light on possible locations where new palliative services could be implemented to service rural and remote areas in particular.
(Costa, 2007)	To evaluate geographic access to health services for elderly patients with hip fractures admitted to public hospitals in the city of Rio de Janeiro, Brazil.	Brazil	To estimate distances travelled by patients through the urban transit grid.	GIS provided a feasible approach for characterising distances travelled (or time spent in transit), by linking administrative and demographic data.
(Wang, 2005)	This research considered both spatial and non spatial factors in examining accessibility to primary healthcare.	US	A two-step floating catchment area (FCA) method was implemented in a GIS to measure spatial accessibility based on travel time.	This research demonstrated how GIS technologies could be used to enhance research in medical geography. First, GIS could be used to integrate spatial and non spatial attribute information in one system and to examine the relationship between them. Secondly, GIS could be used to map spatial patterns interactively and make easy adjustments according to user-defined criteria. Thirdly and perhaps most importantly, GIS could be used to analyze the spatial relationship and conduct complex computational tasks related to spatial data.
(Scott, 1998)	To identify the Canadian population with potential access to intravenous	Canada	Geocoding of hospitals was done. Geographic analysis for population characteristics around these	This study recognized those limitations associated with the use of GIS software, as a digital map is at best only an approximation of the ground truth. It noted that

	tissue plasminogen activator within 3 hours of onset of acute ischemic stroke.		centers was also conducted using service area radii of 32, 64, and 105 km.	inaccuracy in a spatial variable entered from multiple sources, including: (1) temporal changes, e.g., movement in population or political boundaries with time, (2) loss of information on map projection which distorts area, distance, shape or direction and (3) digitization error, e.g., number of significant digits used in latitude/longitudinal plotting. GIS analysis offered the ability to rapidly model patient access to specialized therapies, including the use of rtPA in stroke.
(Lovett , 2002)	The research used the combination of GIS techniques and patient registers to evaluate the accessibility of the whole population of East Anglia (Cambridgeshire, Norfolk and Suffolk) to primary health care services. The objectives were to develop new methods for measuring access to primary health care services, to compare patterns of access to services by public and private transport and to investigate the socioeconomic characteristics of populations with the poorest access to services.	UK	This study employed a vector-based GIS to calculate car travel times, but added a further dimension by considering accessibility via scheduled bus services as well. Another innovation was to use GP patient registers to represent the spatial distribution of the population utilising primary health care services.	Without the use of GIS it would not have been possible to quantify variations in accessibility in the same level of detail. Getting the best from a GIS analysis is, however, sometimes far from straightforward. The quality of input data was critical and a recurring difficulty was the effort required to obtain consistent and reliable information. The research nevertheless has demonstrated a new methodology for evaluating geographical variations in accessibility to primary health care services and had highlighted associations in East Anglia which are of interest and use to audiences in academia, local authorities and the National Health Service.
(Patel, 2007)	To use GIS and reference travel time data from the regional air ambulance provider to: 1) Determine the areas within the province where transfer to	Canada	GIS was used to employ methods of spatial interpolation to create a continuous surface of patient transport times for the different modes of transport. The creation of the isochrone lines made it possible	This paper has shown that GIS is a powerful tool that can be used to determine accessibility to catheterization facilities. However, data limitations dictated that the results are generalizations and should be considered with some caution.

	a hospital for catheter intervention would be the preferred method of treatment for AMI and evaluate the proportion of the adult population living within these defined areas, and thus having rapid access to catheter intervention for AMI; and 2) Determine which areas of the province are best served by a certain mode of transport in terms of fastest travel time.		to begin extracting the adult population (20 years of age and older) having access within different travel time intervals.	
(Hyndman, 2000)	To evaluate spatial access to mammography clinics and to investigate whether relocating clinics can improve global access. To determine whether any change in access is distributed equitably between different social groups	Aust.	New clinics were located using the location/allocation module in GIS Arc Info with a distance exponent coefficient of unity implying a constant effect of distance. The modelling criterion was to minimise the population distance. 4 models were adopted for this study	GIS techniques could be well adapted to study access for different sections of the population. The relationship between social disadvantage and health status was well documented, as well as the fact that health facilities were not usually located where they are most needed
(Wood, 2004)	To assess the extent to which those living in particular small areas (electoral wards) have equity of access to adult inpatient hospice services. We also seek to demonstrate how a measure of potential accessibility to such services can be obtained, and go on to identify areas	UK	GIS was used to calculate “drive times” based on network analysis. Apart from its ability to visualise health, and other, data on a map, thus adding locational context to analysis, it enabled the researcher to undertake analysis which other databases cannot readily perform, notably spatial analyses (for example, assessing how many people live within a particular	GIS could be employed to analyse a wide range of healthcare service locational issues. This research, though the use of GIS had pinpointed localised geographical inequity in hospice service provision, which in turn contributed to the debate on funding additional beds, staff, and other cancer services.

	that are relatively poorly served and relatively deprived.		distance of a healthcare facility).	
(Seymour, 2006)	Firstly, to determine the current provision of brain imaging services for stroke patients in Scotland and to identify current and future resource constraints on radiological departments. Secondly, to assess geographical access to CT brain scanning for suspected stroke in Scotland within a range of travel times and during, as well as within, 'normal' working hours.	UK	Access to CT scanning was assessed using drive time analysis that was the time required to travel by road for CT scanning, using a GIS. By taking a point on the road network (that is, the hospital), the GIS generated an isochrone, based on travel time away from that point, out along the road network. This isochrone can then be used to find all OAs that have their 'central' point fall within the isochrone. As the central point has a population, weighting this provides a good representation of whether the majority of population was within the drive time.	Not specifically described
(Hare, 2007)	To assess geographical accessibility and service utilisation related to ambulatory care sensitive cardio-vascular diseases (CVD) s in Kentucky.		A spatial statistical comparison of the geographical distribution of service usage and travel time to hospitals assisted in assessing the relationship between accessibility and health.	Not specifically described

Appendix 3 - Comparing GIS research relating to Access to food

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(Pearce, 2009)	To assess whether neighbourhood access to fast-food outlets was associated with individual diet-related health outcomes, after taking into account individual-level socio- demographic characteristics and potentially confounding neighbourhood features.	NZ	To georeference all food outlets. Each neighbourhood was represented by its population-weighted centroid and the travel distance to the nearest multinational and locally operated outlet along the road network was calculated using the network functionality in a GIS	Not specifically described
(Timperio, 2008)	To examine associations between the availability of a range of food stores close to home and children's consumption of fruit and vegetables.	Aust.	To determine the availability of the following types of food outlets within 800 m from each child's home in 2004/5.: greengrocers; supermarkets; convenience stores; fast food outlets; restaurants, cafés and takeaway outlets.	GIS allowed an objective assessment of the neighbourhood food environment
(Larsen, 2008)	To use network based GIS accessibility measures to determine the extent to which food deserts exist in London, Ontario	Canada	To determine the accessibility of supermarkets, or the relative ease with which Londoners can reach a supermarket on foot (1000m network buffer) or public transit (10min bus ride + 500m walking)	This study achieved methodological advances by incorporating GIS-based techniques for evaluating accessibility by foot and public transit in an urban setting
(Burns, 2007)	To assess the access to healthy and unhealthy foods using a GIS accessibility programme in a large outer municipality of Melbourne	Aust.	GIS modelling was used to measure access to supermarket and fast food outlets in relation to area-level social advantage. In this study accessibility modelling was based on three different modes of	GIS Accessibility modelling is also a useful method for generating hypotheses which can then be tested on the ground. The method enables community food security requirements to be factored into urban development. GIS modelling has also proved a useful tool for engaging stakeholders in community food security

			transport: car, bus or foot.	issues and forming collaborative links with local government
(Apparicio, 2007)	To verify the presence of food deserts in Montréal using 3 accessibility measures based on spatial analytical techniques in a GIS environment and on multi-dimensional exploratory data analysis.	Canada	To calculate accessibility measures and to aid visualization, geo-referencing of locations. To determine the level of spatial auto-correlation within the 3 measures	Not specifically described

Appendix 4 - Comparing GIS research relating to physical activity

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(Li, 2008)	To examine the relationships between the built environment and its association with health, especially excess adiposity—and physical activity in the immediate pre-Baby boom/ early-Baby Boom generations	US	To derive measures of land-use mix, distribution of fast-food outlets, street connectivity, access to public transportation, and green and open spaces	GIS derived measures coupled with varied measures of walking (i.e., leisure-time, transportation, errands) and general physical activity had direct policy applicability, indicating how major features of the built environment were related to the problem of overweight/obesity and the specific forms of physical activity in local communities.
(Davey, 2008)	To test an ecological intervention using a pragmatic cluster randomized controlled design (RCT) aimed at increasing physical activity (PA) within the community in a deprived inner-city area in the UK.	UK	To derive indices (proximity of PA spaces and facilities, street connectivity, land use mix, population density, mass transport provision, traffic, safety, crime, proximity of food outlets and shops, "Walkability Index", weather and indices of multiple deprivation)	GIS enabled an evaluation of the relationship between environmental characteristics and levels of physical activity and health
(Pikora, 2002)	To develop a comprehensive instrument to measure the physical environment related to walking and cycling in local neighbourhoods.	Aust.	To geocode destinations such as parks or restaurants and to mainly product maps for the study areas	Not specifically described
(Tucker, 2009)	To assess the amount of physical activity engaged in by youth aged 11–13, in relation to the presence of neighbourhood recreational opportunities, objectively measured within a	Canada	To map location of schools, parks, public recreational opportunities, as well as land use types and park coverage. Buffers of 1.6km were created to form school neighbourhood area.	Not specifically described

	geographic information system			
(McGinn, 2007)	To examine the association of physical activity with perceptions of the built environment, perceptions of whether the built environment affects one’s physical activity, and the objectively measured built environment using GIS	US	To derive objective measures of traffic volume, traffic speed, and crashes with leisure, walking, and transportation activity and street connectivity	Not specifically described
(Zhang, 2006)	To create school district characterizations and used them to identify contrastive and comparable school neighbourhoods for community-based childhood obesity and physical activity studies	US	To manipulate multiple data sources to generate objective and quantitative measures of school neighbourhood-level characteristics for school-based studies. GIS technology integrated data from multiple sources (land use, traffic, crime, and census tract) and available social and built environment indicators theorized to be associated with childhood obesity and physical activity. Network analysis and geoprocessing tools were used to integrate these data and to generate objective social and physical environment measures for school districts. Hierarchical cluster analysis was applied to categorize school district groups according to their neighbourhood characteristics.	The combination of GIS and cluster analysis made it possible to objectively characterize urban neighbourhoods and to select comparable and/or contrasting neighbourhoods for community-based health studies
(Owen, 2007)	To compare physical activity levels of residents with similar SES characteristics who lived in high- or low-	Aust.	GIS was used to create an objective walkability index and to identify neighbourhoods that maximized variation in walkability	Not specifically described

	walkable areas			
(Duncan, 2005)	To determine the association between GIS-derived objective measures of environmental attributes and self-report ratings of other environmental measures and two measures of physical activity-attaining 'sufficient' physical activity and participation in recreational walking.	Aust.	GIS-derived measures of street connectivity and proximity to parkland, the number of active people in a 1-km radius	GIS-derived measures were used to determine the relationships among selected variables of the neighbourhood environment for each geocoded location.
(Hilisdon, 2006)	To examine the association between access to quality urban green space and levels of physical activity.	UK	To calculate three measures of access to open green space based on distance only, distance and size of green space and distance, size and quality of green space.	Not specifically described
(McCormack, 2008)	To examine the association between the proximity and mix of neighbourhood destinations and physical activity.	Aust.	To geocode destinations and create buffers in order to count the presence and the mix of destinations located within 400 and 1500 m from respondents' homes.	Not specifically described
(Smith, 2008)	This study relates neighbourhood walkability -- density, pedestrian-friendly design, and two novel measures of land-use diversity—to residents' excess weight.	US	To manipulate multiple data sources to generate objective measures of walkability, including street connectivity.	Not specifically described
(Zhu, 2008)	To examine disparities in the environmental support for walking around 73 public elementary schools in Austin TX	US	To measure the neighbourhood-level walkability and safety.	Utility of GIS data for this type of research seemed promising, because of their increasing availability, precision, and coverage

(Leslie, 2007)	To use a previously established GIS-derived walkability index to classify the extent to which the objective physical characteristics of a local neighbourhood may be conducive or not to walking behaviour.	Aust.	Tax valuation and cadastral (parcel) data, street centreline data, land use, zoning data, shopping centre location data and census data for the ASD were spatially integrated within a GIS to create an environmental characteristic index for each spatial unit	The strength of GIS lay in the capacity to capture, store, manipulate and analyse different spatial characteristics in the research on physical activity and environmental influences

Appendix 5 - Comparing GIS research relating to neighbourhood analysis

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(Langford, 2008)	To examines the influence of alternative population distribution models on GIS-based spatial accessibility analyses using the two-step Floating Catchment Analysis technique.	UK	To test and compare 2wo population models: the de facto standard of even-distribution within census tracts and a dasymetric-based approach and its effect on accessibility measures such as the two-step Floating Catchment Analysis technique.	Its capabilities enable relatively sophisticated areal interpolation procedures to be undertaken, allowing data aggregated across the fixed geography of the census to be re-estimated for any alternative spatial divisions. The real strength of GIS, however, was to combine geometric intersection with additional resources that help to elucidate the true, or at least the most-likely, distribution within census tracts.
(Chin, 2008)	To examine the differences between street and pedestrian networks and how the differences in these networks affect the outcomes of commonly used walkability network measures.	Aust.	To study 3 different connectivity measures – Pedsheds, link node ratio and pedestrian route directness and to illustrate the difference in using pedestrian networks versus conventional street networks	Studies incorporating physical measurements of the urban form need to ensure that the GIS data used provide an accurate spatial representation. This study showed that The presence of parks and paths that connect streets can provide direct pedestrian routes. Ignoring these built environment characteristics in neighbourhood physical activity studies has the potential to understate the connectivity of conventional neighbourhoods when they are present.
(Scott, 2007)	To examine the relationship between the number and proximity of objectively measured neighbourhood physical activity facilities and respondents perceptions and to compare objective and self-report measures as predictors of physical activity.	US	GIS was used to identify all the parks, schools, and commercial sites for physical activity located within a mile of each girl's home.	Not specifically described
(Pearce, 2006)	To develop an innovative methodology to measure geographical access to a	New Zealand	Using GIS, distance measures were calculated from the population weighted centroid of each mesh	The GIS application had the flexibility to measure and map access to community resources at varying spatial scales and for different travel modes.

	range of community resources that has been empirically linked to health.		block to 16 specific types of facilities theorised as potentially health related.	
(Comber, 2008)	This study analysed the provision of accessible urban green space in Leicester in relation to the distribution of ethnic and religious trends. It uses a GIS to apply a network analysis of green space access.	UK	The GIS-based network analysis in conjunction with statistical analysis of socio-economic data was used to analyse the equity of access to community goods and services.	Use of GIS quantified actual access distances using road data rather than inferred ones using buffers or straight line distances. The approach presented in this paper of combining GIS-based network analyses with regression approaches to socio-economic data offered a generic method for quantifying the differences in the provision of community goods and services.

Appendix 6 - Comparing GIS research relating to health service planning

Ref.	Research objective related to GIS	Country	How GIS was used	Strengths and/or Limitations of GIS use
(de Mello, 2001)	To create a GIS so as to characterise patients' health services use and residence hospital flow.	Brazil	By means of postcode geocoding, the GIS enabled identification of patient's place of residence in relation to place of treatment. In addition to distance and network analysis for accessibility studies	GIS allowed fast and simple generation of information
(Hassan, 2005)	To explore the application and suitability of GIS with local community participation in deep tube well planning for arsenic mitigation.	Bangladesh	This paper was concerned with participatory application of GIS in support of community perceptions regarding arsenic mitigation	The incorporation of different participatory mental maps into a digital spatial database allowed the use of conventional GIS techniques to achieve a greater understanding of the safe tube well planning. The combination of different datasets had enhanced the understanding of both the local community and the 'expert' viewpoints.
(Foley, 2002)	To assess the potential applicability of GIS in the study area of East Sussex, Brighton & Hove through a study of informal carers and the provision of short-term care services to those carers.	UK	General mapping purposes	One of the advantages of GIS was speedy data collation. But although the value of technology and systems such as GIS was obvious, the implementation remained one which still needs a considerable amount of thought and development.
(Noor, 2004)	To build a health service provider database from a variety of traditional government and opportunistic non-government sources and positioned spatially these facilities using global positioning systems, hand-	Kenya	GIS calculated euclidean distances (in kilometres) between centroid of each sub location and the nearest public health facility were computed. Researchers divided the sub-locations into three distance categories to public health facilities- within 5, 10 and >10 km distances and interpolated the distance at	The production and utilisation of a comprehensive, spatially defined infrastructure of health service providers linked to vulnerability (disease or economic), was both possible and fundamental to any health sector reform process.

	drawn maps, topographical maps and other sources.		each sub-location and created a national map of physical access to public health facilities.	
(Shortt , 2005)	To develop GP catchment areas by creation of a Synthetic Data Matrix (SDM) which compares patient to GP flow (affiliation) information aggregated at the Census Enumeration District level across a number of catchment areas created using different methodologies.	UK	GIS advanced spatial analysis techniques such as nearest feature analysis, network analysis, mean distances were used in different algorithms	Availability of post coded data and the ability of GIS to handle large data sets had facilitated methodological advances in the definition of health service areas.
(Arcury, 2005)	To determine the importance of geography and spatial behaviour as predisposing and enabling factors in rural health care utilization, controlling for demographic, social, cultural, and health status factors.	US	GIS was used to integrate spatial and non spatial attribute data in the multivariate model	Use of GIS in this analysis had furthered the process of specifying the place of geographic and spatial behaviour variables in determining rural health care utilization.
(Hirshorn, 2003)	To examine the capacity and potential of GIS in gerontological research and practice	US	Study demonstrated utility of some basic GIS visualization and spatial analytical methods	GIS could support numerous applications for community-based gerontological research and practice. In addition, the complementarity of GIS with other research modalities makes it valuable heuristically for both cross-sectional and longitudinal investigations of older populations and their resource environments.
(Moyses, 2008)	To build epidemiological indicators on the experience of dental trauma in 12-year-old	Brazil	The spatial location of the schoolchildren's homes enabled the events to be visualized on a cartographic basis.	The use of a geographic information system (GIS) enabled the spatial visualization of the variables of the population studied, in the quest to understand the complex relationship between health and environment.

	schoolchildren in the city of Curitiba, Brazil, exploring its geographical and population distributions.			
(Deshpande, 2004)	To enumerate, characterise and digitally map all private providers (PPs) using Geographical Information System (GIS) in a rural district in India.	India	GIS software established the geo database for information on blocks, villages, health care providers, etc. in such a way that detailed information on each structure on the map could be displayed. Additional health provider data, health data, socio-economic and demographic data were also added within the GIS.	The use of GIS within the framework of a simple provider survey was an effective tool to produce an overview of the pattern of private health care provision in one district in India.
(Brauner-Otto , 2007)	To document the independent effects of health services on fertility limitation	Nepal	GIS was used to investigate several conceptualizations of spatial distribution—the closest health service provider, all services offered within a defined radius, and a geographically weighted summary of all the services offered within the entire study area.	The models that incorporate geoweighted summary information on all health services in the entire study area performed better than models with more limited information.
(Geanuracos, 2007)	To demonstrate the use of Geographic Information Systems for Planning HIV Prevention Interventions for High-Risk Youths	US/Puerto Rico	GIS-produced maps to determine a neighbourhood and population of focus, recruit appropriate community partners for the focus population and neighbourhood, examine geographic and neighbourhood characteristics that may contribute to HIV infection rates, and garner community support for the project’s objectives.	The use of GIS technology was a relatively inexpensive way for a large amount of data to be analyzed and presented in a comprehensible format to multiple audiences.
(Phillips, 2000)	To combine the patient data of a community health centre (CHC) with	US	GIS was used to produce maps that define the CHC service area and patient demographics and show	Geographic information systems were powerful tools for combining disparate data in a visual format to illustrate complex relationships that affect health care access.

	health care survey data to display the CHC service area, the community's health care access needs, and relationships among access, poverty, and political boundaries.		poor health care access in relation to the CHC service area, CHC utilization in relation to poverty, and rates of health care access by geopolitical region.	These systems could help evaluate interventions, inform health services research, and guide health care policy.

Appendix 7 - Physical activity and dietary statistics in Singapore

The Singapore Census of Population in 2000 reported statistical information relating to the usual mode of transport to work. From 1990 to 2000, there was an increase from 18.1% to 23.7% of the population (aged 15 years and above) who took a car only to work. A decrease from 39.8% to 25.0% took bus only. Slight increase from 5.7% to 8.6% took Mass Rapid Transport (MRT) only and an increase from 6.3% to 13.9% took MRT and public bus only (SingStats, Singapore Census of Population, 2000).

According to the more recent General Household Survey in 2005, public transport remained the most important mode of transport for commuting to work in Singapore. In 2005, one in two residents commuted to work by public transport (public bus, MRT, Light Railway Transport (LRT) or taxi). This proportion had remained stable in the last five years (SingStats, General Household Survey , 2005).

Among public transport users, there was a further shift from bus to MRT, with the opening of the North-East Line. The proportion of resident working persons commuting to work by MRT only or MRT with transfer from/to public bus increased from 23% in 2000 to 25% in 2005. Over the same period, there was a corresponding decline in the propotion commuting by public bus only, from 25% to 22%. Usage of car fell marginally, with the proportion of residents commuting to work by car decreasing from 24% in 2000 to 23% in 2005.

In Singapore, about 60 - 70% of resident working persons in the smaller (1 to 3 rooms) Housing Development Board (HDB) flats and about 50% living in 4 rooms or larger HDB flats, commuted to work by public transport in 2005. This suggested strongly that walking to public transportation means (bus stops and MRT/LRT stations) was an important form of physical activity in Singapore. This also placed strong emphasis on the spatial accessibility or physical proximity of residential homes to public transportation means. HDB is the public housing authority that builds, manages and sells affordable housing in Singapore.

In addition, prior analysis from the National Health Survey 2004 found that among Singapore residents aged 18 to 69 years, nearly one-quarter (24.9%) exercised regularly, 27.0% exercised occasionally, and close to half (48.1%) did not exercise at all. Among those who did not participate in any leisure physical activity, a higher proportion of females (54.8%) than males (41.4%) were physically inactive. The prevalence of physical inactivity was similar among the three ethnic groups, with the highest prevalence in Indians (49.2%), and slightly lower prevalence in Chinese (48.1%) and Malays (47.6%). Physical inactivity increased with age, with the prevalence rising from 29.7% among adults aged between 18 and 29 years to 64.2% among adults aged between 60 and 69 years (MOH, 2004).

Subjective reasons given for Singapore residents aged 18 to 69 years old who did not participate in any sports or exercise during their leisure time cited the following three main reasons for their physical inactivity: "No time due to work / family commitment" (47.7%); "Too tired" (20.7%); and "Too lazy" (16.2%). No attempts were reported on associations of built environment with individual levels of physical activity or other objective analysis of causality or correlations of physical inactivity with environmental attributes in neighbourhoods.

Running or jogging (47.6%) was the most popular leisure time physical activity among Singapore residents aged 18 to 69 years who exercised regularly. Other popular physical activities were brisk walking (42.1%), swimming (28.9%), stretching and muscle toning exercises (e.g. sit-up, push-up etc) (25.1%), gym workout with equipment such as treadmill or power rider (20.1%) and gym workout with weights (19.5%). This may suggest that the accessibility of sports and recreational facilities such as walking/running paths, swimming pools and gyms is an important predictor for higher levels of leisure time physical activities in Singapore.

In Singapore, the prevalence of obesity among adults aged 18 – 69 increased from 5.1% in 1992 to 6.9% in 2004. In addition, 25.6% of adults were found to be overweight (MOH, 2004). Though the prevalence was low, obesity is still a major public health challenge because of its increasing prevalence worldwide and the adverse health consequences associated with it, such as diabetes, heart disease and cancers.

The most recent 2004 National Nutrition Survey (NNS) provided information on the dietary practices and the intake of the major food groups and nutrients of about 1,400 Singaporean residents aged 18-69 years old (HPB., 2004).

The dietary patterns of Singaporeans were unique. Most adult Singaporeans consumed breakfast with only 7.2% skipping it. About six in ten adult Singaporeans had home-prepared breakfast. Amongst those who had their breakfast away from home, the most frequent venue was the hawker centre (21.1%) followed by the workplace canteen (13.1%). The majority of adult Singaporeans had their lunch away from home. The most frequented lunch venues away from home were the hawker centres (41.9%) followed by the workplace canteens or tertiary institutions (26.2%). Seven in ten adult Singaporeans had their dinner at home (73.2%). Among those who eat out, the hawker centre was their most frequent venue (21.7%). Adult Singaporeans dined at hawker centres an average of 7 times per week and at fast food restaurants less than once a week. Almost half (49.3%) of adult Singaporeans had their meals at hawker centres 6 times or more a week (HPB S. H., 2004). Hawker centres in this context refers to a collection of individual stalls selling food at very reasonable prices, in an open-air arrangement.

This information suggests that hawker centres are important sources of food for Singaporeans and it is important to provide consumers dining at hawker centres and food courts the option to ask for healthier choices in their food when they eat out at these food outlets. Therefore, in terms of adult nutrition, the HPB had incorporated 4 programmes to improve dietary choices in recent years (HPB).

Appendix 8 - Mapping of GPAQ physical activity classifications in Singapore

In this research, various classifications of physical activity levels by cut off points for specific amount of physical activity were mapped (Fig 4 to 8) in accordance to the WHO GPAQ definitions in classifying high, moderate and low physical activity levels (Table 1)

Fig 6: NHSS07 Respondents classified as having high physical activity (40.62%, n=2718/6692)

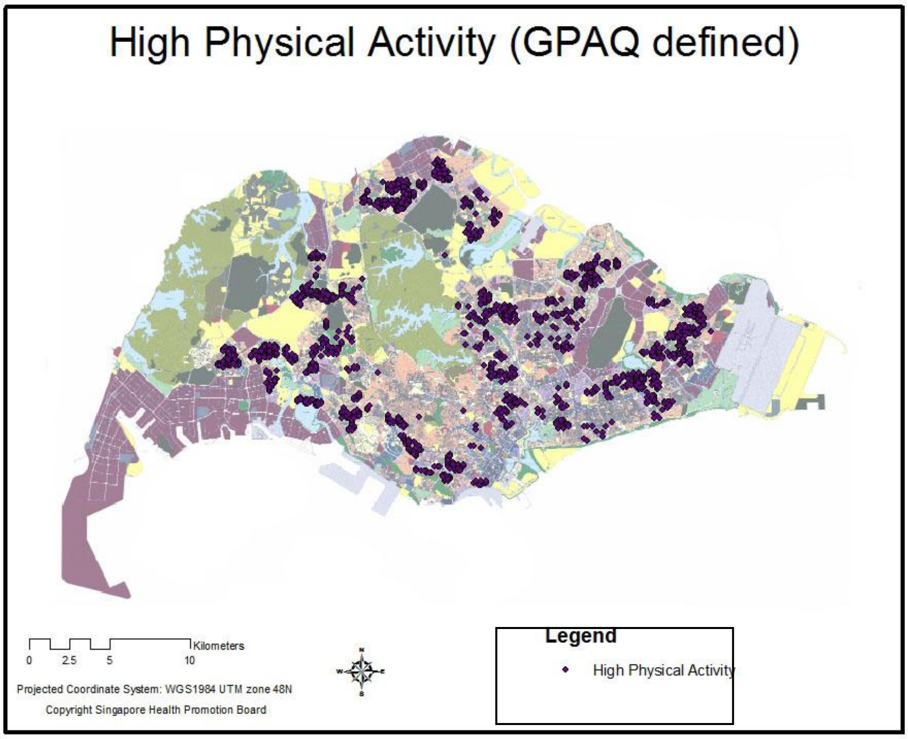


Fig 7: NHSS07 Respondents classified as having moderate physical activity (41.63%, n=2786/6692)

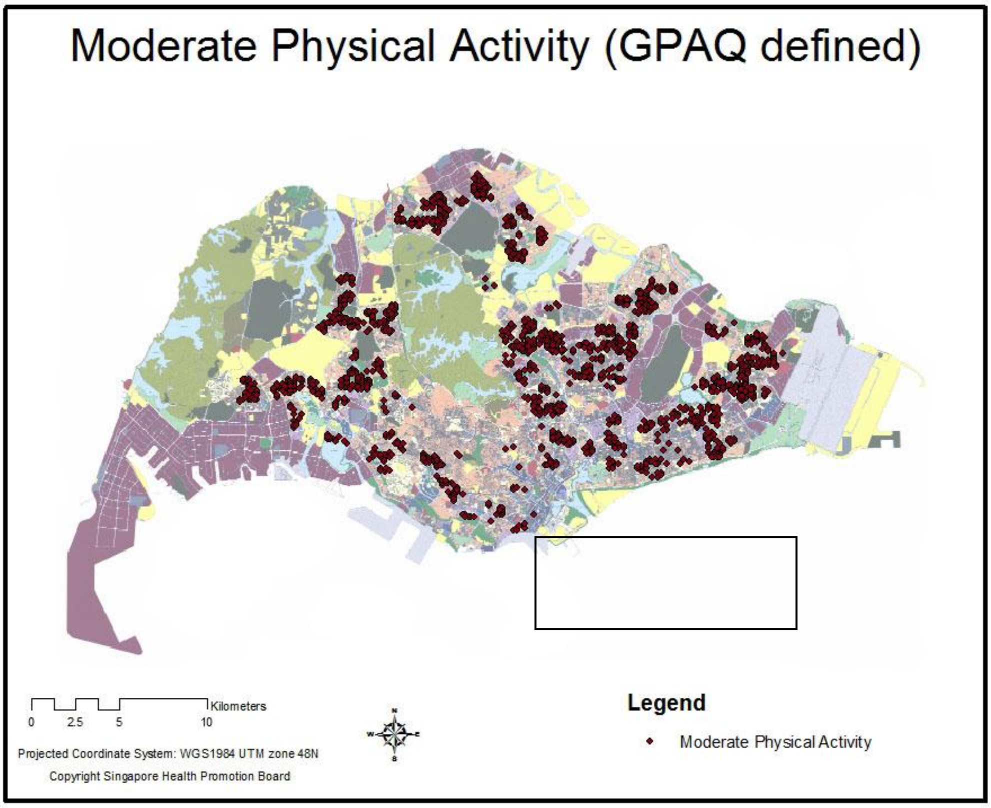


Fig 8:NHSS07 Respondents classified as having low physical activity (17.75%, n=1188/6692)

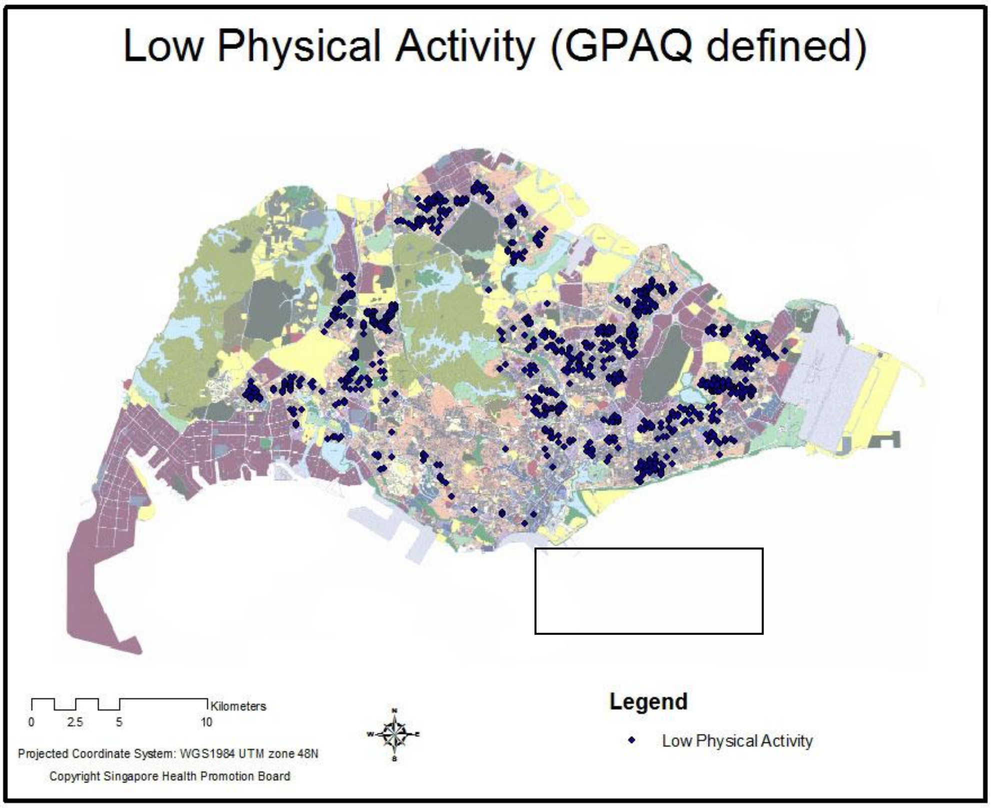


Fig 9: NHSS07 Respondents classified as not engaging in any vigorous activity at all (33.19%, n=2221/6692)

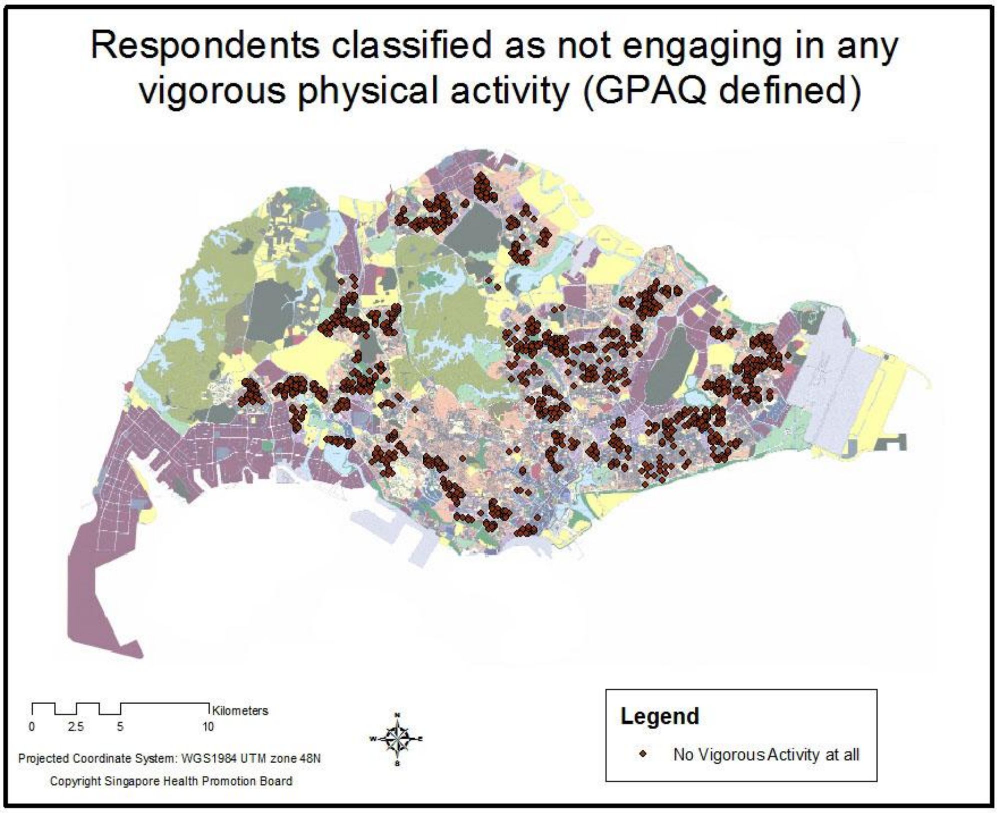
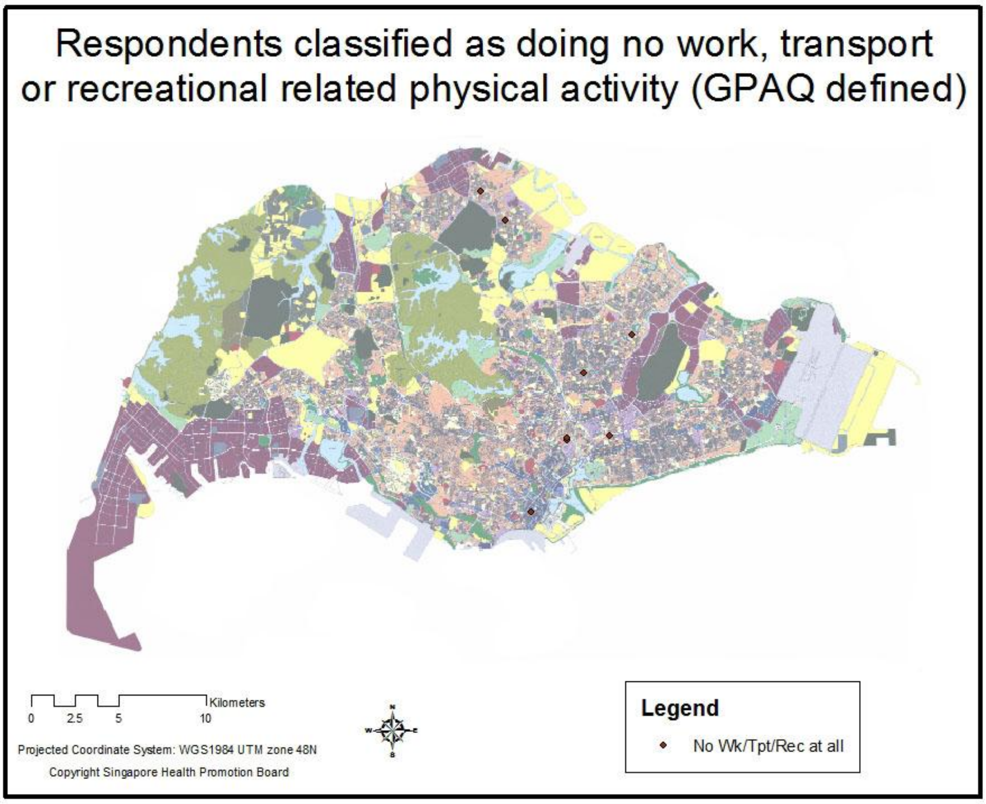


Fig 10: NHSS07 Respondents classified as doing no work, transport or recreational related physical activity (0.001%, n=9/6692)



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