ACCESSIBILITY TO GREEN SPACE IN THE MELBOURNE METROPOLITAN AREA

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A thesis submitted in (partial) fulfillment of the requirements for the degree of Master of Applied Science

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DEC 2013

DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Zhenhuan Hao

ACKNOWLEDGEMENT

I would like to express my sincere appreciation to my first supervisor Dr Gang-Jun Liu (RMIT University) and my second supervisor Professor Kefei Zhang (RMIT University). Without their guidance and support, this thesis would not exist.

Dr Gang-Jun Liu's passionate and insightful inspiration, encouragement, guidance and discussions have accompanied me throughout this research journey and his useful comments have greatly improved the manuscript. When I encountered some difficulties, Dr Gang-Jun Liu always offered timely and helpful support that enabled me to move forward. His knowledge and wise suggestions and tips have enlightened my mind about how to design the programming ideas repeatedly.

I want to thank Professor Kefei Zhang, who provided this great opportunity for me to study in the Australia. Living and studying abroad has not only provided me with great knowledge, but also enriched my experience and broadened my horizon.

My special thanks are to my parents Feng Hao, Yulan Liu, my girlfriend Xiaoqian Li. You support me all the time. Moreover, you gave me the trust, encouragement and financial support, without which I could not have done my research. My love belongs to you forever.

Personally, I am grateful to the school staff: Professor Nicholas Chrisman, Professor John Hearne, Dr Suqin Wu, Miss Eliza Cook, and my fellows: Yujia Cui, Ju Bai, Aekarin Borrirak, Bin Hu, Salahuddin, Ahmad who assisted me and inspired me. I also thank them for showing me the value of education, for their continuous encouragement, and for their willingness to share their knowledge and experience with me. I cannot forget the period studying and living with you at RMIT University.

I am also grateful for the official websites of DSE / ABS / Parks Victoria, when I collected the relevant dataset. Without these data, it is impossible to finish my research. I am appreciating the marvel of ESRI Australia, who provided me the ArcGIS software to resolve the complicated spatial operations.

Zhenhuan Hao

MAY 2013

ABSTRACT

Demand for green space by the public is becoming stronger for aesthetic enjoyment, recreation, clean air and quiet environment. Green space can protect biodiversity, absorb pollutants, adjust urban temperature and increase urban residents' longevity. Accessibility to green spaces has been regarded as a useful measure of the quality of life in urban areas. Adequate and equitable accessibility to green space for all residents in urban areas is an important planning objective in many urban areas in the world, including the Melbourne Metropolitan Area (MMA), to sustain urban residents' quality of life and well-being.

This research focuses on two key research questions: how to measure spatial accessibility to green space in urban areas at fine resolution; and what is the status of spatial inequity in accessibility to green space in the MMA. Guided by the two research questions and based on a systematic review of literature on accessibility in general accessibility to green space in particular, a methodology has been developed for producing results needed to answer the research questions. The methodology involves considerations and procedures for such tasks as:

- selecting the study area,
- collecting and organising the required datasets,
- mapping spatial concentration of population at fine spatial resolution,
- determining the relative attractiveness for each green space in the MMA,
- calculating network constrained walking distance between locations in the MMA,
- measuring green space accessibility for each residential area in the MMA,
- mapping the spatial variation in green space accessibility across the MMA, and
- identifying and mapping spatial clusters of locations with low green space accessibility in the MMA.

This research identifies factors that affect the measure of accessibility, including the attractiveness of a green space, determined according to the characteristics of population characteristics (e.g. age), a set of attributes of green space and travel impedance from residential locations to green space entrances. Attributes of green space considered in this study include the location, area size and extent of each

green space; and the various kinds of facilities present or associated with each green space, such as children's playground, bench, toilet, walking track, sport oval, sport court, water body, and percentage of quiet area within a green space. Spatial and attribute data for these identified factors have been identified, collected, and organised into an ArcGIS-based geodatabase to support subsequent spatial analysis and thematic mapping.

The relative contributions of different kinds of facilities to the attractiveness of a green space have been weighted in relation to four population groups, determined from the 2011 ABS census data, including young (aged 0-15), adult (aged 16-64), aged (aged 65+), and total (aged 0-115). Among all the attributes considered, the area size of a green space plays a significant role.

The accessibility values to neighbourhood green spaces for the four groups of population from each Mesh block (MB) across the MMA are measured with the following four different methods:

- M2SFCA_G, the 2-step floating catchment area modified by the Gaussion function;
- M2SFCA_B, the 2-step floating catchment area modified by the Butterworth filter;
- M3SFCA_G, the 3-step floating catchment area modified by the Gaussion function; and
- M3SFCA_B, the 3-step floating catchment area modified by the Butterworth filter.

Neighbourhood in this study is determined by a (MB based or a green space based) road network distance of 1600 metres. This distance is also applied as the threshold value for determining the catchment size and for limiting the distance decay in the four floating catchment area methods used in this study.

The study applied hot spot analyses to the Mesh Block (MB) level results of spatial overlays between estimated (young, adult, aged, or total) population concentrations and measured accessibility values to show the spatial variation in levels of locational disadvantage in accessibility to green space in the MMA. The outputs from hot spot analyses are used to assist the identification of spatial clusters of disadvantaged locations in terms of green space accessibility. These disadvantaged locations are identified as having high concentrations of (young, adult, old, or total) populations (used as a surrogate of potential demand for green space services) and low values of measured accessibility to green space by these four different population groups (used as a proxy for accessible green space service provision).

This research finds that the study area (i.e. the MMA) is about 770,000 ha in size and holds over 3.8 million residents. About 15% of the MMA (or about 120,000 ha) is occupied by 4678 different sized green spaces. The average size of a green space is about 25 ha, and on average, each green space supports about 850 residents. In general, about 84% of the residents live within a road network distance of 800 m from the nearest green space, and about 97% of the residents live within a road network distance of 1600 m from the nearest green space. According to MB level accessibility measured with the modified floating catchment area method, on average, the percentage of population with relatively high, Medium +, Medium, Medium -, and low accessibility to green space is about 21.2%, 18.5%, 25.6%, 18.7%, and 16.2%, respectively. Spatially, residents in the suburbs and along the green wedges understandably have better access to green space than residents living in other locations. Spatial clusters of disadvantaged residential locations in terms of green space accessibility are shown in a set of maps in the thesis. According to the locational disadvantaged in the MMA measured with the population demands and the provision of green space, on average, the percentage of population with relatively high, Medium +, Medium, Medium -, and low levels of locational disadvantaged area is about 11.9%, 26.4%, 16.7%, 30.1%, and 14.9%, respectively.

These findings should provide valuable evidence for urban planners and public policy makers as well as the general public for formulating future urban plans. The methodology developed in this study should be applicable to other metropolitan areas within and even beyond Australia, should the required datasets are readily available and accessible. The thesis also includes some discussions about the relative merits of the four different floating catchment area based methods and some recommendations for future researches.

Keywords: Accessibility, Green Space, Melbourne, Floating Catchment Area, Geographical Information System, Mesh Block

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CHAPTER 1 INTRODUCTION

1.1 The Importance of Green Space in Urban Areas

Green spaces in urban areas are filled with forests, meadows, lawns, water bodies, streams, paths, trails, or promenades: some small and intimate; others grand and monumental; all invoke pleasant feelings and beautiful images for most of us.

The importance of green space in urban areas has been well documented for its ecological, social and economic functionalities (Rowntree 1988, Takano *et al.* 2002, Kowarik and Korner 2005, Oh and Jeong 2007, Brook 2010).

- From the ecological perspective, green space improves the quality of urban environment by regulating air temperature and moisture, purifying air and water pollution, and sustaining biodiversity (Hirokawa 2011, Sun *et al.* 2013, Watmough *et al.* 2013).
- From the social perspective, green space improves living standards and promoting human health for urban residents by providing accessible public open space for them to conduct leisure activities and social interactions (Tannier *et al.* 2012, Moseley *et al.* 2013).
- From economic perspective, green space helps reduce the negative impacts (e.g. pollution, noise, extreme temperatures) and increase the positive contributions (e.g. fresh oxygen and biomass produced through photosynthesis) from the environment processes, promotes the health condition and hence productivity of the urban residents, and lifts the aesthetic and economic status of the urban system (Elkin *et al.* 1991, Givoni 1991, Tzoulas 2007, Jun *et al.* 2012).

The key role played by public open green space in promoting and sustaining the liveability of the urban system is well recognised by urban planners around the world. Adequate, equitable and easy access to green space in a specified geographical area is regarded as an important issue of human service provision.

For example, urban planners in Melbourne regard improving the quality and distribution of public open green space and ensuring long-term protection of public green space as essential checkpoints to ensure the sustainable growth of

Melbourne and to “consolidate its reputation as one of the most liveable, attractive and prosperous areas in the world for residents, business and visitors” (VDSE 2002).

Generally speaking, most of the green space in urban areas is freely accessible by the general public, like local parks. However, not all of the green space are publicly accessible, like fee-charging golf courses or fenced and privately owned lawns; and some green space are not 24/7accessible by the general public, like sport grounds on school campuses (Figure 1.1.1).

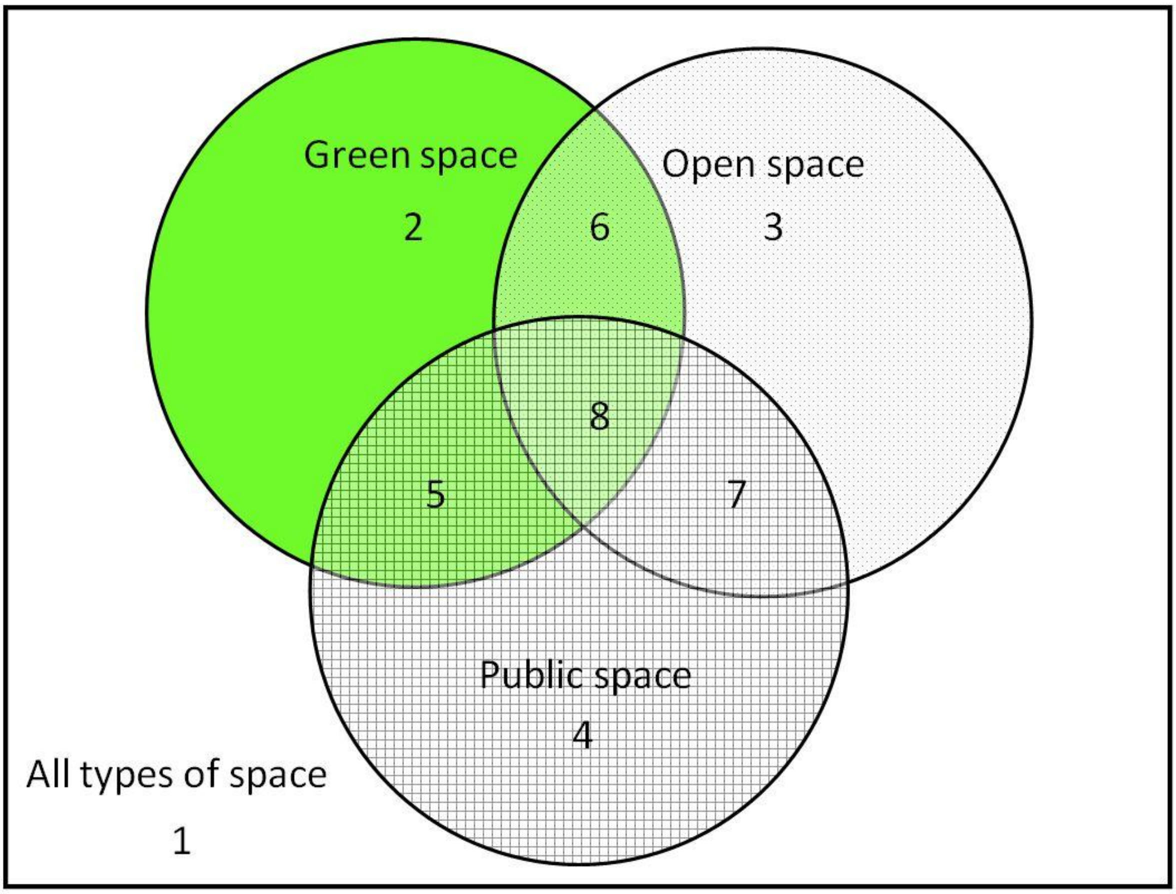


Figure 1.1.1 The concept of public open green space (personal discussion with Dr Gang-Jun Liu). Different types of space are labelled and symbolised as follows: 1. All types of space; 2. Green space (symbolised by green colour), but non-Open and non-Public, e.g. private green space; 3. Open space (symbolised by dots), but non-Green and non-Public, e.g. paved parking; 4. Public space (symbolised by grids), but non-Green and non-Open, e.g. shooting range, Stadiums; 5. Space that is Green and Public (symbolised by green colour with grids), but non-Open, e.g. hunting area; 6. Space that is

Green and Open (symbolised by green colour with dots), but non-Public, e.g. school campus; 7. Space that is Open and Public (symbolised by dots and grids), but non-Green, e.g. Melbourne federation square; and 8. Public Open Green space (symbolised by green colour with grids and dots), e.g. parks, reserves.

This study will focus on green space that is open to, and freely accessible by, the generally public, as defined by domain 8 in Figure 1.1.1, and hereafter in this thesis, the term green space is used interchangeably with public open green space without further clarification.

1.2 Research Objective, Questions and Methods

Now that it has been over 10 years since the publication of the Melbourne 2030 Action Plan, the assessment of the current status of (1) the quality and distribution of local green space, and (2) the spatial variation in accessibility to local green space in the Melbourne Metropolitan Area (MMA), is regarded in this study as both timely and essential for providing useful evidence for urban planners, public policy makers and the general public to ensure the sustainable growth and liveability of the MMA.

Together with fine spatial resolution data sets and GIS-based analytical and visualisation procedures, the concept and related measures of accessibility are deployed in this study for measuring, mapping and better understanding the spatial relationship between the distribution of population and the distribution of green space and green space facilities in MMA. Accessibility to green space is regarded as an effective measure of the quality of urban life (Oh and Jeong 2007).

This study aims at identifying spatial clusters of residential locations with relatively low accessibility to local green space in the MMA. The achievement of this objective involves answering the following set of research questions:

1. What is green space and how to define the attractiveness of green public green space in urban areas?
2. What is accessibility and how to measure accessibility to green public green space in urban areas?

3. How to represent the spatial variation in accessibility to green space in urban areas?
4. How to identify spatial clusters of residential locations with relatively low accessibility to green space in urban areas?
5. What is the current status of spatial inequity in accessibility to green space in the MMA?

Considering the spatial relationships among residential locations, green space distribution and road network configuration, and based upon findings from literature review, the level of service provided by local green space to age-differentiated local residential locations in the MMA is measured, in this study, with the two step floating catchment area (2SFCA) and the three step floating catchment area (3SFCA) methods (Luo and Qi 2009, Luo and Whippo 2012, Wan *et al.* 2012), incorporating distance decaying functions. The general procedure adopted in this study for addressing the set of research questions listed above including the following steps:

1. Conduct literature reviews to clarify and determine concepts, measures and data requirements for studying accessibility to green space in urban areas and methods for mapping spatial variations and identifying spatial clusters;
2. Select and describe the study area, in terms of land use patterns, age-differentiated population distributions, locations of local green space and associated facilities, and road network configuration;
3. Collect required datasets and build a geodatabase to support GIS-based spatial analysis and visualisation;
4. Measure accessibility to green space from each residential location across the study area for different aged groups, and map spatial variation in accessibility to green space across the study area;
5. Identify and map spatial clusters of residential locations with relative low accessibility to green space in the study area for different age groups;
6. Summarise the research results; discuss issues related with the deployed methodology; and recommend directions for further studies.

1.3 Structure of the Thesis

This thesis includes six chapters (Table 1.3.1). In chapter one, the importance of green space in urban areas is briefly discussed; the research objective and associated research questions are set, and the general research methodology is outlined.

In chapter two, findings from literature reviews are summarised, focusing on the following issues: (1) concept of green space and measures of its attractiveness; (2) evolution of government policies on green space in MMA; (3) concepts and models of accessibility and their respective strengths and weaknesses; (4) measures of accessibility to green space in urban areas; (5) issues and methods for presenting spatial variations, including modifiable areal unit problem and thematic classification; (6) methods for identifying spatial clusters, including hotspot analysis.

In chapter three, the research methodology applied in this study is described, including: (1) rationale and criteria for selecting the study area; (2) measures of green space attractiveness, population concentration and travel impedance; (3) measures of accessibility to green space adopted in this study, including the M2SFCA and M3SFCA methods modified with two different distance decaying functions; (4) data sets collection and database structure; (5) procedures for measuring accessibility to green space within the ArcGIS environment; (6) methods for presenting spatial variations in accessibility to green space across the study area and (7) methods for identifying and mapping spatial clusters of residential locations with relative low accessibility to green space in the study area.

In chapter four, the selected study area (i.e. the MMA) is described in terms of its location, extent, land use pattern, population structure and distribution, green space and associated facilities, and road network. Also outlined in the chapter include data sets collected and structure of the geodatabase developed for the study.

In chapter five, accessibility to green space in the study area measured with different methods are presented, including (1) travel impedance to green space from residential locations, as measured by road network distance; (2) measured green space attractiveness for four age groups, namely young (0-15 years), adult (16-64 years), old (65+ years), and total population; (3) accessibility to green space for the four age groups in the study area, as measured by the M2SFCA and M3SFCA methods modified with the Gaussian or the Butterworth distance decaying functions; (4) spatial clusters of residential areas with relatively low accessibility to green space; and (5) summary statistics reflecting the spatial and categorical distributions of population associated with different levels of travel impedance or accessibility to green space in the study area.

Chapter 6 presents conclusions drawn from the study, discussions on some issues associated with the methodology applied, and recommendations for further studies on the topics.

Table 1.3.1 Structure of the thesis

Chapter	Content
1	• Importance of urban green space • Research objective, questions, and methods • Thesis structure
2	• Concepts and measures of accessibility to green space • Methods for mapping spatial variations and identifying spatial clusters
3	• Outputs and inputs • Measures and procedures
4	• Location, extent, and land use • Road network • Population • Green space and facilities
5	• Spatial variations in green space accessibility • Spatial clusters of locational disadvantage in accessing green space
6	• Conclusions • Discussions and Recommendations

CHAPTER 2 LITERATURE REVIEW

To gain current understanding on issues related to the measurement and mapping of accessibility to green space in urban areas, a systematic literature reviews has been conducted, focusing on key concepts like green space and accessibility, key measures of accessibility, and issues related to the representation of spatial variations and the identification of spatial clusters. Key findings from the literature reviews are summarised and presented in the following sections.

2.1 Green Space in Urban Areas

Green space as a concept is usually used to refer to a tract of land that is covered (wholly or partially) with living vegetation (grass and/or trees) and openly accessible by the public free of charge (Figure 1.1.1), and the ecological, social and economic benefits of green space in urban areas are well published (Henderson and Wall 1979, Turner 1992, Talen 1997, Dai 2011).

In 1870, Frederick Law Olmsted used the word "park" in his address " A Consideration of the Justifying Value of a Public Park" to mean a large tract of land set apart by the public for the enjoyment of rural landscape (Czerniak 2007).

The State Government of Victoria (SGV) has defined green space as an area of publicly owned, protected or conserved land, that is set aside primarily for recreation, nature conservation, passive outdoor enjoyment and public gatherings (SGV 2008). SGV stresses that public green space (including publicly owned parks, gardens, reserves, waterways, forecourts and squares, green space on school and universities campuses, nature strips along streets, major sporting venues that are managed by or on behalf of the government) must face to the public freely.

Green spaces generally contain significant numbers of trees and large areas with grass cover. Their environmental contribution are significant. Green space improves the quality of urban environment by regulating air temperature and moisture, purifying air and water pollution, and sustaining biodiversity (Hirokawa 2011, Sun and Chen 2013, Watmough and Atkinson 2013). Green spaces are effective in helping store and process stormwater, channel and cool air temperature in the urban core, and provide habitat for a rich community of plant, animal, bird, aquatic, and microbial species.

Air pollution in urban areas is a significant human health concern as it can cause coughing, headaches, lung, throat, and eye irritation, respiratory and heart disease, and cancer (Bedimo-Rung *et al.* 2005). Green spaces function as "green lung cells" in cleaning, refreshing and enriching the metropolis, improving living standards and promoting human health for urban residents by providing accessible public open space for them to conduct leisure activities and social interactions (Tannier and Vuidel 2012, Moseley and Marzano 2013). Beneficial effects of physical activity on cardio- and cerebro-vascular disease, diabetes, colorectal cancer, osteoporosis, depression and fall-related injuries (Lee and Maheswaran 2011), and on longevity (Takano and Nakamura 2002) are well documented. Green spaces contribute to improved mental health as the provision of natural space enable people to properly rest, relax and thus alleviate stress (Tannier and Vuidel 2012, Moseley and Marzano 2013).

Green spaces provide opportunities for individuals to interact with other people, and are therefore great places for social interactions, neighbourhood acquaintance and the gathering of friends (Moseley and Marzano 2013). Increased levels of physical activity and participation in sport, recreation and social activities due to easy access to and frequent use of green space can promote health, reduce illness, enhance concentration on study and work, increase effectiveness in study and productivity in workplace, and well-being, at both individual and community levels. On the other hand, the reduction in sick time can save residents unnecessary or dispensable spending on the medicines and operation directly which in turn enhance study performance or working outcome.

Green spaces promote the health condition and hence productivity of the urban residents, and lift the aesthetic and economic status of the urban system (Elkin and McLaren 1991, Givoni 1991, Tzoulas 2007, Jun and Li 2012). Green spaces can help minimise the negative impacts (e.g. pollution, noise, extreme temperatures) and maximise the positive contributions (e.g. fresh oxygen and biomass produced through photosynthesis) from the environmental processes. Several studies have found that a closer proximity to green spaces had the positive impact on the property value. In addition, urban green spaces can attract visitors from elsewhere which can lead to significant economic and social benefits (Knetsch 1964, Hammer and Coughlin 1974, Eom and Lee 2009).

Green spaces vary in size and attributes, and hence have different spheres of influences. Some surveys indicate that people visit neighbourhood green space more often than district or regional green space (VDSE 2002).

Neighbourhoods have been regarded as a meaningful territorial component of urban life for most people and a planning ideal in many parts of the world (Lee 1968, Pacione 1982, Martin 1998). The size of neighbourhood is considered to be an intermediate between block and municipality, where each neighbourhood is capable of 100 inhabitants, whose education qualification and income are quite similar to a certain level (Sawicki and Flynn 1996). Residents in the same neighbourhood often but not always share the same socio-economic status and lifestyle (White 1987).

A neighbourhood is designed to provide a number of green spaces that cater for a range of uses; to ensure all dwellings have access to neighbourhood green space within a certain distance (800m, 1200m, or 1600m etc); and to ensure the walking network connects the green space to the broader green space network - as the network of green space may form a key component of a journey through a neighbourhood (Lee 1968, Pacione 1982, Martin 1998).

Where appropriate, neighbourhood green spaces should be located in distinctive parts of the landscape such as corridors and hilltops, and co-located with other community facilities to enable dual use of the space and multi-use destinations such as children's play equipment located adjacent to a community hall, and to maximise opportunities for children and youth to safely access and play at green space without needing to be accompanied by an adult (VDSE 2002).

Neighbourhood green spaces range in size from 1000 m^2 up to around 5000 m^2. They may include lineal green space connecting other green space or forming part of the broader network of green space, and are designed to accommodate a range of groups within their neighbourhood (Cho 2003).

Neighbourhood green spaces located within walking distance usually provide most exercise amenities, and address day-to-day needs of local residents. Neighbourhood green space may help reduce dependence on car use and should be able to support recreational activities to the contiguous neighbourhoods if there are safe and attractive spaces for walking, and if subdivision layouts allow easy movement through and between neighbourhoods (VDSE 2002).

2.2 Green Space in Melbourne Metropolitan Area

Melbourne's international reputation for liveability and its demonstrated ability to attract investment and tourists (VDSE 2002), to a considerable extent, have been attributed to the quality and attractiveness of Melbourne's green space system (SGV 1995), which in turn can be attributed to a succession of good urban planning efforts over the years.

The boundary of green space (including parks, parkways, playground, sportsground, drill grounds, and green space around public buildings and monuments and along water front) has been clearly defined in the 1929 Metropolitan Planning Commission Report, the first urban plan for Melbourne (MTPC 1929). The plan proposed that children's playgrounds should be equipped with swings and slides; a children's playground must be within convenient walking distance (< a quarter of mile); and at least 0.25 acre of the children's playground space would be required for every 1,000 of population. The plan also considered that if 1.75 acres were allowed for every 1,000 people, it would prove sufficient for sport purposes, such as tennis, croquet, bowls, hockey.

The 1954 Melbourne Metropolitan Planning Scheme (TPC 1954), the first update in the urban plan for Melbourne since the 1929 plan, recognised that facilities for relaxation and exercise outdoors are an essential part of urban living, and that the provision of these facilities is a responsibility of civic administration. The 1954 plan showed that the government emphasized the construction and maintenance of green space in Melbourne, and prescribed green space standards for ornamental and rest parks (2 acres per 1,000 people), sports grounds (excluding golf and racing, 4 acres per 1,000 people), and children's playgrounds (1/2 acre per 1,000 people).

The 1971 Planning Policies for the Melbourne Metropolitan Region (SGV 1971) directed development into specific corridor locations and giving new and specific emphasis to conservation of natural environments close to the urban area. The 1971 planning policies defined, among other things:

- A series of permanent non-urban areas or green wedges worthy of conservation because they contained most of the areas of significant landscape, historic and scientific interest, the major agricultural resources, the water catchments, and the major areas supporting significant bird, animal and plant life and

- A series of major green space reservations within the green wedges strategically placed to serve metropolitan needs, to be retained in their present open character and be acquired and used for public recreation as appropriate.

The 1971 planning scheme was also amended to indicate:

- Areas which are intended to be preserved as non-urban in character, in perpetuity, included in one of five zones, designated as conservation zone, landscape zone, special extractive zone, intensive agriculture zone, general farming zone; and
- Areas reserved for various public uses and purposes, including major public green space reservations.

The 1981 Metropolitan Strategy Implementation (SGV 1981) include guidelines for developing and managing green space and recreation facilities, and for selectively funding and establishing a range of metropolitan facilities (SGV 1981). The guidelines aimed at, among other things, helping to create and fund more diverse recreation opportunities, make better use of opportunities such as undeveloped open land, support public and private sector co-operation in developing the recreation and green space system, encourage increased use of local and regional green space, to benefit the community and to enhance the quality of life.

Melbourne has an extensive green space network containing areas of considerable natural and cultural value, providing opportunities for recreation, tourism and enjoyment, and contributing significantly to urban amenity. As Melbourne’s population grows, it is essential to make adequate space available for sport (whether it be active or passive recreation) close to where people live; and to have adequate, well-located and useable green space for recreation, conservation and catchment management in all new communities. Accordingly, the 1995 urban planning for Melbourne, Living Suburbs (SGV 1995), is committed to maintain and extend physical and human services throughout the Melbourne metropolitan area. The 1995 plan aimed at providing clearer guidance in planning schemes for the quantity and quality of green space, developing green space plan for each growth area, developing a green space network of parks, trails, bicycle paths, waterways and habitat corridors throughout the metropolitan area; encouraging shared cricket / footy between schools and local communities, among other things.

The 2002 blueprint for the future of metropolitan Melbourne, Melbourne 2030 (VDSE 2002), aims at making the environment more liveable and attractive and ensuring fairer access to the benefits of growth and change and more equitable access to social, economic and environmental infrastructure. The objectives may be achieved by

- Improving the quality and distribution of local green space,
- Providing distributed green space within easy walking distance (< 800 m or < 10 minutes of walking),
- Maintaining and expanding a quality green space network,
- Ensuring long-term protection and improvement of major green space corridors and other public green space,
- Rectifying gaps in the network of metropolitan green space,
- Improving the design and function of some existing green spaces,
- Acquiring land designated for future parkland across Metropolitan, and
- Delivering additional well located and designed Green space relevant to the new community.

The 2008 updates to Melbourne 2030, Melbourne 2030: a planning update - Melbourne @ 5 million (SGV 2008) and The Victorian Transport Plan (SGV 2008), provide a long-term plan for managing Melbourne's growth and outlined a number of initiatives to ensure that the city remained liveable and sustainable. Delivering Melbourne's newest sustainable communities focused on land use, transport and environmental initiatives, and took an integrated approach to land use and transport planning so that infrastructure and essential services are delivered as new communities in the growth areas of Melbourne are developed (SGV 2008).

The 2008 updates committed to protecting green wedges and set out future priorities for their management, including:

- additional resources to complete the 12 green wedge management plans within agreed timeframes,
- planning scheme controls that continue to deliver the intent of green wedge policy, and

- a high-level whole-of-government mechanism to help clarify management priorities of departments and agencies to coordinate implementation actions for each green wedge.

2.3 The Attractiveness of Green Space

Green spaces are usually associated with various functional facilities, including children's playground, benches, toilets, walking tracks, sport ovals (for cricket and football), baseball fields, netball and tennis courts, and water bodies that offer services and opportunities to help fulfil social, economic, and environmental benefits for individuals and communities (Roemmich *et al.* 2006, Potwarka *et al.* 2008, Weiss *et al.* 2011, Rundle *et al.* 2013).

Many factors influence the attractiveness of a green space (Kurashov 1960, Kahr 1981, Giles-Corti *et al.* 2005, Weiss and Purciel 2011) including its location, size, other attributes, and contextual conditions, and users as well as potential users who prefer proximate, attractive, and larger public green space (Giles-Corti and Broomhall 2005). The location of a green space influences the perceived proximity, accessibility (by local users or to competing local facilities) and quietness (closeness to main roads). The size of a green space provides a variety of opportunities to "lose oneself" or to accommodate functional facilities. Other attributes of a green space may include the availability of functional facilities (such as walking paths, picnic tables, barbecues, toilets or other amenities), aesthetic features (such as the presence of trees, water body and birdlife), and maintenance (e.g. irrigated lawns).

In general, a green space becomes more attractive when it is associated with more facilities, but a facility's attractiveness towards a potential user depends on the user's characteristics such as age.

The contextual conditions of a green space may include: characteristics (e.g. socioeconomic status, age, gender, ethnicity, and psychological factors influencing personal preferences) and needs of potential local users, perceived walkability of connecting footpaths, and neighbourhood safety (Westover 1985, Dingwall *et al.* 1989, CDCP 1999, Wilcox *et al.* 2000, George 2010) , and weather conditions in the region (Sallis *et al.* 1997).

The 'quietness' at different locations within a green space have been related to the perceivable or measured noise levels (Szeremeta 2009).It is suggested that the permissible limit for “green areas” during daytime should be equivalent to a continuous sound level of 55 dB (Szeremeta 2009). Williams (1971) noted that arterial roads with heavy traffic flows (e.g. with many heavy vehicles and buses) can generate a sound level of 68 – 80 dB (Williams 1971). Papafotiou (2004) found that the noise level attenuates gradually from the roads and there is a significant noise reduction of 25dB (from 80dB to 55dB) in the first 60m on average from the heavy traffic. If open spaces are framed by thick vegetation such as shrubs and trees, it can further attenuate the transmission of noise for about 4 dB more than empty space in the first 20 m (Maria *et al.* 2004). For roads with light traffic flows, the noise level is usually less than 55 dB, and therefore, there is no noise related annoyance from the light traffic roads, even within the first 20 m distance from the roads.

To quantify the attractiveness of green spaces, an attractiveness score (Giles-Corti and Broomhall 2005) may be estimated for each green space as follows:

$$\mathrm{Att}_i = \left(\sum_n fac_n \times w_n\right)^{\alpha} \times S_i^{\beta} \qquad \text{(Eqn 2.1)}$$

where Att_i is the attractive score for green space *i*, fac_n is a binary indicator (0,1) of the presence of the *n* th attribute, and w_n is the weight for the *n* th attribute. S_i means the size of green space *i* in hectare. The facility-related (α) and size-related (β) exponential coefficients were used to differentiate relative contributions to the final attractiveness score made by facilities and green space size, and were determined via a linear regression model as 0.52 and 0.85, respectively. This is because people often put emphasize more on the size of a green space than the facilities when associated with a green space (Giles-Corti and Broomhall 2005). To explain the Eqn 2.1, for a green space *i,* the sum of facilities’ weight value is 0.8, and the size is 200 ha, the attractiveness score is $0.8^{0.52} \times 200^{0.85} \approx 80.44$.

Many studies on the relative weights for different types of facilities associated with green space have been conducted (Gidlow *et al.* 2012, Seifolddini and Mansourian 2012, Zhang *et al.* 2013), but no consistency were achieved due to varying emphasis on different conditions, and no relations were made between the facilities’ weights and the age groups of potential users.

2.4 Accessibility, Mobility and Equity

Accessibility, mobility and walkability are terms widely used in literature related to green space studies. Generally speaking, the term accessibility is often used to refer to the easiness for a specific agent to get to a specific destination through a specific network system via specific mode of travelling (Talen and Anselin 1998). Mobility is often used to indicate a specific agent's ability for moving around a specific network system considering all modes of travelling feasible to that agent (Litman 2003). And walkability is often used to imply the perceived easiness of getting around a specific neighbourhood on feet by a specific travelling agent (Inani and Abdul 2012).

2.4.1 Accessibility

One of the distinguishing features of human behaviour is the aspiration and ability to travel and move across the surface of the earth to exchange information and goods over distance (Hodgart 1978). Shopping, migrating, commuting, distributing, collecting, vacationing, and communicating usually occur over some distance. Therefore accessibility is committed to seek special forms of common social behaviour-spatial interaction.

The term "accessibility" is defined as "easily approached or entered" (Pickett 2004), "the quality of being accessible, or of admitting approach" (Oxford 2002), or for the planning context as "the potential for interaction" (Hansen 1959).

In most cases, measures of accessibility include both an impedance factor, reflecting the time or cost of reaching a destination, and an attractiveness factor, reflecting the qualities of the potential destinations.

Researchers have used many different forms of accessibility measures and have raised many important issues about these measures (Handy and Niemeier 1997). Simple "cumulative-opportunities" measures count the number of destinations of interest within a certain time or distance from the origin point, with more choices in both destinations and modes of travel mean greater accessibility by most definitions.

Hansen (1959) defined accessibility as 'the potential of opportunities for interaction' and considered accessibility as a measure of 'the intensity of the possibility of interaction' or 'the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation.' (Hansen 1959).

Ingram (1971) noted that accessibility 'means capable of being reached, thus, implying a measure of the proximity between two points' and that accessibility 'is related to the ability of a transportation system to provide a low cost and/or quick method of overcoming the distance between different locations.' He stated that accessibility 'may loosely be defined as the inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance)' (Ingram 1971). He also made a distinction between the relative accessibility between two points and the integral, or total, accessibility at a point. The relative accessibility is defined as 'the degree to which two places (or points) on the same surface are connected' which is usually asymmetric; and the integral accessibility is defined, for a given point, as 'the degree of interconnection with all other points on the same surface.' He noted that 'the distance separating two points affects the degree of relative accessibility between the points' and proposed the normal or Gaussian curve as the most satisfying distance function for determining the degree of relative accessibility between two points.

Focusing on the use of physical accessibility of population groups to a variety of activities and opportunities to measure regional performance in health, education, income, and the like, Wachs and Kumagai (1973) defined accessibility in terms of 'the ease with which citizens may reach a variety of opportunities for employment and services.'

Wachs and Kumagai (1973) pointed out that:

- *'the accessibility of a site to economic and social activity centres determines its value, the economic and social uses to which it will be put, and the intensity of development which will take place on it',*
- *'there are major spatial and demographic differences in the accessibility of specific urban population groups to a variety of economic and cultural opportunities',*
- *'differences in accessibility affect living conditions within a region',*

- *‘accessibility indicators could help to redirect policy and planning toward the equalization of opportunities’, and*
- *‘current knowledge of the extent to which physical accessibility differences within the metropolitan area exist and influence the relative standards of living of particular groups is quite limited by the availability of pertinent information.’*

Wachs and Kumagai (1973) argued that ‘a useful approach to the measurement of physical accessibility is the determination of the number or density of travel opportunities of particular types within certain time distances or travel-cost ranges from the residential locations of population groups of interest’ (Wachs and Kumagai 1973).

The one of implications of accessibility is "the opportunities available to individuals and companies to reach those places in which they carry out their activities". In the broadest sense of the word, the notion of accessibility has economic, social, technological undertone. Accessibility is perhaps the most important concept in defining and explaining regional form and function because the accessibility of a place to cultural / social / economic resources can determine the value of this place, consequently, influence the tendency of population distribution. The index of accessibility is one of the most important elements to represent the quality of life in a region. Through accessibility, there is a systematic relationship between the spatial distribution and intensity of development, and the quantity and quality of travel within a region (Wachs and Kumagai 1973).

Burns (1976) used accessibility to denote ‘the ease with which any land-use activity can be reached from a location using a particular transportation system’, and used accessibility measures to ‘reflect the level of service provided by transportation systems to various locations’(Burns and Golob 1976). They argued that measures of accessibility based upon *a priori* assumptions about factors influencing travel demand, such as opportunities weighted by a decreasing impedance function of the interaction costs of reaching those opportunities, or cumulative functions of the opportunities reachable within a specified travel time, lack strong underlying theory from which causality in transportation decision making can be inferred. Consequently, they proposed to incorporate a utility-maximizing theory of travel decision-making behaviour into measures of accessibility to opportunities.

Kwan (1998) noted that ‘the concept of accessibility was often defined and operationalized in different ways depending on the problem and context of its application (Ingram 1971, Morris *et al.* 1979, Handy and Niemeier 1997). For examples, accessibility can be regarded as an attribute of locations (place accessibility) indicating how easily certain places can be reached (Dalvi and Martin 1976, Song 1996), or as a property of people (individual accessibility) revealing how easily an individual can reach locations of activity (Guy 1983, Hanson and Schwab 1987). Accessibility measures can be used simply to express either the presence of physical connections or the degree of physical separation between two locations (for example, (Muraco 1971, Edward 1996); or to be more comprehensively determined by both the urban environment and the person-specific space-time autonomy of individuals (e.g. (Burns 1979, Villoria 1989, Miller 1991). Kwan (1998) pointed out that measures of place accessibility ascribe the same level of accessibility to different individuals in the same zone, ignore the different spatiotemporal constraints experienced, and hence accessibility to opportunities enjoyed by these individuals (Pirie 1979, Landau *et al.* 1982, Richardson and Young 1982, Hanson and Schwab 1987).

Focusing on evaluating individual accessibility, rather than place accessibility, Kwan (1998) conceptualised accessibility based on the construct of a prism-constrained feasible opportunity set, and argued that the operationalized space-time measures are more capable of capturing interpersonal differences, especially the effect of space-time constraints, and therefore are more “gender sensitive” and useful for unravelling gender / ethnic differences in accessibility.

Focusing on passenger transport, Geurs and Wee (2004) define accessibility as’ the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s).’ They also made a distinction between ‘access’ (used when talking about a person’s perspective) and ‘accessibility’ (used when taking a location’s perspective). They identified four components of accessibility: land use, transportation, temporal and people.

- The land-use component reflects the amount, quality and spatial distribution opportunities supplied at each destination, the demand for these opportunities at locations of origin, and the confrontation of provision of as well as demand for opportunities, which may result in competition for activities with a restricted capacity.

- The transportation component describes the travel impedance an individual need to overcome due to the distance between an origin and a destination using a specific transport mode, such as the amount of time (travel, waiting and parking), costs (fixed and variable) and effort (including reliability, level of comfort, accident risk, etc.). This impedance results from the confrontation between the provision of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs) and the demand related to both passenger travel and freight travel.
- The temporal component reflects the availability of opportunities at different times of the day, and the time available for individuals to participate in certain activities.
- The people component reflects the needs (depending on age, income, educational level, household situation, etc.), abilities (depending on people's physical condition, availability of travel modes, etc.) and opportunities (depending on people's income, travel budget, educational level, etc.) of individuals. These characteristics influence a person's level of access to transport modes and spatially distributed opportunities, and may strongly influence the total aggregate accessibility result (Cervero and Landis 1997, Shen 1998, Geurs and Ritsema 2003).

Figure 2.4.1 shows the relationships between these components of accessibility. For example, the distribution of activities is an important factor determining travel demand and may introduce time restrictions and influence people's opportunities. A person's needs and abilities influence the valuation of time, cost and effort of movement, types of relevant activities and the times in which one engages in specific activities. Accessibility as a location factor for inhabitants and firms influences travel demand, people's economic and social opportunities and the time needed to carry out activities.

Geurs and Wee (2004) argued that 'an accessibility measure should ideally take all four components and elements within these components into account', noted that 'applied accessibility measures focus on one or more components of accessibility, depending on the perspective taken', and identified four basic perspectives on measuring accessibility: infrastructure-based, location-based, person-based, and utlity-based.

The infrastructure-based measures analyse the (observed or simulated) performance or service level of transport infrastructure (Linneker and Spence 1992, Ewing 1993).

The location-based measures analyse the level of accessibility to spatially distributed activities from origin locations, with or without incorporating capacity restrictions (competition effects) of supplied activity (Hansen 1959, Ingram 1971, Dalvi and Martin 1976).

The person-based measures analyse accessibility at the individual level, founded in the space–time geography of Hägerstrand (1970) and considering limitations on an individual's freedom of action in the environment, i.e. the location and duration of mandatory activities, the time budgets for flexible activities and travel speed allowed by the transport system (Burns and Golob 1976, Pirie 1979, Miller 1991, Kwan 1998, Recker *et al.* 2001).

The utility-based measures analyse the economic benefits that people derive from access to the spatially distributed activities (Koenig 1980, Handy and Niemeier 1997, Dong *et al.* 2006).

Geurs and Wee (2004) listed five criteria of accessibility, including theoretical basis, operationalization, interpretability and communicability, and usability in social and economic evaluations (Figure 2.4.1).

Geurs and Wee (2004) argued that an accessibility measure, in theory, should

- *Be sensitive to changes in the transport system, i.e. the ease or difficulty for an individual to cover the distance between an origin and a destination with a specific transport mode, including the amount of time, costs and effort;*
- *Be sensitive to changes in the land-use system, i.e. the amount, quality and spatial distribution of supplied opportunities, and the spatial distribution of the demand for those opportunities, and the confrontation between demand and provision (competition effects);*
- *Be sensitive to temporal constraints of opportunities; and*
- *Take individual needs, abilities and opportunities into account.*

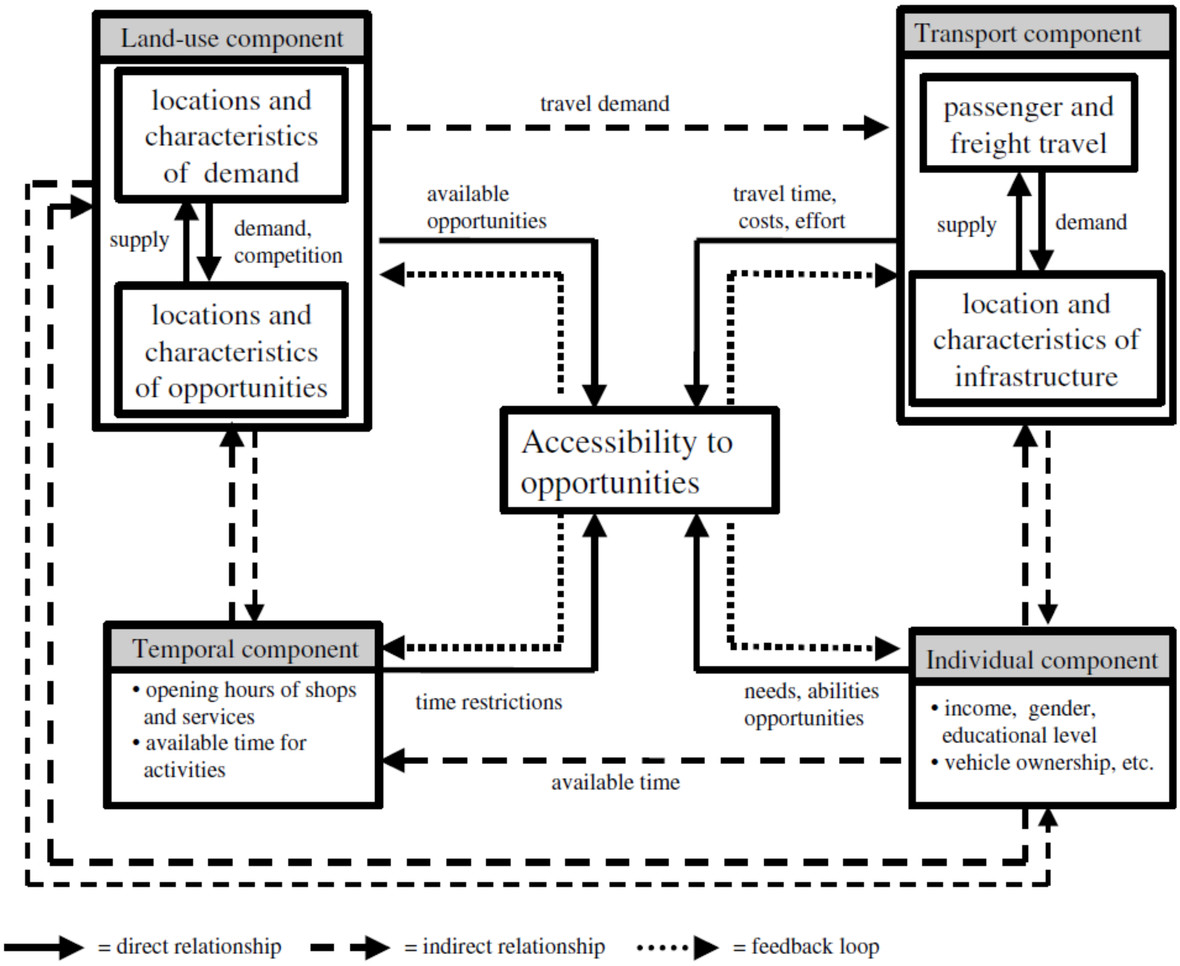


Figure 2.4.1 Relationships between components of accessibility (Geurs and Wee 2004)

Therefore, keeping all other conditions constant, an accessibility measure should behave as follows (Geurs and Van 2004):

- *"If the service level (travel time, costs, effort) of any transport mode in an area increases (decreases), accessibility should increase (decrease) to any activity in that area, or from any point within that area.*
- "*If the number of opportunities for an activity increases (decreases) anywhere, accessibility to that activity should increase (decrease) from any place.*
- *"If the demand for opportunities for an activity with certain capacity restrictions increases (decreases), accessibility to that activity should decrease (increase).*
- *"An increase of the number of opportunities for an activity at any location should not alter the accessibility to that activity for an individual (or groups of*
- *individuals) not able to participate in that activity given the time budget.*

- *“Improvements in one transport mode or an increase of the number of opportunities for an activity should not alter the accessibility to any individual (or groups of individuals) with insufficient abilities or capacities (e.g. drivers licence, education level) to use that mode or participate in that activity.”*

2.4.2 Accessibility and Mobility

The term “mobility” is defined as “the quality or state of being mobile” and “mobile” as “capable of moving or of being moved readily from place to place” (Pickett 2004), or in the context of transportation planning, as the potential for movement, the ability to get from one place to another (Hansen 1959, Handy 1993). For example, the level-of-service measures used in transportation planning are measures of mobility; higher volume-to-capacity ratios mean slower travel times, less ease of movement, and thus lower mobility.

Mobility (or the potential for movement) is related to the impedance component of accessibility, and good mobility is neither a sufficient nor a necessary condition for good accessibility. It is possible for a community to have good mobility but low accessibility, e.g. a community with ample roads, low levels of congestion but relatively few destinations for shopping or other activities, or undesirable or inadequate destinations. It is also possible for a community to have good accessibility with low mobility, e.g. a community with severe congestion but within a short distance of needed and desired destinations.

Efforts that focus on enhancing mobility aim at accommodating growing levels of travel, increasing the potential of movement and improving the efficiency of the system. Efforts that focus on enhancing accessibility aim at the traveller rather than the system and concern if people have access to the activities that they need or want to participate in.

Transportation planning focus on mobility has over time encouraging sprawling patterns of development that limit choices. In the suburban areas of metropolitan regions, transit service is relatively sparse and destinations are generally beyond walking distance, leaving residents with no option but drive. For those who travel by modes other than the automobile and those whose needs and desires are not met by the kinds of shopping, facilities and other services found in the suburbs, the result is a decline in accessibility. Even for those residents who prefer to drive, accessibility will ultimately decline in suburbs as driving become increasingly prevalent (Handy 2002).

Transportation planning focuses on accessibility and creates benefits by expanding choices. For example, the need to drive can be reduced by adopting policies to encourage small-scale retail development in residential areas, thereby bringing shops within walking distance, operating a circulator bus route that links residential areas to commercial areas, or providing access to services via the Internet and eliminating the need for driving altogether. Residents get to do the things they need and want to do while reducing the time and cost devoted to driving, and the community as a whole gets potentially lower costs for building and maintaining roads as well as less negative impacts on the environment.

Many studies relate the mobility with the ability of human being's movement, or regard mobility as the physical ability to execute the movement stably and freely, no matter where the destination is. In recent years, an integrated modelling framework was used to examine the factors affecting urban home shopping activities (Hamed and Easa 1998), to model travellers' post-work activity patterns, and to trace the movements of travellers through space and time (Hamed and Mannering 1993). Therefore, the feasibility of pedestrian travel, public transportation or automobile ownership determines different ‘weights’ of mobility (Dawkins *et al.* 2005). Some studies have concluded that car ownership significantly increases movement from residences to facilities (Lovett *et al.* 2002, Pasaogullari 2004, Lotfi and Koohsari 2009).

Mobility, considering walking as the only mode of transportation, is termed ‘walkability’. Walkability is often used to measure the liveability of a city or town. At first glance, the walkability concept may be regarded to be strictly related to pedestrians. Nevertheless, this is not the case; nor should a walk-friendly environment be regarded as catering only for the needs of walking pedestrians. Neighbourhood walkability calls for mixed-land uses that create shorter distances between residences and destinations. Elements like the directness and variety of routes to destinations and the patterns of interconnecting streets are synergistically determining distances between complementary activities, and can be assessed objectively using geographical information systems (GIS) software. Social and demographic attributes must be taken into account when examining how environments might be related to walking, as such factors may act to moderate the relationship between walkability and walking behaviour. For Australian adults, walking is the most common form of moderate-intensity activity reported in population surveys (ABS 2000). Owen (2007) found that those who live in more-walkable environments in Australia might tend to make more frequent trips to nearby destinations (for example, the neighbourhood green space), which might reduce motor vehicle trips (Owen *et al.* 2007).

2.4.3 Accessibility and Equity

Equity means the fairness of services allocation and concerns primarily 'who gets what" (Wicks and Crompton 1986). Equity indicates a practically impossible situation where all residents have come to an agreement that they are equally treated and reallocation of public services is no longer needed (Talen 1998), because social equity sometimes doesn't coincide with territorial justice (Pinch 1985), and equity in social goods such as public services is in conflict with environmental risk distribution (Humphreys 1988).

There prevails diverse and often competing interpretations of equity. With regard to the equity of services location decisions, Wicks and Crompton (1986) suggested three basic principles: recognizing equal opportunity as the point of departure, encouraging deviations from this point of departure if the deviations benefit the least advantaged, and establishing a minimum threshold below which quantity or quality should not fall.

Based on the efforts of categorizing the definition of equity (Lucy 1981, Crompton and Wicks 1988, Marsh and Schilling 1994), Talen (1998) proposed a scheme of four distinguishable categories of the definition of equity: (1) equality-based equity; (2) compensatory equity; (3) demand-based equity; and (4) market criteria-based equity. The word 'equality' means a situation in which people have the same rights, advantages, and 'equity' means a situation in which all people are treated equally and no one has an unfair advantage (Figure 2.4.2).

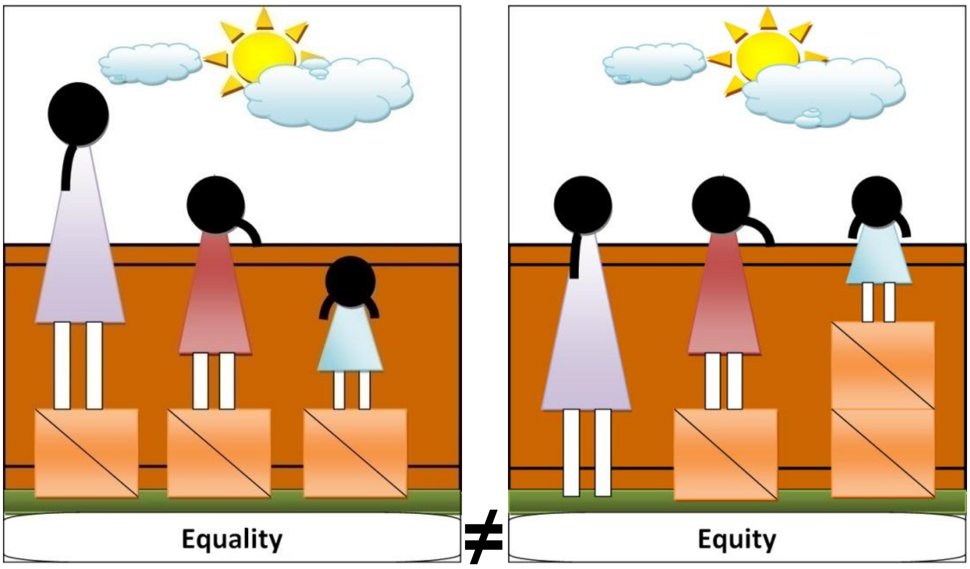


Figure 2.4.2 Equity vs equality

Among these four definitions, the equality-based definition is more commonly used in accessibility studies (Ikporukpo 1987), because it is more amenable to precise measurement. Its data requirements are less stringent than other approaches, and the determination of equity in terms of need, demand or market criteria may require information that may not be readily available (Cho 2003).

Good accessibility to urban public resources and facilities is one of the most important elements of quality of life for urban residents (Pacione 1989). Close proximity to public services contribute to residents' welfare by enhancing their opportunity, enhancing the actual value of a residential property, and leading to savings on travel costs that can be spent on other consumptions (Pacione 1989). Minimizing travel costs to reach services and facilities can result in substantial reallocation of income between urban dwellers (Pahl 1971).

Accessibility is measured in terms of spatial relationship between locations and equity is explained by fair opportunity in services allocation. Accessibility is concerned more with efficiency and attempts to distribute public facilities as uniformly as possible to maximum access, while equity is more concerned with the impact of distribution of public resources or facilities to people who may use them (Nicholls and Shafer 1999). Equity is not always in accordance with efficiency because equity carries a meaning only on the basis of the user's socio-economic or demographic characteristics.

Many studies have explored the issues related to accessibility and equity in services delivery (Ottsmann 1994, Talen 1998, Talen and Anselin 1998, Nicholls and Shafer 1999, Lindsey *et al.* 2001), and accessibility has been used as a social indicator used to discover whether or not equity in distribution of services has been achieved.

In the utilization of services, it is not always useful to measure accessibility simply by means of simple distance. Merely having close proximity to a public resource may not mean it is accessible to some individuals because the cost of using the facility may not be within the scope of the individual's social standing or financial capabilities (Cho 2003).

Ann (1991) used GIS to measure accessibility as straight line distance from residential areas to open green spaces including green belts, rivers, and water bodies (Ann 1991). Some study results revealed that areas within a linear distance of 700m from open spaces composed 98.6% of the entire area of Seoul, and thus the provision of open spaces was judged to be more than adequate (Eom *et al.* 2008, Eom and Lee 2009).

Talen (1998) used an equity mapping approach and a need-based measure of equity derived from professional green space planning standards and planning policy documents to explore accessibility to green space in Pueblo, Colorado. She found that low accessibility appeared to correspond to areas of Hispanic populations.

More recently, the Gaussian-based 2SFCA approach was used to estimate green space accessibility in Georgia (Dai 2011) and the results indicate that Georgia still faces the challenge that many of the census tracts are beyond walkable distance to the nearest green space.

Lindsay and others (2001) explored the nature of green ways as public space in Indianapolis, Indiana. Their study used proximity as a measure of access and simple GIS analysis of census and other data to determine equality of access. The results indicate that minorities and the low have unequal access to trails (Lindsey and Maraj 2001).

In exploring issues related to access and use of green space and recreation facilities by poor and minorities, Gobster (Gobster 1995) found that sections of the Chicago River Corridor adjacent to lower-income minority neighbourhoods tended to have lower vegetation quality, poorer maintenance, and low accessibility as compared to sections adjacent to higher-income ‘white’ neighbourhoods. Gobster (1995) hypothesized that lower-income minority neighbourhoods may not have access to quality open space environments like those available to upper-income majority neighbourhoods.

Wendel (2012) studied the unequal distribution of larger and more desirable green spaces throughout Santa Cruz, Bolivia, and showed that not all urban residents are experiencing the same benefits (Wright *et al.* 2012).

Coombes and others (2010) found that respondents living in high accessibility area to the green space were more likely to achieve the physical activity recommendation and less likely to be overweight or obese. The other finding of Coombes suggests that the provision of good access to green spaces in urban areas may help promote population physical activity (Coombes *et al.* 2010).

Zhang and others (2011) revealed that the developing states in the western and Midwestern US have lower neighbourhood green space accessibility, while, the developed states have higher accessibility (Zhang *et al.* 2011).

2.5 Accessibility Models

The accessibility needs to be measured and cannot be observed directly (Taylor 1976). Many researchers have endeavoured to create and improve the accessibility measurements and a variety of accessibility measures have been created (Hansen 1959, Ingram 1971, Song 1996, Kwan 1998, Talen and Anselin 1998, Geurs and Van 2004, Luo and Qi 2009).

Hodgart (1978) provided a broad review of the literature until the 1970s, and identified five categories of accessibility measure models: (1) travel cost minimization; (2) demand maximization; (3) equity maximization; (4) covering objectives; and (5) spatial interaction models.

Similarly, in research on accessibility of urban greenways, Lindsey categorized five different accessibility measures: (1) container approach; (2) gravity models; (3) travel cost minimization models; (4) covering objectives; and (5) minimum distance models (Lindsey and Maraj 2001).

Geurs classified the accessibility measurements into four basic measurements: (1) Infrastructure-based measurement, (2) Location-based measurement, (3) Person-based measurement, and (4) Utility-based measurement (Geurs and Van 2004).

In the following sections, 7 types of accessibility measures are summarised according to the reviewed literatures:

- Opportunity-based measures, concentrating on the amount of available provisions in the specific area.
- Ratio-based measures, considering the proportion between the demand and provision.
- Impedance-based measures, pointing at the negative side influence of time or spending, contain the travel cost model and travel time model.
- Gravity-based measure, integrating the demand, provision and distance decay to make the spatial accessibility easy to explain. With the development of GIS, some enhanced models have arisen, including the 2SFCA and 3SFCA.
- Spatial-temporal measures, considering the individual movement within a specific area and their personal space and time limitation.
- Utility-based measures, making access decisions from individual's standpoint and subjective feelings, regardless of the objective reality.

2.5.1 Opportunity-based measures

One form of opportunity-based measures is the container approach, which counts the number of presence facilities within a specified area, and a set of approaches that does conceptualize accessibility as the distance relationship between an origin and a destination (Talen 1997). In other words, the container approach measures the accessibility of a fixed area by calculating the amount of facilities. A good example is the presence of a facility such as a green space, health clinic, library, or post office within the unit of analysis such as a census tract or municipally defined service areas. Political scientists, services distribution researchers, and planners have used this approach extensively (Lindsey and Maraj 2001), because it is the easiest approach and needs the least number of variables.

Normally, the container model (Talen and Anselin 1998) can be expressed as：

$$A_i^C = \sum_j s_j \ , \ \forall j \in I \ , \qquad \text{(Eqn 2.2)}$$

where "A_i^C"is a container index for location (tract) "i", and the number or aggregate size, "s_j", is summed for those facilities located within the boundaries "I" of "i". This container-based approach is predominant in the political science literature (Talen and Anselin 1998). This model implies a fundamental assumption that the benefits or advantages of the facilities are limited in the specific area. Hence, the container approach restrictively defines the notion of accessibility to the number of facilities within the spatial unit of analysis. Enhancement to the container approach incorporate the idea that users who live further from the fixed facilities will use the facilities less and therefore have lower levels of satisfaction with them than users who live closer (Lindsey and Maraj 2001).

For measuring green space accessibility, the container-based method was used to summarize the number of green space, or the total area of green space within a neighbourhood or within walking distance buffers in a geographical unit (Delamater 2013). The basic neighbourhood unit under study, such as a census tract, a ZIP code, or a local neighbourhood unit, or the area within the specified walking distances from residential locations, often defines this geographical unit. The percentage of land area used for green space per neighbourhood, as well as the total area of green space averaged by population size are commonly used measures in green space access equity analysis (Zhang and Lu 2011). With this model, higher score (i.e. more green spaces within a critical distance) indicates better result. It is important to note that spatial influences to other geographical units are excluded from consideration (Talen and Anselin 1998).

This approach does not consider the frictional effect of distance travelling to the facilities. Only the destinations (supplies locations) are considered. In reality, both the travel distances and travel costs can reduce a facility's level of attractiveness (Ottsmann 1994). Among the accessibility models, the container approach is the only one that does not consider the effect of distance in accessibility. Another obvious problem with a container approach is edge effects. A defined neighbourhood or a neighbourhood with buffer areas may have no green space inside but may have some or more outside ones near its boundary, but this approach assumes no access to green spaces that are lying outside of the neighbourhood boundary. Thus, the traditional container-based measures could be very biased indicators and could create some unrealistic areas that have no accessibility to green space at all.

The other approaches incorporate the frictional effect of distance in measuring accessibility, but they are more time-consuming and more complex than the container approach (Lindsey and Maraj 2001).

2.5.2 Ratio-based measures

One common application of ratio-based measures is using the relative provision approach to calculate the ratio between provision and demand in specific areas. Ratio-based measure gives the users an intuitive feeling and handy understanding. Usually, the ratio-based measures consider the two variables of demand and provision simultaneously. Ratio-based measures are good for comparing provision between large demand locations areas, and for supporting policy analysts to set minimal standards of provision and to identify underserved areas (Schonfeld *et al.* 1972).

In research on green space, the ratio between green space area and population indicates the green space resources condition per person.

$$A_i = \frac{Supply_i}{Demand_i} \qquad \text{(Eqn 2.3)}$$

The relative provision approach has been widely used by government agencies for urban planning requirements, e.g. to identify areas of workforce shortages, or to prioritise the allocation of health care resources (Schonfeld and Heston 1972). Ratio-based measures have also been applied in many other areas (Schwartz *et al.* 2006). Apparicio et al (2008) calculated number of supermarkets within 1000 m, and divided by share of population (Apparicio *et al.* 2008). Sharkey et al. (2009) counted the number of food stores and fast food restaurants within 1, 3, and 5 miles network distance from population weighted centre of Census Block (Sharkey *et al.* 2009).

Ratio-based measures, however, do have some serious limitations. First, they do not account for area crossing behaviour, which usually happen in small jurisdiction, such as a postal code zone (Connor *et al.* 1994). Second, they do not take the important variable of distance or travel impedance into account. Third, the results and interpretations from study area studies can vary significantly due to the Modifiable Areal Unit Problem (see section 2.6 for more details).

2.5.3 Impedance-based measures

Travel distance, travel time and travel cost are widely applied models for impedance-based measures of accessibility.

The travel distance model measures the minimum travel distance between each location of origin and the nearest destination, and can be expressed as (Talen and Anselin 1998):

$$A_i^E = \min\left|d_{ij}\right| \qquad \text{(Eqn 2.4)}$$

Where " A_i^E " is the index for minimum distance from zone "i" to the nearest facility (Talen and Anselin 1998), and the lower the value of the index, the higher the accessibility.

The advantage of this measure is considering the distance, which is an important element in modern accessibility study, and planners often use this measure to find the best service facility location for a city or country. *ReVelle* (1970) have deduced a series of distance based formulas (ReVelle 1970).

Similar to the container approach, the minimum distance measure does not consider spatial distribution. For instance, the minimum distance model always includes only one facility, even when the facility is not necessarily within the same zone. Specifically, when a zone does not include a facility, the container approach measurement will be zero, while the minimum distance measure will consider the distance to the nearest facility in another zone. When there are multiple facilities in a zone, the container approach will include them all, while the minimum distance measure will count only the distance to the closest facility (Cho 2003). If the assumption is made that consumers are likely to patronize the facility closest to them (as is the case with playgrounds), then the research goal would be to assess how to minimize the inequity of the nearest distance between origin and destination, and therefore a minimum distance measure may be more applicable.

The common types of distance measurement utilized in the past studies include Euclidean distance, Manhattan distance and network distance.

The Euclidean distance (also called Euclidean metric), d_{ij}, is the "ordinary" distance between two points, (xi, yi) and (xj, yj), in the Euclidean plane that one would measure with a GIS software, even with a ruler, given by the following formula:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad \text{(Eqn 2.5)}$$

The 19th century German mathematician Hermann Minkowski replaced the usual distance function or metric of Euclidean geometry by a new metric now known as Manhattan distance. The Manhattan distance between two points, (x_i, y_i) and (x_j, y_j), in the Minkowski plane, d_{ij}, is the sum of the absolute differences of their Cartesian coordinates:

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad \text{(Eqn 2.6)}$$

Network distance measures the least-cumulative distance path (or shortest path) along the road network from each demand location to the closest provision location. When using a GIS software like ArcGIS, the network distance is calculated as the total length of polylines consisting of the shortest path between the origin and the destination, with the length of each polyline segment is calculated as the Euclidean distance along each segment.

Measures based on travel time are more sensitive than distance-based measures since they recognize constraints imposed by demographic, social, economic, and cultural context. The same travel distance may take different time to travel due to travel speed conditioned by factors like travel modes (e.g. wheelchair, walk, bike, car, bus, tram, train) and personal characteristics (e.g. age, physical fitness).

Travel time can be conceptualised and calculated in different ways. The ‘kerb-to-kerb’ travel time is commonly understood as the time which motorist, public transport user, cyclist or pedestrian spends within the publicly accessible infrastructure of the mode; thus, access times to stations or bus stops. Time spent cruising for a parking space etc. are discounted. ‘Door-to-door’ travel time takes these secondary effects into account, but adds a layer of complexity to the analysis that cannot always be supported by available data. In the case of public transport, various methods are used to capture waiting time at stations and stops; a common approach is to count half the service frequency as the average waiting time at system access and during transfers. However, where low frequencies (e.g. more than every 15 min) and a reasonable level of timetable reliability prevail, allowances for waiting time can be reduced as most passengers can be expected to take scheduled departure times into account when appearing at the station or stop. Similarly, where connecting services are coordinated, transfer times can reflect the actual timetable rather than half the service frequency (Curtis and Scheurer 2010).

Considering the physical speed of different modes of transport, the travel time measure can be modified into a 'social speed', or 'effective speed' (Curtis and Scheurer 2010) that considers the time individuals spend on tasks associated with vehicle ownership, and on earning the income required to afford it.

Many recent accessibility studies have used GIS software to measure travel time (see section 2.5.6. for more details).

Travel cost model is simply a measure of the average or total cost between each origin (for example, centroid of census tract) and the destination of scattered facilities. As Talen and Anselin (1998) put it, one of the advantages of using this approach is that the resulting value is expressed in simple money units. The simplest method is to consider only the variable user costs per trip, such as petrol and parking cost and possible road tolls for motorists, and fares for public transport users (Curtis and Scheurer 2010). In such a model, walking and cycling are usually considered free of cost. In principle, the goal of this approach is to minimize the total cost of travel between origin and destination. Therefore, in contrast to the container approach, the lower the score, the higher the accessibility. The accessibility through the travel cost minimization model is calculated as：

$$A_i^T = \sum_j d_{ij} \text{, or } \overline{A_i^T} = \sum_j \frac{d_{ij}}{N} \quad \text{(Eqn 2.7)}$$

Where "d_{ij}" is the travel cost between zone "i" and facility location "j", and "N" is the total number of facilities. If the total number of destinations is the same for each origin, both average travel cost or total travel cost can be calculated (Talen and Anselin 1998).

The monetary expenditures made on travel, the time spent, and the discomfort experienced, as a result of travel, are parts of the costs associated with urban activities. Wachs and others summarized that the income produced by work activities might appropriately be reduced by the costs associated with the daily journey to and from work, and the costs associated with educational, cultural, and recreational activities might appropriately be estimated to include the travel which must take place in order to attend in those activities (Wachs and Kumagai 1973).

The travel cost measures enable the characterization of the distribution of and access to different facilities / resources of a city as a complete package of public goods. The travel cost approach includes some simple intuitive measures, such as the distance from residential neighbourhood to the nearest green space. These direct (Euclidean or network) distance measures of green space accessibility are intuitive and convenient to generate in a geographical information systems (GIS) environment. The major problem of this approach is that it assumes residents would always use the nearest green space with the least travel cost as a space for physical activity. The exclusive use of one nearest green space by local neighbourhood residents is not realistic. A modified distance measure goes to another unrealistic extreme, which takes the average distance from an origin (home or residential neighbourhood) to all its potential green space destinations to measure spatial proximity to green space (Zhang and Lu 2011).

Minimization of transport cost has been the key criterion for determining the location **of** an industry between two resources and a single market (Weber 1909, Wilson 1998)**.** Travel impedance has been widely applied in accessibility related and in location-allocation studies. Network-based travel distances and MB based population data have been used in a composite index to assess locational disadvantage in accessing a set of services / facilities that are deemed essential to the aged population in suburban Melbourne (Engels and Liu 2011, Liu and Engels 2012). To locate solid waste disposal sites with minimized haul costs in a metropolitan environment, Wersan and others (1968) found, via linear programming, that an optimal single disposal site is at the median of the generating sites (Wersan 1962). Both Cooper and Kuehn have independently proposed similar procedures to determine an optimal location for a single plant between provision points that minimized transport costs (Cooper 1963, Kuehn 1963). Heuristic procedures have been used to find an “optimal” warehouse location that minimizing transport cost based on road network distance (Maranzana 1964) or the sum of transport and warehousing costs (Kuehn 1963).

2.5.4 Gravity-based measures

The gravity model is one of the most extensively used accessibility models (Pacione 1989), where both facilities and demands for services are weighted by their size and adjusted the spatial separation between them with distance decay. This gravity model is one example of a spatial interaction model seeks to identify levels of human interaction between different locations based on the principles of Newtonian physics for measuring gravitational interaction between planetary bodies. The gravity model appears to capture and interrelate at least two basic elements: (1) scale impacts: for example, cities with large populations tend to generate and attract more activities than cities with small populations; and (2) distance impacts: for example, the farther the places, people, or activities are apart, the less they interact (Hansen 1959). In this specific use of the model, the force of attraction between residential location and facility location is in exact proportion to the attractiveness of the facility and the size of the residential population, and are inversely proportional to the discounted distance between resident and facility (Pacione 1989).

Early recognition of demographic gravitation was stated in the "law of retail gravitation" (Reilly 1929), expressed by fitting observations of the position of the point of equilibrium intermediate between two cities competing for the retail trade of the surrounding rural dwellers:

$$\frac{N_1}{d_1} = \frac{N_2}{d_2} \qquad \text{(Eqn 2.8)}$$

Where d_1 is the distance from the city that has a population size of N_1, to the said point of balance, and d_2 is the distance from the city that has a population size of N_2. The usefulness of the expression $N_1/d_1=N_2/d_2$ as a determinant of various relations between pairs of cities, e.g. the interchange of telephone calls, is well recognized (Zipf 1947). The concept of the potential of population was applied to describe the distribution of locations of demand and to map the potentials for the United States and other areas (Stewart 1947).

Hansen used the gravity model for empirical examinations of the relationships between residential development and accessibility (Hansen 1959), where accessibility is defined as the potential of opportunities for interaction .

According to Hansen, the accessibility at residential location r_1 to a particular neighbourhood green space g_2 within a threshold distance from r_1 is directly proportional to the attractiveness of g_2 and inversely proportional to some function of the distance separating r_1 from g_2. The total accessibility to green space at r_1 is the summation of the accessibility to each of the individual green space g_i around r_1. Therefore, as more and more green spaces are included into the neighbourhood of r_1, the accessibility to green space at r_1 will increase:

$$A_{12} = \frac{S_2}{d_{12}^{\beta}} \qquad \text{(Eqn 2.9)}$$

Where A_{12} is a relative measure of the accessibility at r_1 to a particular neighbourhood green space g_2 within a threshold distance from r_1; s_2 equals the attractiveness of g_2; d_{12} equals the travel time or distance between r_1 and g_2. β is an exponent describing the effect of the travel time between r_1 and g_2. If there are more than two green spaces involved, the accessibility formula becomes (Talen and Anselin 1998):

$$A_1 = \frac{S_2}{d_{12}^{\beta}} + \frac{S_3}{d_{13}^{\beta}} + \cdots + \frac{S_n}{d_{1n}^{\beta}} = \sum_j^n \frac{S_j}{d_{ij}^{\beta}} \qquad \text{(Eqn 2.10)}$$

Where S_j reflects the attractiveness for each green space g_j, d_{ij} describes the distance between r_i and g_j, and β is an exponent describing the distance decaying effect of the travel distance between r_i and g_j.

Accessibility measures based on the gravity model have been widely used to calculate the variation in the accessibility to provision site (e.g. green space) between locations of demand (e.g. residential areas). For examples, accessibility measures based on the gravity model have been applied in studies on land use (Davidson 1977, Haynes and Fotheringham 1984, De Jong and Eck 1996), green space (Liu *et al.* 2008, Li and Liu 2009), urban planning, transportation analysis, location-allocation modelling and urban social studies (Ma and Cao 2006, Liu and Mao 2008).

According to the gravity model, a residential location's spatial access to green space services can be assumed to be equal to the sum of impedance-weighted green space-to-population ratios of all nearby green space sites. Gravity-based measures emphasize the effect of distance as a deterrent, and assumes that, although consumers can travel anywhere within the city to visit any facility, they are less likely to travel to further locations. The gravity-based measures consider simultaneously all three key elements of accessibility (demand, provision, and travel impedance), and are conceptually and theoretically sounder than all other measures discussed so far.

However, it is not intuitive to interpret the gravity-based accessibility (Luo and Qi 2009), it disregards variations in individual preferences in relation to the desirability of activities (Baradaran and Ramjerdi 2001), and it is difficult to select the proper distance decay function (Joseph and Phillips 1984, Luo and Wang 2003, Guagliardo 2004). In real-world applications, the distance decay coefficient β is usually unknown and might take many mathematical forms. Its form and magnitude can vary greatly with the service type and population under study (Talen and Anselin 1998). Empirical investigation is required to estimate β, and there is little in the literature to suggest probable values for specific applications. Much of the literature that focused on deriving the correct exponent for the gravity model formulation was stimulated by physical science interpretations, including the Newtonian analogy where the square of distance, d_{ij}^2, is the appropriate power function. In empirical analysis, however, the exponent is generally interpreted as the responsiveness of interaction to spatial separation and is expected to vary in terms of social context. Larger exponents indicate that the friction of distance becomes increasingly important in reducing the expected level of interaction between centres (Haynes and Fotheringham 1984). Ingram incorporated the Gaussian distance decay function into the gravity model which showed more merits when compared with straight line (Ingram 1971). The estimation of distance decay weights is quite subjective, and it is still problematic to capture the influence of impedance coefficient on the values of spatial access calculated by gravity-based measures.

Figure 2.5.1 shows the most common forms of β adopted in the literature include linear, inverse-power, negative exponential, Gaussian, and Butterworth filter (Kwan 1998, Langford *et al.* 2012):

Linear decay: $$W_{d(k,j)} = \begin{cases} \frac{d_{\max} - d_{kj}}{dis_{\max}}, (d_{kj} \le d_{\max}) \\ 0, (d_{kj} > d_{\max}) \end{cases}$$ (Eqn 2.11)

Inverse-power decay: $$W_{d(k,j)} = d_{kj}^{-\beta}$$ (Eqn 2.12)

Negative exponential decay: $$W_{d(k,j)} = e^{-\beta d_{kj}}$$ (Eqn 2.13)

Gaussian decay $$W_{d(k,j)} = \frac{1}{e^{d_{(k,j)}^2 / d_{pass}^2}};$$ (Eqn 2.14)

Butterworth filter decay $$W_{d(k,j)} = \frac{1}{\sqrt{1 + (d_{(k,j)} / d_{pass})^n}}.$$ (Eqn 2.15)

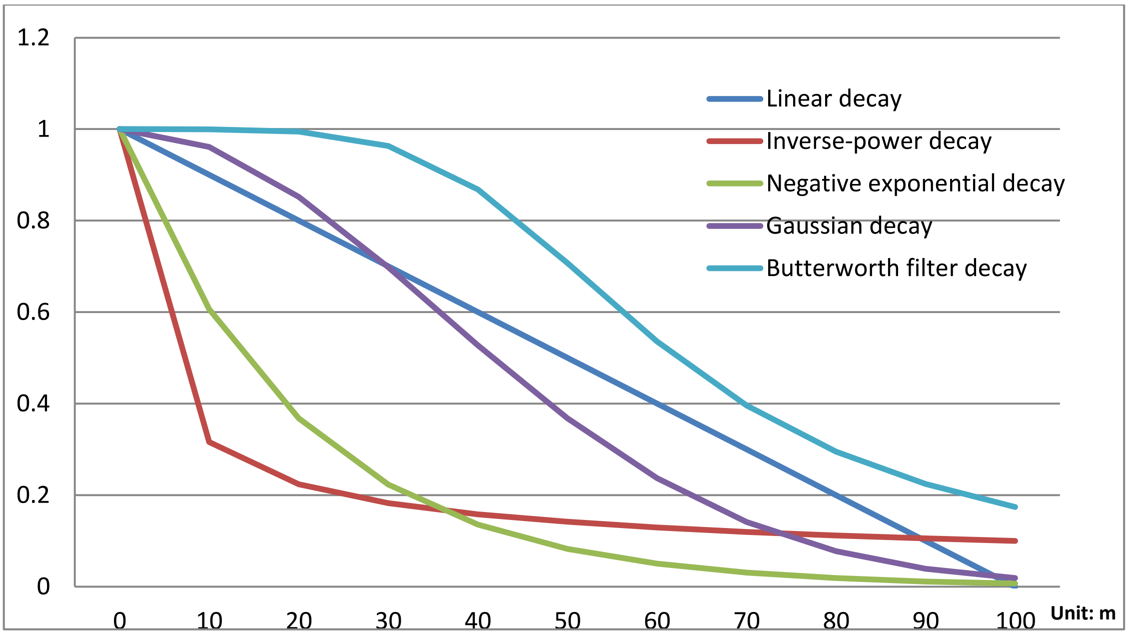


Figure 2.5.1 Common forms of distance decay function

2.5.5 Floating Catchment Area Methods

To overcome the difficulties associated with measures based on the classical gravity model, some floating catchment area methods were proposed, modified, enhanced, and widely applied in many areas (Luo and Qi 2009, Luo and Whippo 2012, Delamater 2013, Stepniak 2013).

Four different floating catchment methods are described in the following sections, including the basic two-step floating catchment area (2SFCA) method (John and Lan 2000, Luo and Wang 2003), the enhanced 2SFCA method (Luo and Qi 2009), the modified 2SFCA methods (Dai 2011, Langford and Fry 2012), and the three-step floating catchment area (3SFCA) method (Wan and Zou 2012).

The basic floating catchment area model stems from the basic gravity model but expresses the model in an operational way. It is known as the two-step floating catchment area (2SFCA) method (Luo and Wang 2003) since it works in two steps which are easy to interpret and implement in a Geographical Information System (GIS) environment:

- The first step is to generate a driving time zone (or catchment) within a threshold travel time (d_0) for each service site j; search all population locations within the catchment; and compute the provision-to-demand ratio, R_j, by

$$R_j = \frac{S_j}{\sum_{k\in\{d(k,j)\le d_0\}} P_K} \qquad \text{(Eqn 2.16)}$$

  Where P_k is the demand (e.g. population) of area unit k within the catchment of service site j, S_j is the provision capacity (e.g. the number of physicians) at service site j, and d_{kj} is the travel time between k and j.

- The second step is to generate a catchment with d_0 as the threshold travel time for each population location i, search all service sites that fall within the catchment, and sum up the provision-to-demand ratios of these service sites as the spatial access index of i:

$$A_i^F = \sum_{j\in\{d(i,j)\le d_0\}} R_j \qquad \text{(Eqn 2.17)}$$

  Where A_i^F is the spatial access index of i, R_j is the provision-to-demand ratio at service site j within the catchment of i, and d_{ij} is the travel time between i and j.

The 2SFCA method has been employed to estimate spatial access to healthcare services in a number of studies (Guagliardo 2004, Langford and Higgs 2006, Wang 2011, Stepniak 2013). However, it is limited in that it assumes all population locations within the catchment to have equal access and disregards the distance impedance within the catchment (Luo and Wang 2003). Based on the 2SFCA method, McGrail and Humphreys (2009) proposed an integrated approach to characterize spatial access to primary care services in rural areas of Victoria, Australia. Specifically, they used an impedance function to overcome the equal access problem within the catchment and adopted service ‘caps’ (i.e., number of service sites), instead of travelling time thresholds, to delineate the catchment size for different steps (McGrail and Humphreys 2009). This integrated approach represents a more reasonable implementation of the basic 2SFCA method.

Accessibility to a service site usually decreases with the increase in travel distance or travel time rather than keeping constant within the service catchment as assumed by the basic 2SFCA method. To consider travel impedance within the catch of a service site and incorporate distance decay effect into the access measure, the basic 2SFCA method has been enhanced by incorporating three sub-zones into the catchment for each service site (Luo and Qi 2009). The enhanced two-step floating catchment (E2SFCA) method also works in two steps:

- The first step is to generate a catchment area for each service site, dividing the catchment into three sub-zones of equal interval and calculating the provision-to-demand ratio, R_j, for the service site according to

$$R_j = \frac{S_j}{\sum_{k \in D_r} P_k W_r} \qquad \text{(Eqn 2.18)}$$

  where S_j is the provision capacity at service site j, P_k is the demand (e.g. population) of at location k within the rth sub-zone D_r, and W_r is a predefined weight for D_r, with the largest weight assigned to the innermost sub-zone and the least weight to the outermost sub-zone.

- The second step calculates the spatial accessibility index of demand location i as the sum of weighted provision-to-demand ratios of all service sites within the catchment of demand location i:

$$A_i^F = \sum_{j \in d_r} R_j W_r \qquad \text{(Eqn 2.19)}$$

  where A_i^F is the spatial access index of demand site i, R_j is the provision-to-demand ratio of service site j that falls within the catchment of demand site i, and W_r is the weight for the rth sub-zone d_r.

Both the basic 2SFCA and the E2SFCA methods define the accessibility using dichotomous measures, assuming locations within a travel threshold are equally accessible and locations beyond the specified travel threshold are equally inaccessible. Although accessibility or inaccessibility to a resource for individuals is practically a dichotomous decision (Luo and Wang 2003, Wang 2011), it is theoretically more appropriate to consider that resources at any locations are accessible by residents, but to different degrees. To this consideration, continuous distance decay functions have been integrated with floating catchment methods (Dai 2011, Wan and Zou 2012):

$$A_i = \sum_{j=1}^{n} \frac{S_j w_{ij}}{\sum_{k=1}^{m} P_k w_{kj}}, w_{ij} = f\left(d_{ij}\right) \text{and } w_{kj} = f\left(d_{kj}\right) \quad \text{(Eqn 2.20)}$$

where A_i is the spatial access index for demand location I; S_j is the provision capacity at service site j; P_k is the demand (e.g. population size) at location k; d_{ij} is the distance from i to j; n and m are the total numbers of provision site and demand location, respectively; and w_{ij} is the distance based weight determined by a specific form of distance decay function $f(d_{ij})$, such as the Gaussian function (Dai 2011) or the Butterworth filter (Langford and Fry 2012).

The two-step floating catchment methods discussed so far do not consider competition among service sites and may tend to overestimate the demand for each service site. Theoretically, it is reasonable to assume the existence of competition among service sites for demand. Practically, the demand at site i for a specific neighbourhood green space j will be influenced by the availability of other neighbourhood green spaces within a specified travel threshold of site i.

To minimize the demand overestimation of the 2SFCA methods, a travel-distance-based competition weight is determined for each pair of demand-provision sites, and the competition weights are then incorporated in the calculation of the demand for each service site in a three-step floating catchment area (3SFCA) method (Wan and Zou 2012):

- *Step 1:* Determine the catchment of a demand location *i* based on a specified travel threshold, divide the catchment into multiple sub-zones with equal travel impedance interval, search all service sites within the catchment, assign a specified weight to each service site based on the sub-zone in which the site lies, and calculate a selection weight for each pair of service site *j* and demand site *i* as follows:

$$G_{ij} = \frac{T_{ij}}{\sum_{k \in \{d(i,k) \le d_0\}} T_{ik}} \qquad \text{(Eqn 2.21)}$$

where G_{ij} is the selection weight between demand location *i* and service site *j*, and all selection weights for a demand location i sum to one; d

(*i*, *k*) is the travel cost (minutes) from *i* to any service site *k* within the demand catchment; d_0 is the catchment size (e.g. driving time of 60 minutes); and T_{ij} is the weight assigned for service site *j* by the demand location i. If a service site is located within the third sub-zone, for example, the specified weight for the sub-zone is assigned to the service site.

- *Step 2:* Determine the catchment area of each service site *j* based on the specified travel threshold, divide the catchment into multiple sub-zones with equal travel impedance interval, search all demand locations within the service catchment, and compute the provision-to-demand ratio (*R*) for service site *j* as follows:

$$R_j = \frac{S_j}{\sum_{r=1,2,3,4} \sum_{k \in d_r} G_{kj} P_k W_r} \qquad \text{(Eqn 2.22)}$$

$$= \frac{S_j}{\sum_{k \in d_1} G_{kj} P_k W_2 + \sum_{k \in d_2} G_{kj} P_k W_2 + \sum_{k \in d_3} G_{kj} P_k W_3 + \sum_{k \in d_4} G_{kj} P_k W_4}$$

where S_j is the provision capacity at service site *j*, W_r is the travel impedance specified for the *r*th sub-zone d_r, G_{kj} is the selection weight between service site *j* and demand site *k*, and P_k is the demand (e.g. population size) at demand site *k*.

- *Step 3:* Compute the spatial access index for demand site *i* as follows:

$$A_i^F = \sum_{r=1,2,3,4} \sum_{j \in d_r} G_{ij} R_j W_r \qquad \text{(Eqn 2.23)}$$

$$= \sum_{j \in d_1} G_{ij} R_j W_2 + \sum_{j \in d_2} G_{ij} R_j W_2 + \sum_{j \in d_3} G_{ij} R_j W_3 + \sum_{j \in d_4} G_{ij} R_j W_4$$

where R_j is the provision-to-demand ratio at service site j within the catchment, calculated from *Step 2*; G_{ij} is the selection weight between i and j, calculated from *Step 1*; and W_r is the weight specified for the rth sub-zone d_r.

A travel impedance of 30 minutes driving is recommended as the threshold by the 2SFCA methods as an appropriate catchment size for analysing spatial access to health care (Luo and Wang 2003). The 3SFCA method extends the catchment size to 60 minutes driving so that isolated rural regions (with a travel impedance of 30–60 minutes driving) can be included in the computation (McGrail and Humphreys 2009, Wan and Zou 2012).

The 3SFCA method assumes that the demand at location i for a nearby service site j is affected by the travel distance from i to j as well as its travel distances to other adjacent service sites. This is a reasonable assumption in practice. For example, the selection weight, G_{ij}, equals one when only one green space is available for a population site but decreases with increasing number of green spaces available within easy reach.

2.5.6 Constraints-based measures

Constraints are barriers that prevent people from reaching their aims, and can be categorized into three levels in time-space terms (ReVelle 1970): capability constraints, coupling constraints, and authority constraints. Capability constraints are limitations to the number of activities a person can accommodate within a given time frame; coupling constraints indicate the need to be in particular places at particular times; and authority constraints determine the times of operation of given activities, or of components of transport infrastructure/service (Bhat and Koppelman 1999).

Constraints-based measures of accessibility, like space-time measures, are originally derived from Hägerstrand's time geography concepts (Hägerstrand 1970), and provide a framework for analysing individual accessibility to services and facilities according to their respective space-time constraints (Weber and Kwan 2003).

Space-time measures of individual accessibility make use of an individual's daily path through time and space and indicate the area (and the potential activities which exist inside that area) an individual can access within the time and mobility available to that individual.

Some of these activities will have to be carried out in a particular place at a definite time (and often for a certain length of time), and should therefore be considered as fixed activities. The individual must accept the time and place of such fixed activities, which commonly include work, school, green space, or childcare responsibilities. These fixed activities provide the spatial and temporal framework for the individual's day as they determine where and when he or she must be, and for how long. If successive fixed activities are not at the same location then the time spent moving between these activity locations will further reduce the time available to engage in other activities (and the slower the mode of transportation, the less time will be available). Other activities can only be engaged in during the time available (if any) between these fixed activities.

Other activities will allow more freedom, as the individual can choose among a range of locations or times to engage in that particular activity, or skip it altogether. These can be considered to be flexible activities, and could include grocery shopping, choosing a gas station, visiting a post office, or renting a video. However, an individual's ability to choose among locations or times for flexible activities will still be limited by the time available to them between fixed activities and the limits of their mobility (Weber and Kwan 2003).

Conventional accessibility measures cannot incorporate individual characteristics; space-time measures of individual accessibility have been used with multilevel modelling to isolate the effects of individual level variations from that of geographica context (Weber and Kwan 2003). Their results from evaluation of the impact of geographical context within the urban environment (both location within cities as well as neighbourhoods characteristics) on individual accessibility show that the influence of context on individual accessibility is weak, as accessibility tends to reflect individual and household characteristics rather than the local urban environment.

Constraint-based measures are regarded as highly suitable for the evaluation of trip-chaining and of spatial clustering effects of activities (Burns 1979, Baradaran and Ramjerdi 2001). Using state-of-the-art GIS software from late 1990s, O'Sullivan, Morrison and Shearer (2000) generated isochronic maps of Glasgow's public transport accessibility (O'Sullivan *et al.* 2000).

However, the information required for constraints-based measures is not usually available from standardised travel surveys and therefore often needs to be collected specifically (Bhat and Koppelman 1999, Geurs and Ritsema 2001). This limits the opportunities for data aggregation over larger areas, and the compatibility of data sets collected in different surveys. In addition, the recognition of time constraints alone does not yet do justice to the full spectrum of motivations for individual travel choices (Baradaran and Ramjerdi 2001). For example, despite an abundance of evidence to its usefulness, isochronic mapping is not yet a widespread practice, possibly due to the magnitude of data that needs to be computed (Curtis and Scheurer 2010). These constraints may fade with further advances in GIS.

2.5.7 Utility-based measures

Utility-based measures are designed to capture the benefit to users from accessibility to opportunities (Bhat and Koppelman 1999, Geurs and Ritsema 2001). The utility-based model appraised the economic and financial benefits that people obtained from accessing specific activities (Geurs and Van 2004). Lucas (2006) emphasized the significance of utility-based measures of accessibility in linking travel behaviour to social and environmental justice (Lucas *et al.* 2006).

Geurs and van Eck (2001) emphasised on the weakness of empirical evidence for the link between infrastructure provision and economic activity, and the relative inability of this approach to capture feedback effects between transport patterns and land use changes over time.

Bhat (1999) highlighted the inevitable bias in defining a set of choices for activities and opportunities to be included in this approach, and its inherent conservatism - inability to predict the emergence of new choices and their effects on travel behaviour.

Baradaran (2001) also mentioned the problematic integration of incoming effects in this approach. While disregarding such effects restricts the efficacy of the model, their inclusion – and consequently, the allocation of a higher utility value on activities performed by higher income earners – raised concerns with 'equity'.

Utility-based measures interpret accessibility as the outcome of a set of transport choices. Utility theory addresses the decision to purchase one discrete item from a set of potential choices, all of which satisfy essentially the same need, and can be used to model travel behaviour and the (net) benefits of different users of a transport system (Geurs and Van 2004).

Utility approaches to accessibility usually rest on two prime assumptions: (a) people associate a cardinal utility with each of the alternatives they are facing (for example: with each available destination, travel mode, route etc) and make the choice associated with the maximum utility to them as individuals; and (b) as it is not possible for a planner to evaluate all factors affecting the utility associated with each alternative by a given individual, this utility can be represented as the sum of a non-random component (for the predictable factors) and a random component (for the non-predictable factors) (Kwan 1998). A utility foundation of accessibility can then be derived from this general framework when applied to destination choice.

Two types of utility-based measures exist in the literature: one based on random utility theory, and uses the denominator of the multinomial logit model, also known as the logsum, as measures of accessibility; the other based on the doubly constrained entropy model, and obtains accessibility measures from Williams' (1976) integral transport-user benefit measure. These measures should result in similar measurements of economic benefits as the logsum benefit measure, since multinomial logit and spatial interaction models are equivalent formally (Anas 1983). The advantage of this balancing factor benefit measure compared to the logsum benefit measure is that it allows the additional interpretation of the balancing factors as utility-based accessibility measures including competition effects.

The logsum serves as a summary measure, indicating the desirability of the full choice set. If it is assumed that each alternative k in choice set TC has total utility U_k, and further, that each individual will select the alternative that maximizes their total utility, then a simple definition for accessibility is (Lerman 1979):

$$A_k = E\ (\ \mathrm{Max}\ U_k), \quad \forall k \in TC \qquad \text{(Eqn 2.24)}$$

Where E denotes the expected value. It is well-known that this value, associated with the deterministic portion of the total utility, V, may be derived under a multinomial logit formulation as (McFadden 1981):

$$A_n = \ln \{\sum e^{(V_{nk})}\},\ \forall k \in TC \qquad \text{(Eqn 2.25)}$$

where, A_n = accessibility for person n. V_{nk} = observable transportation, temporal, and spatial components of indirect utility of choice k for person n.

A second approach to measuring utility-based accessibility is

$$A_i = -\frac{1}{\beta}\ln(a_i) \qquad \text{(Eqn 2.26)}$$

$$A_j = -\frac{1}{\beta}\ln(b_j) \qquad \text{(Eqn 2.27)}$$

$$A_{ij} = -\frac{1}{\beta}\ln(a_i b_j) \qquad \text{(Eqn 2.28)}$$

which represents the expected benefits per trip generated A_i, trip attracted A_j and the trip for between zone i and j, A_{ij}, for a given transportation situation and subjects to trips complying with total trip origins and destinations from the entropy model.

The utility model is different from the previous models because it concentrates on the individual. Geurs and van Wee (2004) noted that the utility-based measures "are able to compute transport-user benefits of both land-use and transport projects, as accessibility changes may be the result of transport changes, land-use changes or both." Utility-based measures incorporate non-linear relationships between accessibility improvements and user-benefit changes, showing diminishing returns. This may suggest that it is better to improve accessibility for individuals at locations with low accessibility levels than at locations that are already well accessible (Koenig 1980, Geurs and Ritsema 2001).

In general, the major disadvantages of utility-based measures are their poor interpretability and communicability, i.e. the measures cannot be easily explained without reference to relatively complex theories, of which most planners and political decision-makers will not have a complete understanding (Koenig 1980).

2.6 Modifiable Areal Unit Problem

The accuracy of accessibility measure are influenced by the spatial units adopted in the analysis (Apparicio and Abdelmajid 2008). Most human-made area units are modifiable and are subject to the notorious modifiable areal unit problem (MAUP). The modifiable areal unit problem (MAUP) is a source of statistical bias that can radically affect the results of statistical hypothetical tests. It affects results when point-based measures of spatial phenomena aggregated into area units. The resulting summary values are therefore (e.g. totals, rates, proportions) influenced by the choice of area unit boundaries.

The issue was discovered in 1934 by Gehlke and Biehl (Openshaw 1983). In 1979, Openshaw and Taylor (1979) worked with the election data of the 99 counties in Iowa and first coined the term MAUP in geographical information sciences (Openshaw and Taylor 1979). In 1983, Openshaw described the MAUP in detail and lamented that "the areal units (zonal objects) used in many geographical studies are arbitrary, modifiable, and subject to the whims and fancies of whoever is doing, or did, the aggregating."(Openshaw 1983). Since then, the MAUP concept is widely adopted by researchers in health (Heather 2010, Jackson 2010), transportation (Wong 2011, Mitra and Buliung 2012), environment and socioeconomic studies (Kardos and Benwell 2007, Raghavan 2012).

The MAUP has two fundamental components: one is the scale problem or aggregation problem; and the other is the zoning problem. The former concerns the different statistical inferences and estimates generated by the same data set that is aggregated into different spatial resolutions, especially aggregating a set of smaller area units into a set of fewer but larger area units. The latter refers to the variation in analytical results due to alternative grouping of the areal units at the same spatial scale (Openshaw and Taylor 1979, Openshaw 1983, Wong 1996). Most, if not all, zoning systems studied by geographers are internally heterogeneous so that the severity of any ecological fallacy depends largely on the nature of the aggregation being studied.

The MAUP implies that different statistical and spatial results may be generated for the same area when using aggregate data sets at different scales or with different geographical partitions (Openshaw and Rao 1995, Green and Flowerdew 1996). This problem becomes especially significant when the distribution of source areas do not correspond with the distribution of the target areas of geographical analysis. This type of MAUP may be avoided if data individuals are collectable or available (Weeks 2004). However, due to issues of privacy and confidentiality, individual based social-economic data like the census data are rarely accessible. Despite the lack of a solution to MAUP, recognizing the scale (aggregation) and grouping (zoning) problems is imperative. The MAUP also implies that the results of multilevel research may be inconsistent across models using different areal aggregations (Mobley *et al.* 2008). There are some classic ways of aerial interpolation for solving this type of MAUP, including the ratio-based approaches to point, line and area features (Lin 2004, Joshi and Kono 2009, Pines 2012).

Practically, the effects of MAUP have been well known for many years to politicians concerned with ensuring that the boundaries of electoral districts are defined in the most advantageous way for them. The practical implications of MAUP are immense for almost all decision-making processes involving GIS technology, Since with the now ready availability of detailed but still aggregated maps, policIES could easily focus on issues and problems, which might look very different if the aggregation scheme used, were changed.

2.7 Thematic Classification

For thematic mapping, many standard schemes are available for classifying a set of numerical attribute values into groups to illustrate the spatial variation patterns, including equal intervals, quintiles, natural breaks (Jenks), and standard deviation (ESRI 2013).

The equal interval scheme divides the range of attribute values into equal-sized sub-ranges, and emphasizes the amount of an attribute value relative to other values. Equal intervals are easier to interpret, good for evenly distributed data values. When data values are clustered, however, there may be many features in one or two classes and no features in other classes (Tyner 2010).

The quantile scheme assigns each class to contain an equal number of data values (ESRI 2013). There are no empty classes or classes with too few or too many values; but similar features are placed in adjacent classes; or features with widely different values are put in the same class. Increasing the number of classes is an effective way to minimize the quantile distortion. The quantile scheme is good for mapping evenly distributed data value, comparing data values associated with roughly equal sized area units, and emphasizing the relative position of a feature among other features. When data values are associated with area units that vary greatly in size, the quantile scheme can generate a spatial pattern that is visually skewed to the larger units.

The (Jenks) natural breaks scheme is data-specific and creates classes based on natural groupings inherent in the data using the Jenks' Natural Breaks algorithm (Jenks 1967). The natural break scheme identifies class breaks where there is a gap between clusters of values, and selects class breaks that best group similar values and maximize the differences between classes. The natural break scheme is good for mapping unevenly distributed or clustered data values; but is not useful for comparing multiple thematic maps built from different underlying information .

The Standard deviation scheme defines each class in terms of its distance or difference from the mean (ESRI 2013). Class breaks are created with equal value ranges that are related to the mean and the standard deviation, usually equal to the mean value plus or minus 1, ½, ⅓, or ¼ standard deviations. The standard deviation scheme is good for mapping normally distributed data values and showing which features are above or below an average value; but the results can be difficult to interpret and the spatial pattern can be skewed by unusually high or low data values (called outliers), causing most features to fall into the same class.

2.8 Spatial Clusters

Spatial clusters are statistically significant clusters of locations with high values (hot spots) or low values (cold spots), identified through so-called hotspot analysis based on local spatial statistical indicators (ESRI 2013), such as the Getis-Ord Gi* statistic (Getis and Ord 1992, 1995) shown in Eqn 2.29:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j - \bar{x} \sum_{j=1}^{n} w_{ij}}{s\sqrt{\frac{n\sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2}{n-1}}}, \quad \bar{x} = \frac{\sum_{j=1}^{n} x_j}{n}, \quad s = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{x})^2}. \qquad \text{(Eqn 2.29)}$$

Where x_j is the attribute value for feature j, $\bar{x}$ and s is the mean and standard deviation of the attribute values respectively; w_{ij} measures the proximity between feature i and feature j; and n is the total number of features in the neighbourhood of i under consideration (Getis and Ord 1992).

For example, the Hot Spot Analysis tool implemented in the ArcGIS calculates the Getis-Ord Gi* statistic for each feature in a dataset, and creates a new Output Feature Class with a z-score and p-value for each feature in the Input Feature Class. The resultant G_iZ scores and p-values indicate where features with either high or low attribute values cluster spatially. This tool works by looking at each feature within the context of neighbouring features. A feature with a high value is interesting but may not necessarily be a statistically significant hot spot. To be a statistically significant hot spot, a feature will have a high value and be surrounded by other features with high values as well. The local sum for a feature and its neighbours is compared proportionally to the sum of all features; when the local sum is very different from the expected local sum, and that difference is too large to be the result of random chance, a statistically significant G_iZ score will result (Ord and Getis 1995).

The G_iZ scores and p-values are measures of statistical significance indicating whether the observed spatial clustering of high or low values is more pronounced than one would expect in a random distribution of those same values (ESRI 2013). A high positive G_iZ score and small p-value for a feature indicates a spatial clustering of high values. A low negative GiZ score and small p-value indicates a spatial clustering of low values. The higher (or lower) the GiZ score, the more intense the clustering. A GiZ score near zero indicates no apparent spatial clustering (Mitchell 2005).

2.9 Summary

In this chapter, a summary of literature review findings on issues related to green space and green space accessibility in urban areas are presented.

The concept of green space in urban areas refer to a tract of land that is covered (wholly or partially) with living vegetation (grass and/or trees) and is openly accessible to the public free of charge. The ecological, social and economic benefits of neighbourhood green space in urban areas are well published. Melbourne's international reputation for liveability, to a considerable extent, have been attributed to the quality and attractiveness of Melbourne's green space system which in turn can be attributed to a succession of good urban planning efforts over the years.

Neighbourhood green spaces are usually associated with various functional facilities, each appealing differently to different age groups of the population. Apart from these functional facilities, many other factors also influence the attractiveness of a green space, including its location, size, other attributes, and contextual conditions. In general, users and potential users prefer proximate, attractive, and larger public green space.

Existing quantitative measures of green space attractiveness emphasizes the areal size of a green space more than the associated functional facilities. Many studies on the relative weights for different types of facilities associated with green space have been conducted but consistency has not been achieved due to varying emphasis on different conditions, and weights of facilities are not related to the age groups of potential users.

Accessibility, mobility, walkability and equity are terms widely used in literature related to green space studies. The term accessibility is often used to refer to the easiness for a specific agent to get to a specific destination through a specific network system by a specific mode of travelling. Mobility is often used to indicate a specific agent's ability for moving around a specific network system considering all modes of travelling feasible to that agent. Walkability is often used to imply the perceived easiness of getting around a specific neighbourhood on feet by a specific travelling agent. Equity means the fairness of services allocation and refers to a situation in which all people are treated equally and no one has an unfair advantage or disadvantage. With regard to the equity of services location decisions, some basic principles proposed include recognizing equal opportunity as the point of departure, encouraging deviations from this point of departure if the deviations benefit the least advantaged, and establishing a minimum threshold below which quantity or quality should not fall.

Generally, the concept of accessibility involves four spatially dispersed components: locations of demand, locations of provision, travel impedance and temporal condition. These components often exhibit spatial mismatches in certain parts of the urban space, leading to less operational efficiency of services / facilities and social inequalities / injustice in areas with low provision and high demand.

Since accessibility cannot be observed directly and needs to be measured, many researchers have endeavoured to create and improve the accessibility measurements. Six types of accessibility measures can be found in the literature, including measures based on opportunities, ratios, travel impedance, gravity, utility and spatial-temporal constraints.

Opportunity-based measures concentrate on the amount of available provisions in the specific area, but ignore both the demands for these opportunities and the associated travel costs to consume the opportunities. Ratio-based measures consider the proportion between the demand and provision but overlook the travel costs, the differences among the demands or among the opportunities, and the spatial configurations of the opportunities, demands and transportation infrastructures. Travel impedance-based measures concerns various forms of the cost of travel, but tend to treat all opportunities or all demands equally. Gravity-based measure, including GIS-based FCA measures, integrating the different opportunities, demands, and distance decayed travel costs, but ignore utilities and constraints at the individual level. Spatial-temporal measures consider the individual movement within a specific area and their personal space and time limitation; and utility-based measures make access decisions from the standpoint of an individual and subjective feelings, regardless of the objective reality.

Among the published measures of accessibility, opportunity-based measures are the simplest to implement, the easiest to interpret, but the least useful in revealing the true spatial variations / patterns of accessibility since it considers only one of the three key components of accessibility. On the other extreme, time-space measures of individual accessibility can reveal the most realistic and detailed spatial variation in accessibility but their applications are constrained by data availability and other limitations inherited by the measures (e.g. no consideration of competition effect).

Accuracy of spatial accessibility measurements can be influenced by the MAUP which consists of the scale problem or aggregation problem, and the zoning problem. The scale problem becomes especially significant when the distribution of source areas does not correspond with the distribution of the target areas of geographical analysis. The zoning problem implies that the results of multilevel research may be inconsistent across models using different areal aggregations, and is often dealt with different areal interpolation methods. It is desirable to reveal spatial variation in accessibility at fine resolution and many areal interpolation methods have been attempted to disaggregate data from larger source areal units to smaller target areal units.

Thematic maps are often used to present simplified views of spatial variations in spatial accessibility, and many standard schemes are available for classifying a set of numerical attribute values into thematic classes to illustrate the spatial variation patterns, including equal intervals, quintiles, natural breaks (Jenks), and standard deviation. It has been a challenge in producing useful thematic maps to show spatial variations of numerical attributes of area units. Different classification schemes and number of classes used often give very different visual impressions for the same dataset.

Spatial statistical techniques have been widely adopted in describing and analysing spatial patterns, and hotspot analysis proved to be an effective approach to reveal spatial clusters hidden in numerical spatial data. To identify and map statistically significant clusters of locations with high values (hot spots) or low values (cold spots), hotspot analysis based on local spatial statistical indicators are widely applied. One of the most popular spatial cluster indicators is the Getis-Ord Gi* statistic which is implemented in the ArcGIS environment and widely applied to identify where spatial features with either high or low attribute values cluster spatially, based on the calculated GiZ scores and p-values.

Based on the research questions raised in Chapter 1 and the findings from literature review presented in this chapter, the methodology developed for this study is presented in the following chapter (i.e. Chapter 3).

CHAPTER 3 METHODOLOGY

3.1 Introduction

According to research objectives, questions and method introduced in Chapter 1 and understandings acquired from literature review summarised in Chapter 2, a GIS-based approach for measuring potential spatial accessibility to green space have been developed for the Melbourne Metropolitan Area. In addition, this study will identify, in the MMA, where spatial accessibility to green space is relatively inadequate. This study consists of the following tasks:

- Select a study area and comprehend data requirements, collection and preparation;
- Design and build up a geodatabase in ArcGIS, including all the related datasets;
- Map and analyse population distribution and concentration after the population disaggregation;
- Identify and map all relevant green spaces in the study area, and compute an attractiveness score for each of these green spaces;
- Calculate network-constrained entrance-to-entrance distance between residential areas and green spaces;
- Calculate gravity-based accessibility index using modified 2SFCA and modified 3SFCA methods, incorporating continuous distance-decaying functions, and identify disadvantaged residential locations in the study area, that having high demand for but low provision of green space;

3.2 Study Area

In order to better measure, map and understand the value and practical significance of accessibility to green space, a study area should satisfy the following selection criteria:

1. Most of the required datasets are available and accessible for the study area to allow the study to concentrate on issues related to the measuring, mapping and analysis of accessibility to green space;
2. The study area should be accessible to enable feasible field based observations and verifications when necessary.
3. The study area should be an important urban area with good records of green space provision and development to enable the assessment of spatio-temporal changes in relationships between provision and demand of urban green space.

Accordingly, the Melbourne Metropolitan Area (MMA) has been selected as an ideal study area where intensive researches on accessibility to green space are deserved. Section 4.1 will present a detailed description of relevant features about the study area.

3.3 Data Requirements, Collection and Management

3.3.1 Data requirements

According to the key components involved in the concept of accessibility (land use, transportation, temporal and people), and guided by the requirements for implementing the modified 2SFCA and 3SFCA measures of accessibility, the data collection efforts in this study have been aimed at clarifying the following three key issues: (1) spatial distribution of population at fine spatial resolution, or based on the smallest possible residential areas; (2) spatial distribution of green spaces that are accessible freely by the residents most of the time; and (3) spatial configuration of local road networks that connecting population at local residential areas and neighbourhood green spaces (Table 3.3.1).

3.3.2 Data collection

The smallest spatial unit at which the 2011 ABS census was released is called Statistical Area Level 1 (SA1), which is represented by a unique seven-digit code and contains such population information usage by year and sex. For the 2011 Census, there are about 37,000 SA1 throughout Australia (this includes the Other Territories of Christmas and Cocos (Keeling) Islands and Jervis Bay). On average, each urban SA1 has about 225 dwellings; but in rural areas, the number of dwellings per SA1 declines as population density decreases.

Table 3.3.1 A summary of data requirements

Dataset	Data type	Description	Data format
Population	Spatial	ABS 2011 SA1 boundary	Polygon
	Attribute	ABS 2011 population count (AGEP)	Table
	Spatial	ABS 2011 MB boundary	Polygon
	Attribute	ABS 2011 population count (MB code, area, total persons)	Table
Land use	Spatial	ABS 2011 MB boundary	Polygon
	Attribute	MB code, area, category	Table
Green Space	Spatial	Green space boundary	Polygon
	Attribute	Green space ID, area, facility and quietness	Table
Road	Spatial	Road centerline	Line
	Attribute	Road ID, class and length	Table
Other Datasets	Spatial and Attribute	Residential address	Point, Table
		MMA boundary	Polygon, Table
		LGA boundary	Polygon, Table
		Locality boundary	Polygon, Table

According to ABS (http://www.abs.gov.au/), the spatial units of SA1 are designed based on the following considerations:

- SA1s should be consistent with both their role as a useful spatial unit and building block capable of aggregation into broader level Australia Statistical Geography Classification (ASGC) spatial units, and with the collectors' workload requirements.
- The chosen SA1 boundaries should, if possible, be readily identifiable on the ground and be defined in terms of permanent features; follow the centre of a road or river if these features are used; and delimit SA1s which conform to existing and proposed land uses.
- The use of major roads as SA1 boundaries in rural areas is avoided, where possible, to minimise splitting of identifiable rural localities.
- SA1s should conform where possible to existing/gazetted suburb boundaries, and must not cross Statistical Local Area (SLA) boundaries and, as a consequence, any other ASGC spatial unit boundary.

- SA1s in aggregate must cover the whole of Australia without gaps or overlaps.
- SA1s are created in response to significant changes in population within a given area, or if boundaries of larger geographical areas change. For example, if the population within an existing SA1 increases to the point of being too large for one collector, the SA1 may be split into two or more SA1s. If growth in the population of a locality or urban centre results in expansion of its boundary, new SA1s may be created by division of the SA1s into which the growth intrudes, so that the new boundary may adequately reflect the urban growth in census results (this process is often referred to as fragmentation). Where necessary, SA1s are created or boundaries adjusted to conform with changes to LGA boundaries.

These considerations are aimed at maintaining as much comparability between censuses as possible. New SA1 boundaries are designed with reference to information obtained from government authorities, census collector comments from the previous census, local knowledge, field inspections, and aerial photography.

Mesh Blocks (MB), as the smallest geographical regions in the ASGC scheme (SA1 is the smallest population units), thus enable a ready comparison of statistics between geographical areas. Age-specific population data for SA1 and digital files containing SA1 and MB spatial boundaries can be downloaded directly from the ABS website (http://www.abs.gov.au/).

All green spaces included in this study are open green spaces that are freely accessible to the public most of the time. Green spaces excluded from this study include all green spaces in school campuses (which are not accessible to the public during schooling hours) and all fee-charging green spaces (including golf courses, stadium etc). In addition, all green spaces whose area size is less than 0.02 ha (200 m^2) are also excluded from this study.

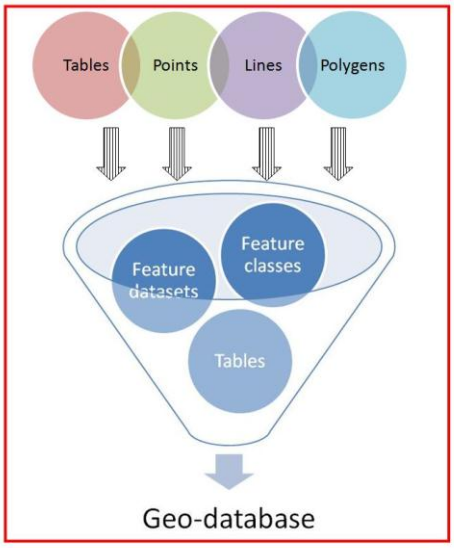
Based on the understanding gained from the literature review and, in addition to the size and quietness of the green space, 9 types of green space facilities have been chosen for this study, including playground, bench, toilet, walking track, sport oval, sport court, and water body. Data on most green space facilities can be downloaded from the Parks Victoria website (http://parkweb.vic.gov.au/), the Department of Sustainability and Environment website (http://www.dse.vic.gov.au/), and the LGAs websites, with some uncertain facilities clarified by personal observation on the Google or in the field.

3.3.3 Data Management

In this study, all datasets collected and prepared are stored and managed with a geodatabase in ArcGIS; and all spatial datasets are projected onto a coordinate system to enable their integration with other geographical data layers within a common coordinate framework, "GDA_1994_MGA_Zone_55", i.e. zone 55 of the Map Grid of Australia, based on Transverse Mercator projection and the Geocentric Datum of Australia introduced in 1994.

A geodatabase combines "geo" (spatial data) with "database" (data repository) to create a central data repository for spatial data storage and management. The geodatabase in ArcGIS is based on a series of simple yet essential relational database concepts to leverage the strengths of the underlying database management system (DBMS). Simple tables and well-defined attribute types are used to store the schema, rule, base, and spatial attribute data for each geographical dataset. This approach provides a formal model for storing and working with spatial and non-spatial datasets. Through this approach, structured query language (SQL) based relational functions and operators can be used to create, modify, and query tables and their data elements.

A geodatabase consists of a set of tables, feature classes and feature datasets (Figure 3.3.1). Feature classes are homogeneous collections of common features, each having the same spatial representation, such as points, lines, or polygons, and a common set of attribute columns, for example, a line feature class for representing road centrelines. The four most commonly used feature classes in the geodatabase are points, lines, polygons, and annotation. A feature dataset is a collection of related feature classes that share a common coordinate system. Feature datasets used to spatially or thematically integrate related feature classes. Their primary purpose is for organizing related feature classes into a common dataset for building a topology, a network dataset, a terrain dataset, or a geometric network.



Geodatabase organisation of source datasets designed for the study
1. Feature classes • Point (e.g. address points, entrance points) • Polyline (e.g. local road polylines, major road polylines) • Polygon (e.g. MB boundary polygons, SA1 boundary polygons, green space boundary polygons, LGA boundary polygons)
2. **Tables** (e.g. population statistical tables, green space facility tables, road attribute tables)
3. Feature datasets • Green space dataset (e.g. green space boundary polygons, green space entrance points, green space facility table) • Population dataset (e.g. MB entrance points, MB boundary polygons, population statistical tables) • Transportation dataset (e.g. road junction points, local road polylines, major road polylines, local road edges, major road edges, road attribute tables) • Administrative dataset (e.g. LGA boundary polygons, Locality boundary polygons, LGA attribute table, Locality attribute table)
4. **Relationship classes** (e.g. entrance points to boundary polygon relationship classes, MB and SA1 relationship class, address point and MB polygon relationship, junction point and edge relationship class)
5. **Raster datasets** (e.g. high resolution base map images)

Figure 3.3.1 Organization of source datasets into a geodatabase in ArcGIS

3.4 Data Processing

3.4.1 Population Data Disaggregation

To minimize the statistical bias due to the MAUP, Mesh block (MB) is selected in this study as the basic geographical unit of analysis. Mesh Blocks are the smallest geographical region in the Australian Statistical Geography Standard (ASGS). MBs are intended to be the basic unit upon which all other administrative, political (both state and federal), suburban, postal, cadastral, and statistical divisions in Australia will be built. Mesh Blocks have been designed to be small enough to aggregate accurately to a wide range of spatial units and thus enable a ready comparison of statistics between geographical areas, and be large enough to protect against accidental disclosure. In 2011, there are approximately 347,000 Mesh Blocks covering the whole of Australia without gaps or overlaps. Mesh Blocks are identified with a unique 11-digit code. They broadly identify land use such as residential, commercial, agricultural and parkland etc. For most MBs in urban residential areas, each covers an area with around 30-60 dwellings. Mesh blocks are about four or five times smaller than the SA1 used for the 2011 ABS census.

SA1 level population data, downloaded from the Australian Census Bureau website, tabulated population counts into 116 single groups from age 0 to age 115. These counts are summarized in this study into 4 age groups: young (age 0-14), adult (age 15-65), old (age 65+), and total (age 0-115).

To enable the measurement of accessibility at the Mesh block (MB) level, population age group data summarised at the SA1 level are spatial disaggregated into the MB level. Technically, this spatial disaggregation can be carried out using one of three methods: the area ratio method, the address point ratio method, and the floor area ratio (FAR) method.

Assuming that the density of population in SA1 is evenly distributed, the area ratio method calculates the ratio of area size between the specific MB zoning area and the total area of the containing SA1. As shown in Eqn 3.1, for MB_i, which is inside $SA1_k$, the area ratio of MB_i to $SA1_k$ can be regarded same as the ratio of MB_i population to $SA1_k$ population, i.e.:

$$\frac{Area\ (MB_i)}{Area\ (SA1_k)} = \frac{Population\ (MB_i)}{Population\ (SA1_k)} \qquad \text{(Eqn 3.1)}$$

Therefore, the population for each MB can be calculated by the area ratio method as indicated in (Eqn 3.2):

$$Population\ (MB_i) = \frac{Area\ (MB_i)}{Area\ (SA1_k)} \times \left[Population\ \left(SA1_k\right)\right] \qquad \text{(Eqn 3.2)}$$

In many cases, the distribution of population can be uneven inside each SA1. Therefore, the area ratio method often does not produce satisfactory outcome. In these cases, it is better to assume that the population are evenly distributed among residential addresses within SA1, and disaggregate population data at the SA1 level into the MB level using the address point ratio method.

The address point ratio method computes the population in each MB by the ratio of address point numbers between the specific MB and the containing SA1. As shown in Eqn 3.3, for MB_i, which is inside of $SA1_k$, the ratio of address point numbers between MB_i and $SA1_k$, can be regarded same as the ratio of MB_i population to $SA1_k$ population, i.e.:

$$\frac{Address\ points\ (MB_i)}{Address\ points\ (SA1_k)} = \frac{Population\ (MB_i)}{Population\ (SA1_k)} \qquad \text{(Eqn 3.3)}$$

Therefore, the population for MB_i can be calculated by the address point ratio method as illustrated in Eqn 3.4:

$$Population\ \ (MB_i) = \frac{Address\ points\ \ (MB_i)}{Address\ points\ \ (SA1_k)} \times Population\ \ (SA1_k) \qquad \text{(Eqn 3.4)}$$

In many cases, the numbers of person living at a residential address are often positively related to the floor area available at that residential address, and are rarely kept constant within a neighbourhood of 20-30 households. Therefore, if data on floor area for each residential address point, and hence for both MB_i and $SA1_k$, are available, the FAR method would produce a better estimate of the actual MB population from the SA1 level population than that from the address point ratio method. With the FAR method, the population for MB_i can be calculated as shown by Eqn 3.5 and Eqn 3.6:

$$\frac{Far\ \ (MB_i)}{Far\ \ (SA1_k)} = \frac{Population\ \ (MB_i)}{Population\ \ (SA1_k)} \qquad \text{(Eqn 3.5)}$$

$$Population\ \ (MB_i) = \frac{Far\ \ (MB_i)}{Far\ \ (SA1_k)} \times Population\ \ (SA1_k) \qquad \text{(Eqn 3.6)}$$

Generally speaking, to spatially disaggregate the population from the SA1 level into the MB level, the address point ratio method should produce a more accurate estimate than that from using the area ratio method, due to uneven spatial distribution of population within most SA1 zones; and the FAR method will produce a more accurate estimate than that from using the address point ratio method, due to variation in household size (as approximated by the floor area) among residential addresses within SA1 zones. In this study, the address point ratio method is implemented because the availability of the address point data and the unavailable floor area data for each residential address.

3.4.2 Green Space Attractiveness Calculation

Many green space properties contribute to a green space attractiveness and hence influence people's choice in using or not using the green space, such as the location and size of a green space, type and quality of facilities present in or near the green space, and if the green space are quiet. Green space properties considered in this study include a green space's location, area, extent, quietness, and facilities present. Key type of facilities considered include playground, bench, toilet, walking track, sport oval, sport court, and water body.

Modified from Giles-Corti (2005), the attractiveness score for each of the 4678 green spaces included in this study, Att_i, is calculated as follows (Eqn 3.7):

$$Att_i = (\sum_n fac_n \times w_n)^{0.52} \times S_i^{0.85} \qquad \text{(Eqn 3.7)}$$

Where fac_n = 1 if type *n* facility present and fac_n = 0 if the facility is absent, S_i is the size of green space *i* in hectare (ha), and w_n is age-based weight assigned to type *n* facility. A higher power value of 0.85 is assigned to green space area in this study to reflect the perceived stronger contribution of green space area towards the overall green space attractiveness.

On the basis of literature review (e.g. Giles-Corti 2005), and personal discussions (with Dr Gang-Jun Liu), green space property weights for different age groups were determined. As shown in Table 3.4.1, for the young age group, playgrounds are deemed most important (30 points), followed by toilets, walking tracks and quietness (10 points each), with sport courts being the least important (2 points each); for the adult age group, sport ovals, as public group facilities, are regarded as the most important (15 points), followed by all types of sport courts (10 points each), while much less importance are assigned to benches, toilets, quietness (5 points each) and playgrounds (0 point); for the old age group, walking tracks, benches, toilets and water bodies are of highest importance(15 points each), followed by quietness (10 points), while sport facilities are regarded as the least important (2-3 points each). The sum of all green space property weights are set to equal 100 points for each age group, including a weight of 20 points assigned for the green space areas.

According to the findings from the literature review, 40 m buffers around busy roads are used to determine the noisy portions of green spaces, and the quietness score for green space i, Qie_i, is calculated as the ratio between the non-noisy portion and the total area of the green space (Eqn 3.8):

$$Qie_i = \frac{AREA_i - NOISY\ \ AREA_i}{AREA_i} \qquad \text{(Eqn 3.8)}$$

where $AREA_i$ is the total area of green space *i*, $NOISY\ AREA_i$ is the portion of $AREA_i$ falling into the 40 m buffer of nearby major roads that often attract heavy traffic and generate annoying traffic noise. Major roads are identified with a 'class code' values of 0, 1, 2, 3, and 12 in the road attribute table associated with the road layer of VICMAP.

Table 3.4.1 Aged-based weights determined for different properties of green space

*w_n		Age Groups			
		Young (0-14)	Adult (15-64)	Old (65-115)	Total (0-115)
Green Space Properties	Playground	30	0	0	5
	Bench	5	5	15	10
	Toilet	10	5	15	5
	Walking track	10	10	15	10
	Sport oval	4	15	3	10
	Tennis court	2	10	3	10
	Water body	5	10	15	15
	Baseball court	2	10	2	5
	Netball court	2	10	2	5
	Quietness	10	5	10	5
	Green space area	20	20	20	20

*These weights are determined based on personal discussions with Dr Gang-Jun Liu.

3.4.3 Travel Impedance Measurement

In this study, travel impedance is measured in terms of road network constrained walking distance. The walking distance from each residential MB area to each green space is measured from MB entrances to green space entrances along the intervening road network links. This involves three steps, (1) identifying entrance points for both MBs and green spaces, (2) measuring walking distances along road network links from each MB's entrance points to each neighbourhood green space, and (3) determining the representative walking distance between the MB to the green space. The entrance points for MBs are identified in this study through the intersection of MB boundary polygons with road network links, and a similar operation is used for identifying entrance points for green spaces. For a pair of MB and neighbourhood green space, the walking distance from each of the entrance points for the MB to their respective closest entrance point for the green space is measured along the intervening road network links. The representative walking distance between the MB to the green space is then determined as the mean of these entrance-to-entrance distances.

For example, as shown in Table 3.4.2, the travel distance between three residential areas (34957, 34966, 34859) and one green space (2332) is calculated in three steps:

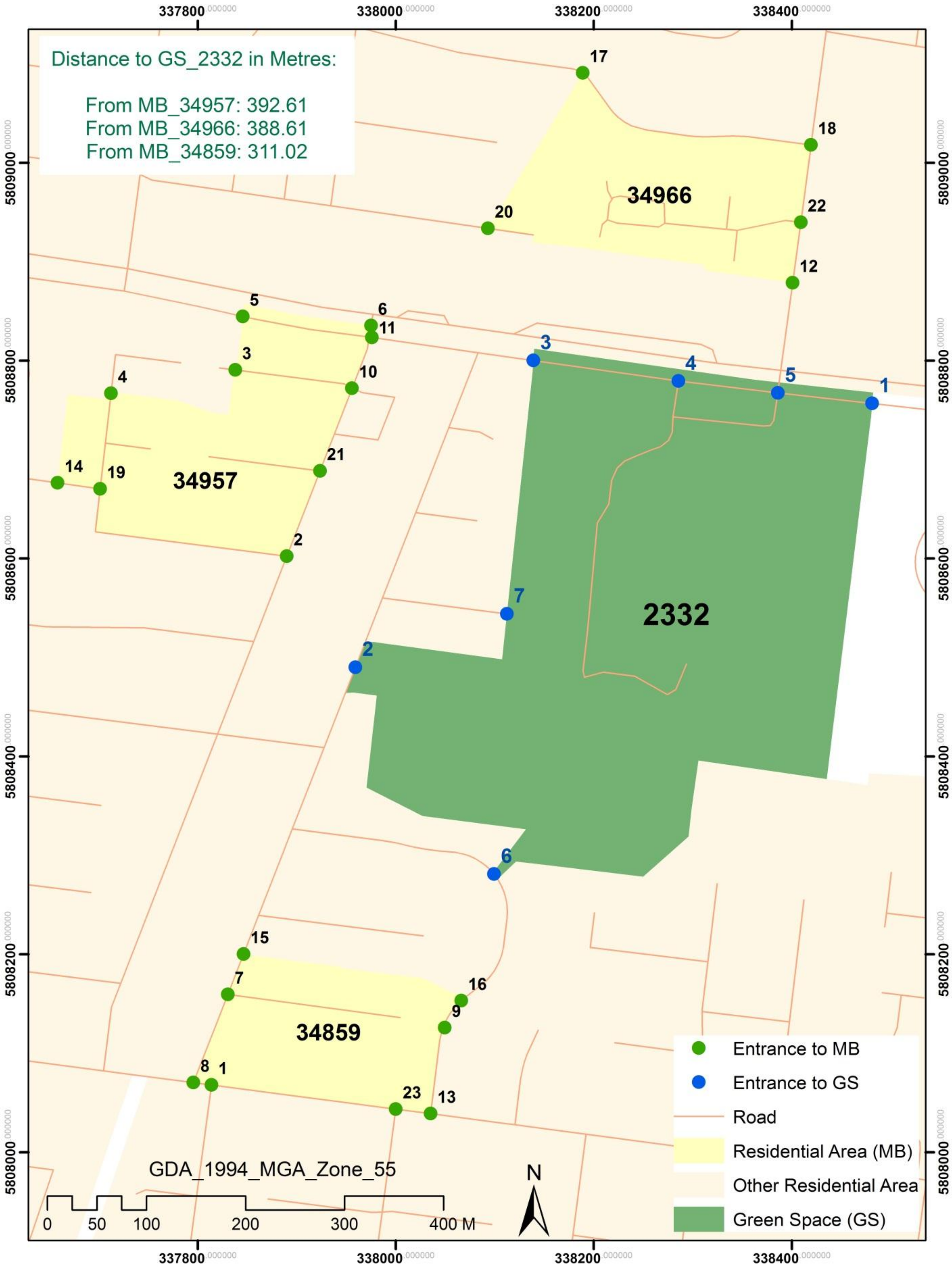
- First, the travel distances between each entrance to a residential area and every entrance to the green space measured along the road network. For example, the travel distances between MB Entrance 1 of the residential area 34859 and the (1 to 7) entrances of the green space 2332 are 1211.59 m, 468.93 m , 670.95 m, 866.61 m, 1115.88 m, 492.46 m, 1014.59 m, respectively, as highlighted in the left hand part of Table 3.4.2.
- Then, the shortest travel distances from all entrances of the residential area to the green space are identified. For example, the shortest travel distances between the 8 entrances of residential area 34859, including MB Entrance 1, 7, 8, 9, 13, 15, 16 and 23, and the green space 2332 are identified as 468.93 m, 354.81 m, 450.48 m, 180.71 m, 269.32 m, 311.08 m, 148.08 m, and 304.77 m, respectively, as highlighted in the right hand part of Table 3.4.2.
- And finally, the shortest distances identified in step two above are averaged to indicate the representative travel distance between a residential area and the green space. For example, the representative travel distance between the residential area 34859 and the green space 2332 is 311.02 m, an average of the eight shortest travel distances listed in step two above.

In this study, a set of Python scripts and ArcGIS software modules have been used to calculate travel distances from each of the residential MBs to their respective set of neighbourhood green spaces in the MMA.

Table 3.4.2 Calculation of entrance-to-entrance distance between one green space (2332) and three MBs (34957, 34966, 34859), as depicted in Map 3.4.1.

MB_ID	MB_ Entrance	Green Space Entrance	Network Distance (m)
34859	1	2	468.93
34859	1	6	492.46
34859	1	7	670.95
34859	1	3	866.61
34859	1	4	1014.59
34859	1	5	1115.88
34859	1	1	1211.59
34957	2	2	388.19
34957	2	3	404.33
34957	2	4	552.31
34957	2	7	590.21
34957	2	6	601.85
34957	2	5	653.60
34957	2	1	749.32
…	…	…	…
34966	20	3	894.23
34966	20	4	1042.21
34966	20	5	1086.10
34966	20	2	1179.11
34966	20	1	1181.81
34966	20	7	1230.52
34966	20	6	1565.41
…	…	…	…

MB_ID	MB Entrance	Nearest Green Space Entrance	Network Distance (m)
34859	1	2	468.93
34957	2	2	388.19
34957	3	3	342.13
34957	4	2	723.99
34957	5	3	296.87
34957	6	3	179.28
34859	7	2	354.81
34859	8	2	450.48
34859	9	6	180.71
34957	10	3	222.15
34957	11	3	164.75
34966	12	5	112.39
34859	13	6	269.32
34957	14	2	670.17
34859	15	2	311.08
34859	16	6	148.08
34966	17	5	509.45
34966	18	5	252.92
34957	19	2	626.81
34966	20	3	894.23
34957	21	3	311.78
34966	22	5	174.07
34859	23	6	304.77



Map 3.4.1 The spatial connectivity between entrances to three residential areas (34957, 34966, 34859) and entrances to a specific green space (2332).

3.4.4 Statistical Summary for Green Space Centred and MB Centred Catchments / Neighbourhoods

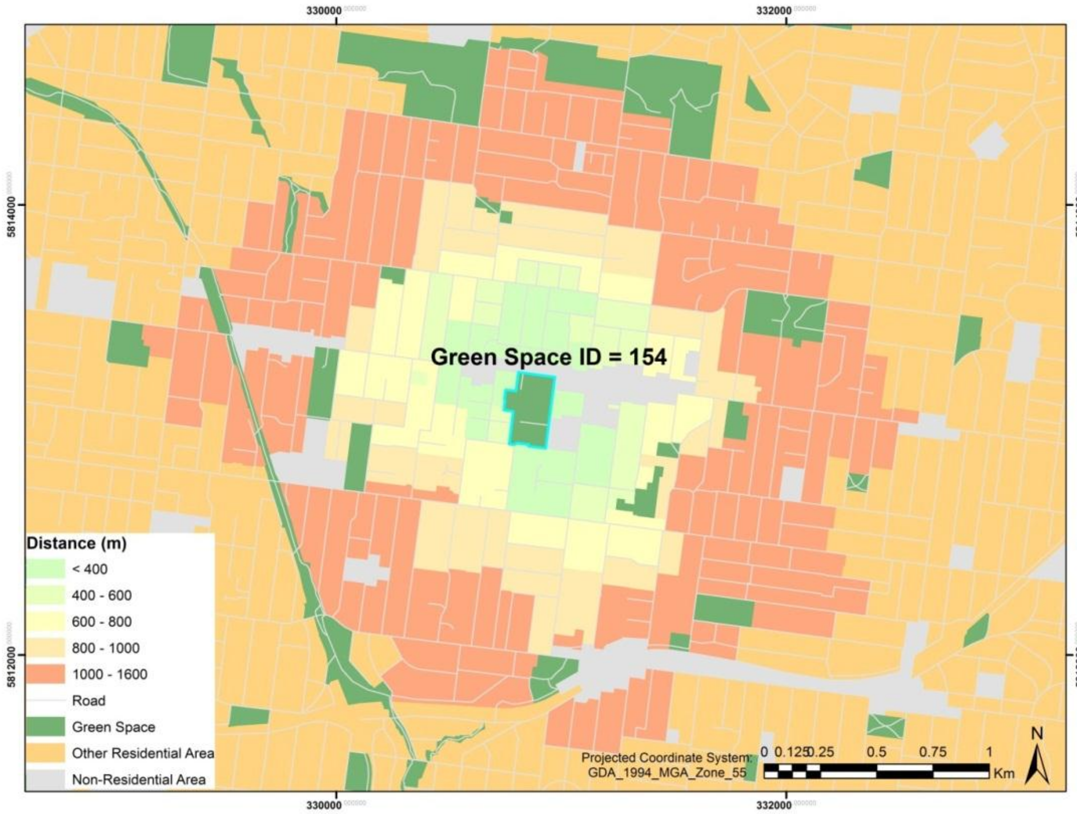
Travel distance between residential MBs and green spaces in the MMA is treated as symmetric in this study due to limited access to relevant traffic data and limited time allowance. The measured trave distances have been used to define both green space centred and MB centred neighbourhood / catchment zones. In addition to their uses for measuring spatial accessibility, these travel distance based neighbourhood / catchment zones can also be used for producing some useful summary statistics.

For example, Table 3.4.3 and Map 3.4.2 provide a green space centred summary of population structures and the spatial relationship between a specific green space (ID = 154) and its surrounding 204 MBs within three specified road network distances of 0-400 m, 0 – 800 m and 0 – 1600 m. And Table 3.4.4, Map 3.4.3 present a MB-based statistical summary of green space availability and show the spatial relationship between a specific MB (ID = 2159) and its surrounding 20 green spaces within three specified road network distances of 0-400 m, 0 – 800 m and 0 – 1600 m.

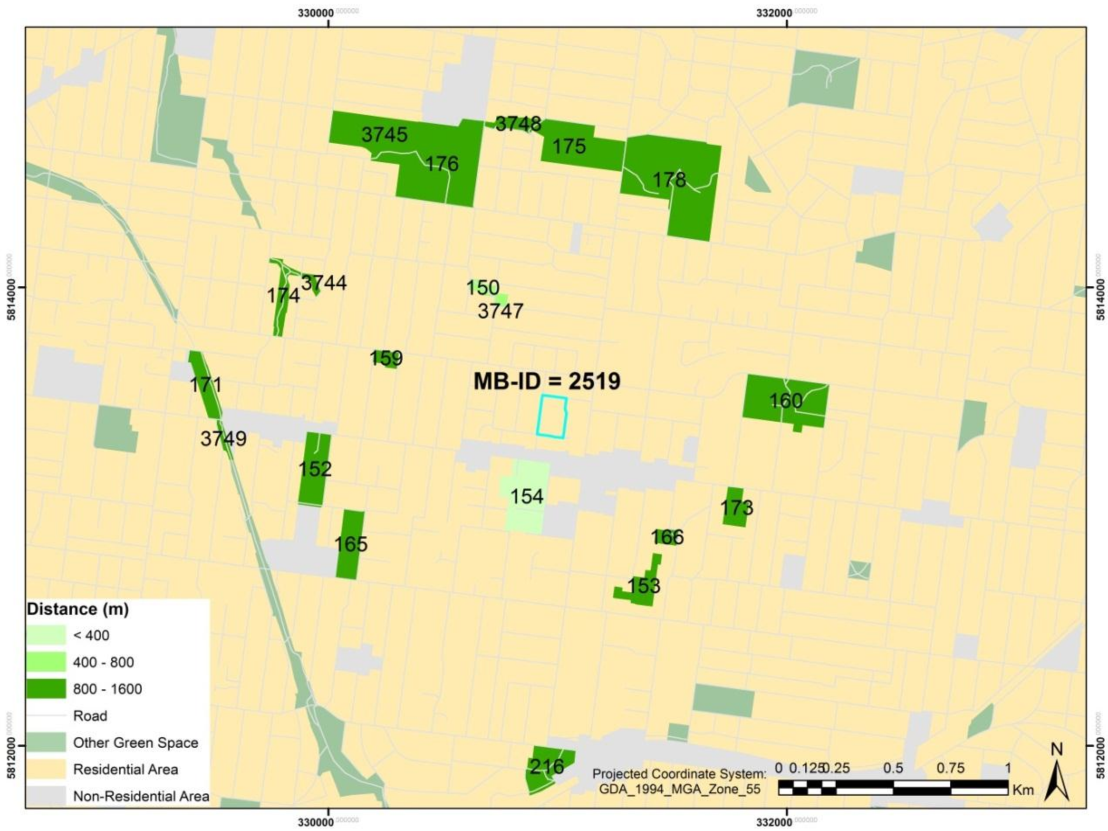
In table 3.4.3, seven summary statistics (including total population, young population, adult population, old population, number of MB, area of MB and average distance) are compared for three different catchment / neighbourhood zones specified with the following three distance bands: 0-400 m, 0-800 m, 0-1600 m. It can be seen that all summary statistics increases as the size of neighbourhood / catchment increases.

Table 3.4.3 Summary statistics for green space (ID=154) centred catchment zones

Distance from a Green Space (ID = 154) to MBs	[0 - 400] m	[0 - 800] m	[0 - 1600] m
Total Population	1249	4213	18410
Young Population	200	640	3152
Adult Population	840	2784	11986
Old Population	209	789	3272
Number of MB	15	51	204
Area of MB (ha)	37.06	129.50	572.46
Average Distance (m)	267.2	509.0	1061.0



Map 3.4.2 Residential MBs within different catchment / neighbourhood zones of Green space 154



Map 3.4.3 Green spaces within different catchment / neighbourhood zones of MB 2519.

Table 3.4.4 Summary statistics for a MB (ID=2519) centred neighbourhood / catchment zones.

MB_ID = 2519	**[0-400] m**	**[0-800] m**	**[0-1600] m**	**Road Network Distance (m) from MB 2519 to the 20 green spaces within 1600 m**
Distance To Closest Green Space (m)	193.9	193.9	193.9	
Average Distance Neighbourhood Green Spaces (m)	193.9	568.1	1153.0	
Area of Green Spaces within Specified Distance (ha)	5.60	6.49	70.99	
Number of Green Spaces within Specified Distance	1	3	20	
ID of the Closest Green Space (= 154)	154	154	154	193.9
		3747	3747	711.7
		150	150	798.8
			159	842.0
			166	1009.3
			173	1019.2
			152	1082.0
			160	1103.2
			153	1107.3
			176	1195.2
			165	1201.6
			178	1304.4
			175	1310.9
			174	1357.9
			3748	1416.6
			3744	1440.2
			3749	1444.7
			171	1446.8
			216	1518.2
ID of the Farthest Green Space (= 3745)			3745	1557.1

3.5 Accessibility Measures

In this study, three key elements are involved in measuring gravity-based accessibility to green space, including:

- the location and size of residential population, used as proxies for assessing the spatial variation in level of demand for green space;
- the location and attractiveness score of green space, used as proxies for assessing the spatial variation in level of green space provision; and
- the road network constrained walking distances between residential areas (represented by MB boundaries) and green spaces, used as a proxy for assessing the spatial variation in level of travel impedance, and hence

accessibility, to neighbourhood green space by local residents across the study area (Figure 3.5.1).

Figure 3.5.1 Key components of accessibility measure in this study

As noted in in Chapter 2, walking is the most frequently used travel mode for accessing neighbourhood green spaces in urban areas, and different accessibility measures may produce different spatial patterns of accessibility. Therefore, in this study the accessibility to green space is measured based on the walking distance along local road networks as outlined in Section 3.4.3. The modified 2SFCA and the modified 3SFCA methods, taking continuous distance decay into account, have both been implemented for measuring accessibility to green space from residential MBs.

3.5.1 Modified 2SFCA method

The modified 2SFCA method is a special case of the gravity model, keeps most of the advantages of a gravity model, and has been implemented in the ArcGIS environment in two steps in this study.

At the 1st step, for each green space location j,

- determine its attractiveness score Att_j;
- indentify all residential MB locations (k) that are within its neighbourhood or catchment defined by a threshold travel distance d_0 from j along road network links;
- discount P_k, the population at location k, using $w_{d(k,j)}$, a specific weight determined from a continuous distance decay function, according to $d(k,j)$, the specific distance between location k and location j;
- sum up all discounted populations within catchment j, as the potential users for green space j;

- calculate R_j, the per capita green space provision at j, as the ratio of Att_i and the summed, discounted populations from all residential locations within catchment j (Eqn 3.9):

$$R_j = \frac{Att_j}{\sum_{k \in (d_{kj} \le d_0)} P_k w_{d(k,j)}} \qquad \text{(Eqn 3.9)}$$

At the 2nd step, for each residential MB location i,

- identify all green spaces (*j*) that are within its neighbourhood or catchment defined by a threshold travel distance d_0 from i along road network links;
- discount each R_j at location j, using $w_{d(i,j)}$, a specific weight determined from a continuous distance decay function, according to $d(i,j)$, the specific distance between location i and location j;
- sum up all discounted per capita green space provisions within catchment i, into A_i, the potential per capita green space accessible from location i, as the measure of spatial accessibility to green space from location i (Eqn 3.10):

$$A_i = \sum_{j \in (dij \le d_0)} R_j w_{d(i,j)} \qquad \text{(Eqn 3.10)}$$

Two continuous distance decay functions, Gaussian function and Butterworth filter (n = 8) have been implemented in this study to determine the values for both $w_{d(k,j)}$ and $w_{d(i,j)}$. Although both functions are able to produce a flat 'pass-band' region with no spatial impedance, followed by a smooth decay in a transition zone such that zero weighting is approximated at the threshold distance (Figure 3.5.2), the distance decay weight based on the Gaussian function decreases faster at shorter distances than that based on the Butterworth filter (n = 8). For example, from 0 m to 230 m, the Gaussian curve dropped almost 20 precent while the Butterworth filter curve remains relatively stable.

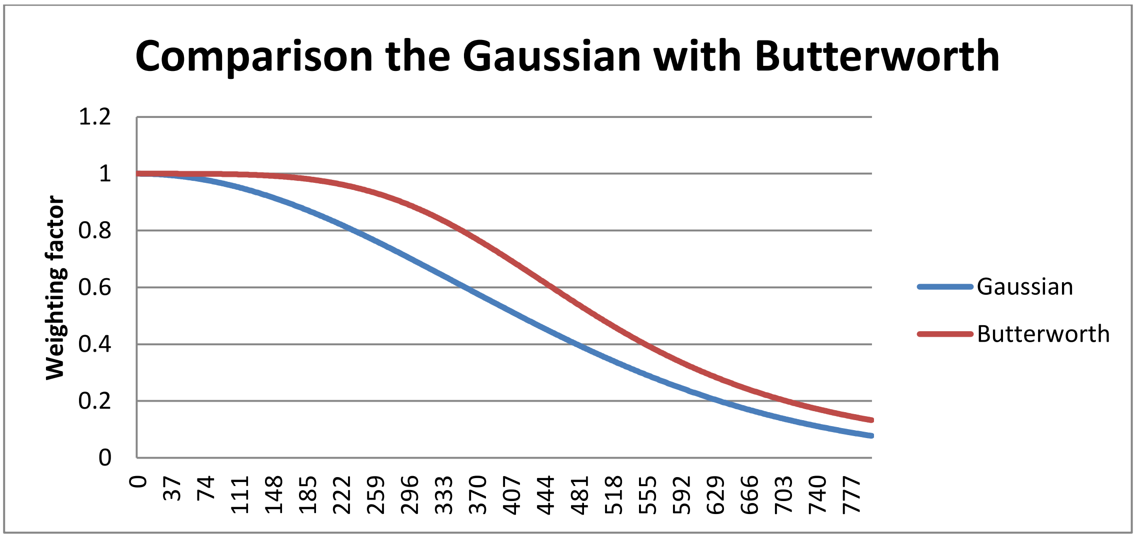


Figure 3.5.2 Comparison of Gaussian decay curve and Butterworth filter curve

In this study, Eqn 3.11 is implemented for calculating distance decay weights based on the Gaussian function, and Eqn 3.12 is implemented for calculating distance decay weights based on the Butterworth filter:

$$w_{d(k,j)} = \frac{1}{e^{d^2_{(k,j)}/d^2_{pass}}} = \frac{1}{e^{d^2_{(k,j)}/1000^2}} \qquad \text{(Eqn 3.11)}$$

$$w_{d(k,j)} = \frac{1}{\sqrt{1+(d_{(k,j)}/d_{pass})^n}} = \frac{1}{\sqrt{1+(d_{(k,j)}/1000)^8}} \qquad \text{(Eqn 3.12)}$$

where $d_{(k,j)}$ is the network distance from MB k to green space j, and d_{pass} is the break point distance used for both the Gaussian function and the Butterworth filter. In this study, d_{pass} is set as 1000m, when a catchment threshold distance of 1600 m (i.e. d_0 = 1600 m) is set for all age groups and used for both the Gaussian function and the Butterworth filter, and the corresponding power coefficient n is defined as 8 for the Butterworth filter. The green space beyond 1600 m from all residential MB locations are assumed in this study to be inaccessible to residents within the MMA, since in practical terms, people are often reluctant to visit a green space beyond 20 minutes of walking from home.

3.5.2 Modified 3SFCA method

Since local population's demand for a green space will decrease when other adjacent green spaces are also available, the modified 2SFCA method tends to overestimate demand for green space from local population.

To minimize demand overestimation from the modified 2SFCA method, a modified 3SFCA method is also implemented in this study. The modified 3SFCA method assumes that the demand from a residential location i for a specific green space j is influenced by the travel distance to green space j as well as the travel distances to other green spaces within the specified catchment or neighbourhood of location i.

In addition to the two step procedure outlined for the modified 2SFCA method, the modified 3SFCA method is implemented in the ArcGIS environment using three steps in this study, by first assigning a competition weight for each pair of population-green space sites, determined from either the Gaussian function or the Butterworth filter.

In Step 1, the selection weight between residential MB location *i* and green space j, is determined for each pair of residential location i and green space j, as follows:

- determine the catchment of a residential MB location i, defined by a threshold travel distance d_0 from i along road network links;
- identify all green spaces *k* within catchment i;
- discount Att_k, the attractiveness score for each green space within catchment i, using a specific distance decay weight, $w_{d(i,k)}$, determined from either the Gaussian function or the Butterworth filter, according to $d(i,k)$, the specific travel distance between location i and location k;
- sum up the discounted attractiveness scores for all green spaces within catchment i;
- discount Att_j, the attractiveness score for green space j, using a specific distance decay weight, $w_{d(i,j)}$, determined from either the Gaussian function or the Butterworth filter, according to $d_{(i,j)}$, the specific travel distance between location i and location j;
- calculate the selection weight between residential MB location *i* and green space j by Eqn 3.11:

$$K_{ij} = \frac{Att_j W_{d(i,j)}}{\sum_{k \in (d_{ik} \le d_0)} Att_k w_{d(i,k)}} \qquad \text{(Eqn 3.13)}$$

In Step 2, for each green space j:

- determine its attractiveness score Att_j;
- identify all residential MB locations (t) that are within its neighbourhood or catchment, defined by a threshold travel distance d_0 from j along road network links;
- discount P_t, the population at location t, using both $w_{d(t,j)}$ (a specific distance decay weight determined from either the Gaussian function or the Butterworth filter, according to $d(t,j)$, the specific travel distance between location t and location j) and K_{tj} (the selection weight between residential MB location t and green space j);
- sum up all discounted populations within catchment j, as the potential users for green space j;
- calculate R_j, the per capita green space provision at j, as the ratio of Att_j and the summed, discounted populations from all residential locations within catchment j (Eqn 3.12):

$$R_j = \frac{Att_j}{\sum_{t \in (d_{tj} \le d_0)} K_{tj} P_t w_{d(t,j)}} \qquad \text{(Eqn 3.14)}$$

In Step 3, for each residential MB location i:

- identify all green spaces (m) that are within its neighbourhood or catchment defined by a threshold travel distance d_0 from i along road network links;
- discount each R_m at location m, using both $w_{d(i,m)}$ (a specific distance decay weight determined from either the Gaussian function or the Butterworth filter, according to $d_{(i,m)}$, the specific travel distance between location i and location m) and K_{im} (the selection weight between residential MB location i and green space m);
- sum up all discounted per capita green space provisions within catchment i, into A_i, the potential per capita green space accessible from location i, as the measure of spatial accessibility to green space from location i (Eqn 3.15):

$$A_i = \sum_{m \in (d_{im} \le d_0)} R_m w_{d(i,m)} \quad \text{(Eqn 3.15)}$$

3.5.3 Mean accessibility measures

Green space attractiveness is deemed in this study, to be specific for each of the four age groups (young, adult, old and total), and the M2SFCA and the M3SFCA methods are both modified by two different continuous distance decay functions (i.e. the Gaussian function and the Butterworth filter). Consequently, 16 different accessibility measures are implemented (Table 3.5.3). To simplify the presentation of the results, a mean accessibility measure is derived for each of the four age groups as follows (Eqn 3.16):

$$MA_i = \frac{A_{M2SFCA\_G\_i} + A_{M2SFCA\_B\_i} + A_{M3SFCA\_G\_i} + A_{M3SFCA\_B\_i}}{4} \quad \text{(Eqn 3.16)}$$

where i indicates one of the four age groups of young, adult, old, and total population.

Table 3.5.3 Accessibility measures implemented in this study

		Young (0 – 14)	Adult (15 – 64)	Old (65 – 115)	Total (0 – 115)
Modified 2SFCA	**2G**	Y2G	A2G	O2G	T2G
	2B	Y2B	A2B	O2B	T2B
Modified 3SFCA	**3G**	Y3G	A3G	O3G	T3G
	3B	Y3B	A3B	O3B	T3B
Mean Accessibility Measures		**MA_Y**	**MA_A**	**MA_O**	**MA_T**

Results related to these mean accessibility measures are presented in Chapter 5, and results associated with the other 16 different accessibility measures can be found in Appendices 1 and 2.

3.6 Spatial Variations and Spatial Clusters

Quintile-based thematic maps are used in this study to show spatial variations in population density, population concentration, green space accessibility, and the level of locational disadvantage. Getis-Ord Gi* based hotspot analysis is used to identify and locate spatial clusters of high population density, high population concentration, low green space accessibility, and high level of locational disadvantage. Spatial clusters of high locational disadvantage indicate residential areas where green space accessibilities or green space provisions are low and population demand for green space are high .

It is assumed in this study that the accessibility measured at each residential MB indicates the per capita green space available to, or the level of green space provision accessible from that MB Based on the mean accessibility scores, each residential MB in the study area is assigned its respective quintile rank of green space provision: ① (low accessibility), ② (medium -), ③ (medium), ④ (medium +), or ⑤ (high accessibility).

It is also assumed in this study that the level of demand for green space at each residential MB is positively related to population density and population concentrations of specific age groups. Hence, the level of demand for green space for each residential MB is determined in terms of ranked population density for total population. For young, adult and old populations or age groups, the level of demand for green space at each residential MB is determined in terms of both the ranked population density and the ranked population concentration. Each residential MB in the study area is assigned its respective quintile rank of population density or population concentration: ① (low population density or population concentration), ② (medium -), ③ (medium), ④ (medium +), or ⑤ (high population density or population concentration). The rules followed in the study for assigning each residential MB the level of demand for green space are summarised in Table 3.6.1. Any residential MB that satisfies the following conditions is assigned the highest level of demand for green space (indicated by ⑤ in Table 3.6.1): density ranked ⑤ (high) and concentration ranked ⑤ (high); density ranked ⑤ (high) and concentration ranked ④ (medium+); and density ranked ④ (medium+) and concentration ranked ⑤ (high).

For each specific age group, the level of locational disadvantage at each residential MB is determined based on the relationship between the ranked level of green space provision and the ranked level of green space demand. The rules followed in the study for assigning each residential MB the level of locational disadvantage are summarised in Table 3.6.2. Any residential MB that satisfies the following conditions is assigned the highest level of locational disadvantage (indicated by ⑤ in Table

3.6.2): provision ranked ① (low) and demand ranked ⑤ (high); provision ranked ① (low) and demand ranked ④ (medium+); and provision ranked ② (medium -) and demand ranked ⑤ (high).

Table 3.6.1 Levels of demand for green space* (*Personal discussion with Dr Liu)

Concentration / Density	Low ①	Medium – ②	Medium ③	Medium + ④	High ⑤
Low ①	①	①	②	②	③
Medium – ②	①	②	②	③	④
Medium ③	②	②	③	④	④
Medium + ④	②	③	④	④	⑤
High ⑤	③	④	④	⑤	⑤

Table 3.6.2 Levels of locational disadvantage (Personal discussion with Dr Liu)

Provision / Demand	Low ①	Medium – ②	Medium ③	Medium + ④	High ⑤
Low ①	③	②	②	①	①
Medium – ②	④	③	②	②	①
Medium ③	④	④	③	②	②
Medium + ④	⑤	④	④	③	②
High ⑤	⑤	⑤	④	④	③

3.7 Summary

This chapter presents the research methodology applied in this study for measuring and mapping spatial variations in green space accessibility and spatial clusters of residential areas with locational disadvantage.

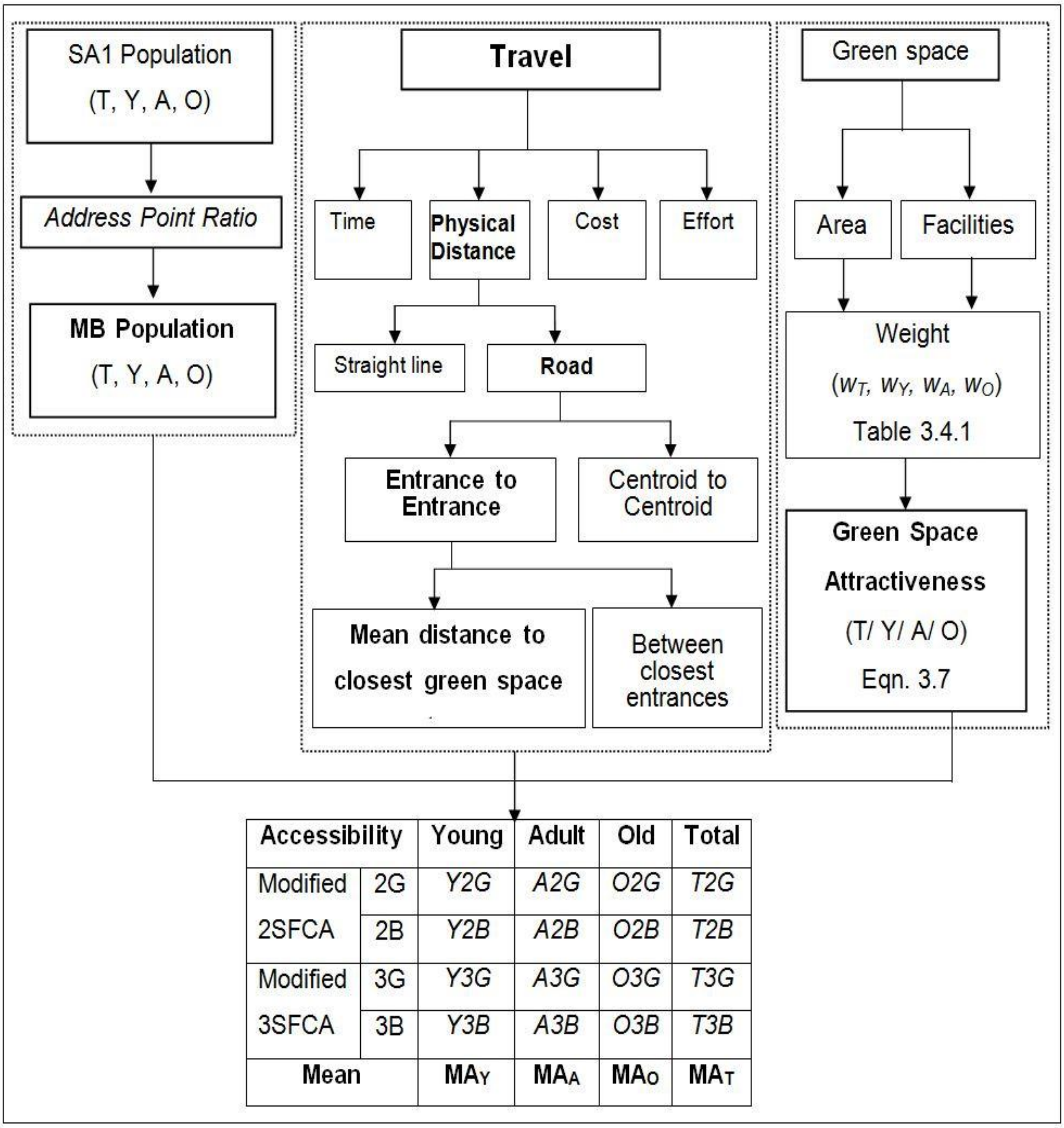
The MMA is selected as the case study area due to its urban settings, long history of green space planning, and rich and accessible spatial datasets, including residential addresses and population, green space, transportation and other relevant datasets. Comprehensive literature reviews also indicate that few studies, similar to the one presented in this thesis, exist for the MMA.

Age-group-based green space accessibility and the level of locational disadvantage are measured and determined for each residential MB in the study area, using gravity-based floating catchment area measures, quintile-based ranks, and spatial overlay operations, through the following procedures:

- disaggregate the SA1 level populations into MB level, using address point ratios;

- calculate the population density (for all four age groups) and population concentration (only for the young, adult and age groups);
- determine the level of green space demand according to population density (for total population) or according to both the population density and the population concentration (for the young, adult and age groups);
- determine the specific attractiveness score for each green space with the neighbourhood of each residential MB in the MMA;
- measure the travel impedance between each green space and residential MB in terms of entrance-to-entrance walking distance along local roads;
- calculate the floating catchment area based accessibility scores using four different methods, including M2SFCA_B, M2SFCA_G, M3SFCA_B and M3SFCA_G;
- calculate the mean accessibility scores and determine the level of green space provision; and
- determine the level of locational disadvantage based on both level of green space demand and level of green space provision.

Quintile-based thematic maps are then generated to show spatial variations in population density, population concentration, green space accessibility, and level of locational disadvantage. Getis-Ord Gi* based hotspot analysis is used to identify and locate spatial clusters of high population density, high population concentration, low green space accessibility, and high level of locational disadvantage. Spatial clusters of high locational disadvantage indicate residential areas where green space accessibilities or green space provisions are low and population demand for green space are high. Figure 3.7.1 and Figure 3.7.2 provide the flow charts of this methodology.



Accessibility		Young	Adult	Old	Total
Modified 2SFCA	2G	*Y2G*	*A2G*	*O2G*	*T2G*
	2B	*Y2B*	*A2B*	*O2B*	*T2B*
Modified 3SFCA	3G	*Y3G*	*A3G*	*O3G*	*T3G*
	3B	*Y3B*	*A3B*	*O3B*	*T3B*
Mean		**MA_Y**	**MA_A**	**MA_O**	**MA_T**

Figure 3.7.1 The procedure implemented for measuring accessibility to green space

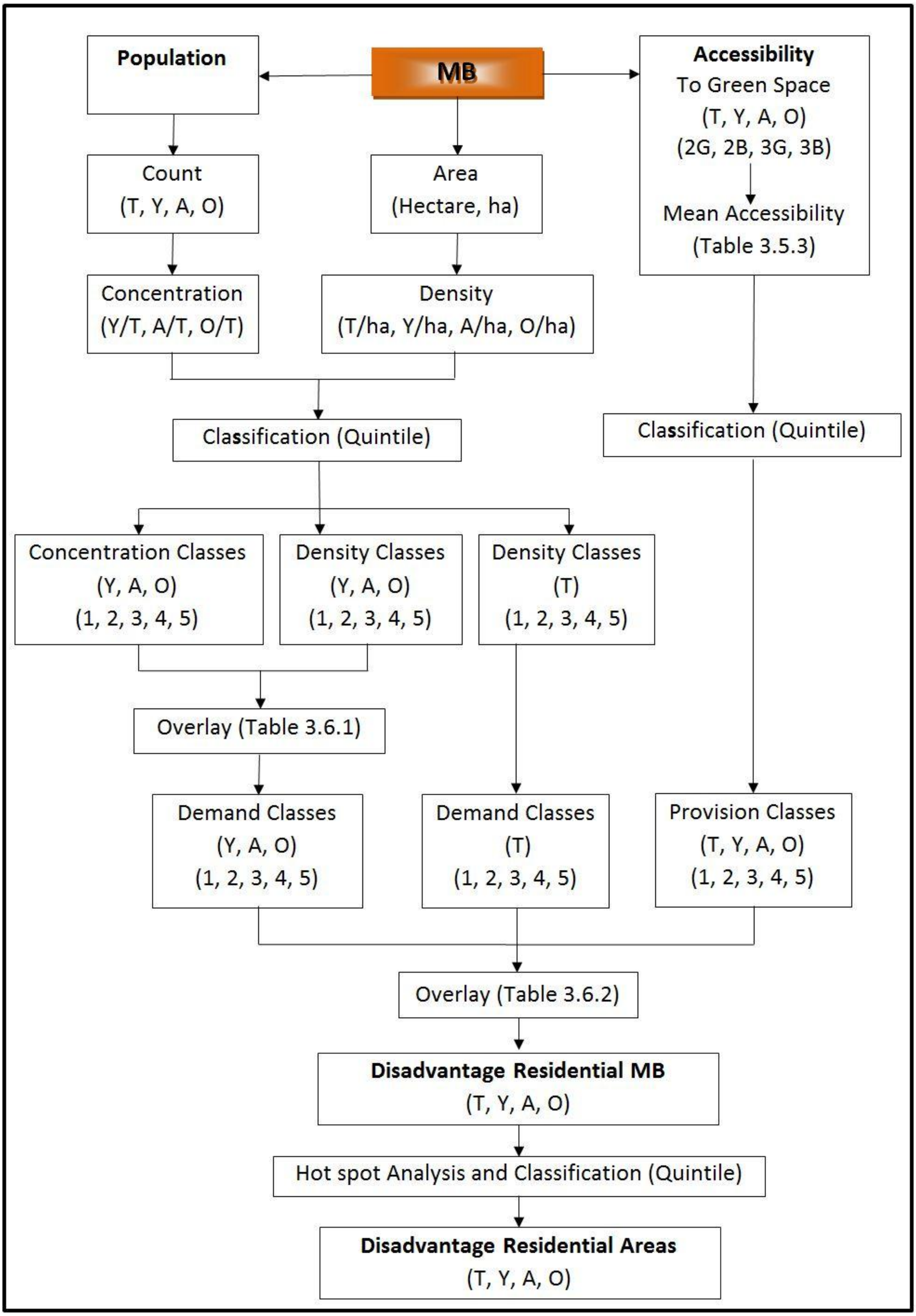


Figure 3.7.2 The procedure implemented for identifying disadvantaged residential areas

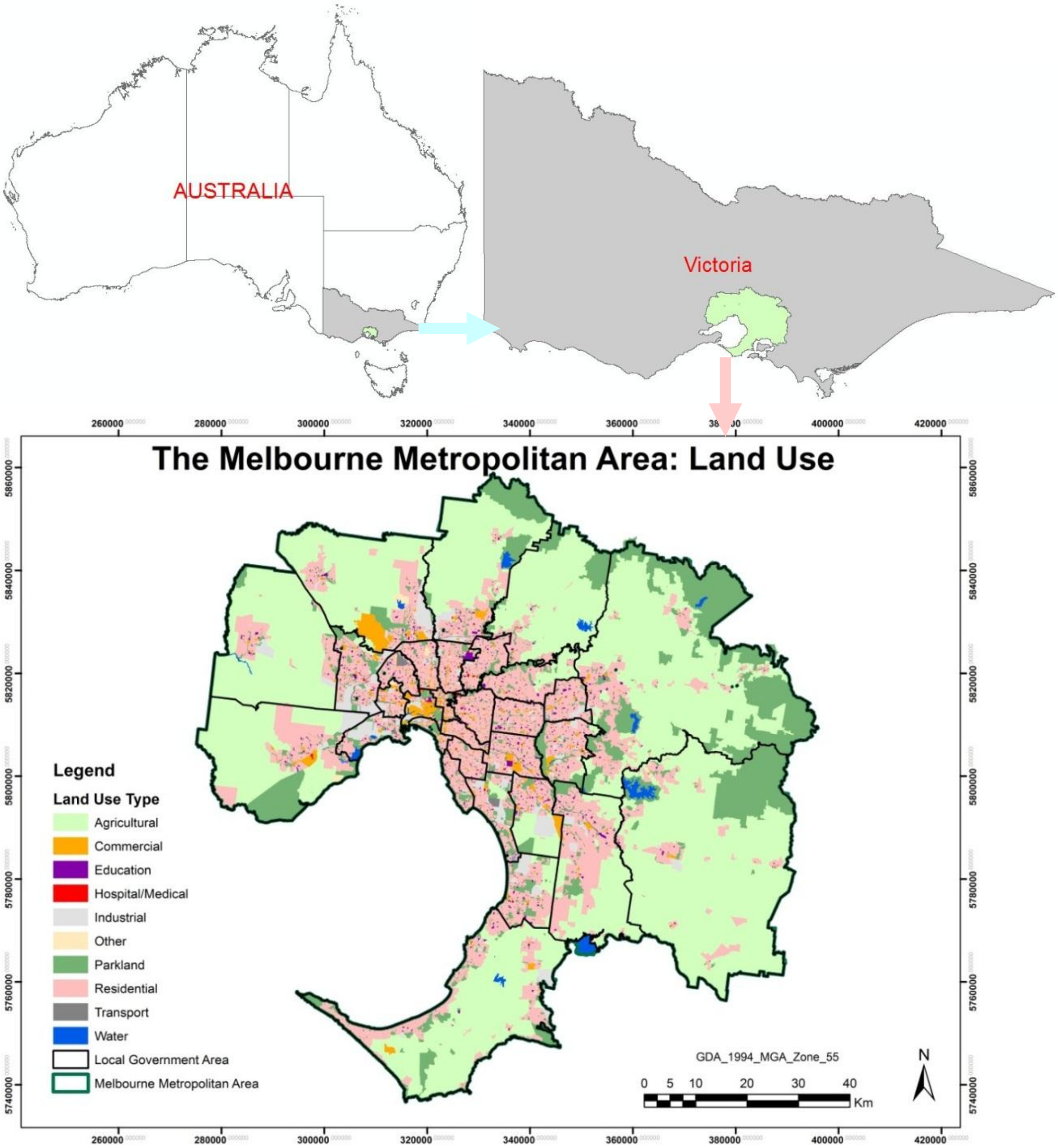
CHAPTER 4 STUDY AREA AND DATA SOURCES

4.1 The Study Area: Location and Land Use

Melbourne is the capital, and the most populous city, in the state of Victoria, and the second most populous city in Australia. The study area is centred at 37° 48′ 49″ S, 144° 57′ 47″ E in WGS84, with a total population of over 3.8 million residing over an area of over 760000 ha. The whole study area consists of 31 Local Government areas (LGAs) or 550 localities. According to ABS 2011 census, the study area contains 9549 Statistical Area 1 (SA1) units and 53003 Mesh Blocks (MBs).

Map 4.1.1 shows the spatial distribution of major land use types, and Figure 4.1.1 provides a statistical summary of the land use structures. Spatially, residential areas concentrate towards the centre of the study area, and are surrounded by a broad zone of agricultural fields. Green spaces of various sizes and shapes are scattered among the residential areas and aligned with major river valleys. Some large areas of green spaces, mainly national parks, are located along the NE edge of the study area. Statistically, over 55% of the study area are used for agriculture, a little more than 22% for residential and about 16% (over 118000 ha) is parkland and green space. For the remaining 7% of the area, industrial land use take a little over 3%, commercial land use close to 2%, education and waterbody each close to 1 % and less than 0.3% are used for transportation. These statistics are just a rough indication of the land use structure,which are derived from the ABS 2011 census data at the MB level.

Several considerations have resulted in the selection of the MMA as the study area for this research. Firstly, MMA-wide neighbourhood planning has been very active from the 1929 city planning to the latest Melbourne 2030 planning. Therefore, many MMA-wide background information regarding public services in relationship to neighbourhood planning is available (VDSE 2002). Secondly, the MMA is a typical urban area, and there is a great deal of spatial data available, including census, road network, green space location. These data sets are essential for carrying out this current study. Thirdly, Melbourne is identified as one of the most liveable cities in the world. One of the major contributory elements to this liveability is the quality and amount of green space, as indicated by many local residents in a recent household survey undertaken by the government (SGV 2008).



Map4.1.1 Location and land use pattern of the Melbourne Metropolitan Area.

Land Use Type	Area	%
Agricultural	424958	55.19%
Commercial	13167.7	1.71%
Education	5749.63	0.75%
Hospital	458.7	0.06%
Industrial	23647.6	3.07%
Parkland	122424	15.90%
Residential	170115	22.17%
Transport	2254.93	0.29%
Waterbody	5426.5	0.70%
Other	1182.22	0.15%

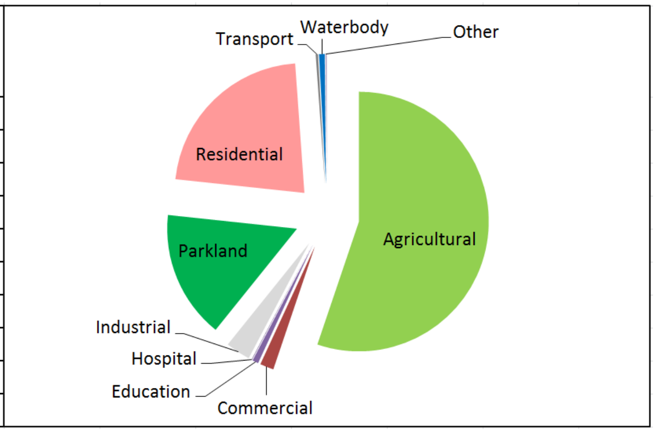


Figure 4.1.1 The ratio of land use in study area

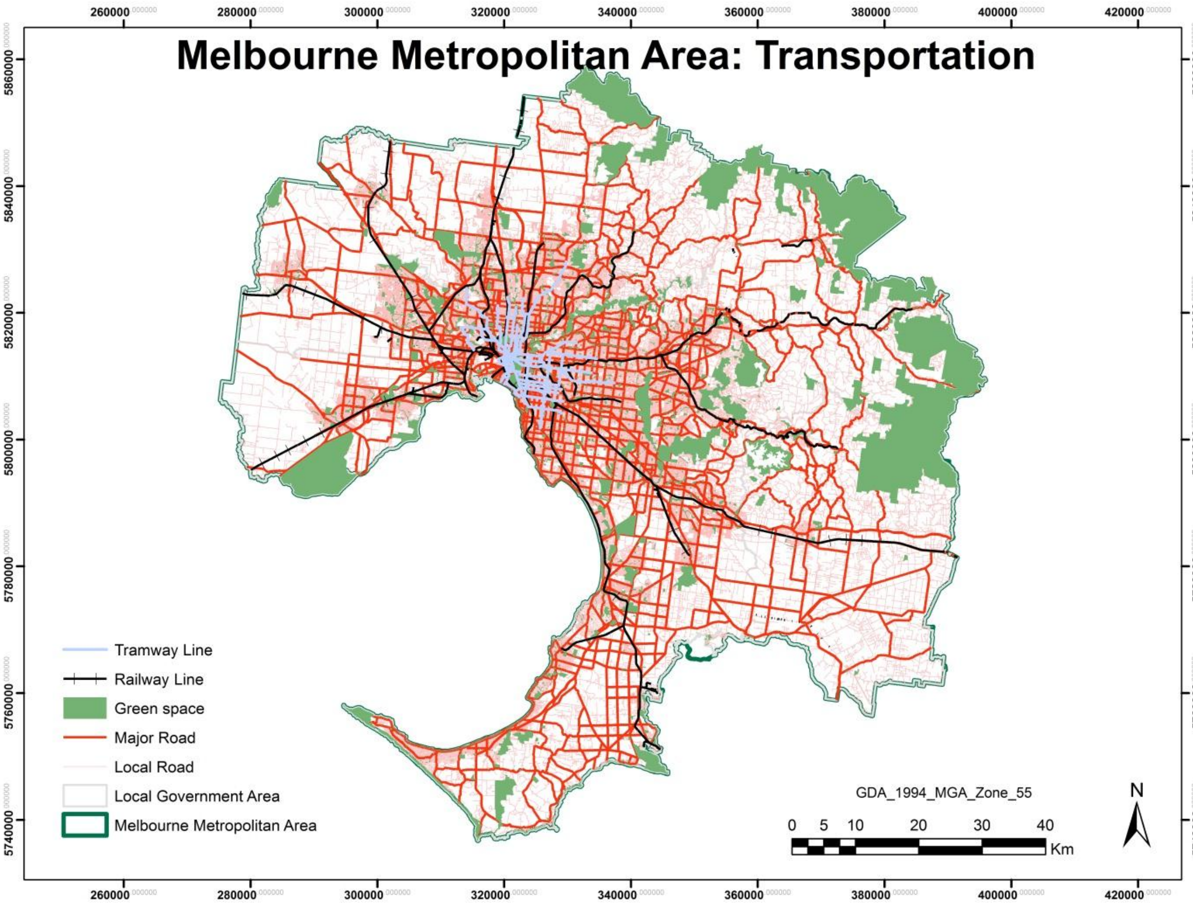
4.2 Transportation

The study area has a very developed transportation infrastructure, consisting of rail based tramways and railways and dense road networks (Map 4.2.1). In this study, however, walking along local roads are regarded as the most popular mode of travel for urban residents to access neighbourhood green spaces in the MMA, and all walking distance calculations are based on the local roads.

In summary, the MMA has a total road length close to 36000 km, consisting of about 6000 km of major roads and over 30000 km of local roads. On average, the MMA has about 40 m local road per hectare and about 8 m local road per person. Table 4.2.1 provides some LGA-based summary statistics, such as the lengths of major roads and local roads, the lengths of local roads per unit of area or per person, as well as the total population and area. The ratio of local road length (m) and LGA area (ha) is regarded as local road density (m/ha), and the ratio of local road length (m) and LGA population is regarded as per capita local road length (m/person). As can be expected, the peripheral LGAs, like Cardinia, Yarra Ranges and Nillumbik, have a lower density and longer length of local road per person, compared to LGAs close to the CBD of the MMA, such as Yarra, Port Phillip and Stonnington - which have much higher local road densities, as shown in Map 4.2.2 and in Map 4.2.3.

In terms of local road length per capita (Figure 4.2.1), the top three LGAs include Cardinia (45.98 m / person), Yarra Ranges (26.14 m / person) and Nillumbk (25.17 m / person), and the bottom three are Port Philip (3.15 m / person), Glen Eira (3.25 m / person) and Stonnington (3.48 m / person). In terms of local road density (as shown in Figure 4.2.2), the top three LGAs include Yarra (143.02 m / ha), Port Philip (133.35 m / ha) and Stonnington (125.10 m / ha), and the bottom three LGAs are Melton (21.15 m / ha), Cardinia (22.47 m / ha) and Yarra Ranges (26.14 m / ha).

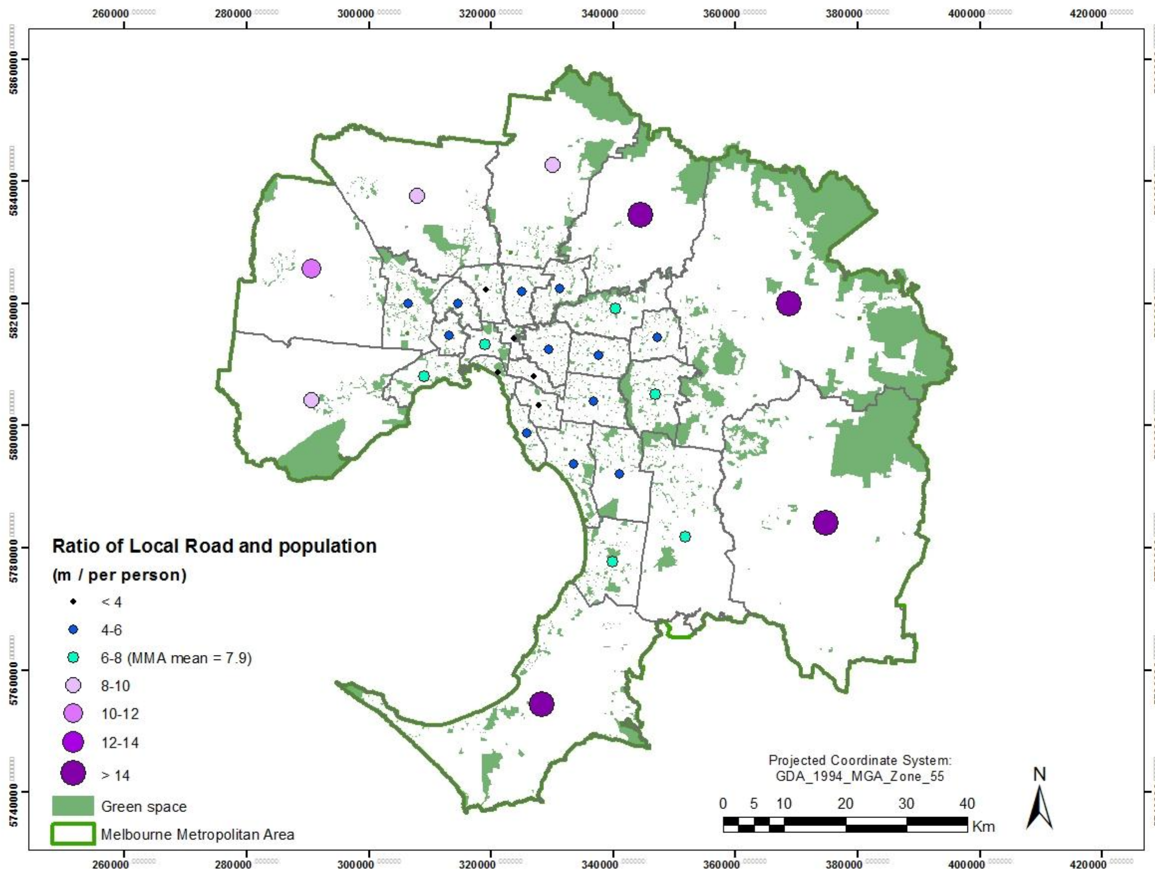
Note: *Due to the fact that quite a large portion of the Yarra Ranges LGA with little residential land use is excluded from the study area adopted in this research, all LGA-based summary statistics for the Yarra Ranges are referring only to the included portion of it and are not applicable to the whole Yarra Ranges LGA. Due to the same reason, any LGA-based rankings presented in this study should be viewed in the same manner.*



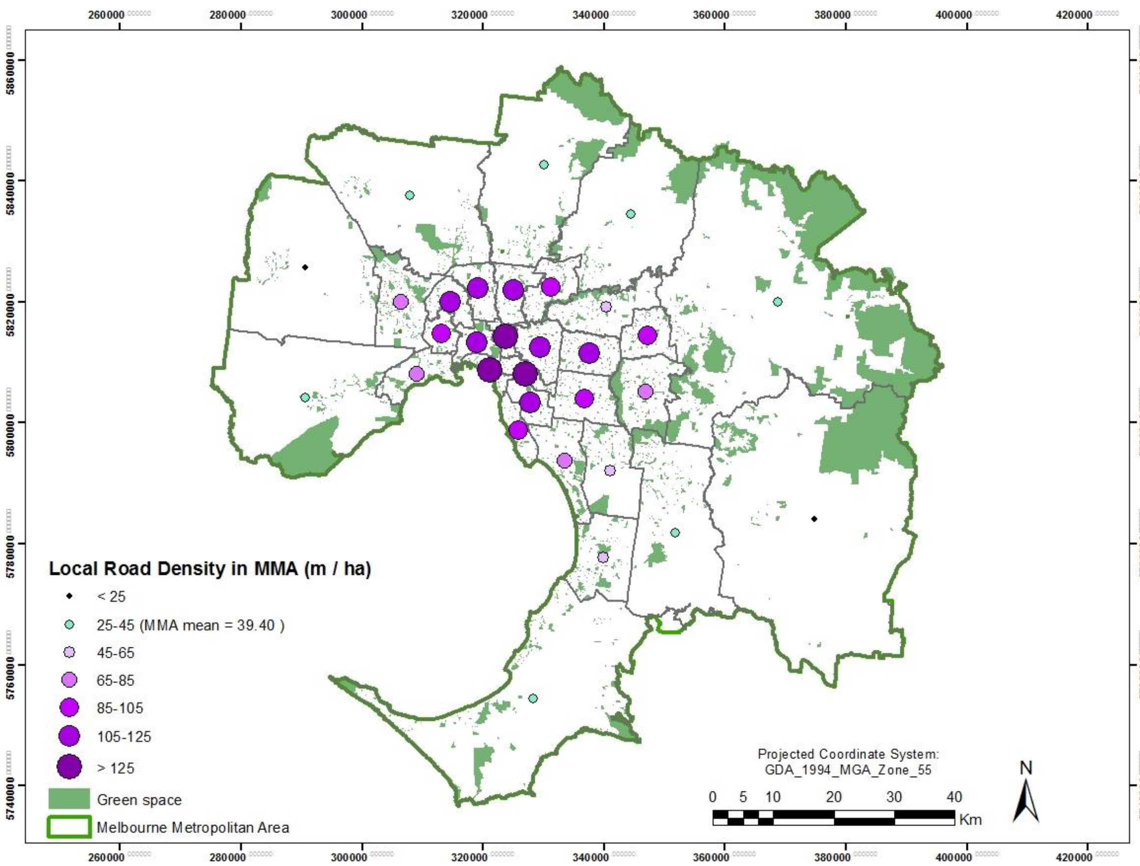
Map 4.2.1 The multi transportation ways in the MMA

Table 4.2.1 The basic statistics about the LGA road network

LGA	Major Road (m)	Local Road (m)	Local Road Density (m / ha)	Local Road (m / person)	Total Population	Size of LGA (ha)
BANYULE	82205.11	624375.33	99.69	5.28	118249	6263.11
BAYSIDE	92778.48	374226.48	101.31	4.13	90510	3693.88
BOROONDARA	137875.65	655380.37	108.88	4.14	158363	6019.11
BRIMBANK	211284.34	1025454.12	83.08	5.64	181824	12343.58
CARDINIA	506369.16	2876026.39	22.47	45.93	62612	127988.86
CASEY	332137.98	1751462.93	44.15	7.02	249560	39667.00
DAREBIN	97146.92	577318.04	107.97	4.26	135456	5346.93
FRANKSTON	164014.19	801134.78	61.89	6.38	125535	12944.90
GLEN EIRA	88847.30	424166.77	109.63	3.25	130633	3868.90
GREATER DANDENONG	177128.24	790457.45	61.05	5.82	135718	12947.41
HOBSONS BAY	95045.81	542439.74	84.53	6.44	84203	6417.41
HUME	274287.95	1551113.38	30.83	9.44	164354	50313.44
KINGSTON	143798.37	742246.33	81.29	5.29	140201	9130.87
KNOX	146710.94	888197.72	78.01	6.01	147760	11386.18
MANNINGHAM	136198.17	724917.76	63.96	6.66	108919	11333.15
MARIBYRNONG	60755.89	320148.14	102.44	4.62	69371	3125.09
MAROONDAH	93249.09	533297.53	86.86	5.22	102102	6139.90
MELBOURNE	151319.29	403711.92	107.64	6.61	61065	3750.52
MELTON	188911.70	1116014.09	21.15	10.54	105846	52774.10
MONASH	154705.91	853959.88	104.81	5.03	169856	8147.46
MOONEE VALLEY	97587.75	474408.75	110.03	4.49	105567	4311.59
MORELAND	105495.24	585626.21	114.74	3.99	146616	5103.97
MORNINGTON PENINSULA	608427.28	2396075.80	33.19	17.73	135143	72202.52
NILLUMBIK	185150.73	1284525.54	29.73	25.17	51029	43213.25
PORT PHILLIP	86086.39	272432.84	133.35	3.15	86517	2042.97
STONNINGTON	89085.15	320667.75	125.10	3.48	92196	2563.38
WHITEHORSE	111232.52	689966.87	107.35	4.55	151533	6427.15
WHITTLESEA	275870.52	1458068.38	29.82	9.62	151605	48899.28
WYNDHAM	283811.46	1430564.06	26.41	9.04	158212	54161.29
YARRA	68082.57	279721.36	143.02	3.81	73323	1955.80
YARRA RANGES	501370.59	3482742.82	26.14	26.94	129270	133240.59
MMA	**5746970.70**	**30250849.55**	**39.40**	**7.91**	**3823148**	**767723.62**



Map 4.2.2 The ratio of local road and population in LGA



Map 4.2.3 The density of local road in LGA

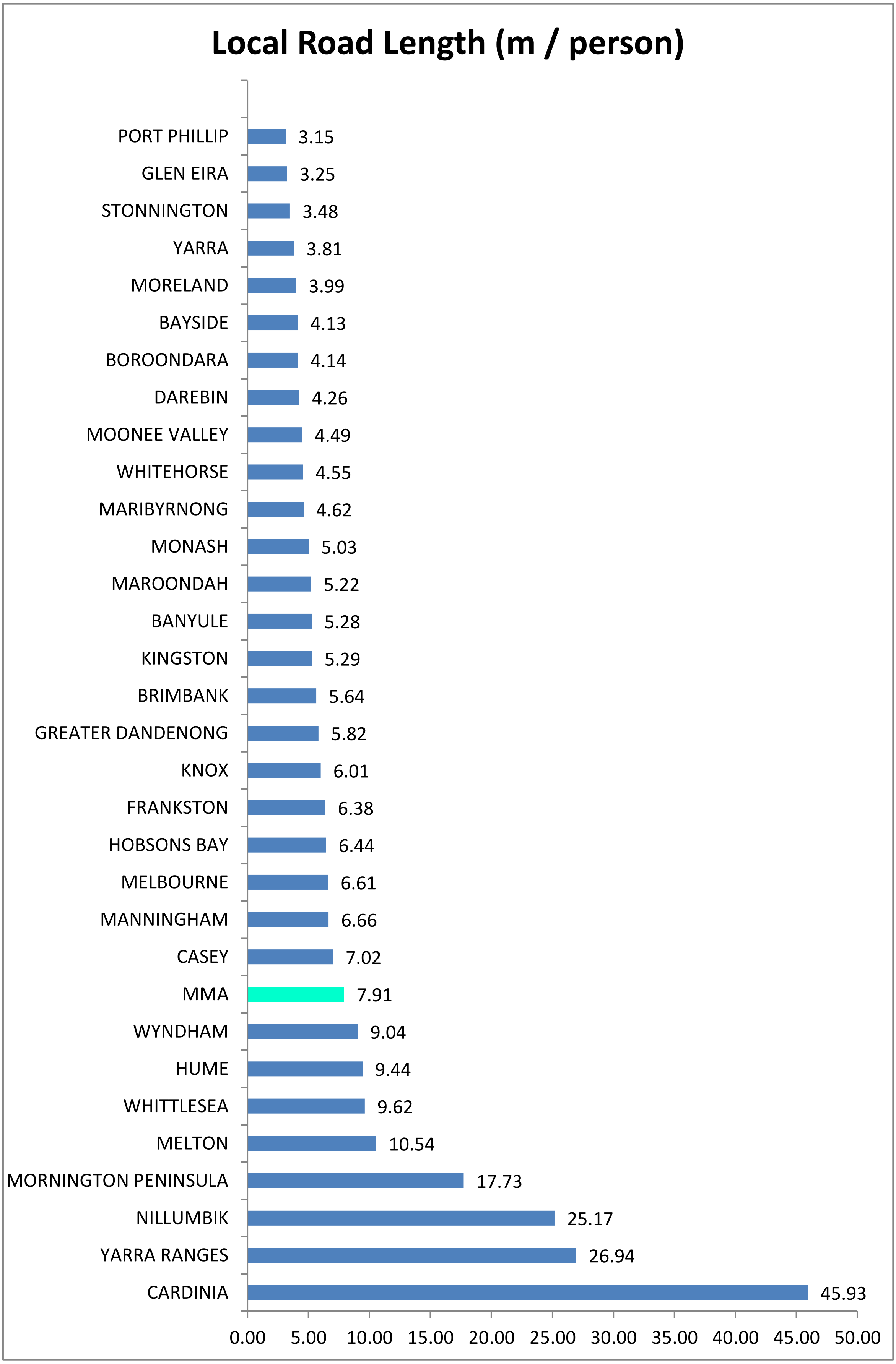


Figure 4.2.1 The ranking of local road length in LGAs

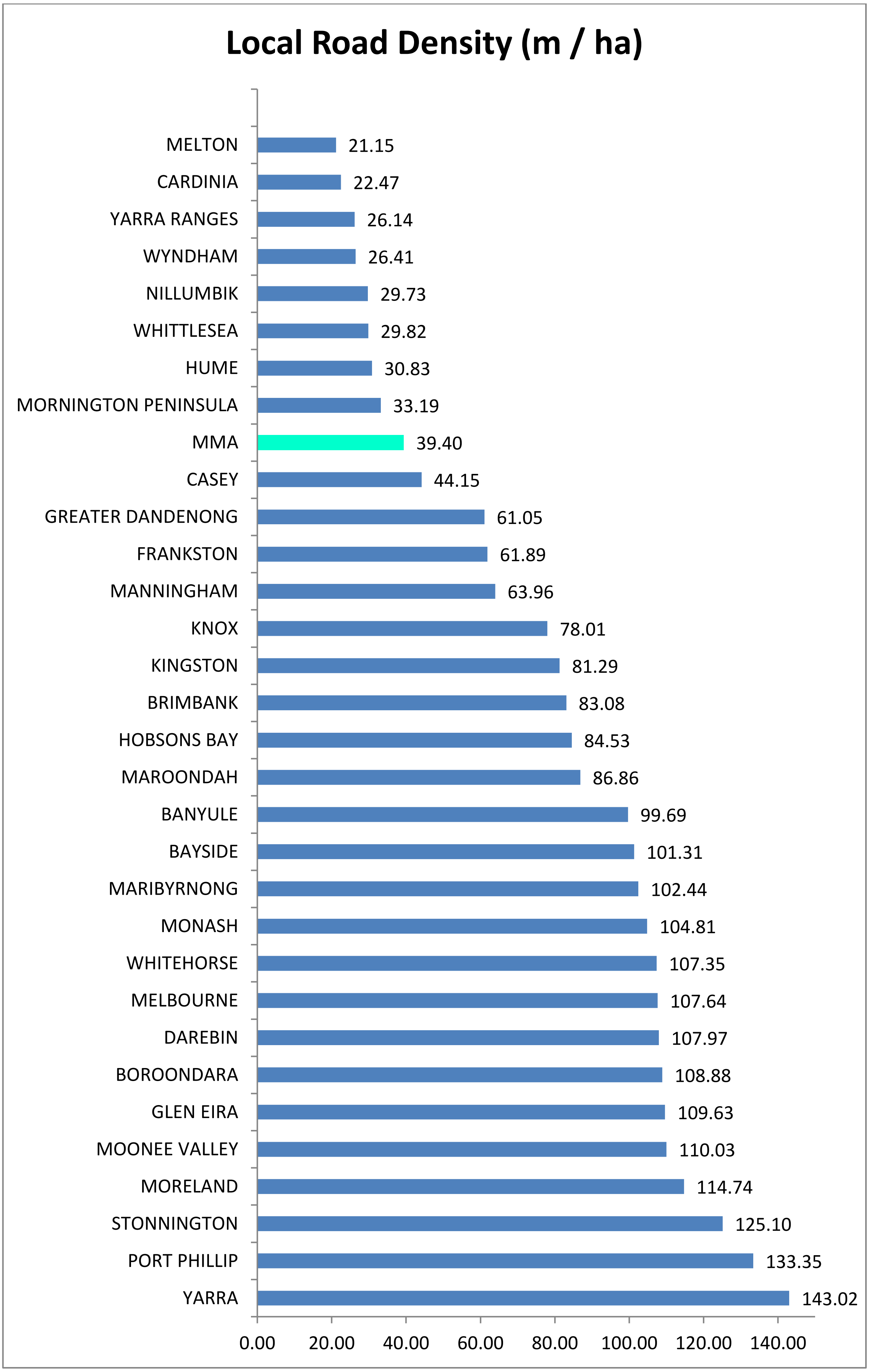


Figure 4.2.2 The ranking of local road density in LGAs

4.3 Population Distribution

According to the 2011 ABS census, the MMA has a population of about 3.8 million, living in about 40,000 residential MBs across 31 LGAs. The total population has been classified into three age groups, with the majority being adults (aged 15-64, 68.33%), followed by the young (aged 0-14, 18.64%) and the old (aged 65+, 13.03%). Table 4.3.1 and Figure 4.3.1 show some LGA-based summary statistics and ranking of population (total, young, adult, old), area (total, residential), area ratio (residential/total) and number of residential MBs.

In the MMA, an average residential Mesh Block have about 95 persons, including 18 young persons, 65 adults and 12 old persons; and an average LGA have a population size of 123327 persons, including 22982 young persons, 84271 adults and 16074 old persons. For the LGA-based total population, Casey (249560 persons), Brimbank (181824 persons) and Monash (169856 persons) rank the top three and Nillumbik (51029 persons), Melbourne (61065 persons) and Cardinia (62612 persons) the bottom three. This ranking is maintained for the adult population. For the LGA-based young population, Casey (58779 persons), Wyndham (38119 persons) and Hume (37940 persons) are the top three and Melbourne (5827 persons), Yarra (8283 persons), and Port Phillip (9307 persons) the bottom three. For the LGA-based old population, Monash (29458 persons), Mornington Peninsula (28721 persons) and Whitehorse (26359 persons) are the top three, with Nillumbik (4247 persons), Melbourne (4654 persons) and Cardinia (6023 persons) being the bottom three. For the residential to total area ratio, Glen Eira has the highest (84.7%) and Cardinia the lowest (6.3%), as shown in Figure 4.3.2.

LGA-based and MMA-based residential density (Persons per hectare residential area, A_r) and population density (persons per hectare total are, A_t) for the four age groups are summarised in Table 4.3.2, and illustrated in Figure 4.3.3 (for residential density) and in Figure 4.3.4 (for population density). On average, every 100 ha (or one km^2) of residential area (A_r) in the MMA carries 2247 persons, including 419 young persons, 1536 adults and 293 old persons. At the LGA level, Melbourne (12276 persons), Yarra (8037 persons) and Port Phillip (7983 persons) rank the top three for total population, and Cardinia (771 persons), Mornington Peninsula (881 persons) and Yarra Range (931 persons) rank the bottom three.

In terms of population density, every 100 ha (or one km^2) of land area (A_t) in the MMA carries 498 persons, including 93 young persons, 340 adults and 65 old persons. At the LGA level, Port Phillip (4235 persons), Yarra (3749 persons) and Stonnington (3597 persons), rank the top three for total population, and Cardinia (49 persons), Yarra Range (97 persons) and Nillumbik (118 persons) rank the bottom three (Table 4.3.2, Figure 4.3.4).

Table 4.3.1 Some LGA-based summary statistics

(on populations, total area (A_t), residential area (A_r), residential to total area ratio (A_r/A_t) and total number of residential MBs (MB*) for each LGA in the MMA)

LGA_NAME	Total_Pop	Young_Pop	Adult_Pop	Old_Pop	A_r (ha)	A_t (ha)	A_r / A_t	MB*
NILLUMBIK	51029	10837	35963	4247	3438.41	43213.25	7.96%	448
MELBOURNE	61065	5827	50558	4654	497.43	3750.52	13.26%	517
CARDINIA	62612	15320	41265	6023	8126.06	127988.86	6.35%	606
MARIBYRNONG	69371	11399	50832	7134	1516.46	3125.09	48.53%	773
YARRA	73323	8283	57545	7501	912.37	1955.80	46.65%	794
HOBSONS BAY	84203	15150	57471	11565	2434.27	6417.41	37.93%	921
PORT PHILLIP	86517	9307	68805	8418	1083.70	2042.97	53.05%	1222
BAYSIDE	90510	17859	56353	16305	2749.05	3693.88	74.42%	988
STONNINGTON	92196	11814	66746	13624	1990.14	2563.38	77.64%	1205
MAROONDAH	102102	19425	67924	14739	4573.20	6139.90	74.48%	1115
MOONEE VALLEY	105567	17845	70979	16791	2929.28	4311.59	67.94%	1148
MELTON	105846	26566	72910	6359	5853.70	52774.10	11.09%	922
MANNINGHAM	108919	17944	69776	21190	5859.01	11333.15	51.70%	1102
BANYULE	118249	21046	78391	18815	4724.75	6263.11	75.44%	1287
FRANKSTON	125535	24101	84594	16860	6611.22	12944.90	51.07%	1389
YARRA RANGES	129270	26733	87849	14693	13878.88	133240.59	10.42%	1249
GLEN EIRA	130633	23298	87977	19374	3275.68	3868.90	84.67%	1489
MORNINGTON PENINSULA	135143	25462	80956	28721	15342.07	72202.52	21.25%	2214
DAREBIN	135456	21820	93510	20158	3580.20	5346.93	66.96%	1498
GREATER DANDENONG	135718	24644	92319	18724	3635.71	12947.41	28.08%	1333
KINGSTON	140201	24875	92887	22457	4240.14	9130.87	46.44%	1664
MORELAND	146616	23573	100760	22250	3638.03	5103.97	71.28%	1542
KNOX	147760	27583	102314	17858	6021.09	11386.18	52.88%	1353
WHITEHORSE	151533	26188	98967	26359	4914.84	6427.15	76.47%	1588
WHITTLESEA	151605	31846	104415	15335	6749.74	48899.28	13.80%	1425
WYNDHAM	158212	38119	110305	9777	10653.16	54161.29	19.67%	1451
BOROONDARA	158363	27606	107058	23682	4647.68	6019.11	77.22%	1737
HUME	164354	37940	112417	14005	8520.13	50313.44	16.93%	1362
MONASH	169856	26433	113976	29458	5572.27	8147.46	68.39%	1748
BRIMBANK	181824	34833	126316	20643	5721.67	12343.58	46.35%	1681
CASEY	249560	58779	170273	20568	16424.50	39667.00	41.41%	2220
MMA	3823148	712455	2612411	498287	170115.00	767724.00	22.16%	39991

Table 4.3.2 The 2011 population densities of the four age groups for each LGA in the MMA

(Persons /Ha, A_r = residential area, A_t = total area)

LGA_NAME	Total_Pop/A_r	Young_Pop/A_r	Adult_Pop/A_r	Old_Pop/A_r	Total_Pop/A_t	Young_Pop/A_t	Adult_Pop/A_t	Old_Pop/A_t
CARDINIA	7.71	1.89	5.08	0.74	0.49	0.12	0.32	0.05
MORNINGTON PENINSULA	8.81	1.66	5.28	1.87	1.87	0.35	1.12	0.40
YARRA RANGES	9.31	1.93	6.33	1.06	0.97	0.20	0.66	0.11
NILLUMBIK	14.84	3.15	10.46	1.24	1.18	0.25	0.83	0.10
WYNDHAM	14.85	3.58	10.35	0.92	2.92	0.70	2.04	0.18
CASEY	15.19	3.58	10.37	1.25	6.29	1.48	4.29	0.52
MELTON	18.08	4.54	12.46	1.09	2.01	0.50	1.38	0.12
MANNINGHAM	18.59	3.06	11.91	3.62	9.61	1.58	6.16	1.87
FRANKSTON	18.99	3.65	12.80	2.55	9.70	1.86	6.53	1.30
HUME	19.29	4.45	13.19	1.64	3.27	0.75	2.23	0.28
MAROONDAH	22.33	4.25	14.85	3.22	16.63	3.16	11.06	2.40
WHITTLESEA	22.46	4.72	15.47	2.27	3.10	0.65	2.14	0.31
MMA	22.47	4.19	15.36	2.93	4.98	0.93	3.40	0.65
KNOX	24.54	4.58	16.99	2.97	12.98	2.42	8.99	1.57
BANYULE	25.03	4.45	16.59	3.98	18.88	3.36	12.52	3.00
MONASH	30.48	4.74	20.45	5.29	20.85	3.24	13.99	3.62
WHITEHORSE	30.83	5.33	20.14	5.36	23.58	4.07	15.40	4.10
BRIMBANK	31.78	6.09	22.08	3.61	14.73	2.82	10.23	1.67
BAYSIDE	32.92	6.50	20.50	5.93	24.50	4.83	15.26	4.41
KINGSTON	33.07	5.87	21.91	5.30	15.35	2.72	10.17	2.46
BOROONDARA	34.07	5.94	23.03	5.10	26.31	4.59	17.79	3.93
HOBSONS BAY	34.59	6.22	23.61	4.75	13.12	2.36	8.96	1.80
MOONEE VALLEY	36.04	6.09	24.23	5.73	24.48	4.14	16.46	3.89
GREATER DANDENONG	37.33	6.78	25.39	5.15	10.48	1.90	7.13	1.45
DAREBIN	37.83	6.09	26.12	5.63	25.33	4.08	17.49	3.77
GLEN EIRA	39.88	7.11	26.86	5.91	33.76	6.02	22.74	5.01
MORELAND	40.30	6.48	27.70	6.12	28.73	4.62	19.74	4.36
MARIBYRNONG	45.75	7.52	33.52	4.70	22.20	3.65	16.27	2.28
STONNINGTON	46.33	5.94	33.54	6.85	35.97	4.61	26.04	5.31
PORT PHILLIP	79.83	8.59	63.49	7.77	42.35	4.56	33.68	4.12
YARRA	80.37	9.08	63.07	8.22	37.49	4.24	29.42	3.84
MELBOURNE	122.76	11.71	101.64	9.36	16.28	1.55	13.48	1.24

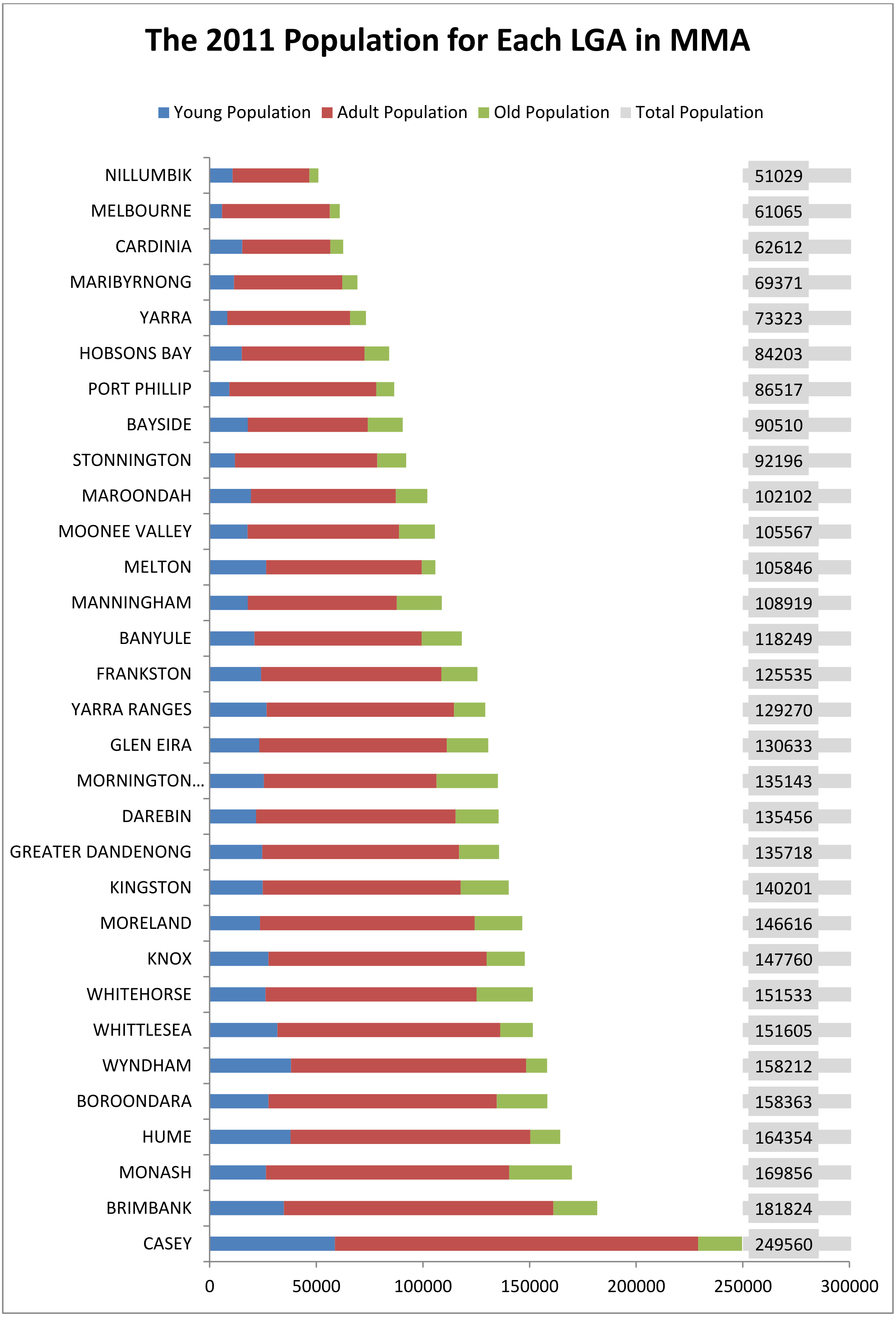


Figure 4.3.1 The population for the four age groups for each LGA in the MMA.

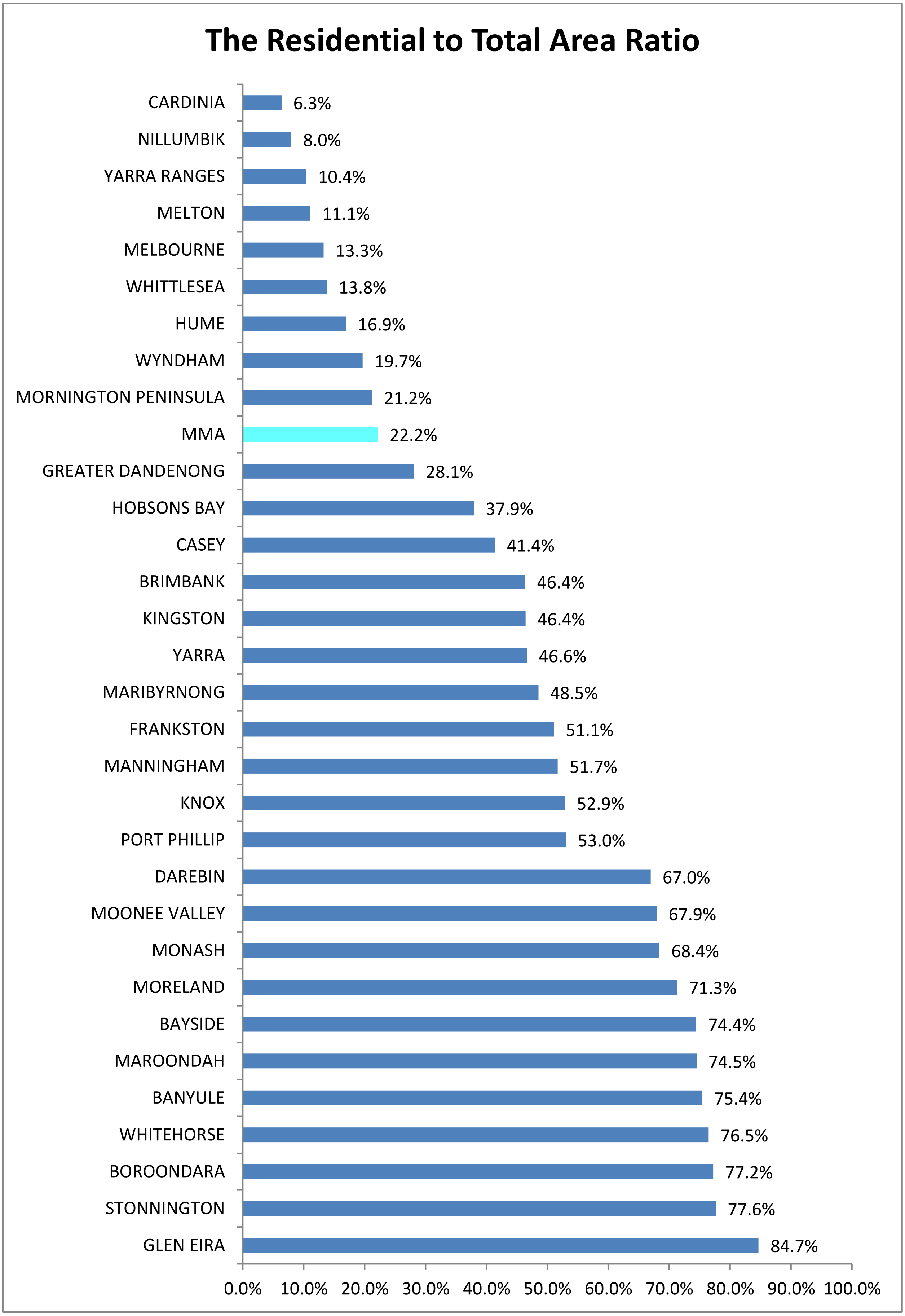


Figure 4.3.2 The residential to total area ratio for each LGA in the MMA

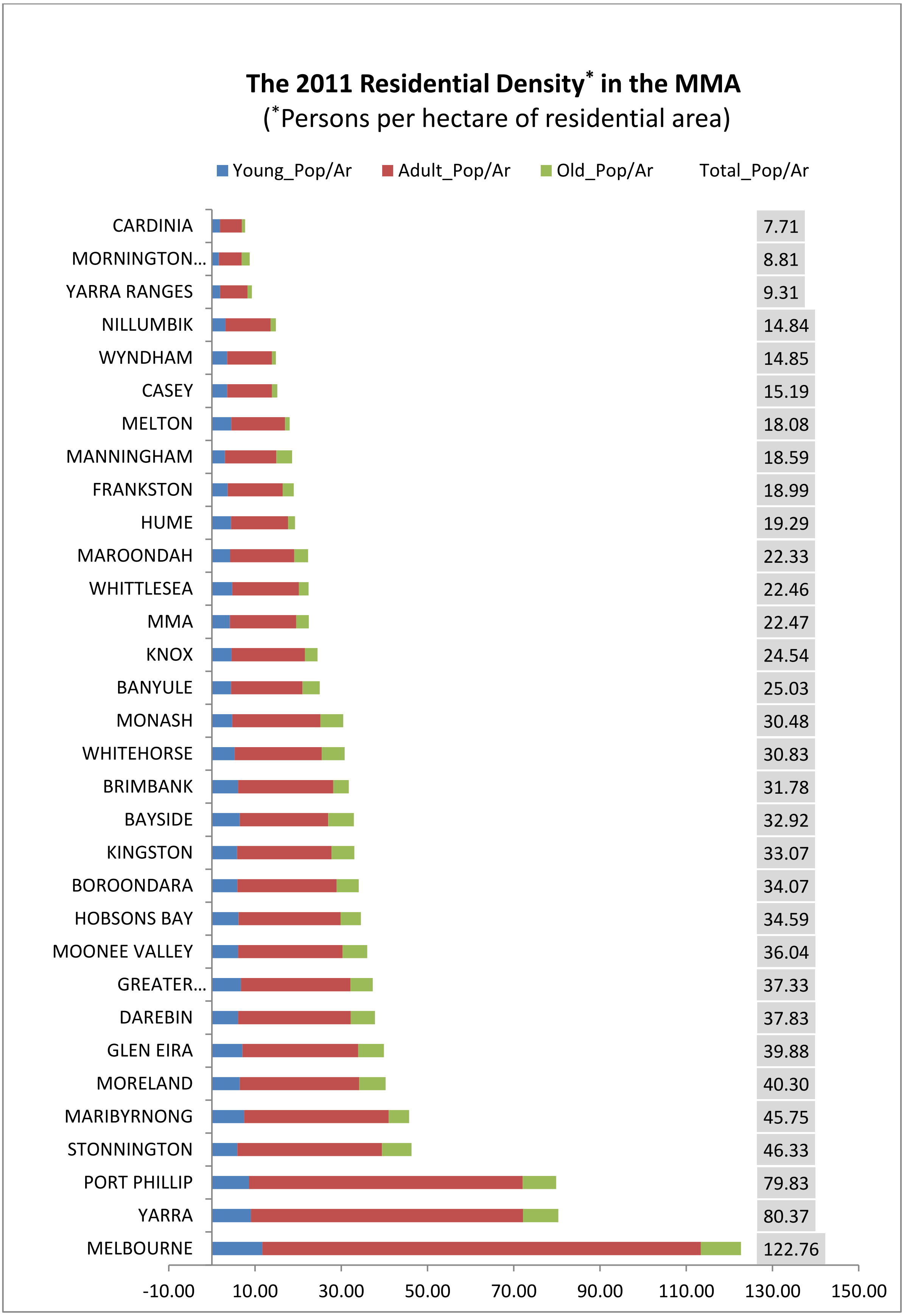


Figure 4.3.3 The 2011 residential density (persons per hectare of residential area) of the four age groups for each LGA in the MMA

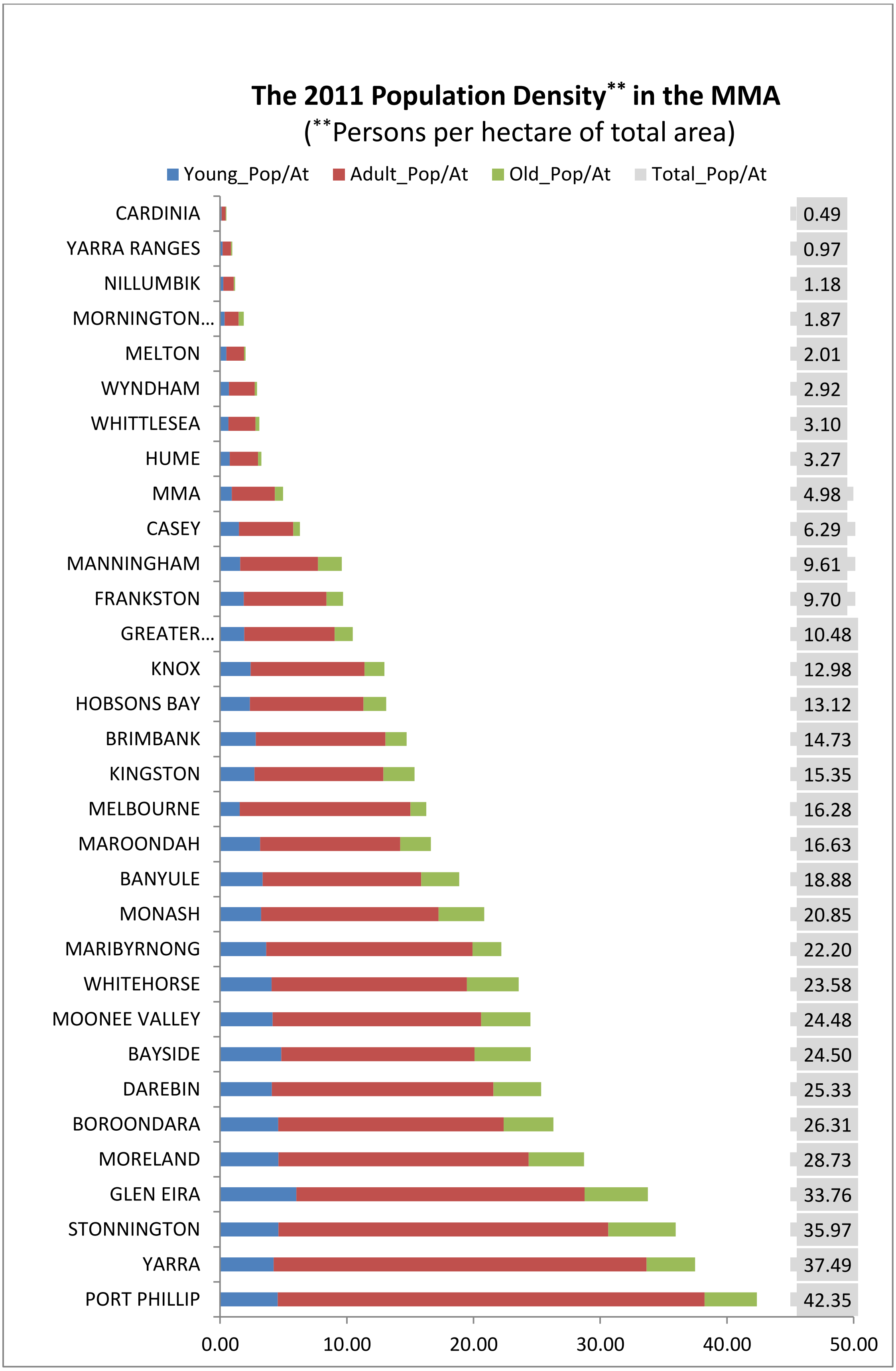


Figure 4.3.4 The 2011 population density (persons per hectare of total area) of the four age groups for each LGA in the MMA

Spatial variations in population densities for the four age groups at the Mesh Block level across the MMA are shown in Map 4.3.1 (total), Map 4.3.2 (young), Map 4.3.3 (adult) and Map 4.3.4 (old), using quintile-based class limits, which are summarised in Table 4.3.3.

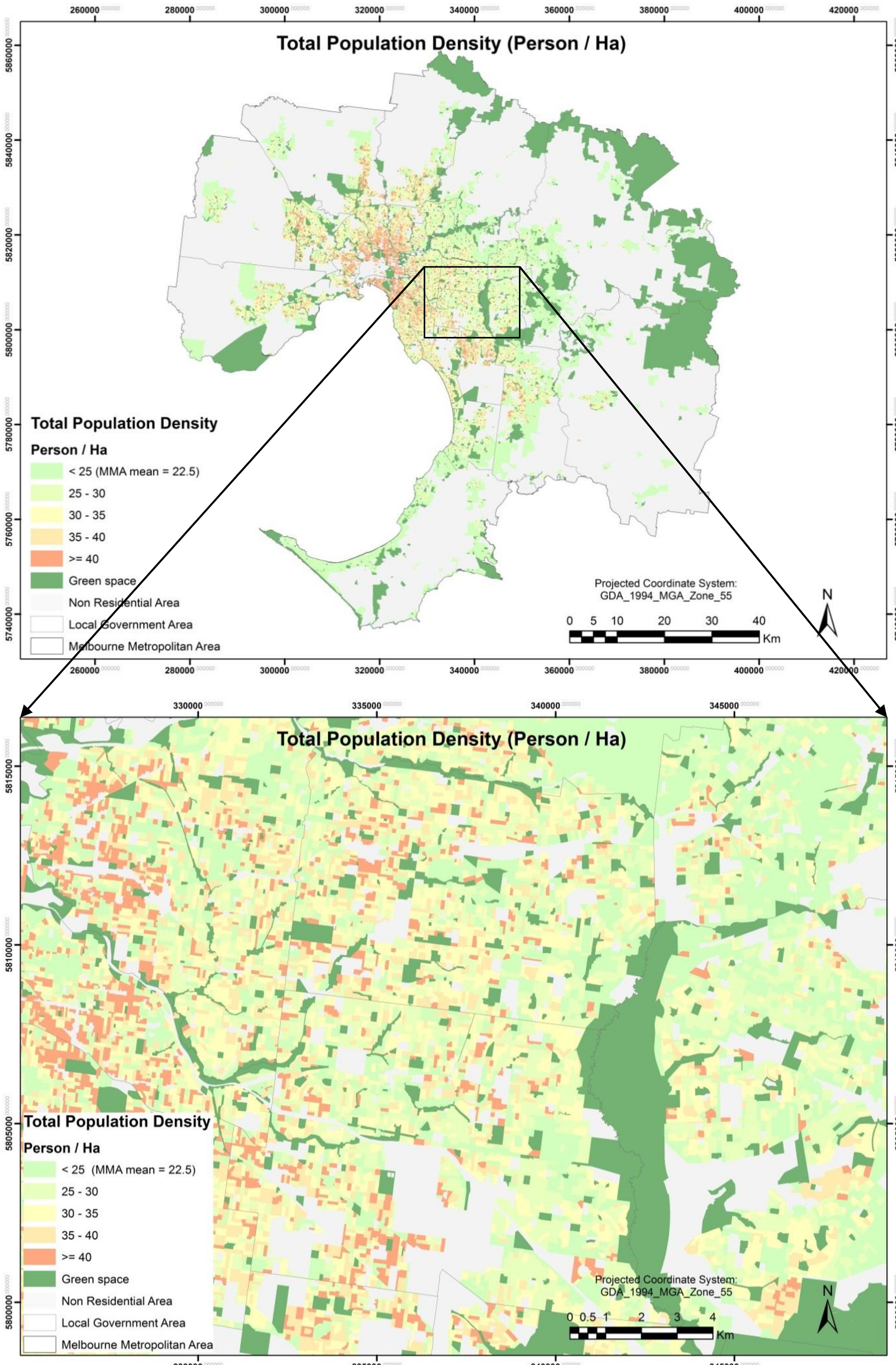
These maps shown that:

- densities for the total population (the MMA mean = 22.5 persons / ha) and the adult population (the MMA mean = 15.4 person / ha) show similar spatial variations, i.e. both are highly concentrated in the inner suburbs close to the CBD of the MMA;
- high density clusters of young population (the MMA mean = 4.2 persons / ha) occur in both the inner suburbs and the southeast, west and north peripheral suburbs; and
- high density clusters of old population (the MMA mean = 2.9 person / ha) appear in both the inner suburbs and the zone of middle suburbs.

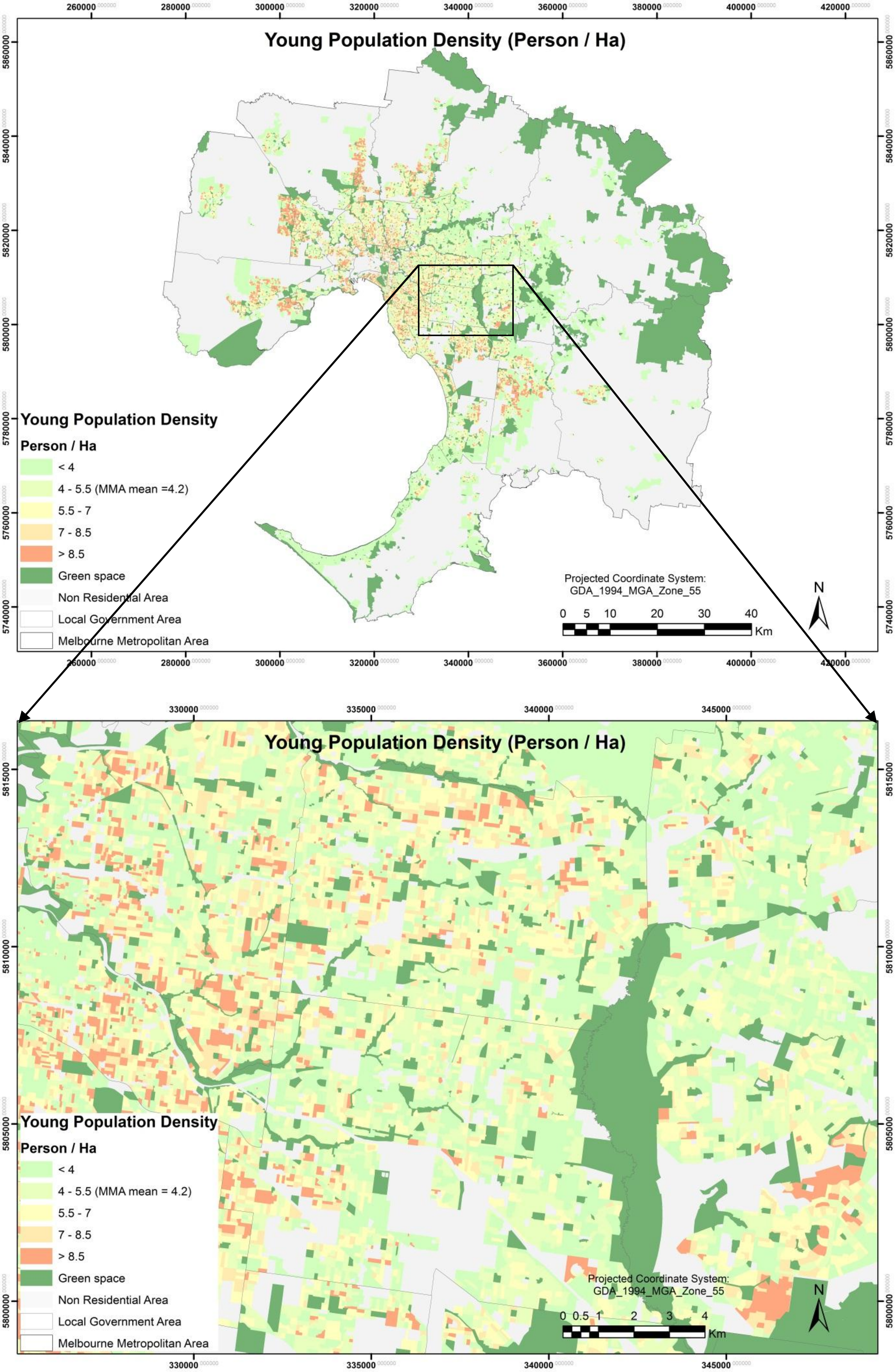
These spatial patterns are more clearly shown in the set of hot spot maps, i.e. Map 4.3.5 (total), Map 4.3.6 (young), Map 4.3.7 (adult) and Map 4.3.8 (old), classified into seven levels based on the GiZ scores (see section 3.10 for more details): very low, low, medium -, medium, medium +, high, very high. The "very low" label means very low density.

Table 4.3.3 Population density quintile class limits for the four age groups

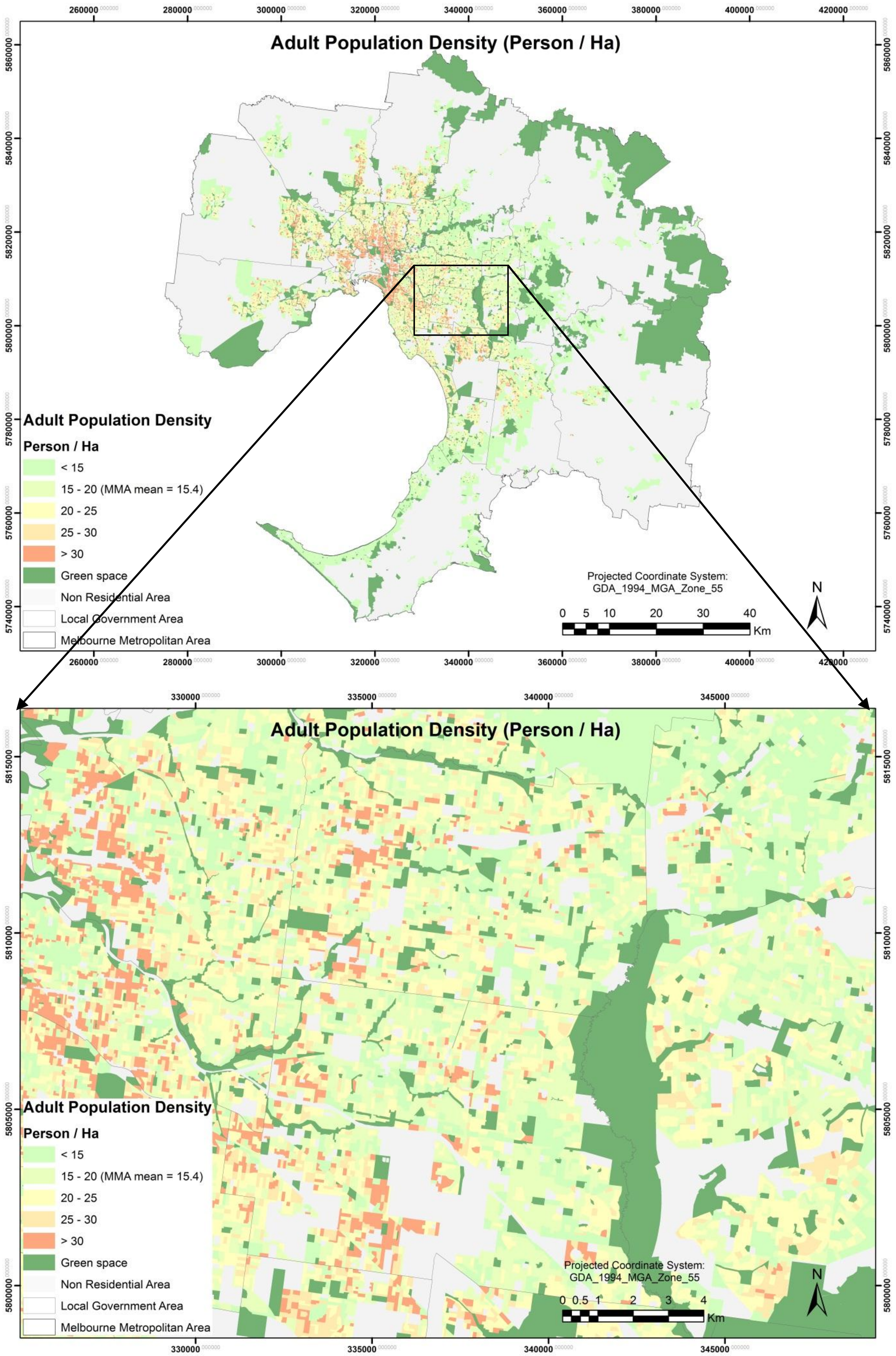
Population Group	**Population Density** (persons/ha)				
	Low	**Medium -**	**Medium**	**Medium +**	**High**
Total	< 25	25 - 30	30 - 35	35 - 40	> 40
Young	< 4	4 - 5.5	5.5 - 7	7 -8.5	> 8.5
Adult	< 15	15 - 20	20 - 25	25 – 30	> 30
Old	< 1.5	1.5 - 3	3 – 4.5	4.5 - 6	> 6



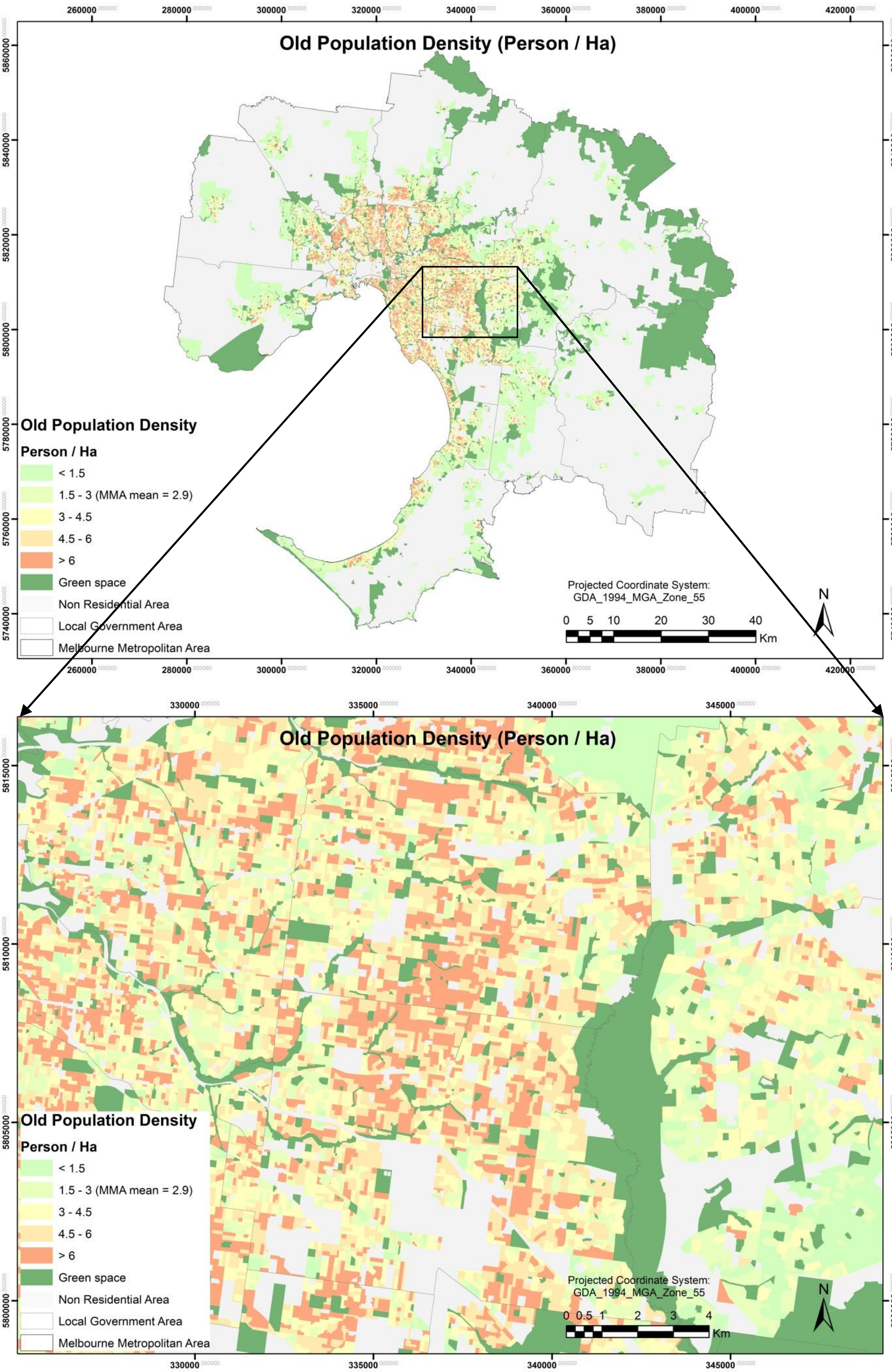
Map 4.3.1 The total population (age 0-115) density in the MMA



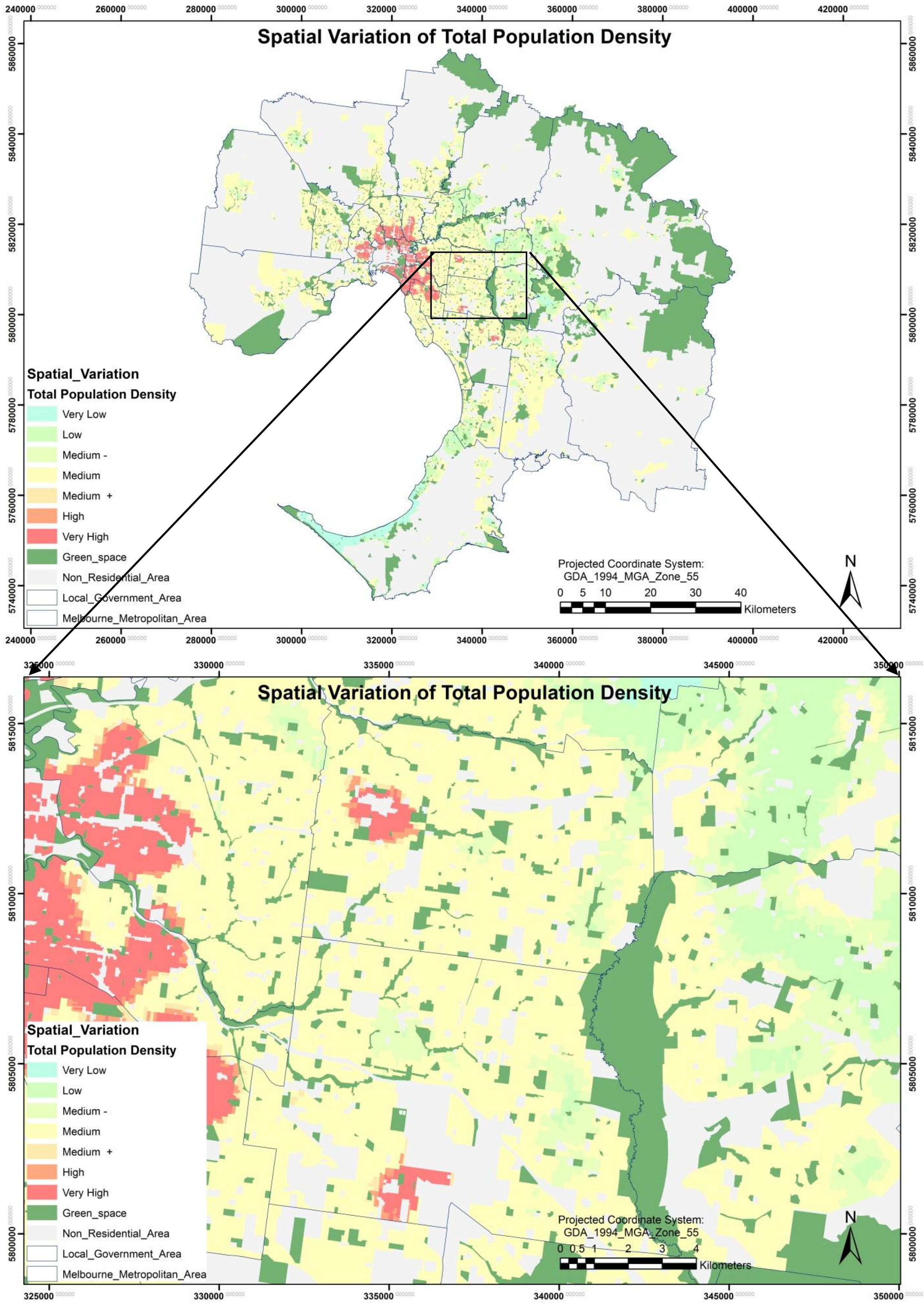
Map 4.3.2 The young population (age 0-14) density in the MMA



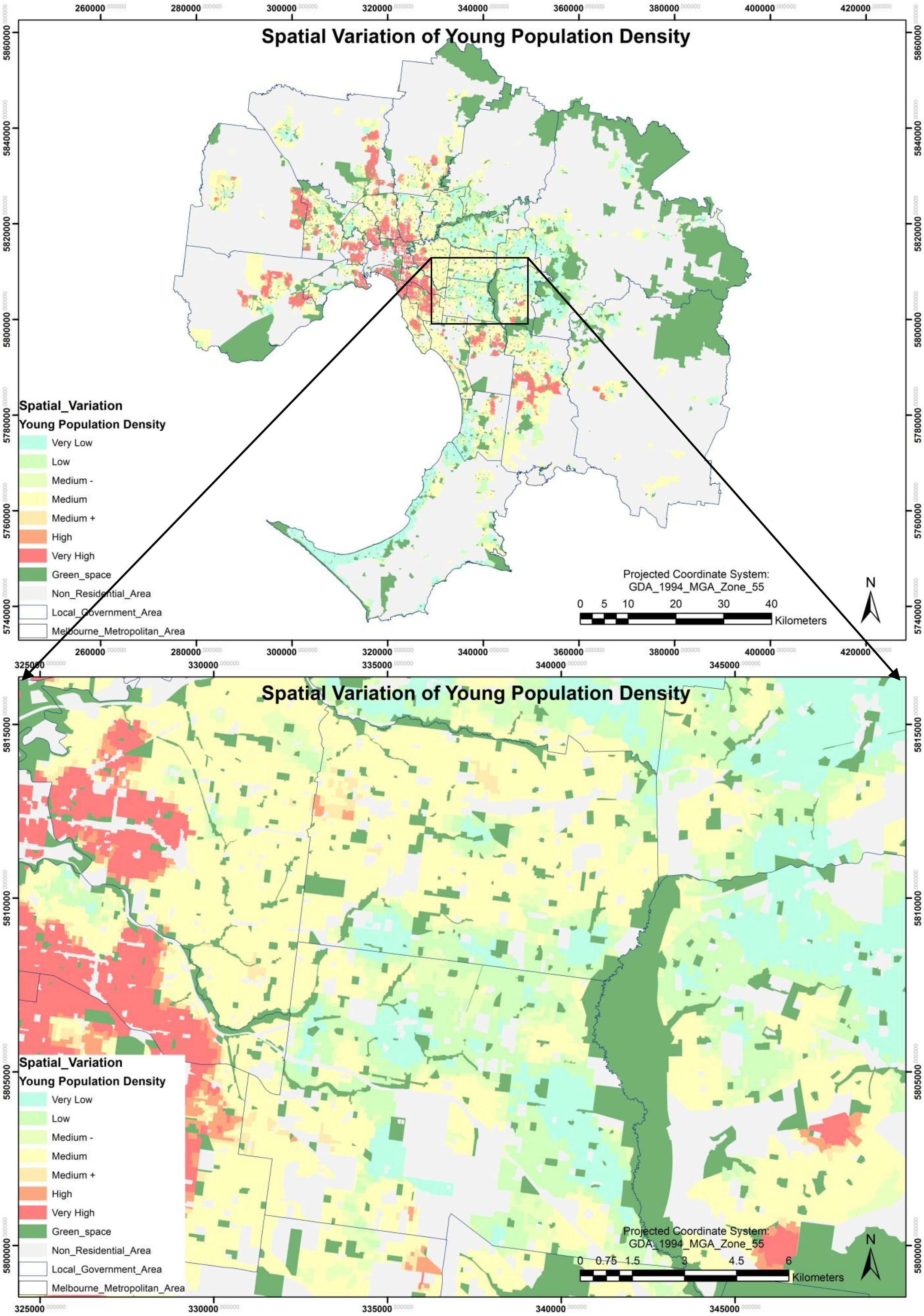
Map 4.3.3 The adult population (age 15-64) density in the MMA



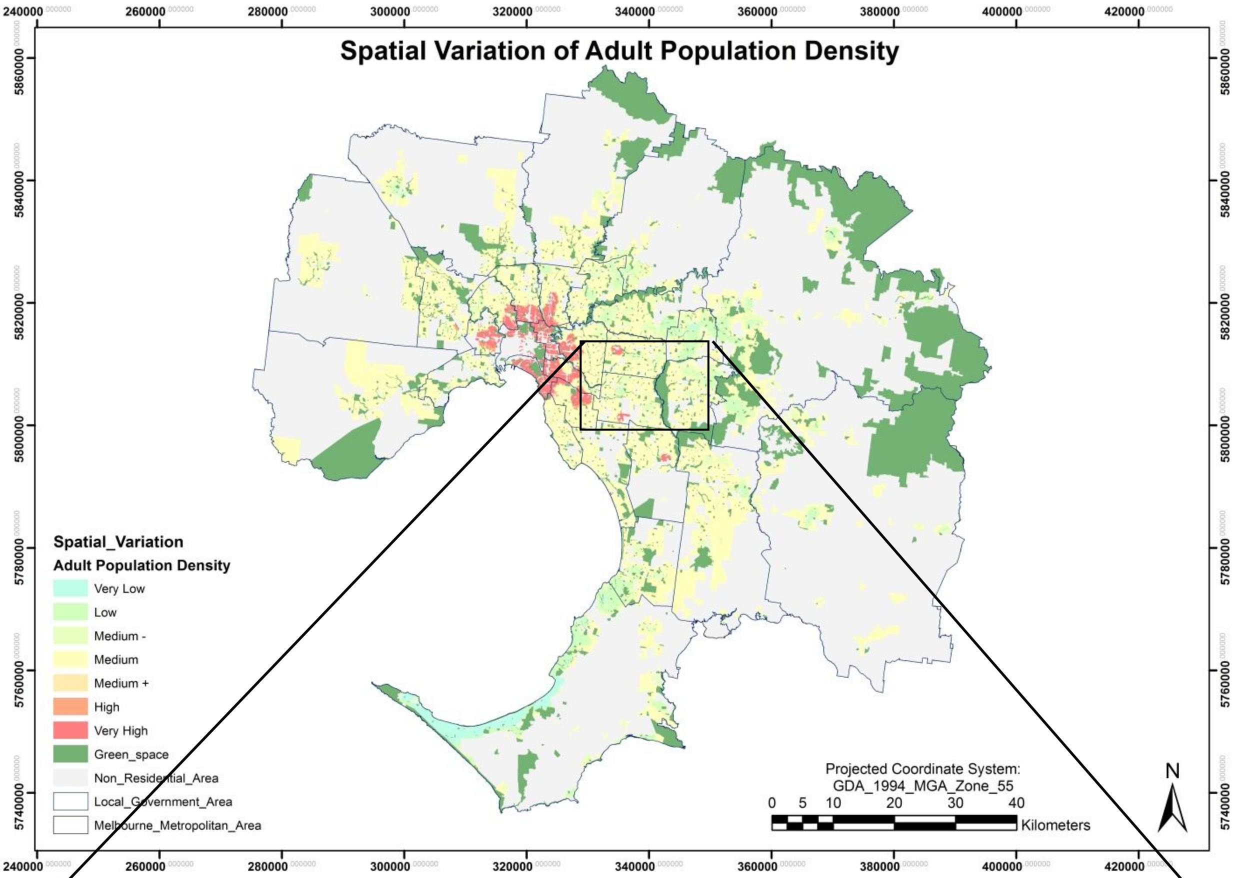
Map 4.3.4 The Old population (age 65+) density in the MMA

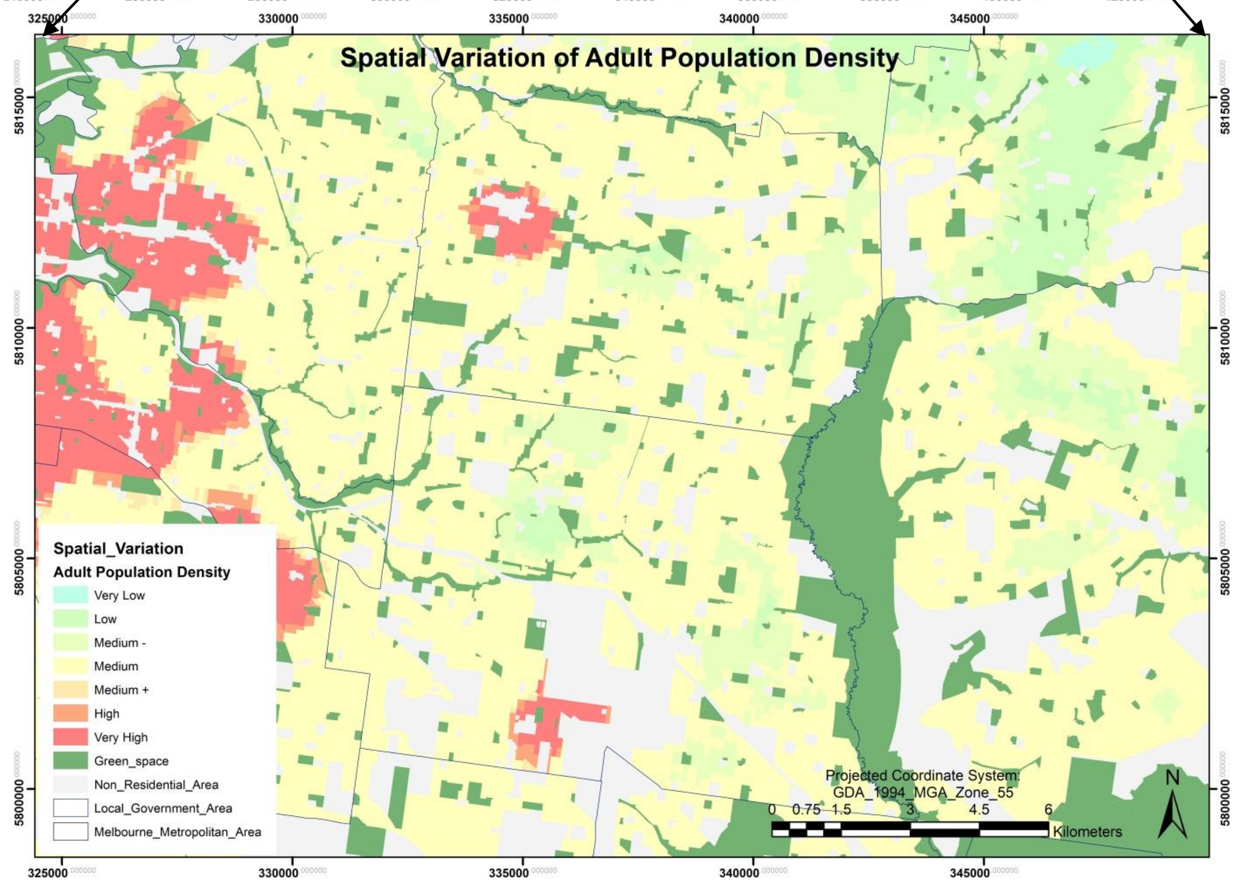


Map 4.3.5 The spatial variation of total (age 0-115) population density

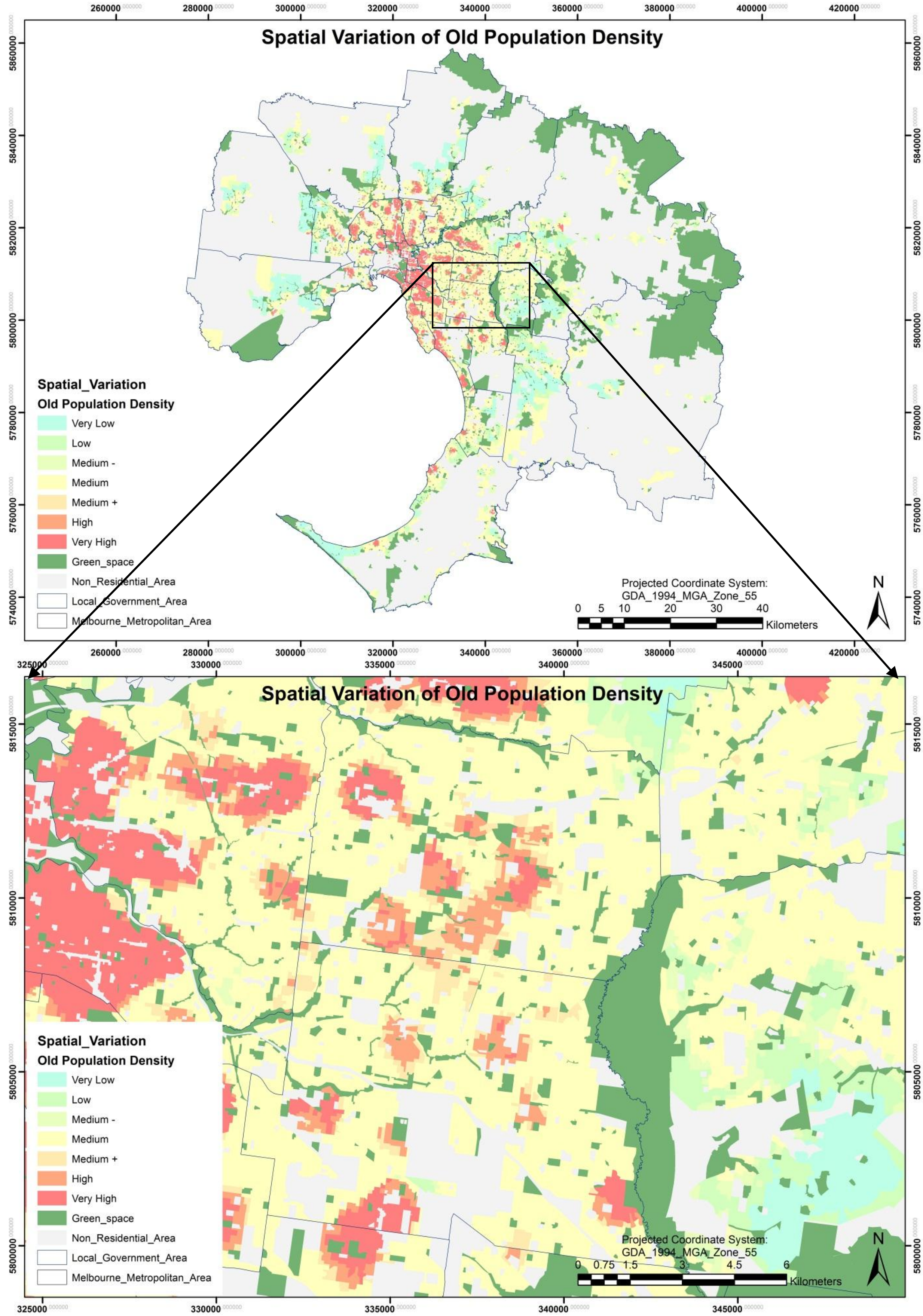


Map 4.3.6 The spatial variation of young (age 0-14) population density





Map 4.3.7 The spatial variation of adult (age 15-64) population density



Map 4.3.8 The spatial variation of old (age 65+) population density

Spatial variations in population concentrations for the young, adult and old age groups at the Mesh Block level across the MMA are shown in Map 4.3.9 (young), Map 4.3.10 (adult) and Map 4.3.11 (old), using quintile-based class limits, which are summarised in Table 4.3.4.

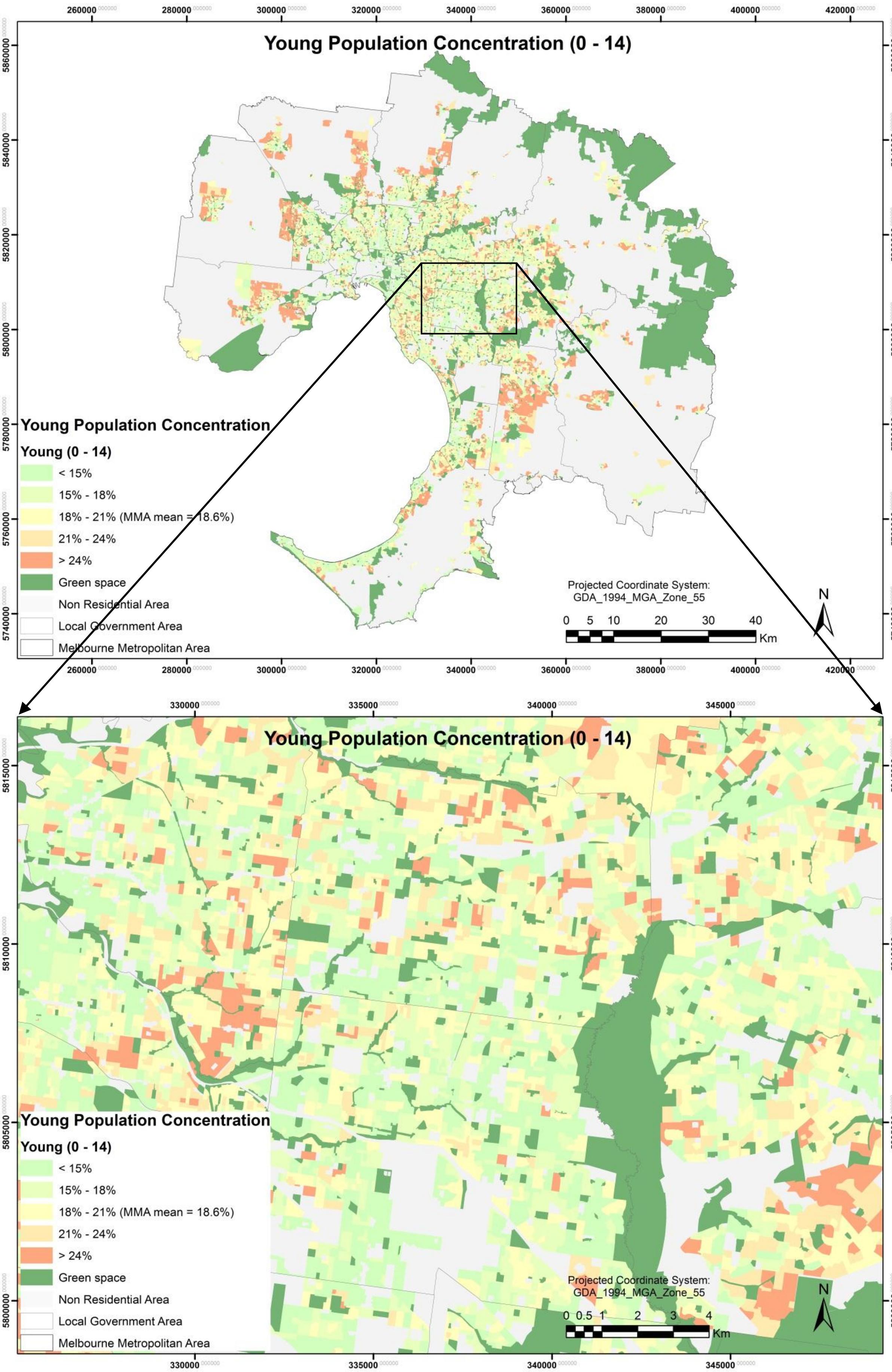
These maps shown that :

- clusters of high concentration of young population (the MMA mean = 18.6%) occur mainly in the peripheral suburbs;
- clusters of high concentration of adult population (the MMA mean = 68.3%) appear in both the inner suburbs and the peripheral suburbs.
- clusters of high concentration of old population (the MMA mean = 13.0%) appear mainly in the zone of middle suburbs and some peripheral suburbs, especially in the Mornington Peninsula.

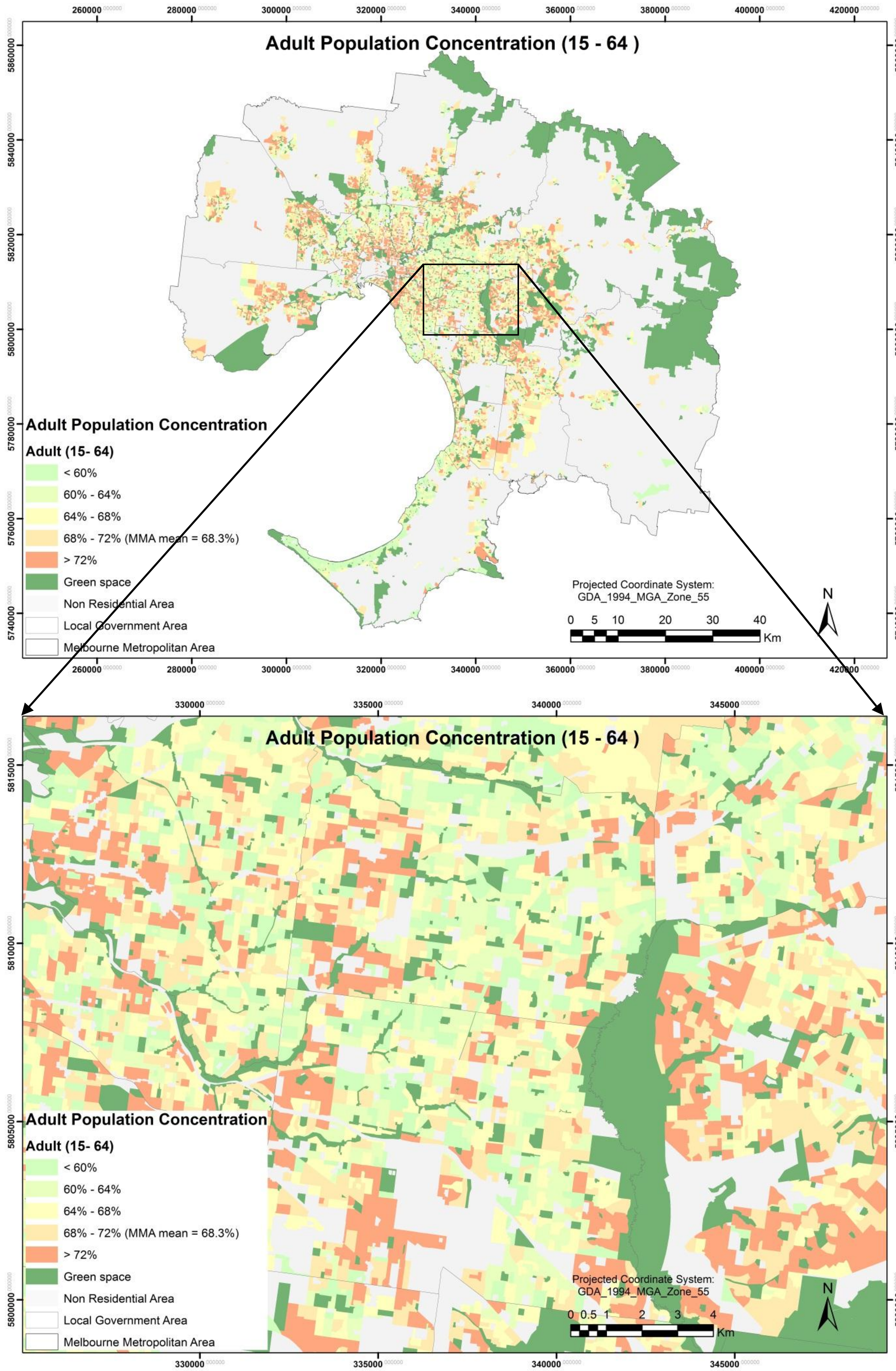
These spatial patterns are more pronounced in the set of hot spot maps, i.e. Map 4.3.12 (young), Map 4.3.13 (adult) and Map 4.3.14 (old), classified into seven levels based on the GiZ scores (see section 3.10 for more details): very low, low, medium -, medium, medium +, high, and very high. The "very low" level means very low concentration.

Table 4.3.4 Population concentration quintile class limits for the four age groups

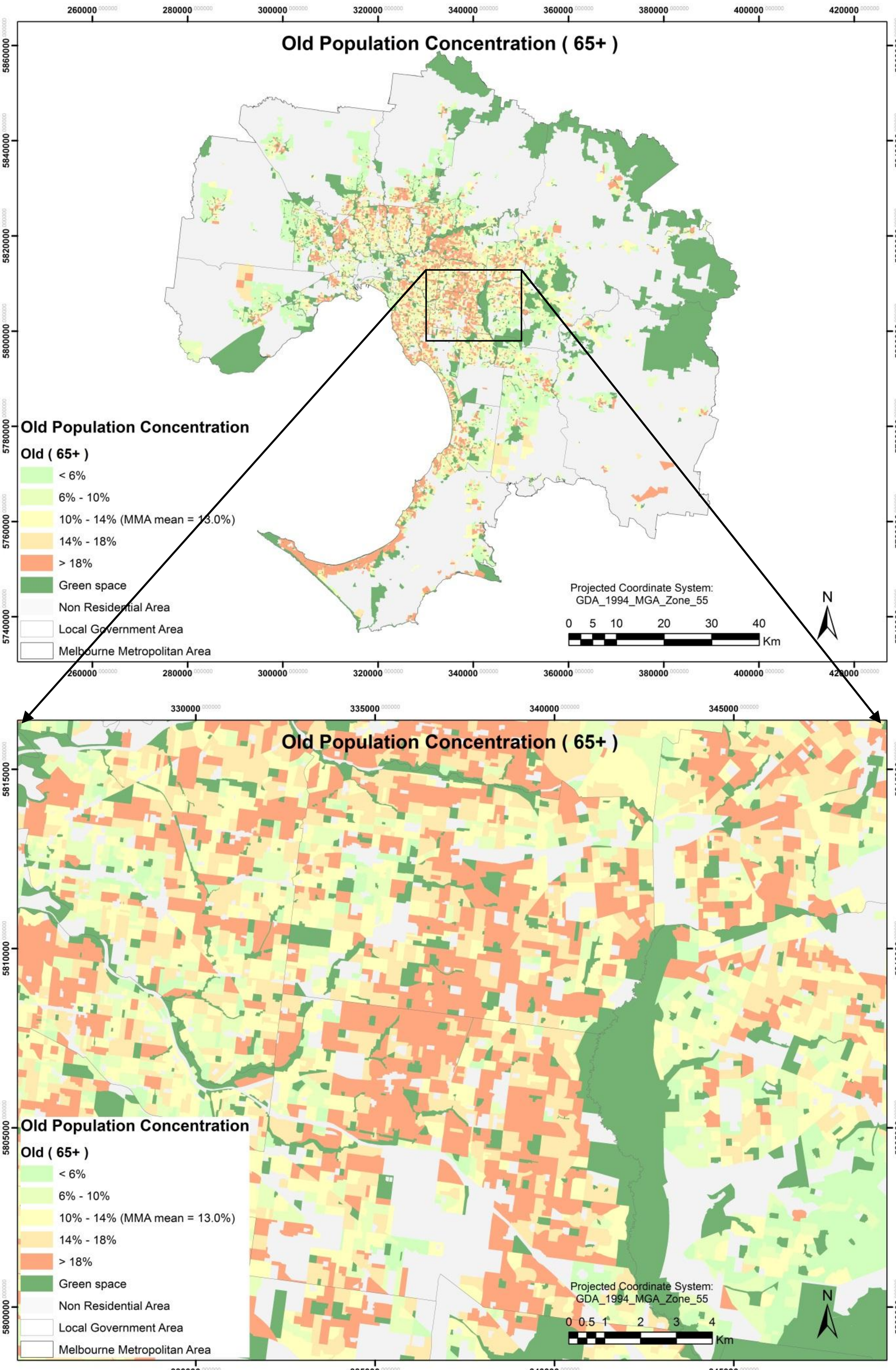
Population Group	Population Concentration (%)				
	Low	Medium -	Medium	Medium +	High
Young	< 15	15 - 18	18 - 21	21 - 24	> 24
Adult	< 60	60 - 64	64 - 68	68 – 72	> 72
Old	< 6	6 - 10	10 – 14	14 - 18	> 18



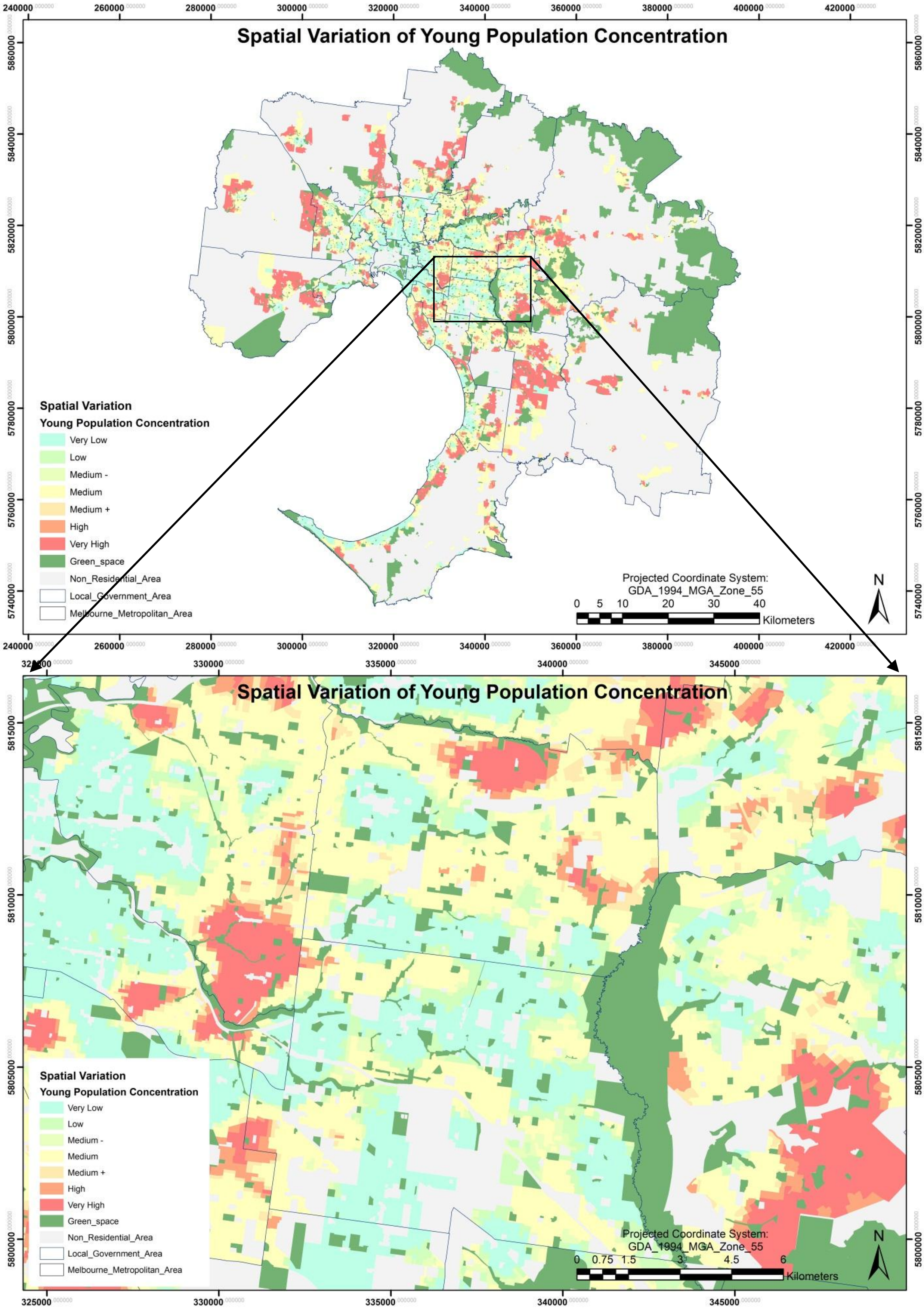
Map 4.3.9 The young population concentration (age 0-14) density in the MMA



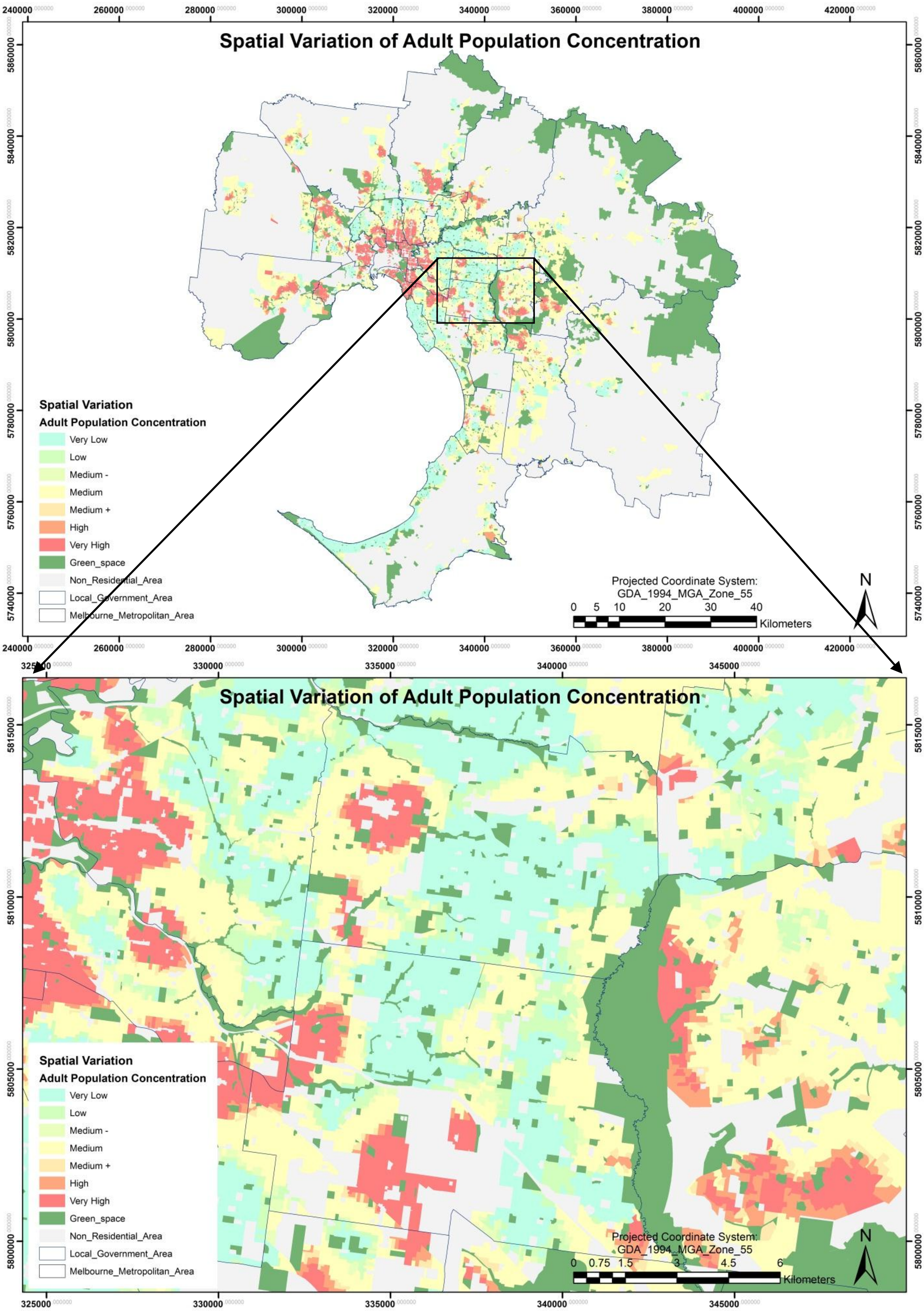
Map 4.3.10 The adult population concentration (age 15-64) density in the MMA



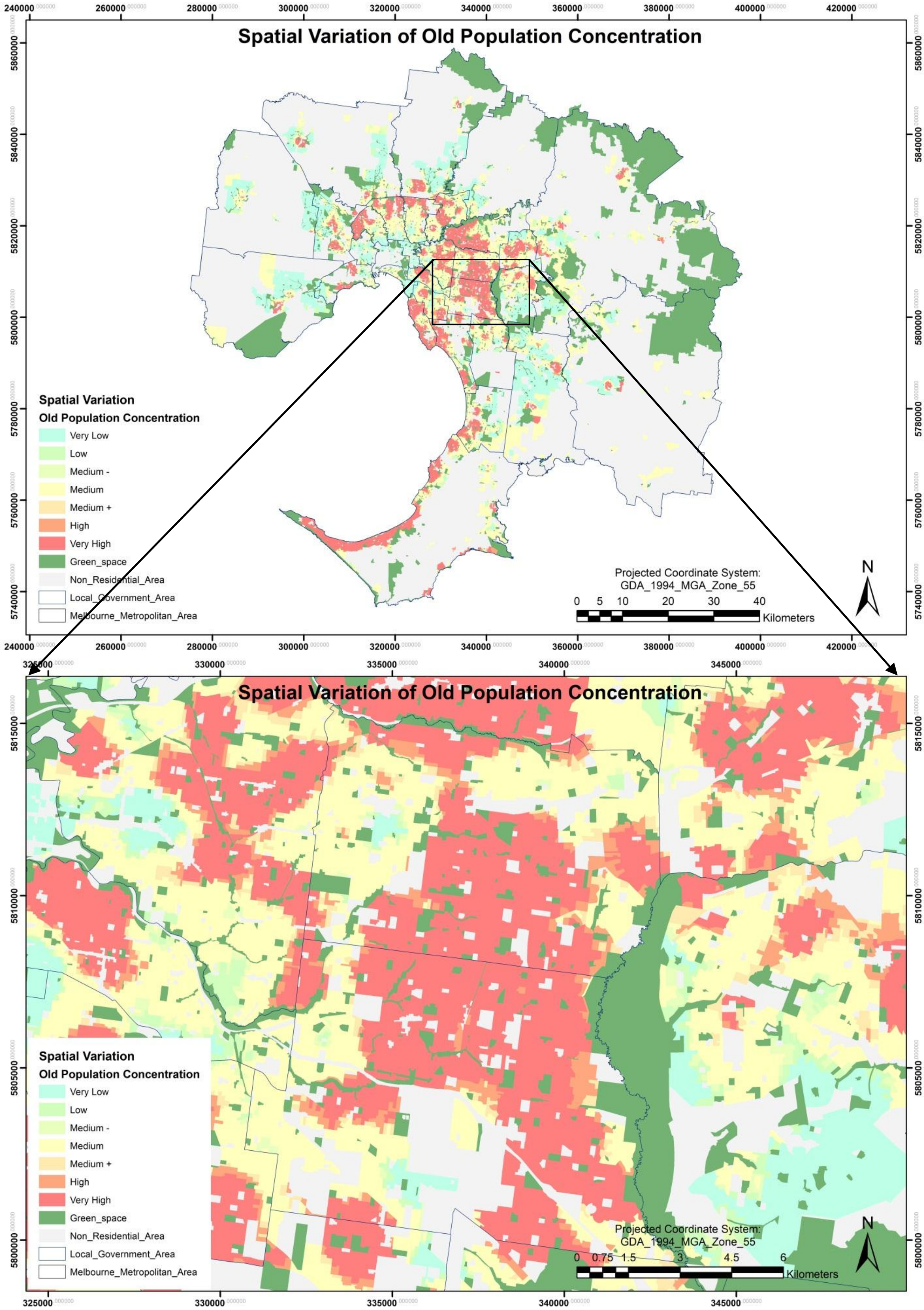
Map 4.3.11 The old population concentration (age 65+) density in the MMA



Map 4.3.12 The spatial variation of total (age 0-115) population concentration



Map 4.3.13 The spatial variation of total (age 0-115) population concentration



Map 4.3.14 The spatial variation of total (age 0-115) population concentration

4.4 Green Space: Type, Size, Facility and Quietness

Green space is a major contributor to the liveability of urban residents in the MMA. The MMA green space network consists of national and state parks, major (regional) parks managed by Parks Victoria, the metropolitan trail network, linear reserve corridors including green wedges along major waterways, and green space along coastal and water foreshores.

Based on the criteria established in section 3.6, a total number of 4678 neighbourhood green spaces, over 118,000 ha in total area, have been included into this study. Table 4.4.1 presents some green space related summary statistics for each of the 31 LGAs in the MMA, Figure 4.4.1 summarises the types and number of facilities associated with green spaces in the MMA, and Map 4.4.1 shows the spatial distribution of green spaces included in this study. About 15.39% of the MMA are covered by these green spaces. The actual percentage of green space in the MMA should be higher if all types of green spaces are included. On average, in the MMA, each green space has an area of 25.26 ha, about 800 persons share one green space or 32 persons share one hectare of green space, and each person enjoys about 310 m^2 of green space.

Figure 4.4.2 ranks the 31 LGAs in terms of area ratio between green space and total area (the MMA mean = 15.4%): the top three are Yarra Ranges (31.7%), Knox (24.3%) and Port Phillip (23.6%), and the bottom three include Melton (2.7%), Hume (4.7%) and Casey (6.5%). Map 4.4.2 presents the spatial variation of LGA-based area ratio between green space and total area according to this ranking.

Figure 4.4.3 ranks LGAs based on area ratio between green space and total residential area in each LGA (the MMA mean = 69.5%): the top three LGAs include Yarra Ranges (304.0%), Cardinia (223.0%) and Melbourne (160.8%), and the bottom three are Glen Eira (8.2%), Maroondah (10.3%) and Stonington (11.7%). Map 4.4.3 presents the spatial variation of LGA-based area ratio between green space and total residential area according to this ranking.

Figure 4.4.4 ranks LGAs according to per capita green space in square metres (the MMA mean = 309.1 m^2 / person): the top three include Yarra Ranges (3263.8 m^2 / person), Cardinia (2894.5 m^2 / person) and Nillumbik (1060.6 m^2 / person) and the bottom three are Glen Eira (20.6 m^2 / person), Stonington (25.3 m^2 / person) and

Darebin (34.5 m^2 / person). Map 4.4.4 presents the spatial variation of LGA based per capita green space in square metres according to this ranking.

Apart from the size of each green space and the types of facilities associated with each green space (Figure 4.4.1), the quietness for each green space is also assessed in terms of proportion of a green space area under the influence of traffic noise (Map 4.4.5).

Based on fair principle, for all population, each facility weight fluctuates from five to ten, excluding the green space itself, which has the 20 as weight coefficient. All the facilities can download or observe in reality except the quietness item. Using the noise influence area to predict the quietness level is a feasible way. In the MMA, over 45% of the 4678 green spaces' quietness are impacted by the major road, although only about 4% of the green space area (= 5277.40 ha) are regarded as noisy under the impact of major busy roads (Map 4.4.5).

Table 4.4.1 The total green space area in each LGA

LGA_NAME	Number_of_GS	GS Area (ha)	LGA_AREA (ha)	Resident_Area (ha)	Ratio_GS_LGA	Ratio_GS_Residential
YARRA RANGES	201	42191.18	133240.59	13878.88	31.67%	304.00%
CARDINIA	70	18123.18	127988.86	8126.06	14.16%	223.03%
MORNINGTON PENIN	600	6786.77	72202.52	15342.07	9.40%	44.24%
WYNDHAM	122	8560.56	54161.29	10653.16	15.81%	80.36%
MELTON	106	1427.82	52774.10	5853.70	2.71%	24.39%
HUME	152	2383.35	50313.44	8520.13	4.74%	27.97%
WHITTLESEA	119	9319.25	48899.28	6749.74	19.06%	138.07%
NILLUMBIK	91	5412.14	43213.25	3438.41	12.52%	157.40%
CASEY	231	2562.30	39667.00	16424.50	6.46%	15.60%
GREATER DANDENON	104	1713.88	12947.41	3635.71	13.24%	47.14%
FRANKSTON	240	1806.94	12944.90	6611.22	13.96%	27.33%
BRIMBANK	274	2472.72	12343.58	5721.67	20.03%	43.22%
KNOX	111	2765.31	11386.18	6021.09	24.29%	45.93%
MANNINGHAM	148	2199.04	11333.15	5859.01	19.40%	37.53%
KINGSTON	223	1455.27	9130.87	4240.14	15.94%	34.32%
MONASH	136	752.60	8147.46	5572.27	9.24%	13.51%
WHITEHORSE	156	726.04	6427.15	4914.84	11.30%	14.77%
HOBSONS BAY	191	1037.08	6417.41	2434.27	16.16%	42.60%
BANYULE	137	824.73	6263.11	4724.75	13.17%	17.46%
MAROONDAH	100	471.76	6139.90	4573.20	7.68%	10.32%
BOROONDARA	193	681.07	6019.11	4647.68	11.32%	14.65%
DAREBIN	108	467.14	5346.93	3580.20	8.74%	13.05%
MORELAND	150	650.19	5103.97	3638.03	12.74%	17.87%
MOONEE VALLEY	131	598.27	4311.59	2929.28	13.88%	20.42%
GLEN EIRA	50	269.33	3868.90	3275.68	6.96%	8.22%
MELBOURNE	52	799.62	3750.52	497.43	21.32%	160.75%
BAYSIDE	148	389.51	3693.88	2749.05	10.54%	14.17%
MARIBYRNONG	59	306.05	3125.09	1516.46	9.79%	20.18%
STONNINGTON	93	233.37	2563.38	1990.14	9.10%	11.73%
PORT PHILLIP	119	481.48	2042.97	1083.70	23.57%	44.43%
YARRA	63	298.43	1955.80	912.37	15.26%	32.71%

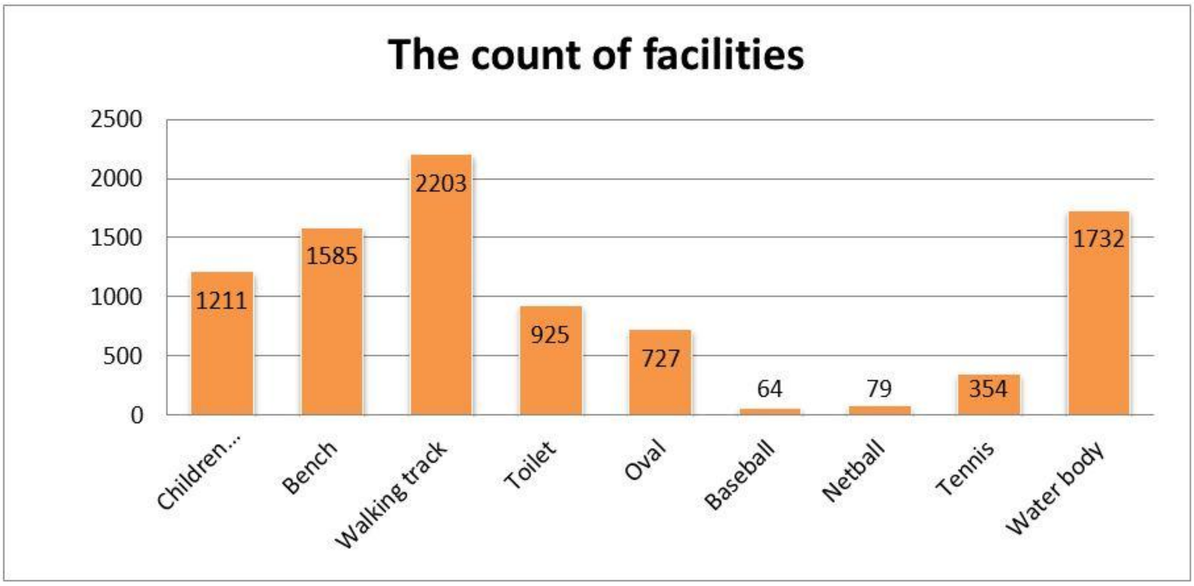
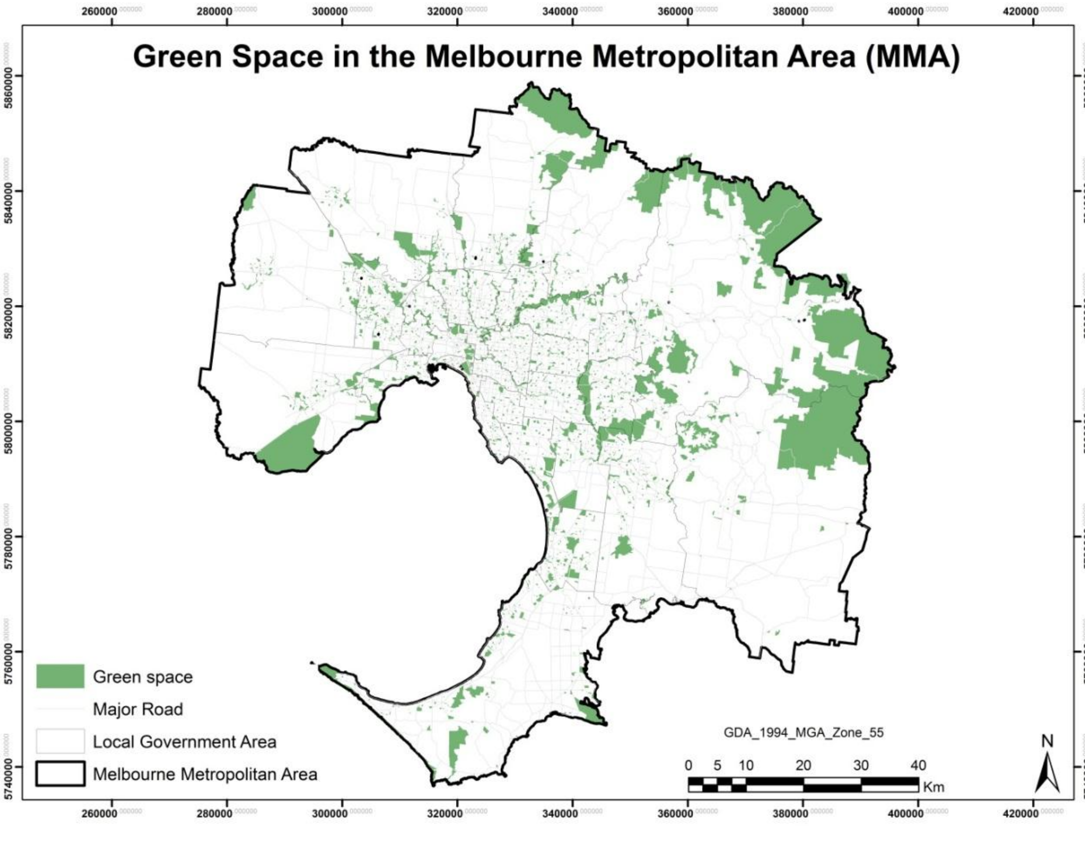
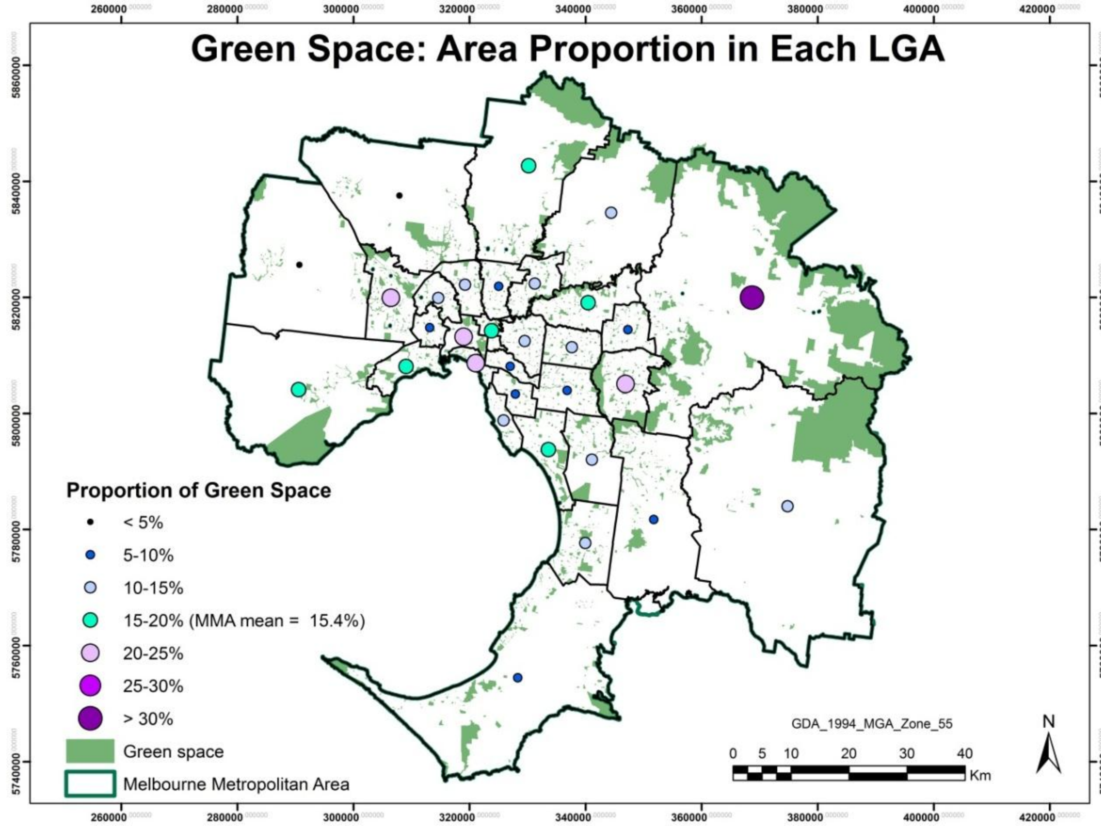


Figure 4.4.1 The count of green space facilities



Map 4.4.1 The distribution of green space in the MMA



Map 4.4.2 The map of green space area proportion in each LGA

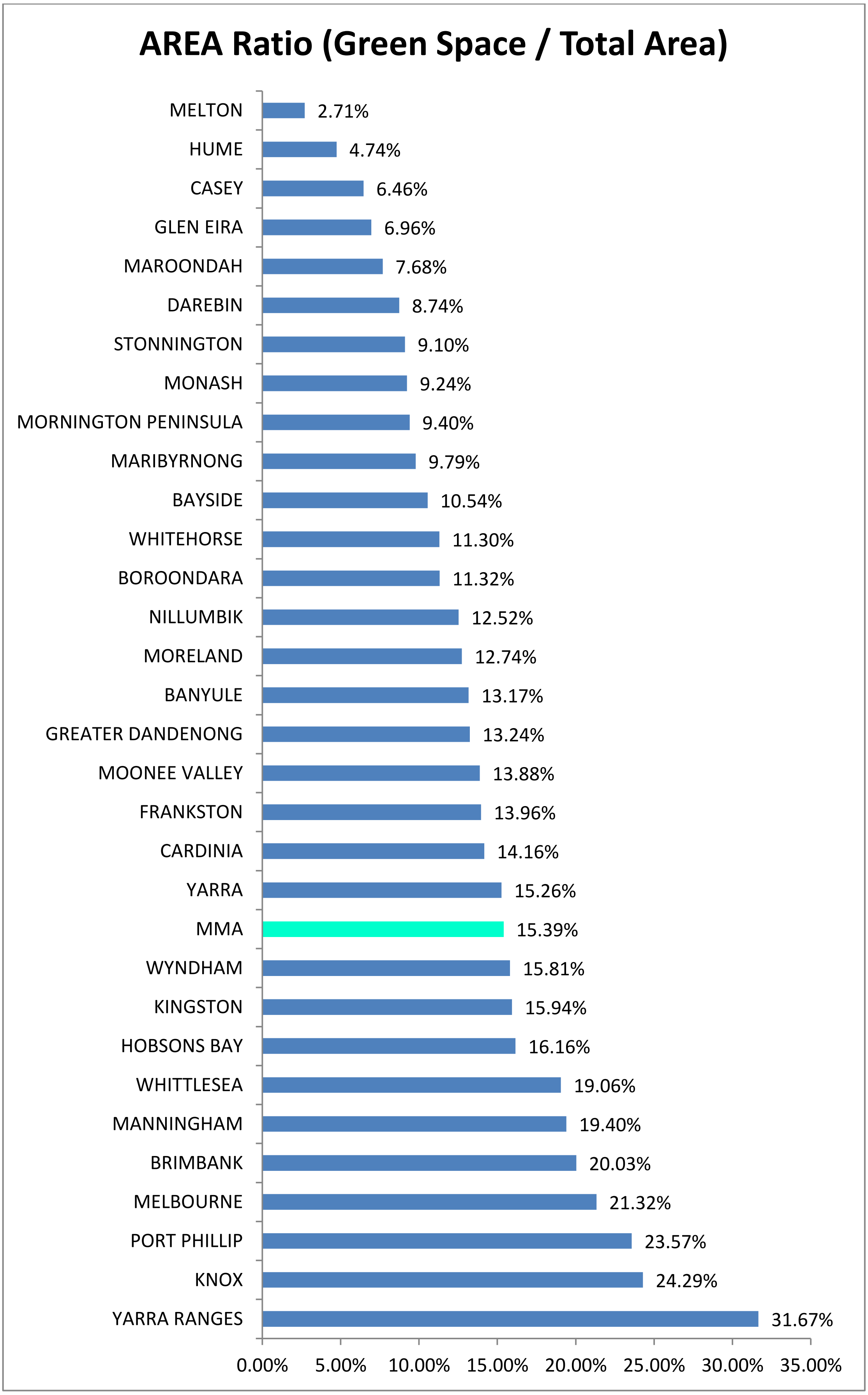


Figure 4.4.2 The area ratio (green space / total area) in each LGA

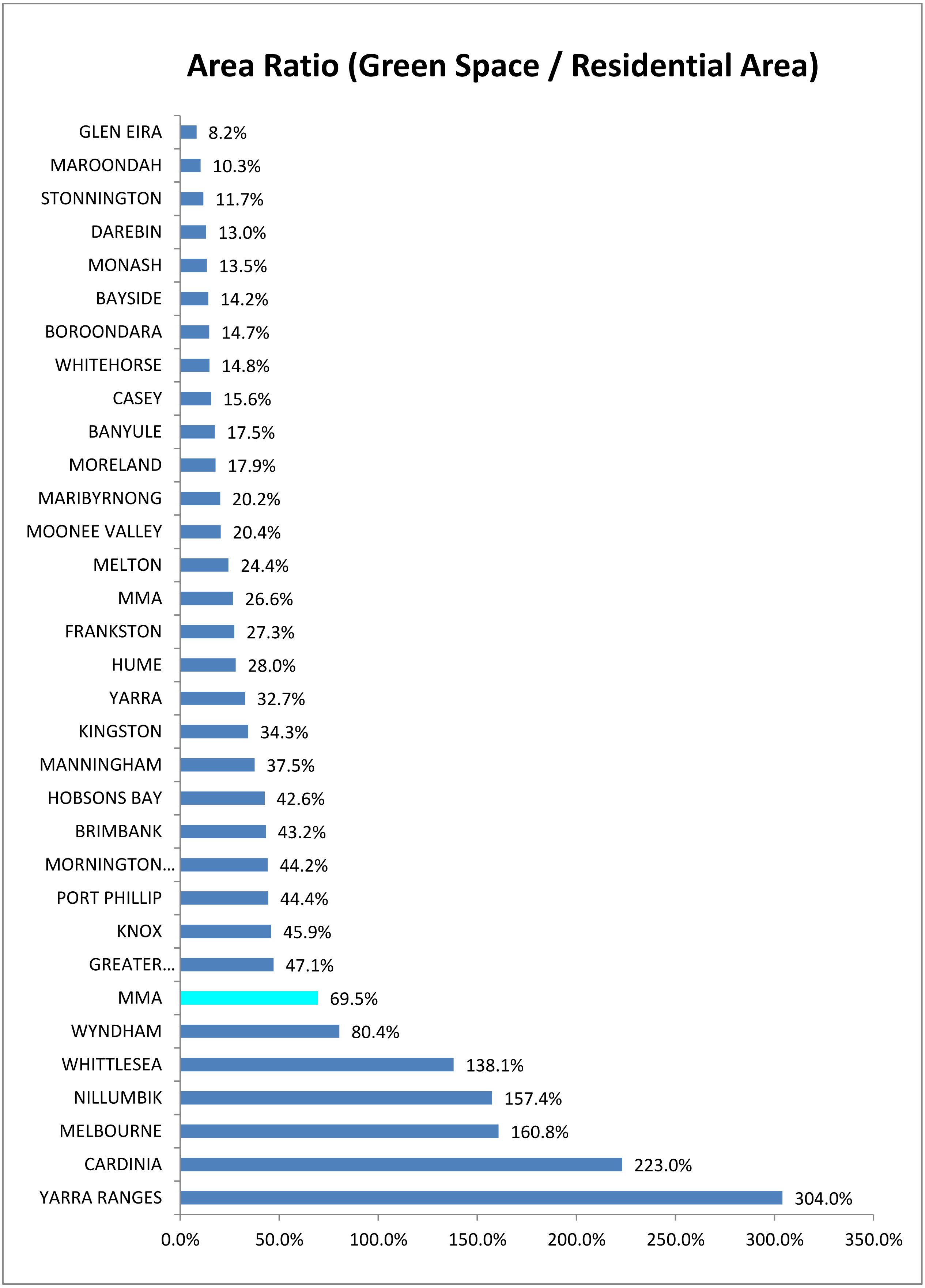


Figure 4.4.3 The area ratio (green space / residential area) in each LGA

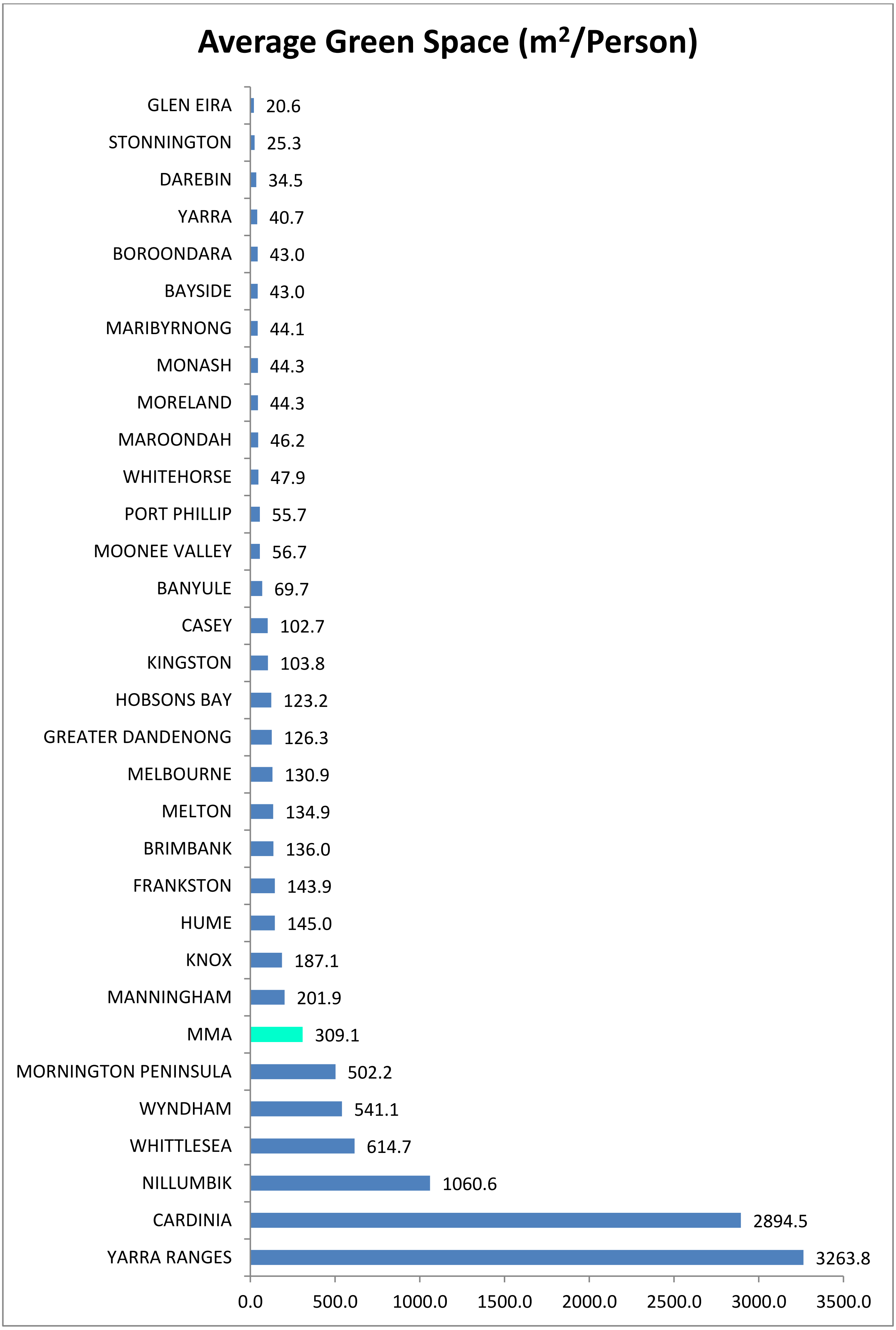
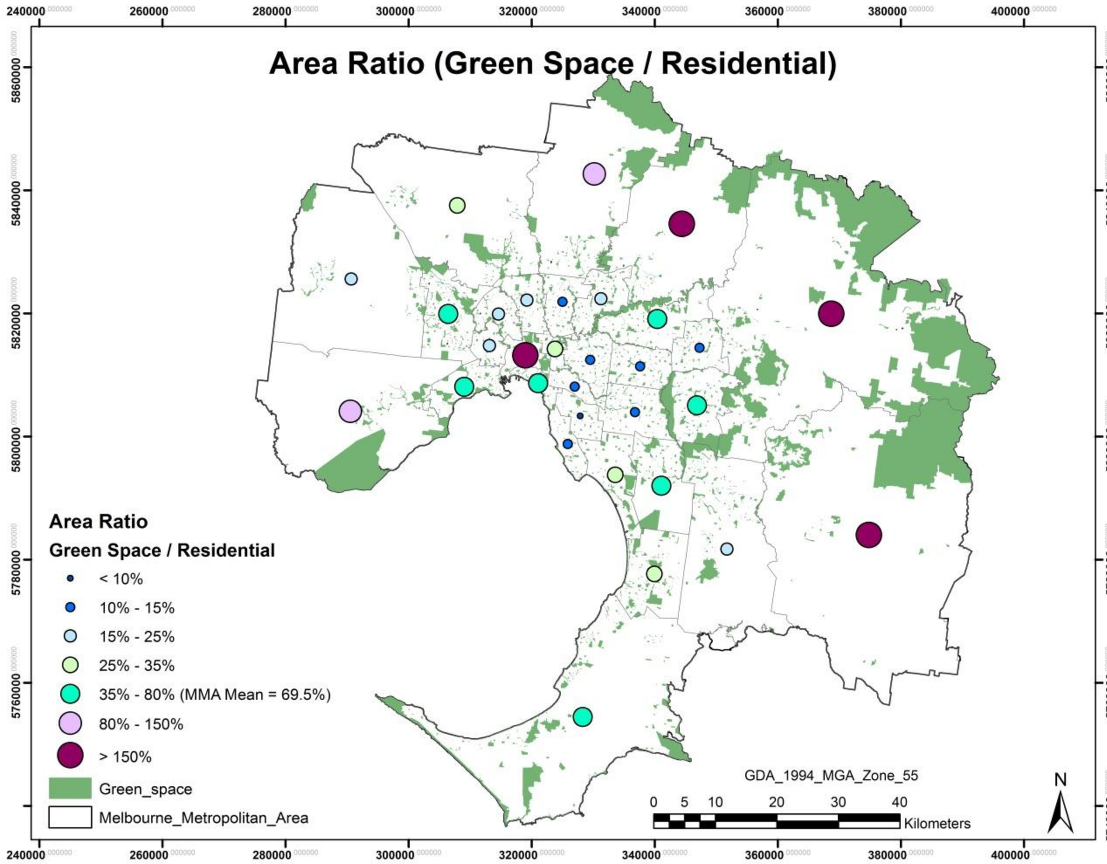
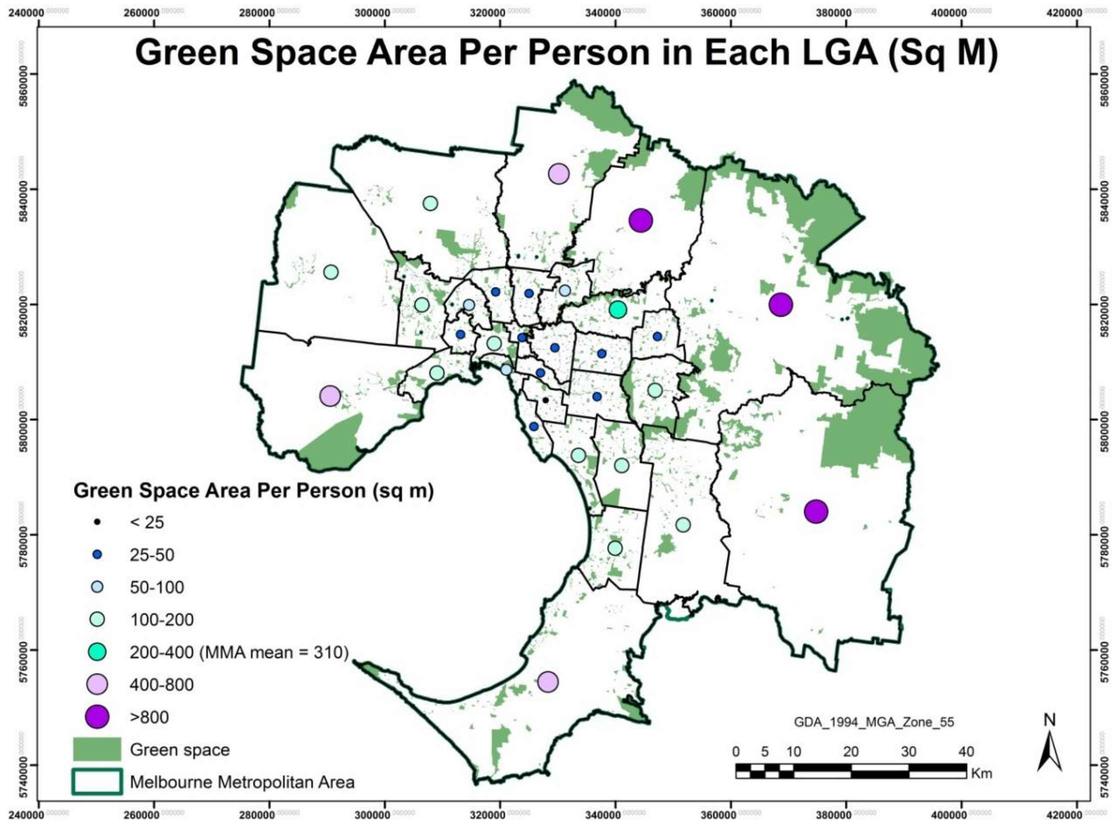


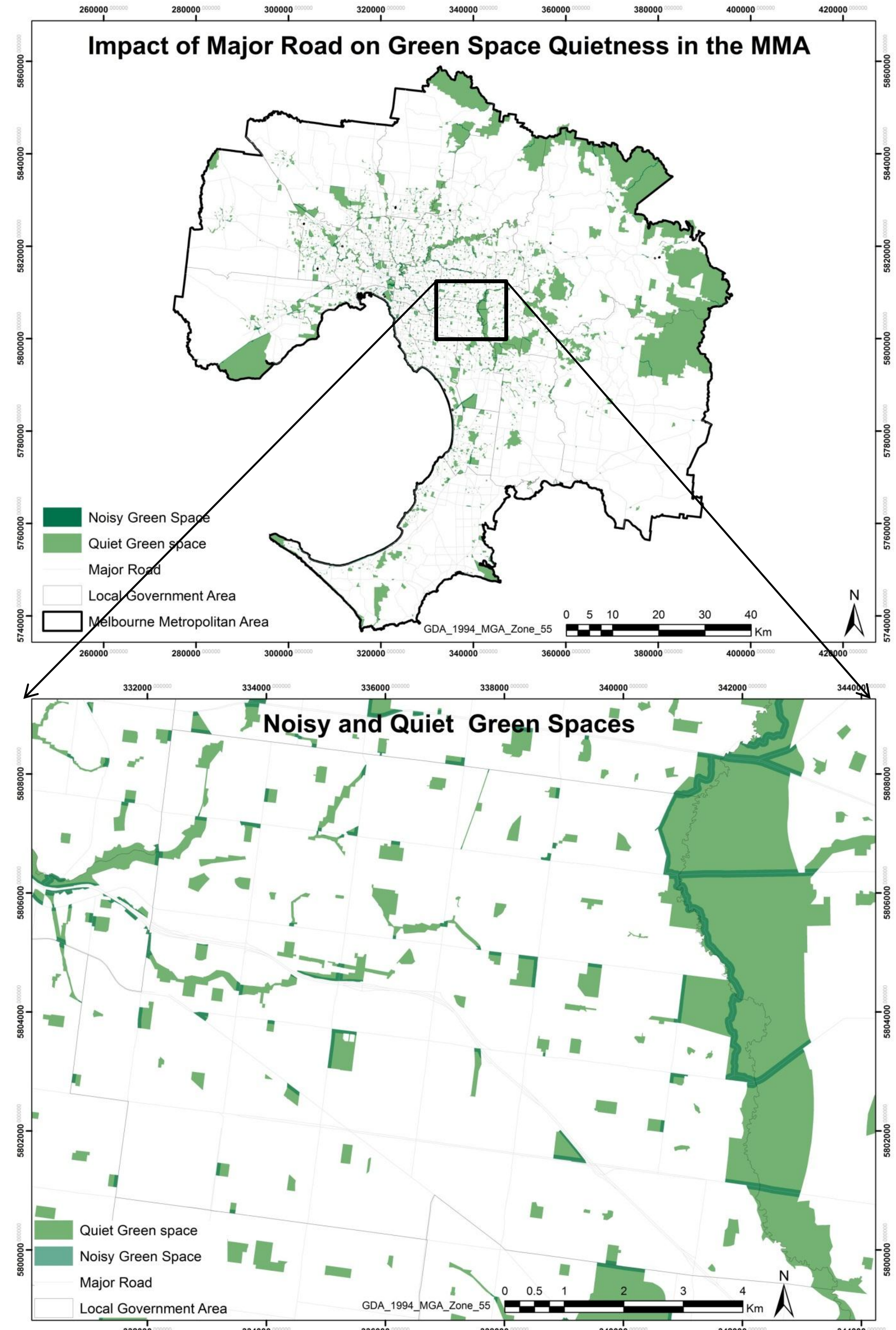
Figure 4.4.4 The average green space area per person in 31 city councils



Map 4.4.3 The map of green space area per person in each LGA



Map 4.4.4 The map of green space area per person in each LGA



Map 4.4.5 The impact area of major road

4.5 Data Sources and Geodatabase Organisation

Table 4.5.1 presents a summary of the spatial and census data sets collected for this study and Figure 4.5.1 presents a catalogue view of the organisation these datasets in an ArcGIS geodatabase.

All population related datasets have been collected from the ABS website (www.abs.gov.au), including both spatial boundaries for both SA1 and MB units and 2011 age-specific population for SA1 units. The spatial boundaries are downloaded as shapefiles and imported into the ArcGIS geodatabase as polygon feature classes. The age-specific population counts for SA1 units are downloaded as an Excel spreadsheet and are imported as a table into the geodatabase and linked to SA1 polygons via SA1 Code. The boundary for the study area and the LGA boundaries have also been downloaded from the ABS website and imported as polygon feature classes into the geodatabase. The land use information, including the residential areas or MBs, are extracted from the MB-based attribute called Category, and imported as polygon feature classes into the geodatabased.

The green space datasets have been downloaded and merged from websites of individual LGAs (e.g. www.knox.vic.gov.au) and Parks Victoria (www.parkweb.vic.gov.au). Wherever needed, high-resolution aerial images are consulted for verification. Sometimes, fieldworks prove to be an effective way to overcome difficulties or resolve confusions in data verification. The collection of green space data, including data on green space facilities, is time-consuming. Special attention have been paid to the accuracy and adequacy of the data. The extents of green space are imported as a polygon feature class into the geodatabase, and the facility data are imported as a table into the geodatabase and are linked to the green space polygons via unique green space IDs.

The road network data, including both major roads and local roads, have been extracted from the VicMap transportation layer and imported as line feature classes into the geodatabase. The road line feature classes are then built into a road network dataset within the geodatabase to support subsequent measurement of travel distances along the road network. Other spatial datasets like the address points and the railway lines have also been extracted from VicMap layers and imported as point feature class and line feature class into the geodatabase.

Table 4.5.1 The detail information of geodatabase in this study

Data	Description	Data type	Source
Melbourne road	Current road network - complete	Line	DOT (http://www.transport.wa.gov.au/)
Australia_Boundary	Current boundary of Australia	Polygon	ABS (http://www.abs.gov.au/)
CENSUS_2011_SA1	2011 SA1 level population	Table	ABS (http://www.abs.gov.au/)
Green_space	2011 boundaries of green spaces	Polygon	Parks Victoria (http://parkweb.vic.gov.au/)
Greenspace_facilities	Facilities in each green space	Table	LGAs (e.g. www.knox.vic.gov.au)
Greenspace_points	Centroids of green spaces	Point	LGAs (e.g. www.knox.vic.gov.au)
Local_Government_Area	Current boundaries of Local Government Areas	Polygon	ABS (http://www.abs.gov.au/)
Major_road	Current road network - only busy roads	Line	Vicmap (http://www.dse.vic.gov.au/)
MB_ID_TO_MB_CODE	Unique MB ID established for this study	Table	Derived
Mel_mb_residential	2011 residential Mesh Blocks	Polygon	ABS (http://www.abs.gov.au/)
Mel_mb_residential_points	2011 residential Mesh Block centroids	Point	ABS (http://www.abs.gov.au/)
Mel_tr_rail	Current Metro railways and tramways	Line	Vicmap (http://www.dse.vic.gov.au/)
Mel_tr_rail_infrastructure	Current Metro train Stations	Point	Vicmap (http://www.dse.vic.gov.au/)
Melbourne_address_points	Current address points	Point	Vicmap (http://www.dse.vic.gov.au/)
Melbourne_locality	Current boundaries of Localities	Polygon	ABS (http://www.abs.gov.au/)
Melbourne_MB	2011 boundaries of Mesh Blocks	Polygon	ABS (http://www.abs.gov.au/)
Melbourne_Metropolitan_Area	Current boundary of Local Government Areas	Polygon	ABS (http://www.abs.gov.au/)
Melbourne_SA1	Current boundary of Statistical Area level 1 units	Polygon	ABS (http://www.abs.gov.au/)
VICTORIA_Boundary	Current boundary of Victoria	Polygon	ABS (http://www.abs.gov.au/)

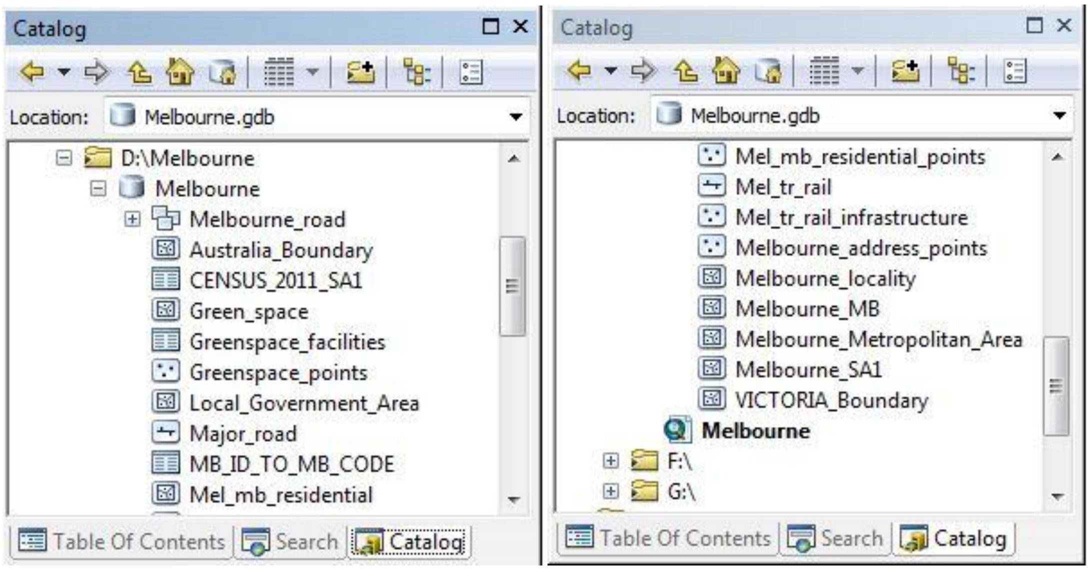


Figure 4.5.1 The catalogue view of the geodatabase built for this study

4.6 Summary

As one of the most liveable cities of the world, the Melbourne Metropolitan Area now has a population over 4 million, including over 68% of adults, close to 19% of young persons and over 13% of old persons.

There are about 40000 residential mesh blocks, taking up more than 22% of the study area. An average mesh block in the MMA has about 95 persons, including 18 young persons, 65 adults and 12 old persons. On average, in the MMA, each km^2 of residential area carries 2274 persons, including 419 young persons, 1536 adults and 293 old persons, compared to each km^2 of land area carrying 498 persons, including 93 young persons, 340 adults and 65 old persons. As expected, population are highly concentrated in the inner suburbs, with some high-density and high concentration clusters of young population occurring in the peripheral suburbs and some high density and high concentration clusters of old population in the zone of middle suburbs.

There are over 4600 neighbourhood green spaces in the MMA, and about 16% of the MMA are occupied by various public open green spaces (over 118000 ha), due to a long history of liveability-centred urban planning practices. The actual percentage of green space in the MMA should be higher if all types of green spaces are included. In the MMA, each green space on average have an area of 25.26 ha; about 800 persons share one green space or 32 persons share one hectare of green space; and each person enjoys about 310 m^2 of green space.

Apart from the size of each green space and the types of facilities associated with each green space (including playground, bench, toilet, walking track, sport oval, sport court, water body), the quietness for each green space is also assessed in terms of proportion of a green space area under the influence of traffic noise. In the MMA, over 2200 green spaces have walking tracks, over 1700 green spaces have water bodies, about 1600 green spaces have benches, over 1200 green spaces have playgrounds, and over 900 green spaces have toilets. In the MMA, over 45% of the 4678 green spaces' quietness are impacted by the traffic noisy from nearby major roads, but only about 4% of the green space area (about 5300 ha) are regarded as noisy due to busy traffic from nearby major roads.

Although land use for transportation account for less than 0.3% of the MMA, the study area has a well-developed transportation infrastructure, with a total road length close to 36000 km, including over 30000 km of local roads. On average, the MMA has a local road density of 40 m / ha, with the inner LGAs exceeding 125 m / ha and the peripheral LGAs under 30 m / ha. Each person in the MMA has about 8 m of local roads, with the inner LGAs under 4 m / person and the peripheral LGAs over 25 m / person.

Apart from residential area, green space and transportation, other types of land use in the MMA include agriculture (over 55%), industrial (a little over 3%), commercial (close to 2%), education (close to 1%) and water body (close to 1%).

A range of high quality spatial datasets and census datasets are available for the MMA which have been gathered and imported into a geodatabase, ready to support subsequent tasks of spatial analyses and thematic mapping.

CHAPTER 5 GREEN SPACE ACCESSIBILITY IN THE MMA

In this chapter, spatial variations in accessibility to green space measured with different methods, and spatial clusters of residential areas with high locational disadvantage, in the study area, are presented with a set of maps, tables and charts.

Section 5.1 presents spatial variations in travel distance to green space from residential areas, as measured by road network distance. Section 5.2 summarises spatial relationships between residential areas and green spaces for three different neighbourhood zones. Section 5.3 summarises measured green space attractiveness to four types of population, namely the young (0-15 years), adult (16-64 years), old (65+ years), and the total population. Section 5.4 presents spatial variations in accessibility to green space for the four groups of population, based on the Mean Accessibility measures. Section 5.5 presents spatial variations in estimated potential demand to the green space, estimated provision of green space, as well as the identified disadvantage areas. Section 5.6 presents some ranks of the 31 LGAs in terms of green space accessibility and locational disadvantage.

This chapter also presents summary statistics reflecting the spatial and categorical distributions of population associated with different levels of green space accessibility and locational disadvantage.

5.1 Travel Distance between Green Space and Residential Area

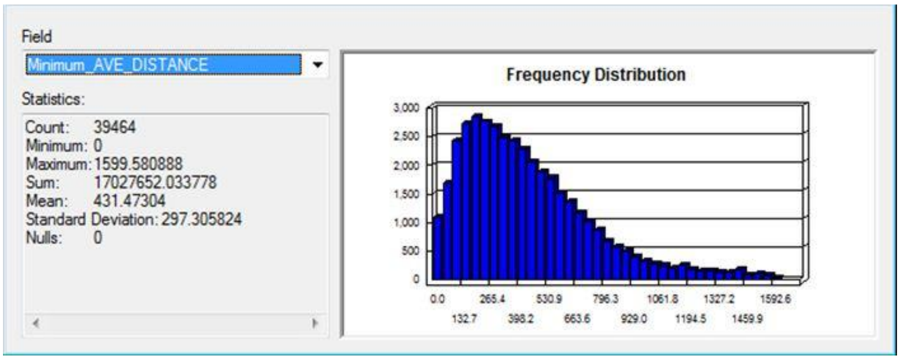
The travel distance between the entrances of a residential area and their closest entrances to a green space is measured in metres along the road network. The boundaries of residential areas and green spaces are extracted from the corresponding MB boundaries defined in the 2011 ABS census geography.

Since the data of the actual entrances are not available, the entrances to a residential area are defined in this study by the points of spatial intersection between residential MB polygons and the road network lines. The entrances for green space are defined in the same manner. There are about 415266 entrances to 39991MB and 33220 entrances to 4678 green spaces identified in the MMA. On average, each MB has about 10 entrances and each green space has about 7 entrances.

The travel distance between the residential area and green space is limited to 1600 m, beyond which less than 2.4% (or 111) green spaces and about 1.3% (or 527) residential MBs are found. In other words, any green space located beyond a travel distance of 1600 m along the road network from any residential MB in the study area is regarded as inaccessible and unattractive. It is worth to note that in this study a cut off distance of 3200 m has been applied in the search of entrances to residential areas to ensure unbiased travel distance calculation. This cut off distance is determined by considering the size distribution of residential areas in the MMA. In total, over 23 million origin-destination (OD) distances have been measured.

Based on the 1600 m neighbourhoods, there are over half a million residential MB-Green Space combinations in the MMA. For each MB, its accessibility to green space can be crudely described by two travel distances: (1) the travel distance to its nearest green space (Figure 5.1.1 above), and (2) the mean travel distance to all green spaces within the 1600 m neighbourhood. In the MMA, within a residential neighbourhood defined by a road network distance of 1600 m, the average travel distance between all residential MBs and their respective nearest green space is about 431.5 m (Figure 5.1.1 below). The average travel distance between all residential MBs and their respective neighbourhood green spaces is about 1087.4 m.

Map 5.1.1 shows the spatial variations in travel distance from each MB to the nearest green space within the 1600 m neighbourhood, and Map 5.1.2 shows the average distance from each MB to all green spaces that are located within the 1600 m neighbourhood.



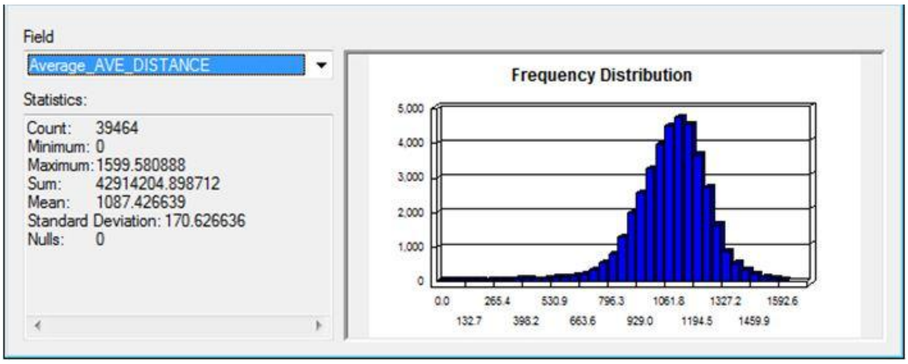
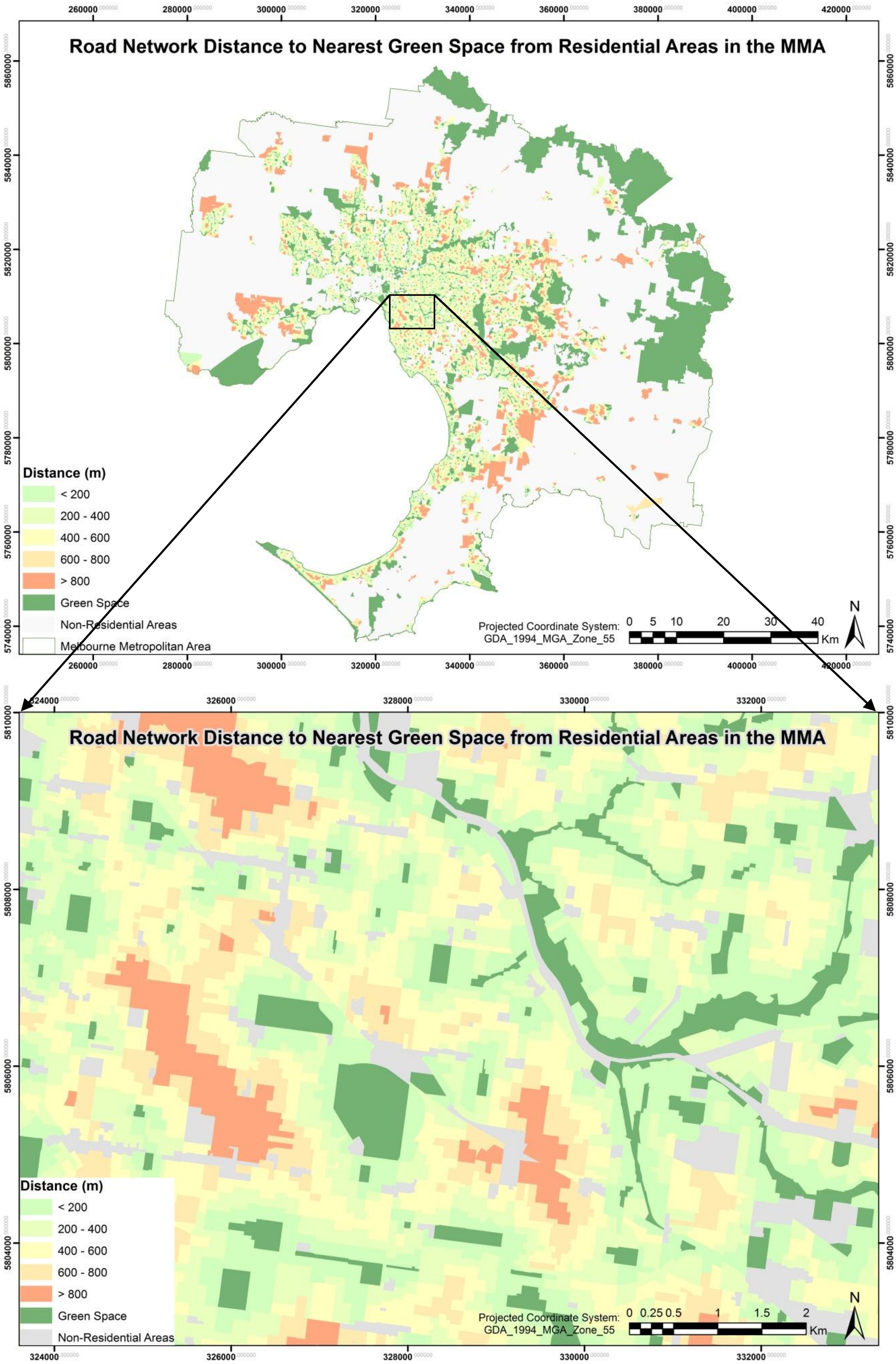
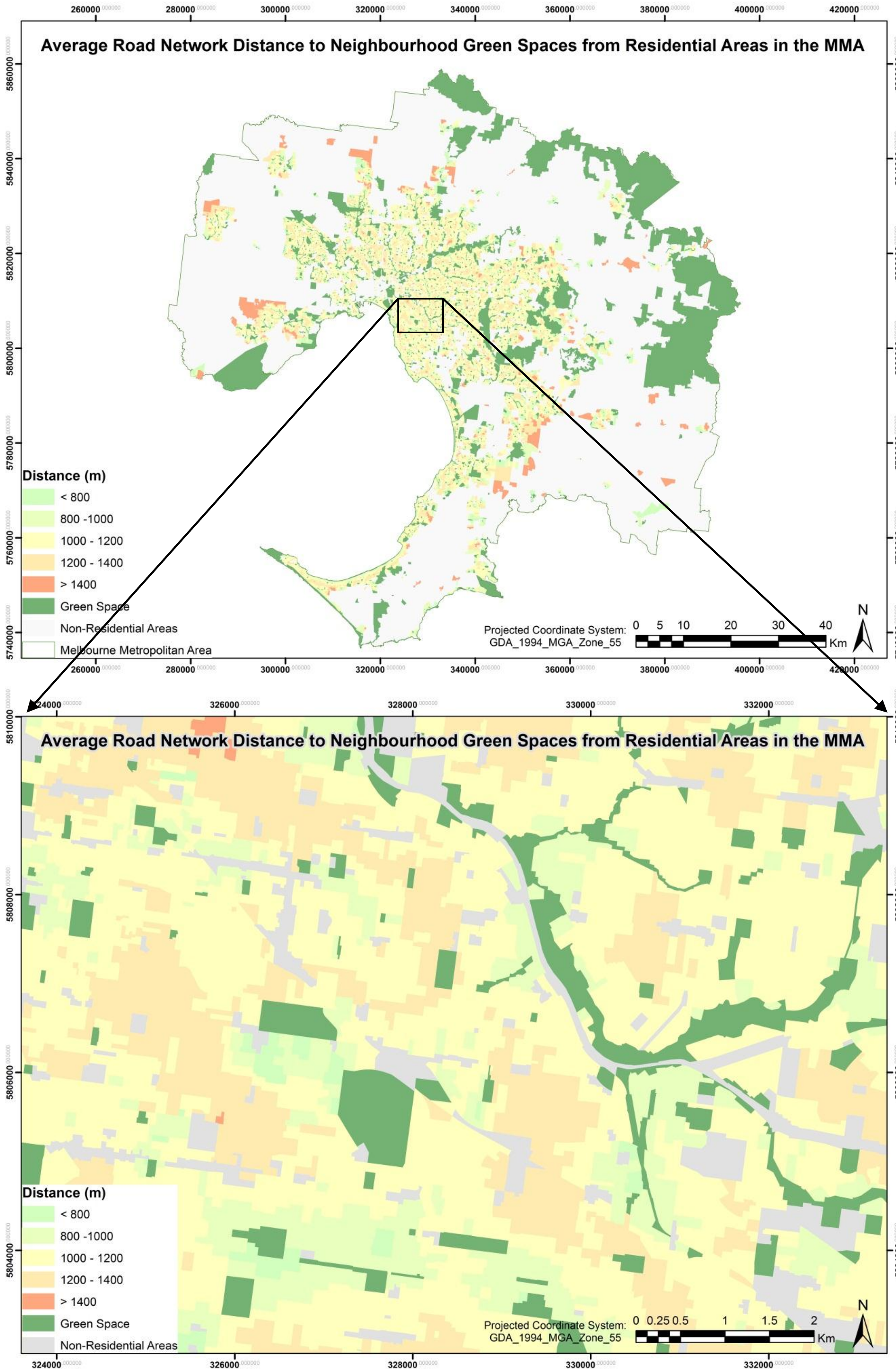


Figure 5.1.1 The frequency distribution of representative travel distances between residential MBs and their nearest green spaces (above) and their neighbourhood green spaces (below) in the MMA.



Map 5.1.1 Spatial variations in MB-based travel distance to nearest green space.



Map 5.1.2 Spatial variations in average MB-based travel distance to all green spaces within 1600m.

In general, residential MBs within about 25 km distance from the CBD have shorter travel distances to the corresponding nearest or neighbourhood green spaces than those located beyond 25 km distance from the CBD. In contrast, most residential MBs located in the periphery of the MMA have longer travel distances to their respectively nearest or neighbourhood green spaces, even with the presence of many bigger and attractive nation parks.

Due to road network constraints, some residential MBs can have larger than visually perceived travel distances to their respectively nearest green spaces. For example, a residential MB that have a straight-line distance of 200 m from its nearest green space may actually have an entrance-to-entrance travel distance of 800 m measured along the road network.

For a specific residential MB, the mean travel distance to all green spaces within the 1600 m neighbourhood can be equal to the travel distance to its nearest green space, in the case that only one green space exists in the entire neighbourhood. Alternatively, the average distance can be much less than the travel distance to its nearest green space, when more than one green space exists in the neighbourhood. For example, if MB *i* has two green spaces within its 1600 m neighbourhood, one is 300 m away, and the other one is 1100 m away; the average travel distance to these two green spaces for MB *i* would be 700 m, but the nearest green space is actually 300 m away from the MB.

A longer measured mean travel distance to green space within the 1600 m neighbourhood for residential MBs located to the periphery of the MMA may be attributable to the following factors: within the neighbourhoods, there are fewer green spaces, which are also located farther away from the residential MBs, and the road densities are lower (see section 4.6).

Within its 1600 m neighbourhood, each residential MB in the MMA has, on average, about 13.3 green spaces (Figure 5.1.2, above), or about 110.6 ha of green space area (Figure 5.1.2, below).

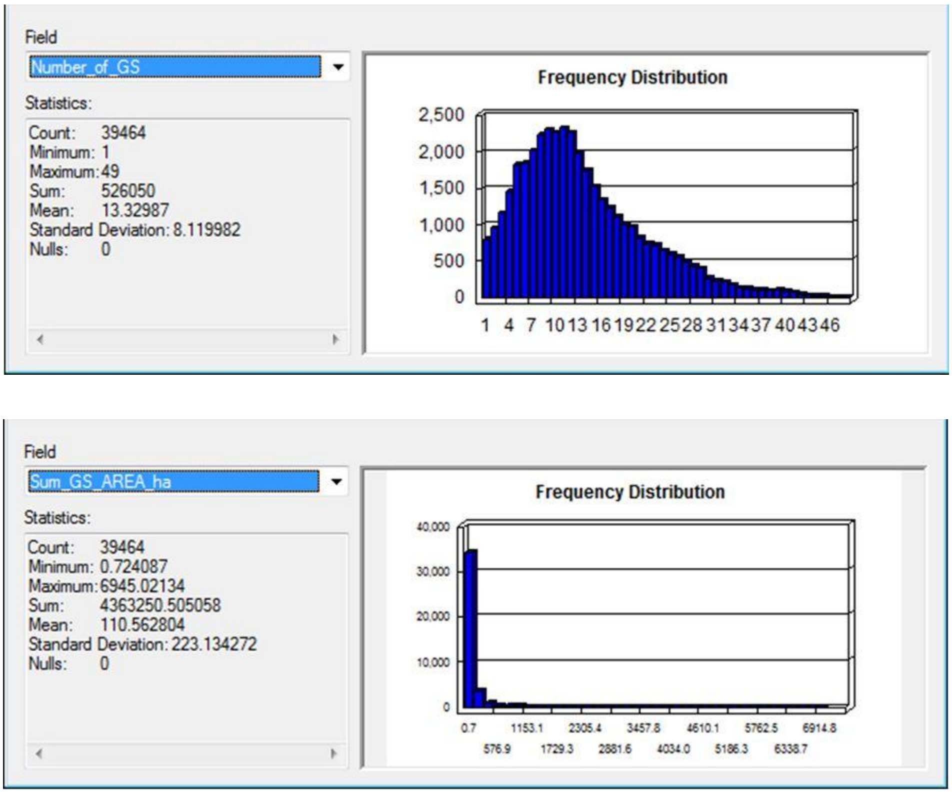


Figure 5.1.2 Frequency distributions of MB-based average number of green space (above) and average area of green space (below) within a 1600 m neighbourhood.

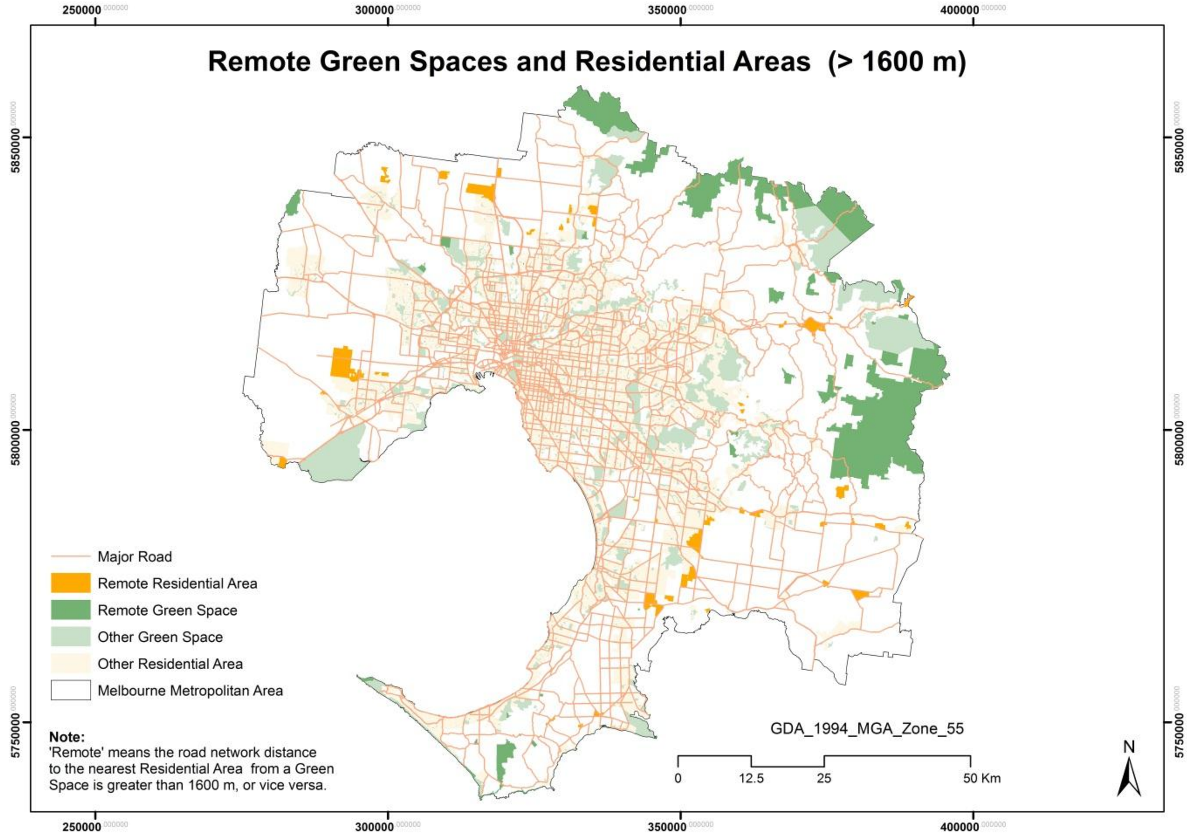
5.2 Spatial Relationships between Residential Population and Green Space Availability

The spatial relationships between green space availability and population have been examined in this study, first at the per MB and per green space level for all MBs and all green spaces in the MMA, and then aggregated into three zones of specified road network distances: 0-400 m, 0 – 800 m, and 0 – 1600 m.

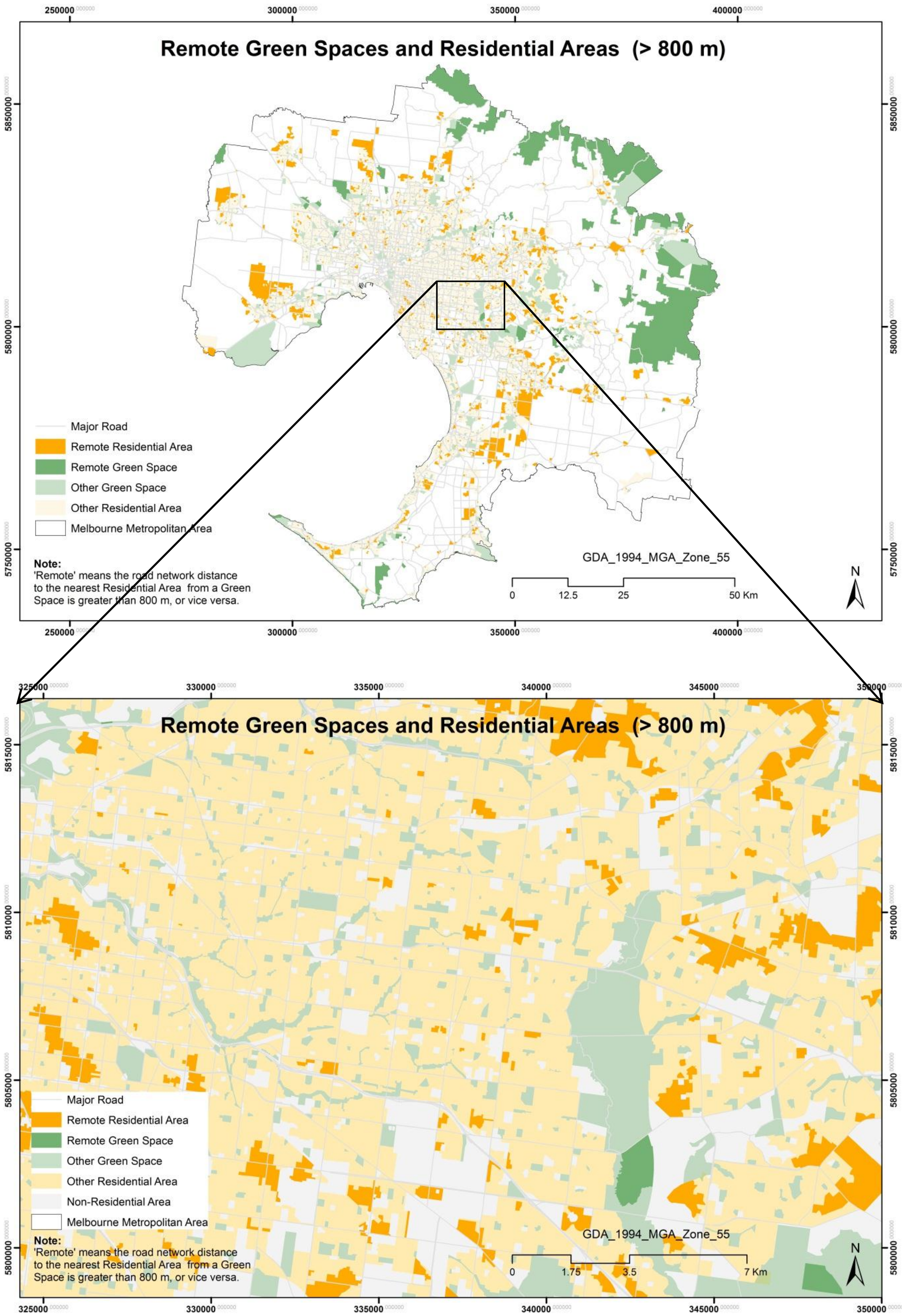
The statistics examined for each green space and for each of the three zones around green spaces include: numbers of (total, young, adult, old) persons, total number of MBs, total area (ha) of MBs, and average distances between green space and residential MBs.

The statistics examined for each MB and for each of the three zones around MBs include: total green space area (ha), shortest road network distance to the nearest green space (m), mean shortest road network distance to all green spaces within the specified neighbourhood (m), and total number of green spaces within the specified neighbourhood.

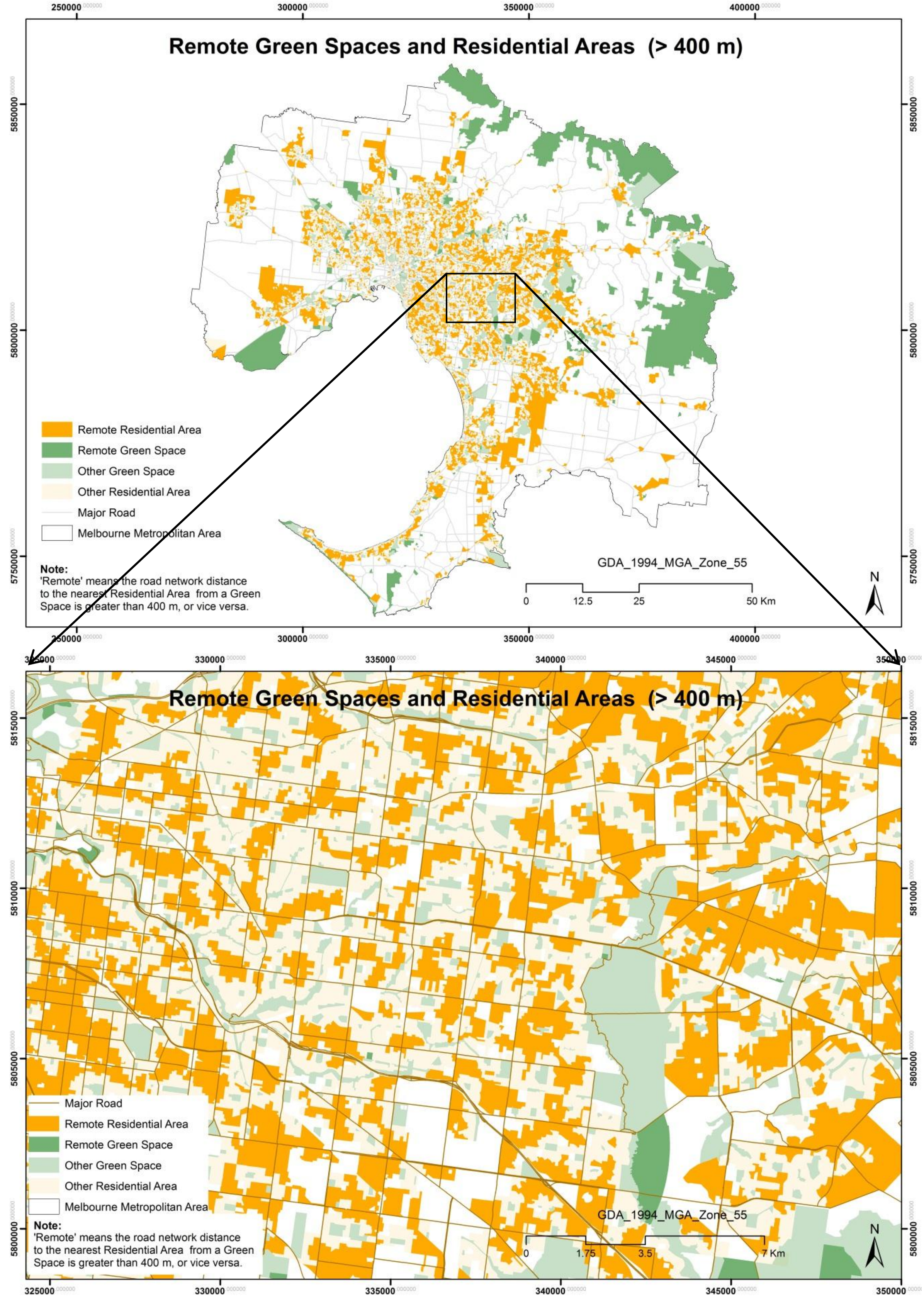
Maps 5.2.1 to Map 5.2.3 show the spatial distributions of remote residential MBs and remote green spaces across the MMA, as defined by the 1600 m, 800 m and 400 m neighbourhoods, respectively. The remote green spaces located beyond 1600 m of any residential MB are all located in the edge of MMA. Most of them are national parks, which are designed for regional instead of neighbourhood entertainments.



Map 5.2.1 The remote green space over 1600m to MB



Map 5.2.2 The remote green space over 800m to MB



Map 5.2.3 The remote green space over 400m to MB

Tables 5.2.1 to 5.2.4 present some green space based observations for a set of MB and population related variables for three different neighbourhood zones (i.e. within 400 m, 800 m or 1600 m) and the remote zone (i.e. beyond 1600 m). These observations are summarised in Table 5.2.5 and Table 5.2.6, and depicted in Figure 5.2.1 and Figure 5.2.2. On average,

- over 50%, 85%, or 98% of the residents or residential MBs in the MMA have at least one green space accessible within 400 m, 800m, or 1600m of walking distance along local road network, respectively;
- for each green space, there are about 5, 8 or 9 residential MBs located within 400 m, 800m, or 1600m of walking distance along local road network, respectively;
- for each green space, there are about 20 ha, 30 ha or 35 ha residential area located within 400 m, 800m, or 1600m of walking distance along local road network, respectively; and
- the average walking distance from green spaces to residential MBs are about 250 m, 500 m and 1000 m for the 400 m, 800 m and 1600 m green space-based neighbourhoods, respectively.

Tables 5.2.7 to 5.2.10 present some observations of MB-based summaries of green space area and residential population for three different neighbourhood zones (i.e. within 400 m, 800 m or 1600 m) and the remote zone (i.e. beyond 1600 m). These observations are summarised in Table 5.2.11 and depicted in Figure 5.2.3. On average,

- over 90% of green spaces, and less 40% of green space area are located within the 400 m neighbourhoods of residential MBs;
- for each residential MB, there are about 2, 4 or 13 green spaces located within 400 m, 800m, or 1600m of walking distance along local road network, respectively;
- for each residential MB, there are about 16 ha, 30 ha or 110 ha of green space area located within 400 m, 800m, or 1600m of walking distance along local road network, respectively; and
- the average walking distance from residential MBs to their respective nearest green spaces are about 220 m, 355 m and 430 m for the 400 m, 800 m and 1600 m green space-based neighbourhoods

As expected, the number of residential MBs, green spaces and their combinations generally increase with the size of the neighbourhood. As shown in Table 5.2.6 and Table 5.2.11, there are 21236 residential MBs, 4273 green spaces, and 38337 combinations for the 400 m neighbourhoods; 35140 residential MBs, 4481 green spaces and 126720 combinations for the 800 m neighbourhoods; 39464 residential MBs, 4567 green spaces and 526050 combinations for the 1600m neighbourhoods. Beyond a travel distance of 1600 m, a green space or a residential MB is regarded as mutually remote, unattractive and inaccessible on foot, even though there are 527 such remote residential MBs and 111 such remote green spaces, it is pointless to consider their combinations because their respective neighbourhoods become too large to be accessible by pedestrians.

Table 5.2.1 Green space-based summary statistics for the 400m neighbourhood.

OBJECTID *	GS_ID	Sum_POP_T	Sum_POP_Y	Sum_POP_A	Sum_POP_O	Sum_MB_AREA_ha	Number_of_MB	Average_distance
1	1	1627	290	1137	200	55.410446	17	255.825868
2	2	1322	327	864	131	31.706409	14	291.692916
3	3	1863	345	1253	265	56.65116	22	219.858086
4	4	1211	195	821	195	37.267759	17	217.004942
5	5	1556	271	1066	219	47.136336	20	227.580074
6	6	820	137	537	146	36.25354	10	277.104515
7	7	1500	308	981	211	39.130721	15	242.583793
8	8	2244	371	1417	456	55.489097	19	248.491256
9	9	1274	188	832	254	37.653804	12	272.514265
10	10	1180	202	813	165	36.935383	15	253.869044
11	11	1474	372	925	177	49.055192	13	259.811013
12	12	1488	269	1046	173	48.061337	17	254.811114
13	13	797	141	584	72	25.817888	10	262.222224
14	14	1125	248	747	130	38.17083	13	247.281913
15	15	1379	244	963	172	46.034104	17	266.500944
16	16	448	88	330	30	16.176692	4	286.202978
17	17	622	97	412	113	17.521689	6	325.697109
18	18	888	165	549	174	28.438465	10	260.707566
19	19	509	88	316	105	15.973705	6	250.429837
20	20	696	125	450	121	22.759192	8	230.927312

Table 5.2.2 Green space-based summary statistics for the 800m neighbourhood.

OBJECTID *	GS_ID	Sum_POP_T	Sum_POP_Y	Sum_POP_A	Sum_POP_O	Sum_MB_AREA_ha	Number_of_MB	Average_distance
1	1	3350	599	2288	463	113.795433	34	425.750402
2	2	3058	643	2060	355	85.323	35	477.659294
3	3	4578	868	3109	601	155.191584	53	439.600104
4	4	4508	812	3006	690	139.817056	54	494.598772
5	5	4171	796	2838	537	121.562412	47	466.763005
6	6	3251	585	2199	467	124.574648	36	503.155984
7	7	3921	726	2660	535	117.353532	45	502.491153
8	8	5597	882	3570	1145	157.739814	58	516.260095
9	9	5366	804	3410	1152	149.048789	54	519.222287
10	10	3496	687	2381	428	102.81137	41	474.895313
11	11	4225	829	2927	469	266.359514	35	499.955769
12	12	3078	578	2097	403	92.062916	35	433.641501
13	13	4174	712	2920	542	129.31839	51	528.011527
14	14	4616	856	3124	636	133.727025	52	499.368302
15	15	3239	482	2086	671	102.573866	38	460.852401
16	16	1229	262	821	146	45.803535	12	519.203645
17	17	2480	438	1648	394	85.588757	29	567.140365
18	18	3344	643	2252	449	106.764124	38	528.371621
19	19	2333	442	1562	329	77.165101	27	551.461675
20	20	3754	651	2423	680	119.290109	42	561.444612

Table 5.2.3 Green space-based summary statistics for the 1600m neighbourhood.

OBJECTID *	GS_ID	Sum_POP_T	Sum_POP_Y	Sum_POP_A	Sum_POP_O	Sum_MB_AREA_ha	Number_of_MB	Average_distance
1	1	13485	2403	8986	2096	412.613256	152	1110.377978
2	2	10995	2016	7358	1621	311.734177	135	1088.530366
3	3	13087	2382	8901	1804	495.108424	149	951.836046
4	4	14005	2399	8978	2628	504.032485	154	984.750825
5	5	15522	2780	10703	2039	483.027706	182	1074.655464
6	6	13861	2377	9170	2314	466.653622	152	1093.93152
7	7	14670	2500	9938	2232	458.835703	172	1039.188313
8	8	19029	3132	12719	3178	609.172584	223	1089.315852
9	9	19320	3262	12902	3156	643.435096	220	1081.27278
10	10	11610	2069	7899	1642	358.611598	141	1024.725156
11	11	10379	1923	6779	1677	479.766932	98	1016.866633
12	12	9901	1760	6663	1478	297.161318	110	994.852599
13	13	15280	2834	10429	2017	542.208127	177	1037.724339
14	14	12592	2215	8451	1926	388.58515	142	996.69652
15	15	17951	2983	11984	2984	566.582144	202	1116.195061
16	16	10659	1884	6734	2041	483.148684	110	1214.492872
17	17	12163	2038	7944	2181	570.514492	137	1100.96196
18	18	13130	2279	8748	2103	403.640114	146	1046.176396
19	19	12695	2201	8452	2042	389.99148	141	1110.622329
20	20	15385	2674	10232	2479	472.297887	173	1080.295048

Table 5.2.4 Green space-based summary statistics for a set of remote green spaces.

OBJECTID *	GS_ID	POP_T	POP_Y	POP_A	POP_O	Sum_MB_area_ha	Number_of_MB
1	413	3823148	712454	2612409	498285	170114.87	39991
2	420	3823148	712454	2612409	498285	170114.87	39991
3	1021	3823148	712454	2612409	498285	170114.87	39991
4	1591	3823148	712454	2612409	498285	170114.87	39991
5	1878	3823148	712454	2612409	498285	170114.87	39991
6	1902	3823148	712454	2612409	498285	170114.87	39991
7	1917	3823148	712454	2612409	498285	170114.87	39991
8	1936	3823148	712454	2612409	498285	170114.87	39991
9	1946	3823148	712454	2612409	498285	170114.87	39991
10	1959	3823148	712454	2612409	498285	170114.87	39991
11	1964	3823148	712454	2612409	498285	170114.87	39991
12	1967	3823148	712454	2612409	498285	170114.87	39991
13	1968	3823148	712454	2612409	498285	170114.87	39991
14	1970	3823148	712454	2612409	498285	170114.87	39991
15	1980	3823148	712454	2612409	498285	170114.87	39991
16	1987	3823148	712454	2612409	498285	170114.87	39991
17	1990	3823148	712454	2612409	498285	170114.87	39991
18	2062	3823148	712454	2612409	498285	170114.87	39991
19	2070	3823148	712454	2612409	498285	170114.87	39991
20	2138	3823148	712454	2612409	498285	170114.87	39991
21	2139	3823148	712454	2612409	498285	170114.87	39991

Table 5.2.5 The percentage and size of population in different neighbourhood zones

Distance from Green Space to MB		[0, 400] m	[0,800]m	[0,1600]m	Beyond 1600m	Total
Total	persons	1984758	3311548	3767505	55643	3823148
	%	51.9	86.6	98.5	1.5	100.0
Young	persons	354946	597971	698495	13959	712454
	%	49.8	83.9	98.0	2.0	100.0
Adult	persons	1363926	2264337	2574240	38169	2612409
	%	52.2	86.7	98.5	1.5	100.0
Old	persons	265886	449240	494770	3515	498285
	%	53.4%	90.2%	99.3%	0.7%	100.0%

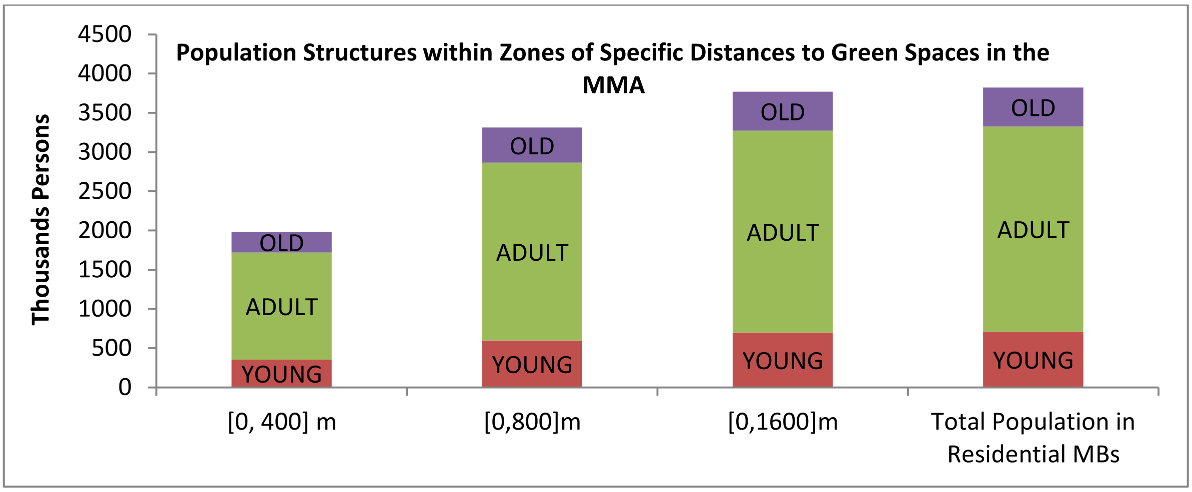


Figure 5.2.1 Population Structures within Zones of Specific Distances to Green Spaces in the MMA

Table 5.2.6 The percentage and amount of MB and MB area in certain distance level

Distance to MB from green space	[0, 400] m	[0,800]m	[0,1600]m	Beyond 1600m	Total
Number of MBs	21236	35140	39464	527	39991
	53.1%	87.9%	98.7%	1.3%	100.0%
Total MB Area (ha)	73869.17	131741.39	160777.99	9336.88	170114.87
	43.4%	77.4%	94.5%	5.5%	100.0%
Average number of MB per green space	5	8	9	n/a	9
Average area of MB per green space (ha)	17.29	29.40	35.20	n/a	36.36
Average Distance from green space to MBs (m)	248.6	506.2	1087.4	n/a	n/a

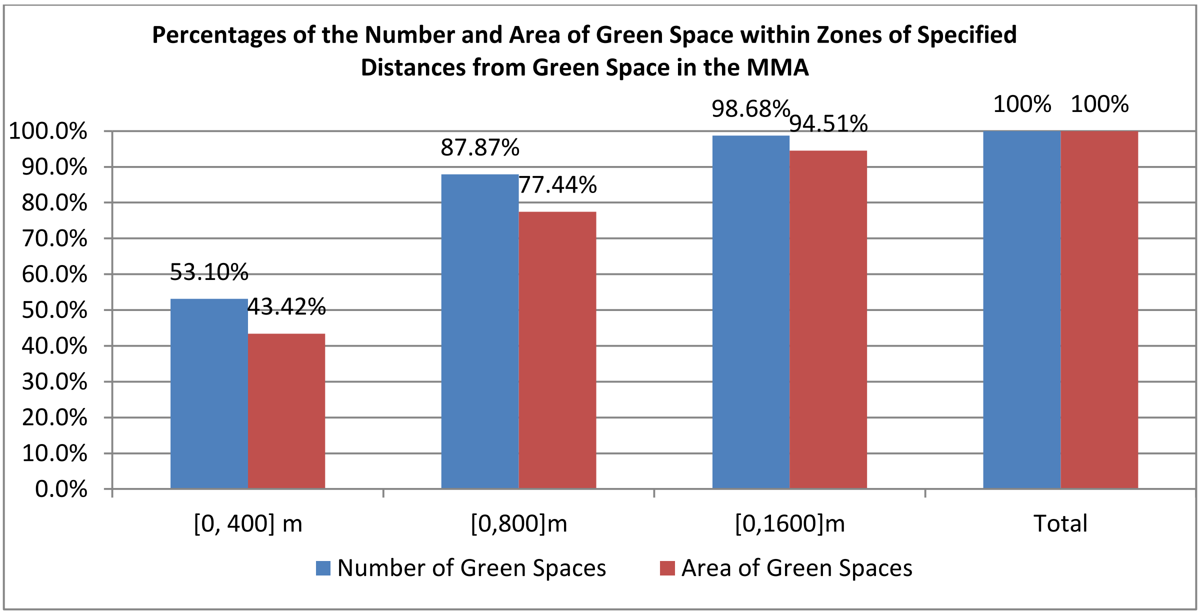


Figure 5.2.2 Percentages of the Number and Area of Green Space within Zones of Specified Distances from Green Space in the MMA

Table 5.2.7 MB-based summary statistics for the 400m neighbourhood

OBJECTID *	MB_ID	Sum_GS_AREA_ha	Number_of_GS	POP_T	POP_Y	POP_A	POP_O	Minimum_distance	Mean_distance
1	2	26.486826	1	89	14	60	15	76.560174	76.560174
2	3	26.486826	1	157	26	113	18	319.69455	319.69455
3	5	8.744549	2	72	13	50	9	15.869728	121.359281
4	6	6.46989	2	98	16	66	16	147.326559	204.983464
5	7	5.946813	4	75	13	54	8	201.979552	270.00241
6	8	22.037148	4	92	18	66	8	235.732851	303.963977
7	9	1.518877	1	50	8	37	5	195.212601	195.212601
8	11	0.649067	1	84	24	52	8	286.949886	286.949886
9	12	1.331129	1	62	15	42	5	336.686073	336.686073
10	13	8.752368	2	147	25	106	16	224.519996	296.071047
11	14	5.848144	1	77	15	53	9	226.858903	226.858903
12	15	26.542495	2	101	16	69	16	226.37589	258.38258
13	16	18.362509	2	68	14	45	9	267.700552	318.289271
14	17	0.811633	1	93	12	68	13	244.023988	244.023988
15	18	0.811633	1	109	22	73	14	330.399793	330.399793
16	19	6.212771	1	122	21	92	9	334.253881	334.253881
17	20	37.786034	5	118	17	84	17	75.475797	239.670594
18	21	6.212771	1	87	18	55	14	220.630986	220.630986
19	23	3.867796	1	81	14	60	7	334.954695	334.954695
20	26	7.98368	2	88	15	46	27	292.864766	298.311468

Table 5.2.8 MB-based summary statistics for the 800m neighbourhood

OBJECTID *	MB_ID	Sum_GS_AREA_ha	Number_of_GS	POP_T	POP_Y	POP_A	POP_O	Minimum_distance	Mean_distance
1	1	7.202495	2	76	8	48	20	479.238549	600.870105
2	2	30.348129	2	89	14	60	15	76.560174	239.241111
3	3	49.060112	4	157	26	113	18	319.69455	561.33817
4	4	41.450742	5	123	22	87	14	423.885623	594.152169
5	5	17.251875	7	72	13	50	9	15.869728	463.005422
6	6	34.280269	9	98	16	66	16	147.326559	508.170015
7	7	30.543089	12	75	13	54	8	201.979552	506.56419
8	8	28.100998	9	92	18	66	8	235.732851	515.789484
9	9	7.357058	5	50	8	37	5	195.212601	532.597066
10	10	20.349717	4	104	22	59	23	447.821385	593.946556
11	11	42.57303	8	84	24	52	8	286.949886	613.496906
12	12	41.685183	7	62	15	42	5	336.686073	545.732435
13	13	29.710566	12	147	25	106	16	224.519996	498.070058
14	14	20.349717	4	77	15	53	9	226.858903	472.589621
15	15	38.063159	5	101	16	69	16	226.37589	399.169224
16	16	41.304742	6	68	14	45	9	267.700552	536.308229
17	17	17.351966	5	93	12	68	13	244.023988	587.351453
18	18	30.811023	3	109	22	73	14	330.399793	412.237196
19	19	6.212771	1	122	21	92	9	334.253881	334.253881
20	20	55.540291	8	118	17	84	17	75.475797	386.341392

Table 5.2.9 MB-based summary statistics for the 1600m neighbourhood

OBJECTID *	MB_ID	Sum_GS_AREA_ha	Number_of_GS	POP_T	POP_Y	POP_A	POP_O	Minimum_distance	Mean_distance
1	1	31.616478	15	76	8	48	20	479.238549	1116.549189
2	2	135.823248	12	89	14	60	15	76.560174	1094.982481
3	3	74.829328	12	157	26	113	18	319.69455	1063.67076
4	4	92.331527	18	123	22	87	14	423.885623	1123.052124
5	5	65.854402	23	72	13	50	9	15.869728	969.70786
6	6	77.2898	22	98	16	66	16	147.326559	951.347961
7	7	93.307704	26	75	13	54	8	201.979552	956.264721
8	8	88.947357	24	92	18	66	8	235.732851	1008.772292
9	9	94.094293	26	50	8	37	5	195.212601	1006.960693
10	10	83.138336	22	104	22	59	23	447.821385	1186.181707
11	11	82.80842	15	84	24	52	8	286.949886	899.080398
12	12	96.774081	16	62	15	42	5	336.686073	921.842037
13	13	78.447473	27	147	25	106	16	224.519996	928.878655
14	14	90.313411	20	77	15	53	9	226.858903	1129.537839
15	15	106.581218	21	101	16	69	16	226.37589	1055.872323
16	16	92.409637	17	68	14	45	9	267.700552	924.326847
17	17	85.54193	18	93	12	68	13	244.023988	1089.977991
18	18	82.756882	13	109	22	73	14	330.399793	1092.009126
19	19	98.717858	12	122	21	92	9	334.253881	1151.495432
20	20	146.48007	16	118	17	84	17	75.475797	845.937587

Table 5.2.10 MB-based summary statistics for a set of remote MBs

OBJECTID *	MB_ID *	Shortest_distance	POP_T	POP_Y	POP_A	POP_O
231	23760	5401.881408	62	10	44	8
232	23761	5397.146087	52	8	37	7
225	23590	5310.769602	33	4	24	5
229	23661	5270.719063	4	1	3	0
224	23589	5216.798719	43	6	31	6
230	23707	5200.352147	53	8	38	7
228	23660	5106.927506	41	7	29	5
222	23526	5072.2749	68	11	48	9
223	23527	5072.075191	12	2	8	2
226	23591	5072.075191	31	5	22	4
450	37299	5070.372075	80	14	52	14
393	37197	4214.502814	2	0	2	0
364	36665	3914.502814	147	24	96	27
227	23641	3884.652933	213	31	146	36
221	23525	3861.732005	247	35	170	42
124	8344	3490.357361	220	43	156	21
217	16232	3288.386066	129	30	92	7
118	8312	3288.028119	0	0	0	0
119	8336	3280.810821	88	12	66	10
197	15929	3272.361493	146	42	99	5

Table 5.2.11 The percentage and amount of green space in each distance level

Distance from MB to green spaces	[0, 400] m	[0,800]m	[0,1600]m	Beyond 1600m	Total
Number of Green Spaces	4273	4481	4567	111	4678
	91.3%	95.8%	97.6%	2.4%	100.0%
Total Green Space Area (ha)	43841.49	55104.78	67866.69	50299.71	118166.4
	37.1%	46.6%	57.4%	42.6%	100.0%
Mean Shortest Distance from MB to Green Spaces (m)	217.2	354.9	431.5	n/a	458.4
Average Distance from MB to Green Spaces (m)	248.6	506.2	1087.4	n/a	n/a
Average Green Space Area (ha) per MB	16.56	30.28	110.56	n/a	2.95
Average number of green space per MB	1.81	3.61	13.33	n/a	13.17

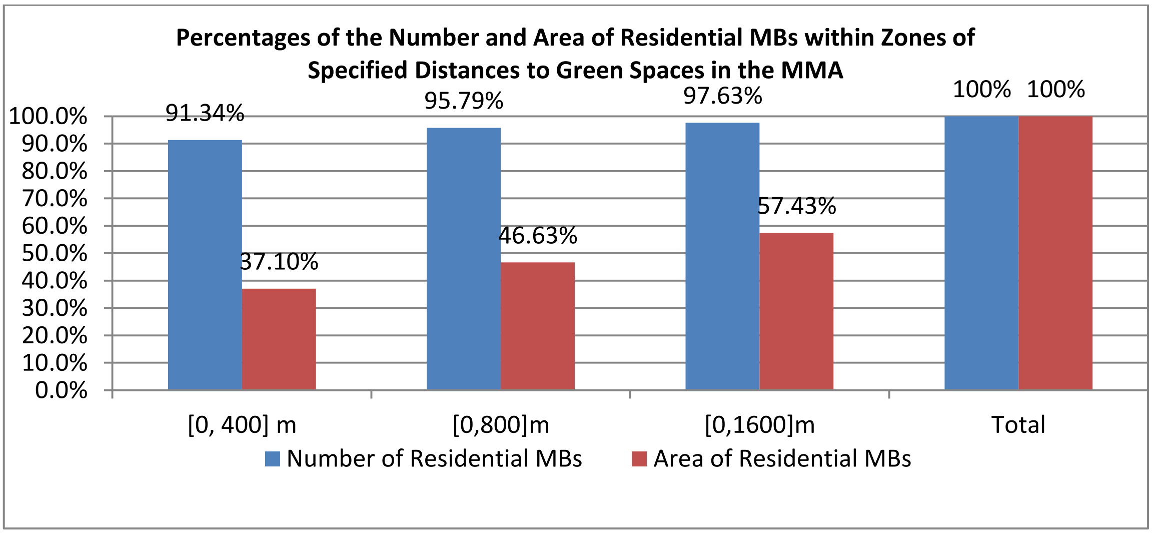


Figure 5.2.3 Percentages of the Number and Area of Residential MBs within Zones of Specified Distances to Green Spaces in the MMA

5.3 The Attractiveness of Green Spaces in the MMA

In this study, the attractiveness of a green space is determined in terms of its area and associated facilities, and are weighted differently by different age groups of the local population (see section 3.4). Table 5.3.1 shows a sample of green spaces with the set of green space properties used to derive facility-based and total attractiveness scores for each green space. Table 5.3.2 and Table 5.3.3 both show a sample of green spaces with age-differentiated facility-based attractiveness for each green space. As expected, larger green spaces with more associated facilities (e.g. Baxter Park) usually have a higher attractiveness than smaller green spaces with fewer facilities associated (e.g. Campbell St Reserve).

Log-transformed median, mean and quintile break values of green space attractiveness scores, as summarised in Table 5.3.4 and Figure 5.3.1, are used to generate the statistics summarised in Table 5.3.5. As shown in Figure 5.3.2, these set of break values are also used to produce the set of thematic maps (Map 5.3.1 to Map 5.3.4) for depicting the spatial variations in green space attractiveness for the four population groups across the MMA.

As expected from Formula 3.7 (see section 3.4), both the summary statistics shown in Table 5.3.5 and spatial patterns shown in Map 5.3.1 to Map 5.3.4 indicate that :

- larger green spaces are more attractive than smaller green spaces;
- similarly sized green spaces, and green spaces with more facilities present are more attractive than green spaces with less or no facilities present; and
- quintile-based statistical distributions of green space area, mean green space area and mean green space attractiveness for the four aged groups of MB-based population are all strongly influenced by the size of green spaces.

For example, on average:

- the total green space area for the 1st (the least attractive), 2nd, 3rd, 4th and 5th (the most attractive) quintiles are about 600 ha, 1300 ha, 2600 ha, 5300 ha and 108400 ha, respectively;

- the mean green space area for the 1st (the least attractive), 2nd, 3rd, 4th and 5th (the most attractive) quintiles are about 0.6 ha, 1.4 ha, 2.8 ha, 5.6 ha and 116 ha, respectively; and
- the mean green space attractiveness for the 1st (the least attractive), 2nd, 3rd, 4th and 5th (the most attractive) quintiles are about 4, 8, 16, 32 and 320, respectively.

Table 5.3.1 Properties for each green space (a sample)

Green space Name	Children_play	Bench	Walking_track	Toilet	Sport Oval	Baseball	Netball_Ball	Tennis	Water Body	Quietness	Area
bunguyan reserve	1	1	1	1	1	1	0	1	0	0.936441	12.67743
ross reserve	1	1	1	1	1	0	0	0	1	0.909859	14.69974
presidents park	0	1	1	1	1	1	0	0	1	0.908579	80.43147
campbell st reserve	0	1	0	1	1	1	0	1	1	0.905897	23.54139
warrandyte state park	1	1	1	1	0	0	0	1	1	0.88091	7.716977
blind creek	1	1	0	1	1	0	0	1	1	0.880848	11.80818
civic reserve	1	1	1	1	1	0	0	0	1	0.842443	27.34076
mornington park	1	1	1	1	1	0	0	0	1	0.838032	9.97031
hall reserve	1	1	1	1	1	0	0	0	1	0.837718	10.00373
percy trevand memorial park	1	1	0	1	1	0	0	1	1	0.833096	6.588479
darling park	1	1	1	1	1	0	0	0	1	0.818325	7.9043
deakin university burwood campus	1	1	1	1	1	0	0	0	1	0.789832	10.32191
norris bank reserve	1	1	1	1	0	0	0	1	1	0.787628	14.17527
canning reserve and tea gardens	1	1	1	1	1	0	0	0	1	0.735256	10.79356
baxter park	1	1	1	1	1	0	0	0	1	0.718647	68.0141
rj rowley reserve	1	1	1	1	1	0	1	1	0	0.7017	6.8816
royal park	0	1	1	1	1	1	0	0	1	0.697249	18.37719

Table 5.3.2 Age-differentiated facility-based attractiveness for each green space (a sample)

Green space Name	Facility_attractive_TOTAL	Facility_attractive_YOUNG	Facility_attractive_ADULT	Facility_attractive_OLD
bunguyan reserve	79.682206	87.364412	79.682206	82.364412
ross reserve	79.549297	93.098594	69.549297	92.098594
presidents park	79.542893	65.085785	79.542893	94.085785
campbell st reserve	79.529485	57.058971	79.529485	82.058971
warrandyte state park	79.404551	90.809102	64.404551	91.809102
blind creek	79.404239	84.808479	69.404239	79.808479
civic reserve	79.212215	92.42443	69.212215	91.42443
mornington park	79.190161	92.380322	69.190161	91.380322
hall reserve	79.188591	92.377182	69.188591	91.377182
percy trevand memorial park	79.165478	84.330957	69.165478	79.330957
darling park	79.091627	92.183254	69.091627	91.183254
deakin university burwood campus	78.949162	91.898324	68.949162	90.898324
norris bank reserve	78.938142	89.876284	63.938142	90.876284
canning reserve and tea gardens	78.67628	91.35256	68.67628	90.35256
baxter park	78.593234	91.186469	68.593234	90.186469
rj rowley reserve	78.508501	85.017002	78.508501	80.017002
royal park	78.486243	62.972486	78.486243	91.972486

Table 5.3.3 Age-differentiated total attractiveness (see Formula 3.7) for each green space (a sample)

Green space Name	Total_attractiveness_TOTAL	Total_attractiveness_YOUNG	Total_attractiveness_ADULT	Total_attractiveness_OLD
bunguyan reserve	84.38873	88.52594	84.38873	85.85413
ross reserve	95.619	103.7681	89.16728	103.187
presidents park	405.4384	365.2792	405.4384	442.43
campbell st reserve	142.6697	120.0454	142.6697	145.0116
warrandyte state park	55.2395	59.23214	49.54122	59.57042
blind creek	79.30022	82.06237	73.93948	79.50989
civic reserve	161.6817	175.1855	150.7246	174.1973
mornington park	68.5822	74.30254	63.93305	73.88321
hall reserve	68.77687	74.5129	64.11443	74.09237
percy trevand memorial park	48.21765	49.82883	44.94795	48.27003
darling park	56.26156	60.92604	52.44271	60.58146
deakin university burwood campus	70.52074	76.31609	65.72509	75.88312
norris bank reserve	92.34018	98.78636	82.75548	99.3564
canning reserve and tea gardens	73.11877	79.02507	68.12862	78.57405
baxter park	349.3891	377.4617	325.5183	375.3035
rj rowley reserve	49.81874	51.9253	49.81874	50.31423
royal park	114.7968	102.3754	114.7968	124.6635

Table 5.3.4 Age-based mean, median and quintile break values of green space attractiveness

GS Attractiveness*	Total	Young	Adult	Old
Q1 / Q2 Break Value	1.78	1.87	1.73	1.85
Q2 / Q3 Break Value	2.43	2.50	2.37	2.51
Median	2.77	2.84	2.72	2.86
Mean	2.90	2.95	2.85	2.98
Q3 / Q4 Break Value	3.10	3.15	3.05	3.18
Q4 / Q5 Break Value	3.82	3.87	3.79	3.90
Standard Deviation	1.31	1.30	1.32	1.32

Note: the values presented in this table are log transformed total green space attractiveness scores.

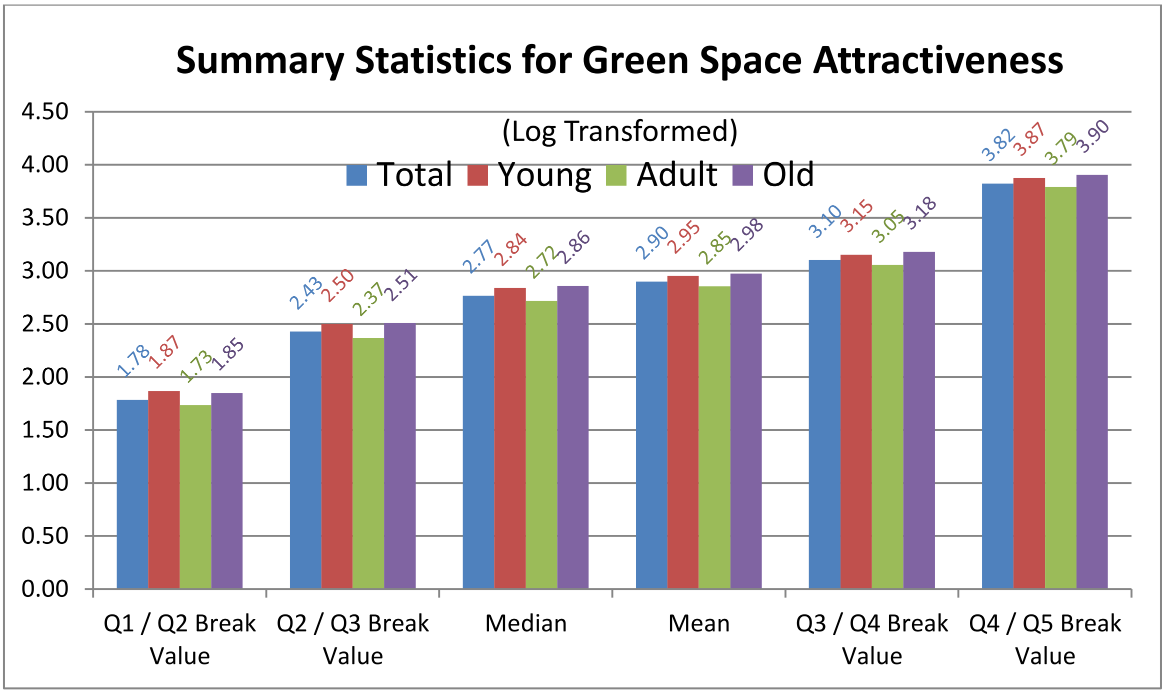


Figure 5.3.1 Mean, median and quintile break values of green space attractiveness for the four groups of MB-based population in the MMA

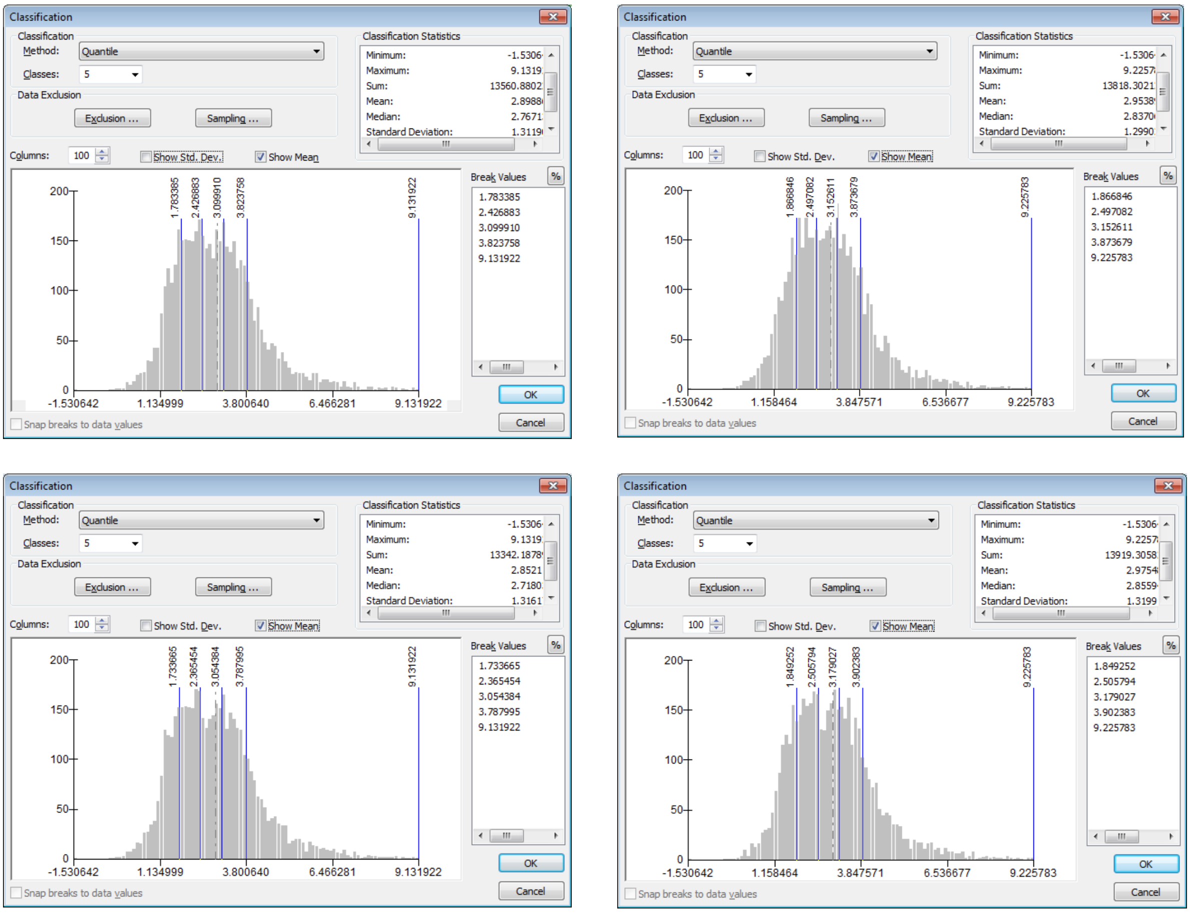
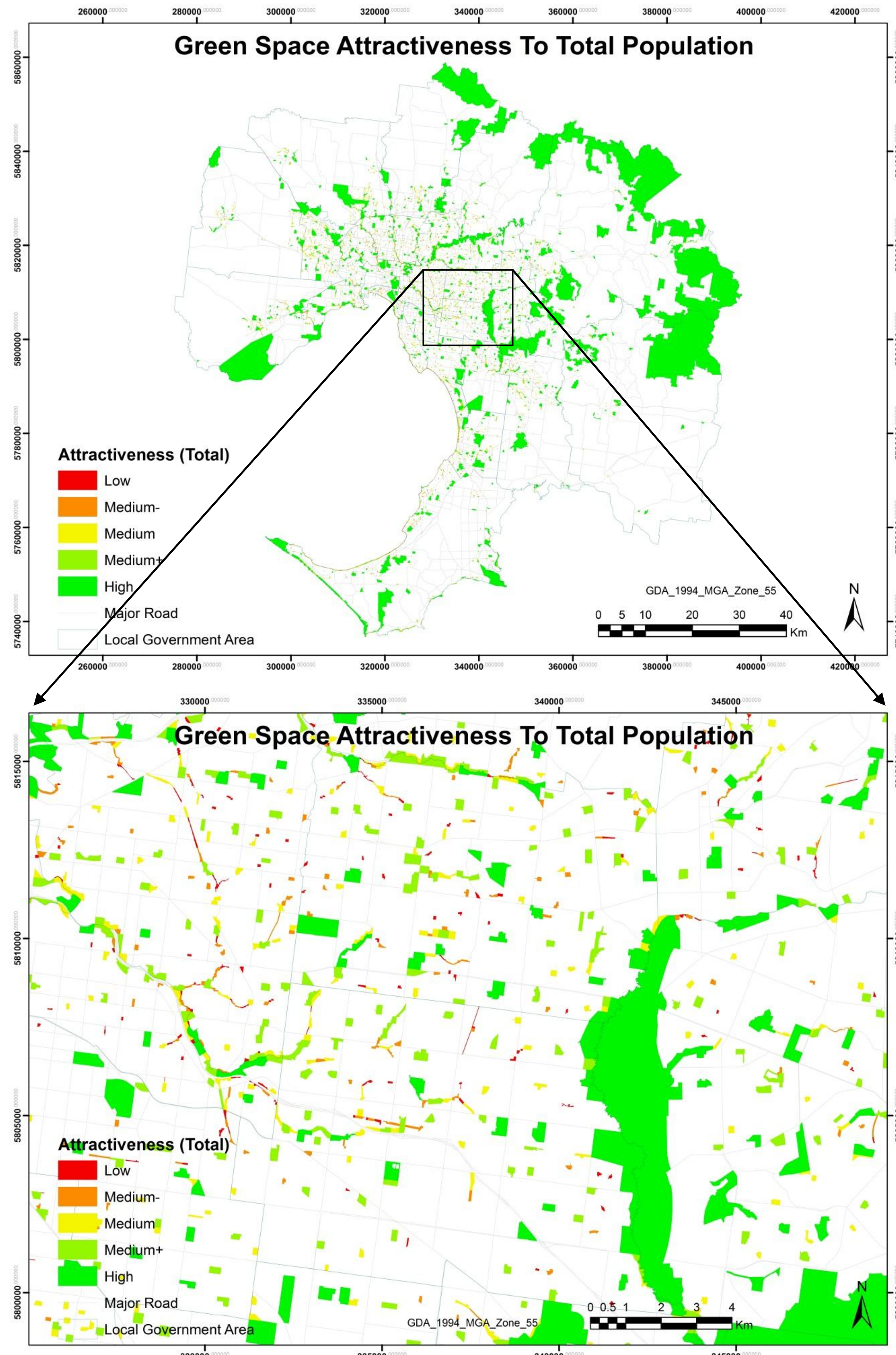


Figure 5.3.2 Sumary statistics and quintile break values used for producing Map 5.3.1 (top left), Map 5.3.2 (top right), Map 5.3.3 (bottom left) and Map 5.3.4 (bottom right).

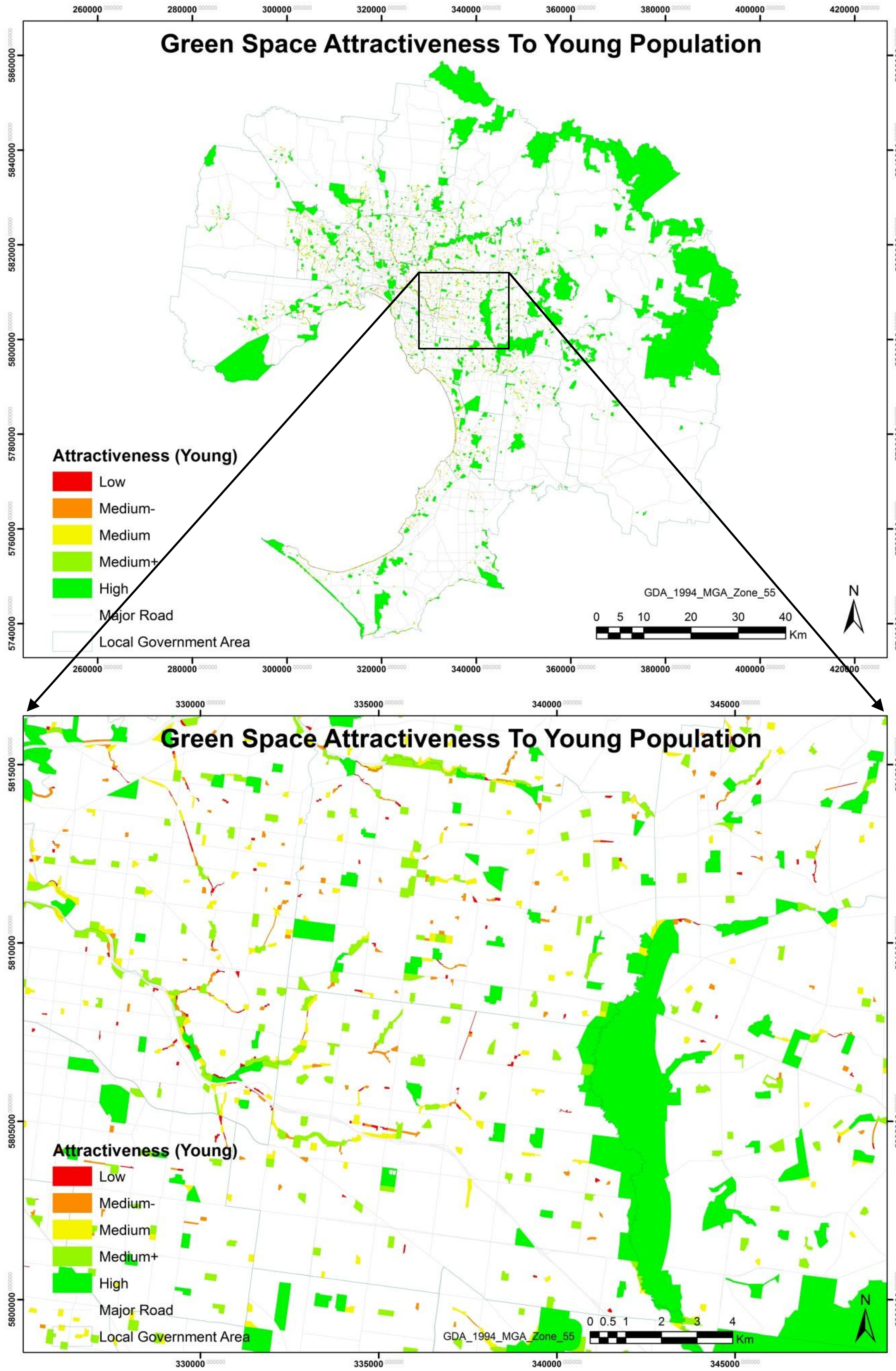
Table 5.3.5 Age-based quintile summary of green space numbers, areas, facilities and attractiveness scores

		1st Quintile	2nd Quintile	3rd Quintile	4th Quintile	5th Quintile
Total GS Number	T	935	936	937	934	936
	Y	936	936	936	935	935
	A	936	936	935	935	936
	O	936	935	937	935	935
Total GS Area (Ha)	T	577.92	1281.39	2615.08	5280.92	108411.09
	Y	586.19	1290.34	2616.79	5295.47	108377.60
	A	571.36	1281.17	2598.38	5292.33	108423.16
	O	579.81	1286.24	2613.37	5272.37	108414.60
Mean GS Area (Ha)	T	0.62	1.37	2.79	5.65	115.82
	Y	0.63	1.38	2.80	5.66	115.91
	A	0.61	1.37	2.78	5.66	115.84
	O	0.62	1.38	2.79	5.64	115.95
number GS Facilities	T	1745	2275	2713	3461	3428
	Y	1737	2246	2740	3464	3435
	A	1804	2266	2690	3442	3420
	O	1751	2257	2728	3499	3387
Average GS Facilities	T	1.87	2.43	2.90	3.71	3.66
	Y	1.86	2.40	2.93	3.70	3.67
	A	1.93	2.42	2.88	3.68	3.65
	O	1.87	2.41	2.91	3.74	3.62
Mean GS Facility Attractiveness	T	32.95	38.21	42.32	49.11	49.82
	Y	36.81	45.08	49.11	54.48	53.09
	A	30.34	33.74	37.85	44.82	46.33
	O	37.53	43.92	49.58	57.49	58.65
Mean GS Attractiveness	T	3.98	8.42	16.23	31.98	307.77
	Y	4.25	9.08	17.32	33.39	320.15
	A	3.80	7.95	15.39	30.59	299.65
	O	4.26	9.05	17.55	34.62	341.33

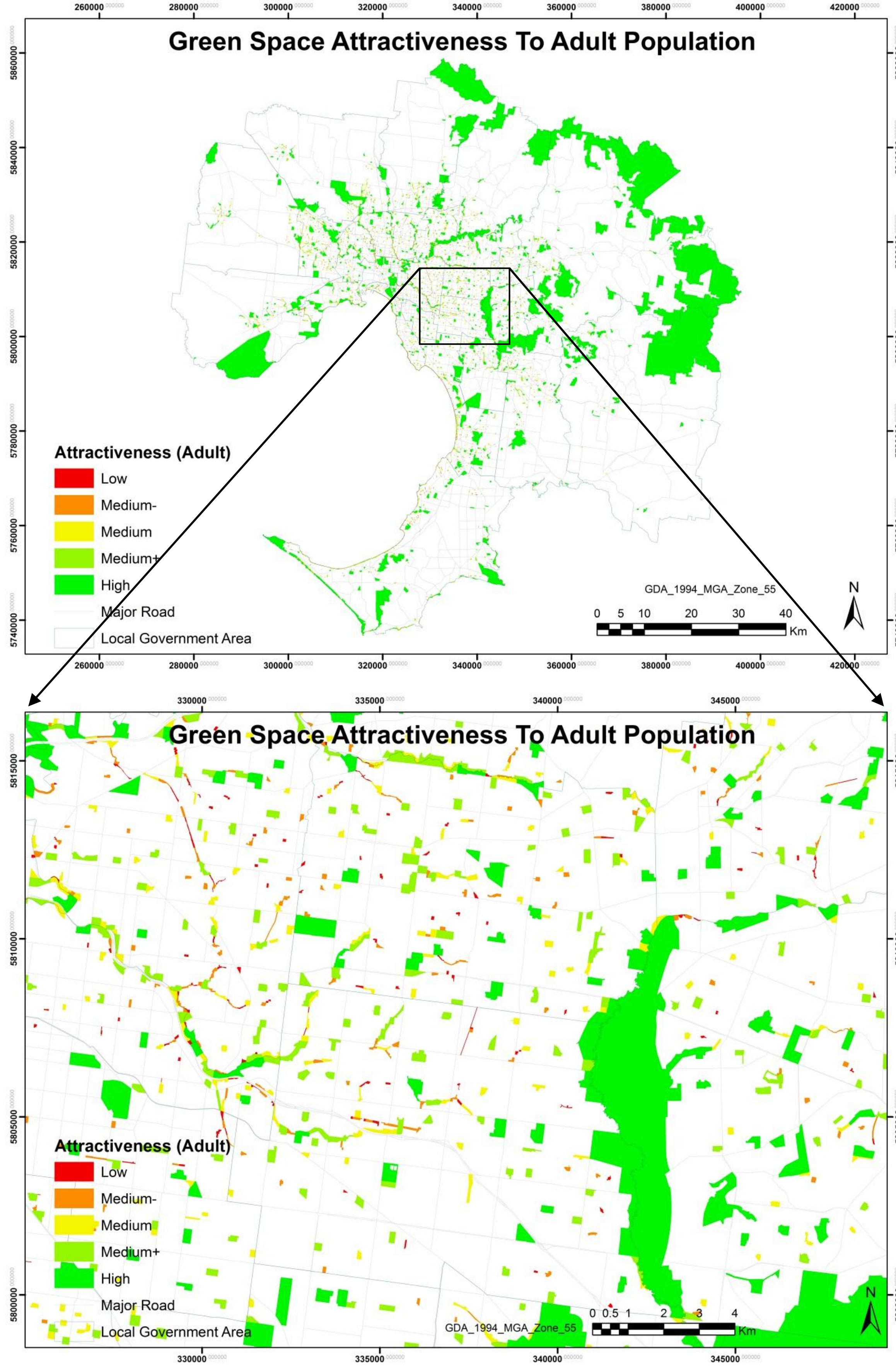
Notes: T = Total, Y = Young, A = Adult, O = Old; The five quintiles are defined according to the break values presented in Table 5-3.3 and indicated in Chart 5-3.1



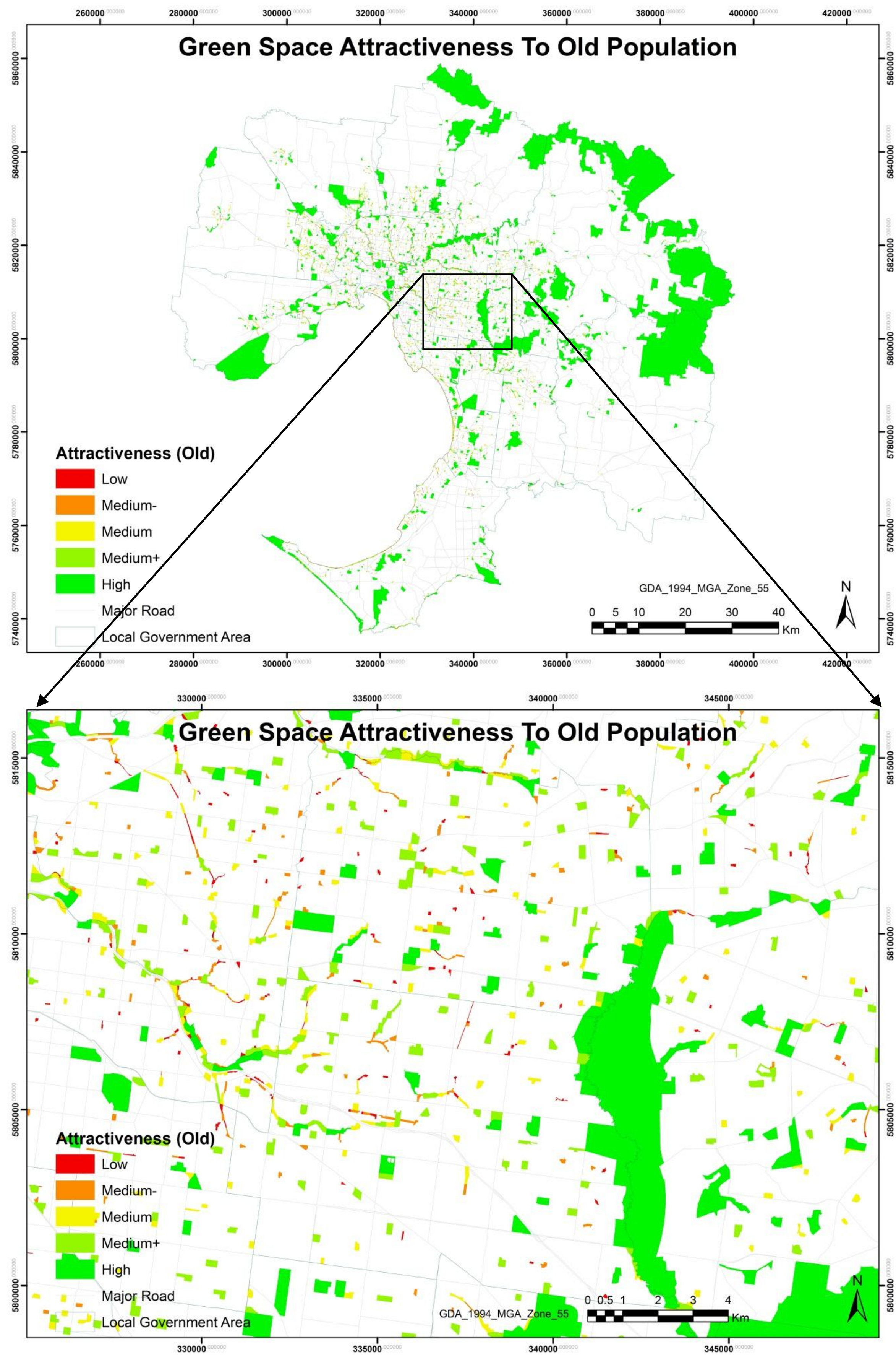
Map 5.3.1 Spatial variation in green space attractiveness to MB-based total population in the MMA



Map 5.3.2 Spatial variation in green space attractiveness to MB-based young population in the MMA



Map 5.3.3 Spatial variation in green space attractiveness to MB-based adult population in the MMA



Map 5.3.4 Spatial variation in green space attractiveness to MB-based old population in the MMA

5.4 Green Space Accessibility in the MMA

As described in section 3.6, four different floating catchment area based accessibility measures (i.e. M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B) have been calculated for each age group in each residential MB, from which a mean accessibility score is derived for each age group in each residential MB. Accordingly, four quintile-based thematic maps of green space accessibility have been produced: one for each age group (i.e. total, young, adult or old), to show the spatial variations in accessibility to green space from residential MBs in the MMA. In addition, four tables are also generated, one for each age group, to summarise the number of persons, number of residential MBs and the total residential area that fall within each of the five quintiles. The quintile class limits for the four age groups are based on log transformed accessibility scores (Table 5.4.1).

Table 5.4.1 Quintile class limits* for the four age groups based on log transformed accessibility scores

Age Group	**Accessibility to Green Space – Quintile Class Limits**				
	Low	**Medium -**	**Medium**	**Medium +**	**High**
Total	< -4.5	[-4.5, -4.0)	[-4.0, -3.5)	[-3.5, -3.0)	⩾ -3.0
Young	< -3.0	[-3.0, -2.5)	[-2.5, -2.0)	[-2.0, -1.5)	⩾ -1.5
Adult	< -4.0	[-4.0, -3.5)	[-3.5, -3.0)	[-3.0, -2.5)	⩾ -2.5
Old	< -2.5	[-2.5, -2.0)	[-2.0, -1.5)	[-1.5, -1.0)	⩾ -1.0

*Note: some rounding offs have been applied to avoid too many floating points for easy application.

The spatial variations in level of green space accessibility are shown in Map 5.4.1 (total), Map 5.4.2 (young), Map 5.4.3 (adult) and Map 5.4.4 (old). Some summary statistics are presented in Table 5.5.2 for the 4 age groups, including the number of persons, residential area, and their respective percentages, that belong to each of the five levels or classes of green space accessibility.

Table 5.4.2, Map 5.4.1, Map 5.4.2, Map 5.4.3 and Map 5.4.4 show the quintile-based summary and spatial pattern of mean accessibility to green space using MB-based population for the four age groups. (Namely, the Accessibility results).

The percentages of the population groups and the associated residential area that have relatively low accessibility to green space (i.e. the 1st quintile class displayed with **Cantaloupe** colour in the map) are:

- 16% of the total population living in 18% of the residential area,
- 13% of the young population living in 14% of the residential area,
- 21% of the adult population living in 21% of the residential area, and
- 13% of the old population living in 15% of the residential area.

In contrast, the percentages of the population groups and of the associated residential area that have relatively high accessibility to green space (i.e. the 5^{th} quintile class and displayed with **Tzavorite Green** colour in the map) are:

- 21% of the total population living in 33% of the residential area,
- 29% of the young population living in 39% of the residential area,
- 17% of the adult population living in 29% of the residential area, and
- 24% of the old population living in 40% of the residential area.

Based on the 2011 ABS census, there are 617314 persons, including 94613 young persons, 555246 adults and 64474 old persons who live in areas with relatively low accessibility to green space; and there are about 807036 persons, including 206817 young persons, 443195 adults and 120934 old persons live in areas with relatively high accessibility to green space in the MMA.

Table 5.4.2 The summary statistics of population and residential area for the 4 age groups in the 5 green space provision levels (Also the accessibility results)

Population (persons) and residential area (ha) for the 4 age groups in 5 GSP levels		Level of Green Space Provision (GSP)										
		Low		Medium -		Medium		Medium +		High		Total
Total	Persons	617314	16.2%	713324	18.7%	976862	25.6%	708612	18.5%	807036	21.1%	3823148
	MB Number	6209	15.5%	7457	18.7%	10175	25.4%	7497	18.8%	8653	21.6%	39991
	MB Area	30676	18.0%	23551	13.8%	34356	20.2%	25840	15.2%	55692	32.7%	170115
Young	Persons	94613	13.3%	95509	13.4%	156140	21.9%	159375	22.4%	206817	29.0%	712454
	MB Number	3605	9.0%	5133	12.8%	8718	21.8%	9550	23.9%	12985	32.5%	39991
	MB Area	24649	14.5%	16700	9.8%	29589	17.4%	33273	19.6%	65904	38.7%	170115
Adult	Persons	555246	21.3%	572881	21.9%	639906	24.5%	401181	15.4%	443195	17.0%	2612409
	MB Number	8078	20.2%	8760	21.9%	9781	24.5%	6155	15.4%	7217	18.1%	39991
	MB Area	36485	21.5%	26939	15.8%	33509	19.7%	23058	13.6%	50124	29.5%	170115
Old	Persons	64474	12.9%	103327	20.7%	122406	24.6%	87144	17.5%	120934	24.3%	498285
	MB Number	5186	13.0%	7116	17.8%	8828	22.1%	7312	18.3%	11549	28.9%	39991
	MB Area	25096	14.8%	21834	12.8%	29269	17.2%	26346	15.5%	67570	39.7%	170115

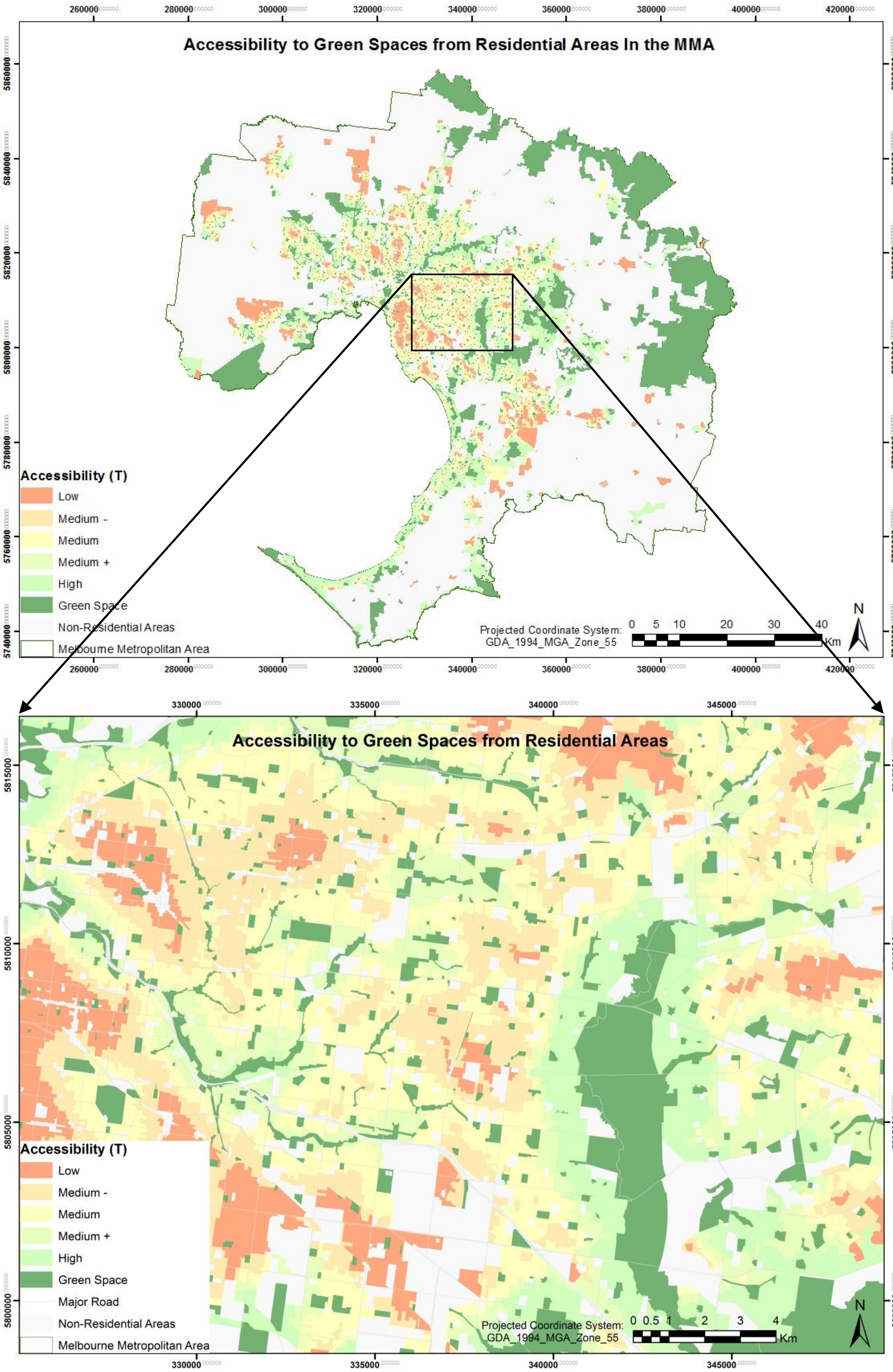
LGA rankings, based on percentage of age group-based populations and residential areas associated with low accessibility to green space, are listed in Table 5.4.3 and Table 5.4.4, and compared to the MMA-wide mean values. In most of these cases, Glen Eira ranks the highest, either in terms of age group-based populations or in terms of age group-based residential areas.

Table 5.4.3 LGA rankings: based on percentage of age group-based populations associated with low accessibility to green space

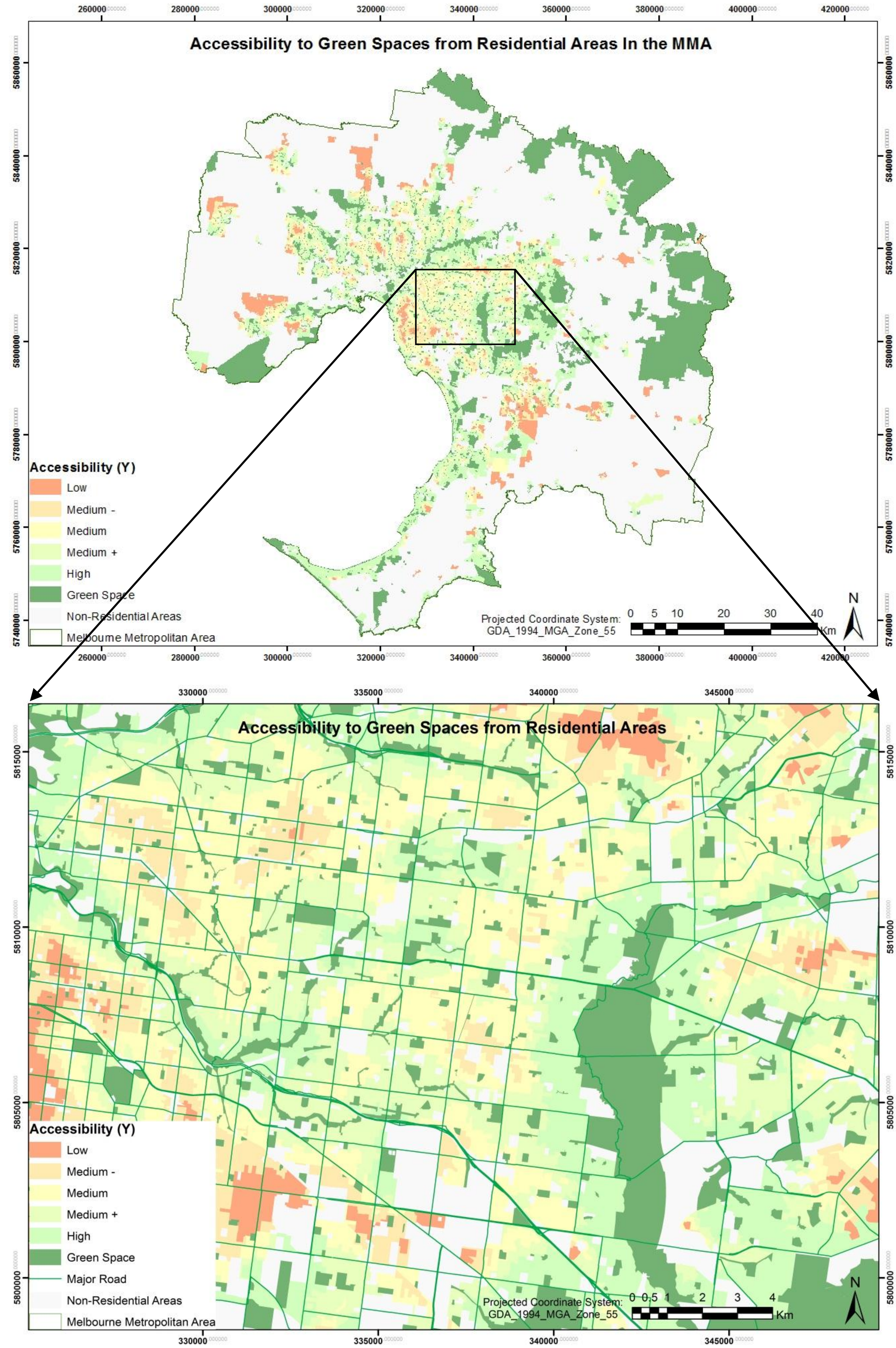
RANKING	Pop_T		Pop_Y		Pop_A		Pop_O	
1	YARRA	0.00%	YARRA	0.00%	BANYULE	1.86%	YARRA	0.00%
2	BANYULE	0.52%	WHITEHORSE	0.00%	WHITEHORSE	4.44%	HOBSONS BAY	0.33%
3	HOBSONS BAY	2.35%	MELBOURNE	0.00%	NILLUMBIK	5.01%	MELBOURNE	0.49%
4	WHITEHORSE	2.42%	BANYULE	0.07%	HOBSONS BAY	5.20%	BANYULE	2.16%
5	NILLUMBIK	3.26%	BOROONDARA	0.24%	YARRA	5.78%	NILLUMBIK	2.38%
6	BRIMBANK	4.27%	HOBSONS BAY	1.30%	MANNINGHAM	7.14%	BRIMBANK	3.87%
7	MANNINGHAM	5.67%	MANNINGHAM	2.12%	BRIMBANK	8.07%	HUME	4.67%
8	KNOX	5.81%	GREATER DANDENONG	2.69%	FRANKSTON	8.32%	PORT PHILLIP	4.72%
9	MELBOURNE	6.23%	NILLUMBIK	2.81%	MORNINGTON PENINSULA	8.81%	MARIBYRNONG	4.93%
10	FRANKSTON	6.72%	BRIMBANK	2.87%	KNOX	9.33%	FRANKSTON	5.74%
11	MORNINGTON PENINSULA	7.25%	MOONEE VALLEY	2.94%	MAROONDAH	10.46%	MORNINGTON PENINSULA	5.99%
12	MAROONDAH	8.48%	KNOX	3.35%	MELBOURNE	11.52%	MELTON	6.20%
13	MOONEE VALLEY	11.12%	KINGSTON	3.43%	YARRA RANGES	11.77%	KNOX	7.77%
14	KINGSTON	11.21%	MAROONDAH	3.81%	GREATER DANDENONG	15.86%	WHITEHORSE	8.44%
15	YARRA RANGES	11.35%	MARIBYRNONG	5.44%	KINGSTON	16.07%	YARRA RANGES	9.05%
16	GREATER DANDENONG	11.64%	MONASH	5.68%	MOONEE VALLEY	17.84%	WYNDHAM	9.16%
17	BOROONDARA	13.78%	PORT PHILLIP	5.69%	BAYSIDE	19.25%	BOROONDARA	10.86%
18	BAYSIDE	15.97%	FRANKSTON	5.89%	BOROONDARA	20.41%	MOONEE VALLEY	11.01%
19	MMA	16.15%	STONNINGTON	7.03%	MMA	21.25%	CASEY	11.21%
20	MONASH	17.17%	DAREBIN	7.60%	MONASH	23.11%	MANNINGHAM	11.53%
21	MARIBYRNONG	18.25%	MORNINGTON PENINSULA	8.20%	WHITTLESEA	24.29%	MAROONDAH	11.63%
22	MELTON	18.37%	MORELAND	8.82%	PORT PHILLIP	25.45%	MMA	12.94%
23	MORELAND	19.01%	BAYSIDE	9.13%	MELTON	26.79%	GREATER DANDENONG	13.46%
24	PORT PHILLIP	19.30%	YARRA RANGES	11.62%	MORELAND	26.84%	MORELAND	15.68%
25	WHITTLESEA	19.41%	MMA	13.28%	MARIBYRNONG	31.66%	KINGSTON	15.91%
26	DAREBIN	23.45%	WHITTLESEA	17.23%	DAREBIN	32.45%	WHITTLESEA	16.82%
27	HUME	28.98%	MELTON	22.17%	HUME	35.75%	DAREBIN	19.21%
28	CASEY	30.76%	GLEN EIRA	26.42%	CASEY	37.61%	MONASH	19.99%
29	WYNDHAM	35.60%	HUME	35.12%	WYNDHAM	38.71%	BAYSIDE	24.15%
30	STONNINGTON	38.41%	CASEY	35.60%	CARDINIA	40.70%	STONNINGTON	37.18%
31	CARDINIA	39.97%	CARDINIA	40.58%	STONNINGTON	46.27%	CARDINIA	41.67%
32	GLEN EIRA	41.17%	WYNDHAM	40.68%	GLEN EIRA	53.79%	GLEN EIRA	43.67%

Table 5.4.4 LGA rankings: based on percentage of age group-based residential areas associated with low accessibility to green space

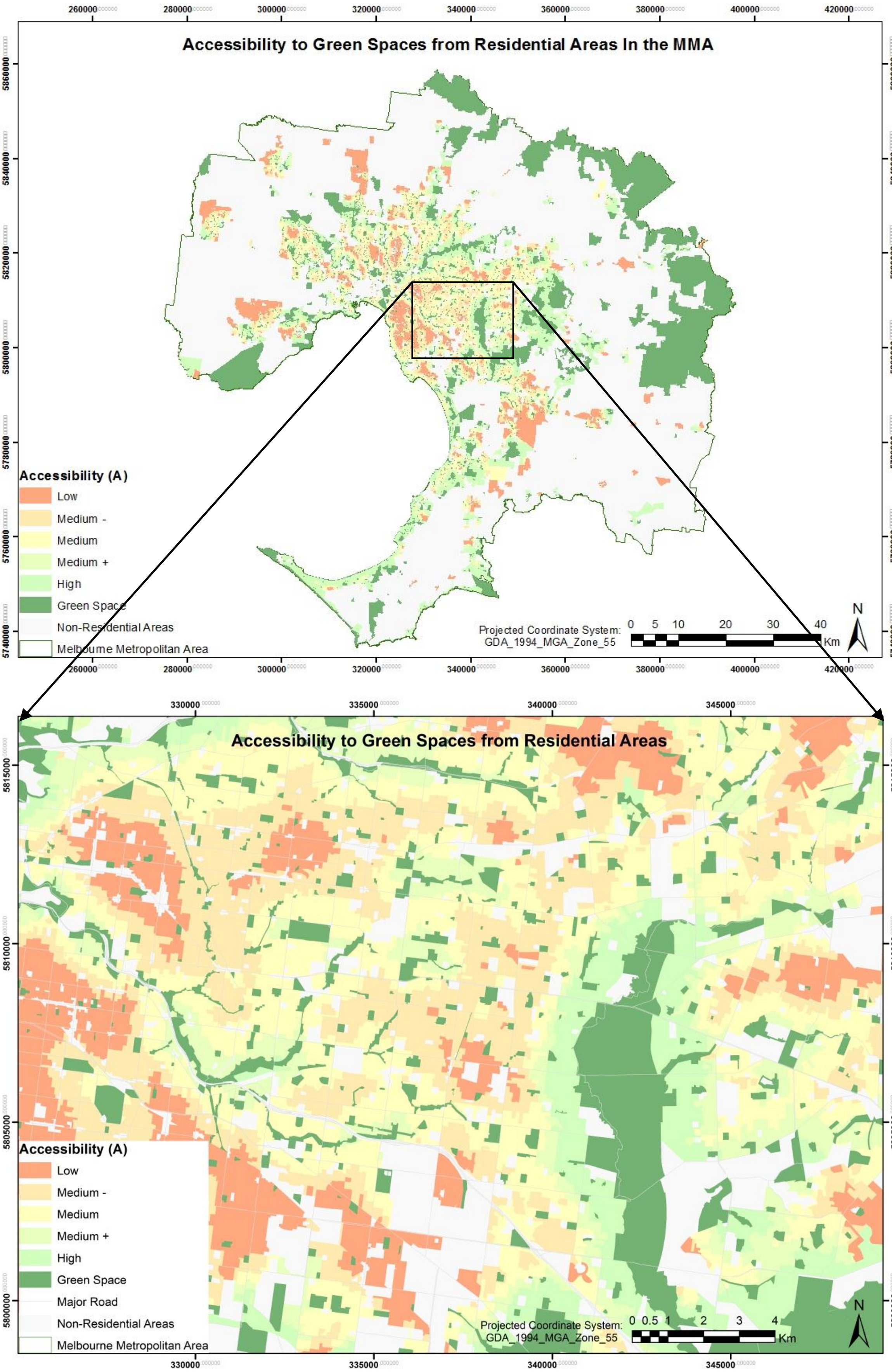
RANKING	Area_T		Area_Y		Area_A		Area_O	
1	YARRA	0.00%	YARRA	0.00%	BANYULE	1.75%	YARRA	0.00%
2	BANYULE	0.56%	WHITEHORSE	0.00%	YARRA	3.77%	MELBOURNE	0.33%
3	HOBSONS BAY	2.18%	MELBOURNE	0.00%	WHITEHORSE	4.12%	HOBSONS BAY	0.38%
4	WHITEHORSE	2.36%	BANYULE	0.09%	HOBSONS BAY	4.53%	BANYULE	1.79%
5	BRIMBANK	3.71%	BOROONDARA	0.24%	FRANKSTON	5.65%	NILLUMBIK	1.99%
6	MELBOURNE	3.82%	HOBSONS BAY	0.97%	MORNINGTON PENINSULA	6.56%	BRIMBANK	2.66%
7	FRANKSTON	4.51%	BRIMBANK	2.17%	NILLUMBIK	7.10%	FRANKSTON	3.33%
8	NILLUMBIK	5.77%	NILLUMBIK	2.53%	BRIMBANK	7.26%	MARIBYRNONG	4.90%
9	MORNINGTON PENINSULA	5.84%	MOONEE VALLEY	2.66%	MELBOURNE	7.74%	KNOX	6.12%
10	KNOX	6.88%	FRANKSTON	3.16%	MANNINGHAM	9.61%	MORNINGTON PENINSULA	6.87%
11	MANNINGHAM	8.42%	MAROONDAH	3.26%	KNOX	10.56%	PORT PHILLIP	7.69%
12	MAROONDAH	8.79%	GREATER DANDENONG	3.43%	MAROONDAH	10.98%	WHITEHORSE	7.97%
13	MOONEE VALLEY	9.44%	KINGSTON	3.56%	YARRA RANGES	12.66%	MAROONDAH	8.95%
14	BOROONDARA	10.20%	MARIBYRNONG	4.11%	KINGSTON	15.25%	MOONEE VALLEY	9.42%
15	KINGSTON	10.87%	KNOX	4.17%	MOONEE VALLEY	15.35%	BOROONDARA	10.28%
16	GREATER DANDENONG	11.83%	MANNINGHAM	4.24%	BOROONDARA	15.51%	YARRA RANGES	10.88%
17	YARRA RANGES	12.39%	PORT PHILLIP	4.28%	GREATER DANDENONG	16.39%	MANNINGHAM	10.97%
18	MONASH	13.72%	MONASH	4.78%	MONASH	17.99%	GREATER DANDENONG	11.38%
19	BAYSIDE	15.33%	MORNINGTON PENINSULA	5.18%	BAYSIDE	19.14%	MELTON	14.35%
20	MARIBYRNONG	15.77%	STONNINGTON	6.46%	MORELAND	20.82%	MMA	14.75%
21	MORELAND	15.79%	DAREBIN	6.74%	MMA	21.45%	KINGSTON	15.04%
22	MMA	18.03%	MORELAND	7.26%	WHITTLESEA	23.49%	MORELAND	15.10%
23	PORT PHILLIP	18.93%	BAYSIDE	8.42%	PORT PHILLIP	24.08%	WHITTLESEA	15.95%
24	WHITTLESEA	19.55%	YARRA RANGES	12.10%	DAREBIN	27.70%	DAREBIN	18.82%
25	DAREBIN	20.46%	MMA	14.49%	MARIBYRNONG	28.06%	MONASH	19.93%
26	CARDINIA	29.45%	WHITTLESEA	15.68%	CARDINIA	30.25%	CASEY	21.01%
27	MELTON	30.58%	GLEN EIRA	22.67%	MELTON	35.53%	BAYSIDE	21.80%
28	CASEY	32.17%	MELTON	27.10%	CASEY	38.69%	HUME	22.30%
29	STONNINGTON	34.54%	CARDINIA	29.09%	STONNINGTON	42.40%	CARDINIA	27.86%
30	GLEN EIRA	40.25%	CASEY	32.23%	HUME	46.68%	STONNINGTON	32.86%
31	HUME	41.57%	HUME	41.03%	WYNDHAM	47.88%	WYNDHAM	34.57%
32	WYNDHAM	46.13%	WYNDHAM	46.29%	GLEN EIRA	53.21%	GLEN EIRA	43.37%



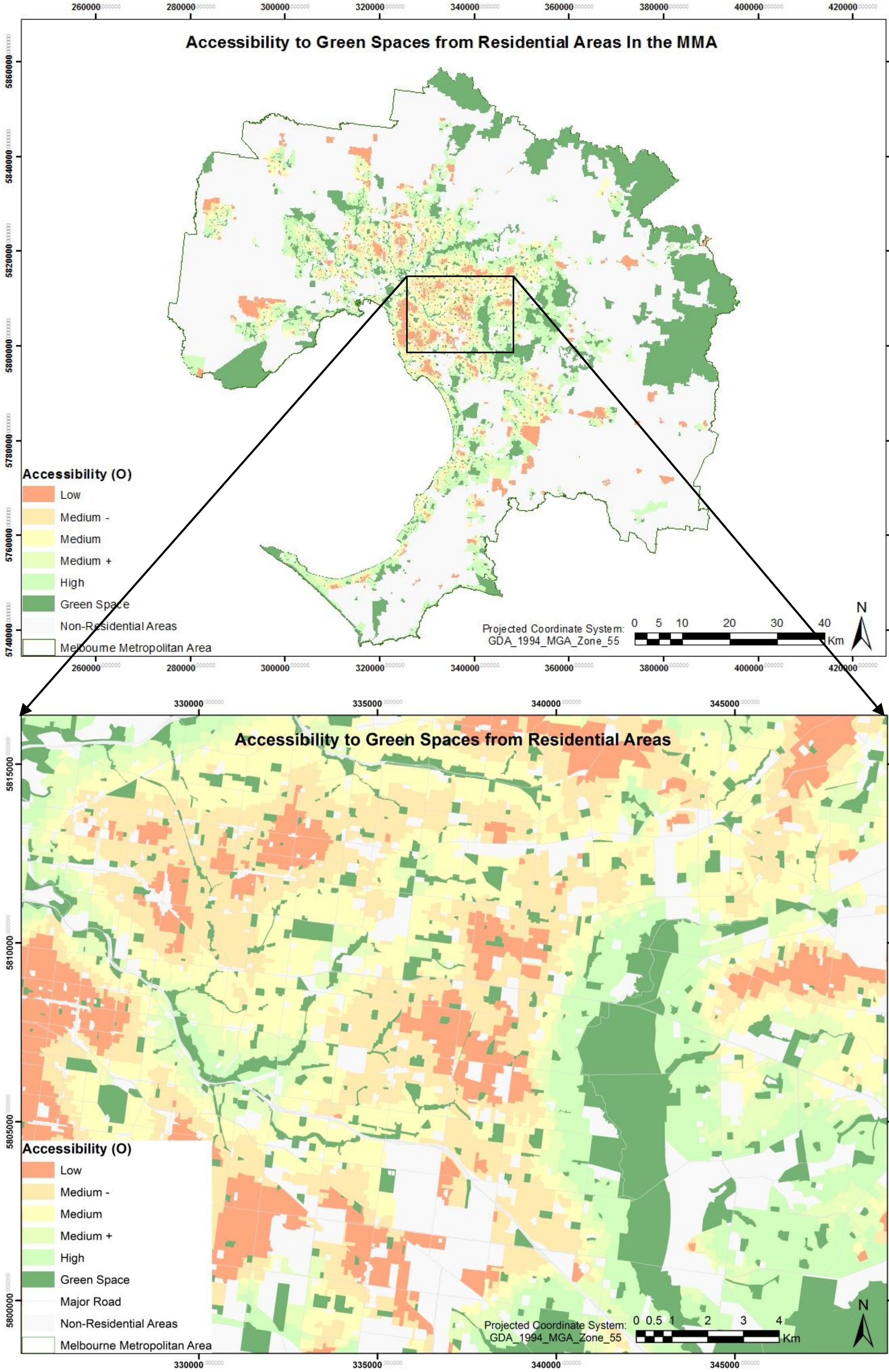
Map 5.4.1 The accessibility to green space from residential Areas for Total population



Map 5.4.2 The accessibility to green space from residential Areas for Young population



Map 5.4.3 The accessibility to green space from residential Areas for Adult population



Map 5.4.4 The accessibility to green space from residential Areas for Old population

5.5 Locational Disadvantage in Green Space Accessibility

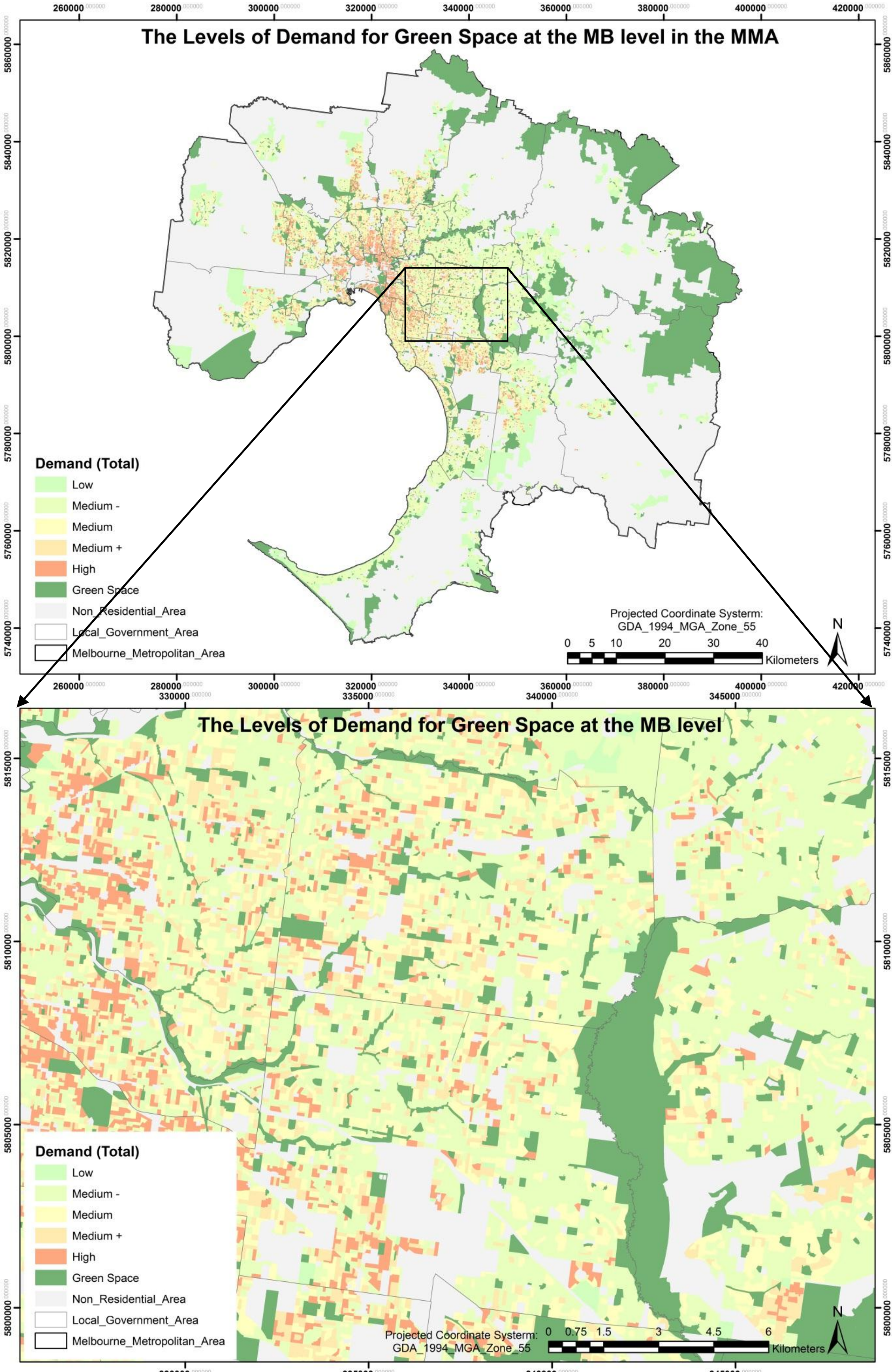
In this study, the level of locational disadvantage in green space accessibility for a particular residential MB is determined by comparing its estimated level of green space provision and demand; and using hotspot analysis to identify and map spatial clusters of residential areas with high levels of locational disadvantage in green space accessibility in the MMA (see Section 3.6).

5.5.1 Levels of Provision and Demand for Green Space

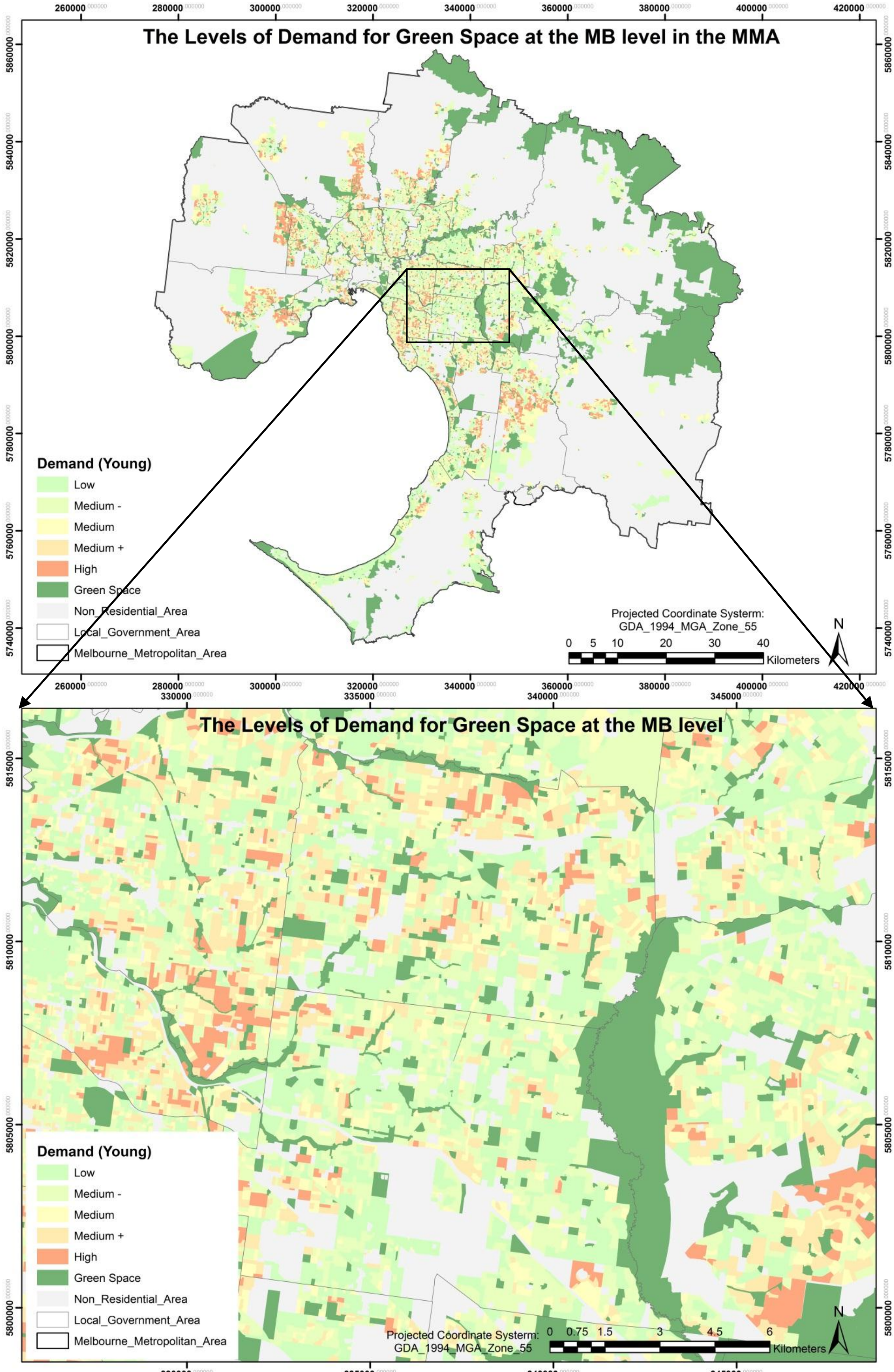
In this study, the level of green space provision for each residential MB is taken to equal the quintile-based ranks of accessibility to green space from the MB (see Section 3.6 and Section 5.4). The age-specific spatial variations in quintile ranked accessibility classes are shown in Map 5.4.1 (total), Map 5.4.2 (young), Map 5.4.3 (adult) and Map 5.4.4 (old), which are classified according to the quintile break values of log-transformed mean accessibility scores summarised in Table 5.4.1.

Since the level of demand for green space at a residential location is assumed to be positively related to population density (see Section 3.6), the spatial variation in the level of demand for green space by the total population, shown in Map 5.5.1, is identical to the spatial variation in total population density as shown in Map 4.3.1. Both Map 5.5.1 and Map 4.3.1 are classified into five levels based on the respective quintile break values.

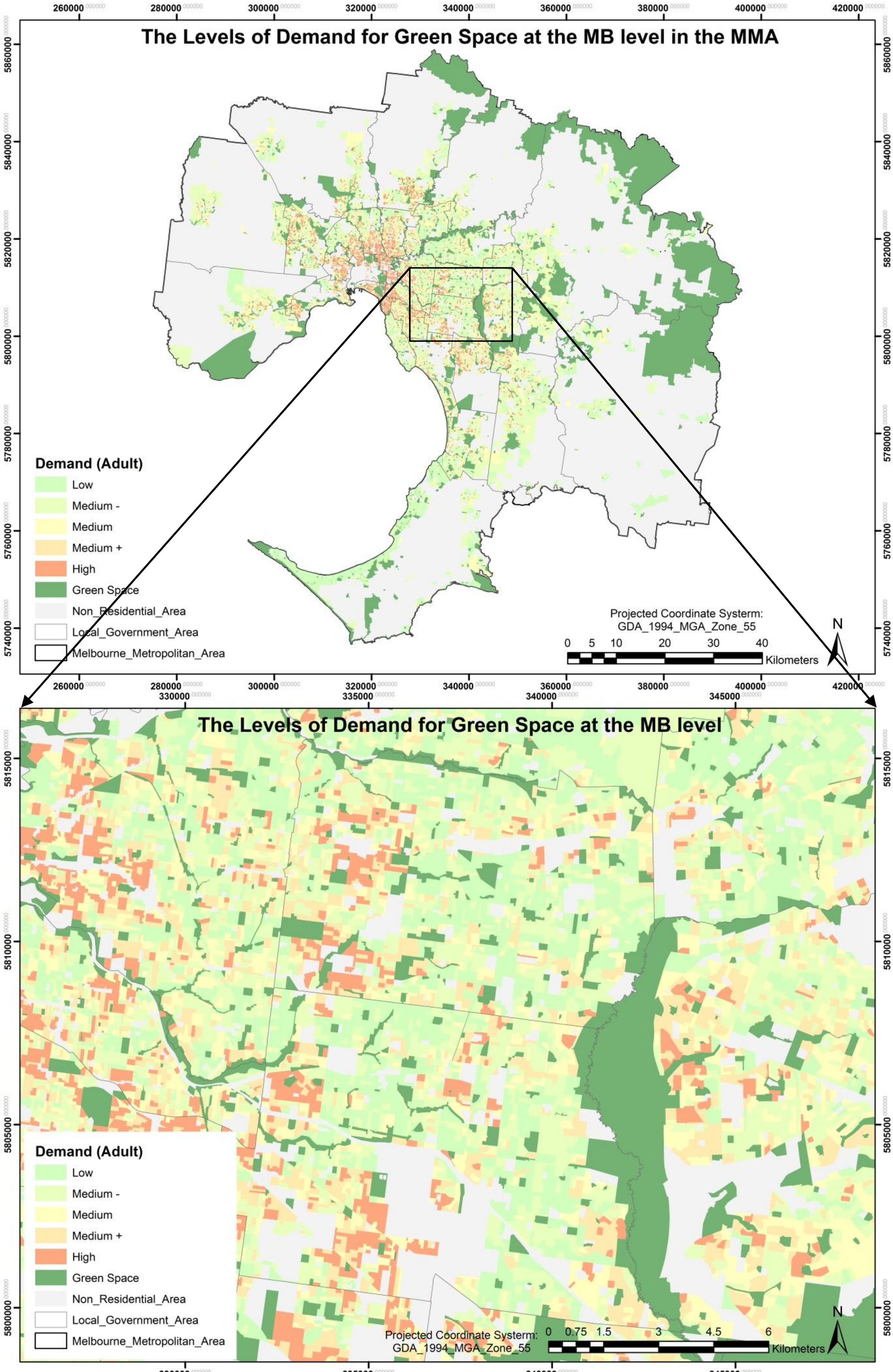
Given that the level of demand for green space at a residential location is positively related to both population density and population concentration of specific age groups (see Section 3.6), the spatial variation in the level of demand for green space by young persons, shown in Map 5.5.2, is determined by spatial variations in their population density (Map 4.3.2) and concentration (Map 4.3.9). Similarly, the spatial variations in the level of demand for green space by adults (Map 5.5.3) and old persons (Map 5.5.4) are also determined by spatial variations in their respective density (Map 4.3.3 and Map 4.3.4) and concentration (Map 4.3.10 and Map 4.3.11). The five levels shown in Map 5.5.2, Map 5.5.3 and Map 5.5.4 are determined according to the method illustrated in section 3.6 (Table 3.6.1).



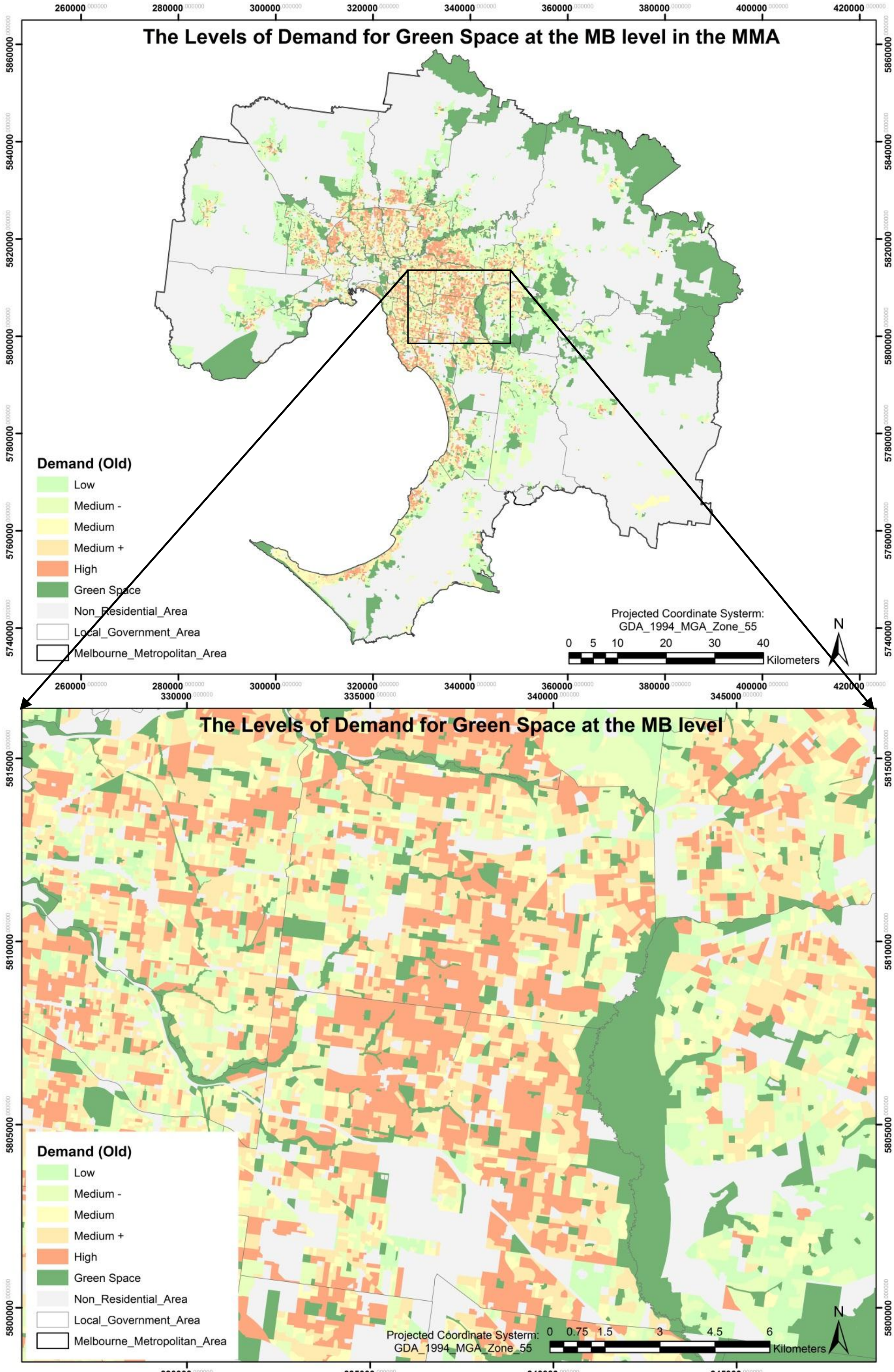
Map 5.5.1 The levels of total population demand for green space at the MB level



Map 5.5.2 The levels of young population demand for green space at the MB level



Map 5.5.3 The levels of adult population demand for green space at the MB level



Map 5.5.4 The levels of old population demand for green space at the MB level

5.5.2 Level of Locational Disadvantage: Comparison between Demand and Provision of Green Space

The level of locational disadvantage for a residential MB can be determined by comparing its level of demand to its level of provision (see Section 3.7 and Table 3.7.2). The outcome of such comparisons is to rank each residential MB as one of the five levels as listed and described in Table 5.5.1, one for each population group.

Table 5.5.1 Descriptions for different levels of disadvantage

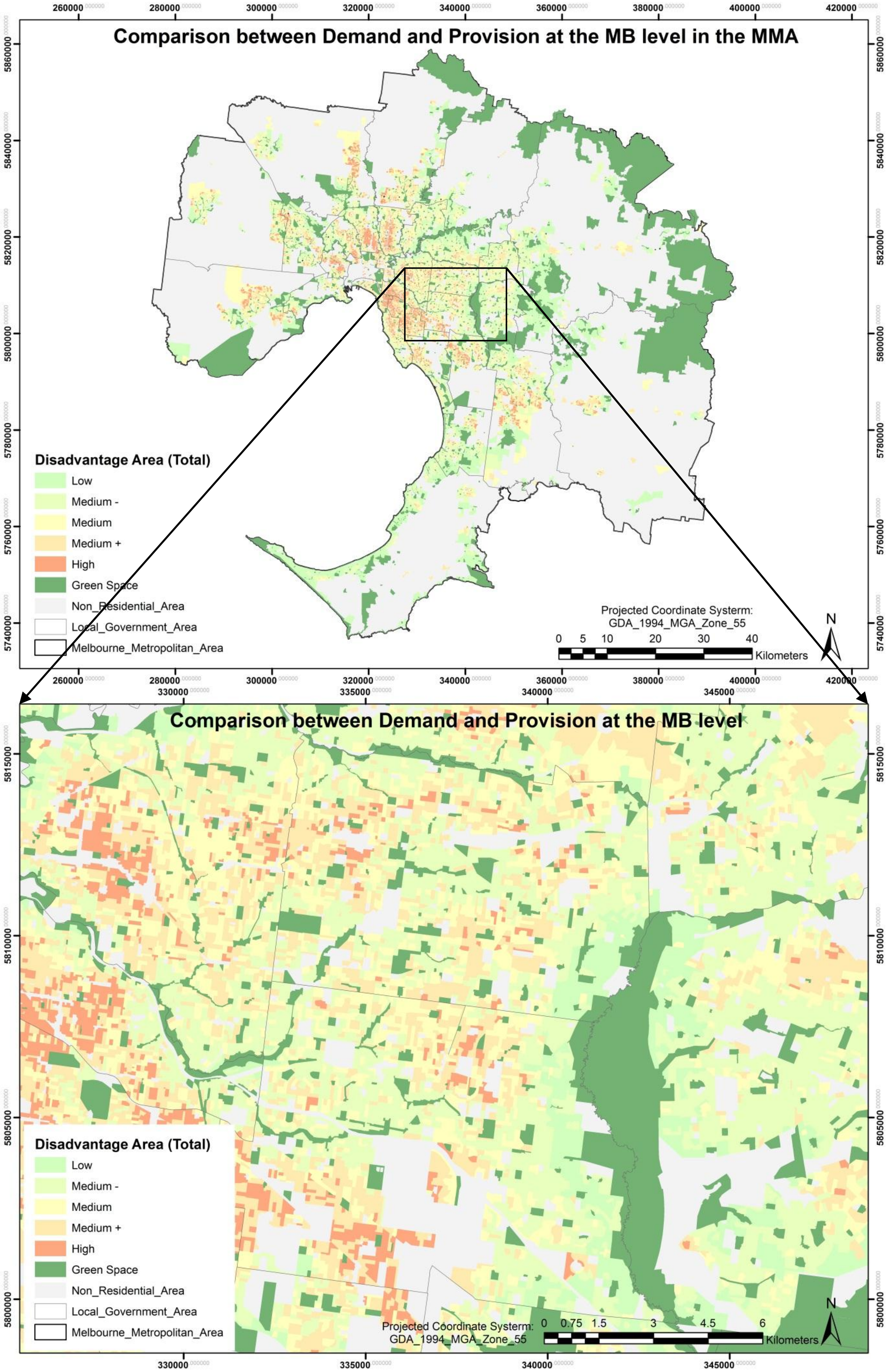
Level of Disadvantage	Description
High	The residential MB or residential area has a relatively high demand for green space and low provision of green space.
Medium +	The residential MB or residential area has a relatively high demand for green space and medium provision of green space, or a medium demand to green space and relatively low provision of green space.
Medium	The residential MB or residential area has a relatively high demand for green space and relatively high provision of green space, or a medium demand to green space and medium provision of green space, or a relatively low demand to green space and relatively low provision of green space.
Medium -	The residential MB or residential area has a medium demand for green space and relatively high provision of green space, or a relatively low demand to green space and medium provision of green space.
Low	The residential MB or residential area has a relatively low demand for green space and relatively high provision of green space.

Resulting from the joint influence of MB-level provision and demand for green space, the spatial variations in the age-specific level of locational disadvantage in green space accessibility are shown in Map 5.5.5 (total), Map 5.5.6 (young), Map 5.5.7 (adult) and Map 5.5.8 (old). Some age-specific summary statistics are presented in Table 5.5.2, including number of persons, residential area, and their respective percentages, that belong to each of the five levels or classes of locational disadvantage. Residential areas and populations associated with a high level of locational disadvantage are characterised by a relative high level of demand for green space but a relatively low level of green space provision, and hence the priority areas for implementing relevant improvement measures.

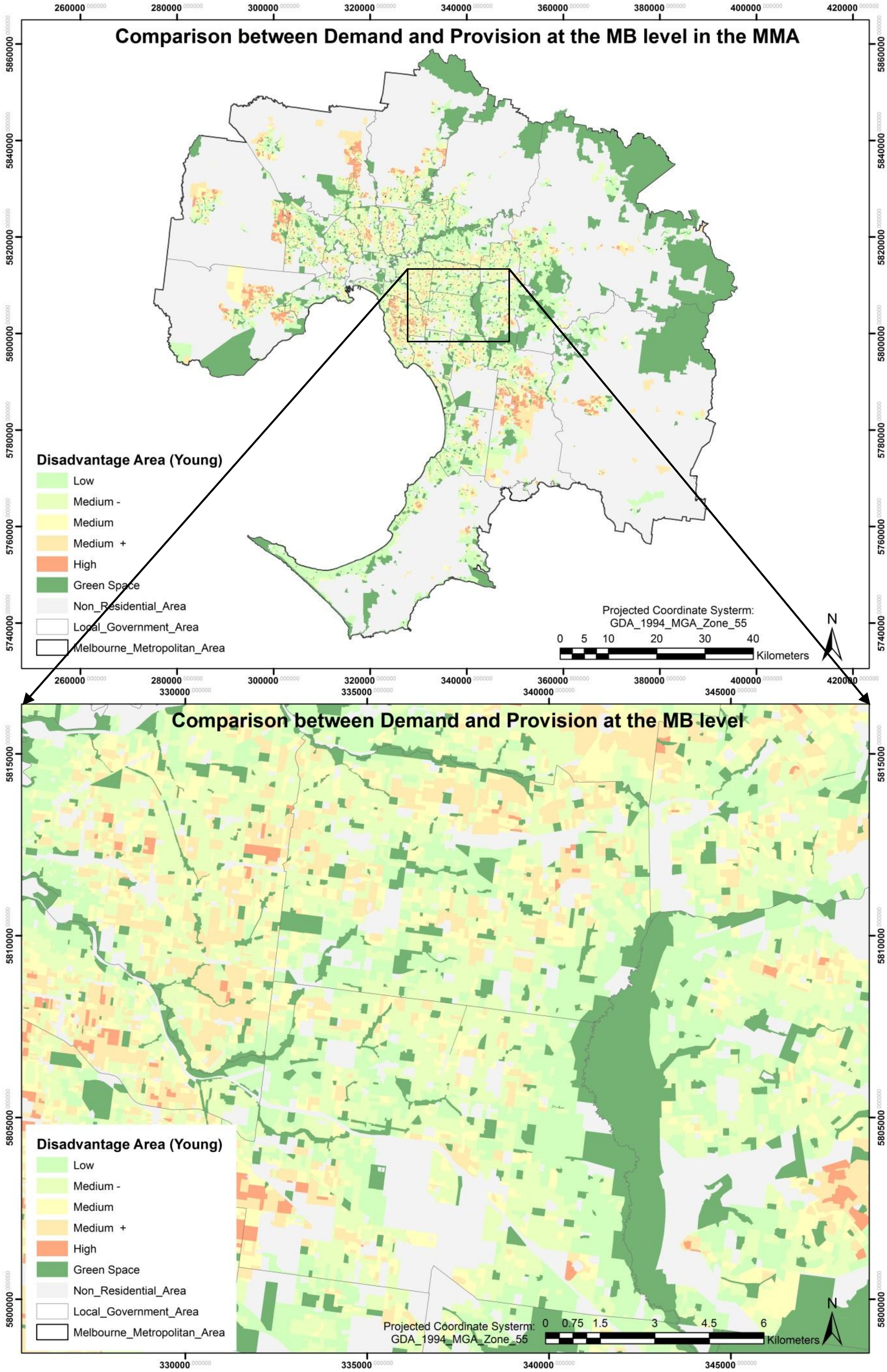
Table 5.5.2 indicates that there are about 12% of the total population and a corresponding 29% of the residential area associated with a high level of locational disadvantage (i.e. the 5th quintile class displayed with **Cantaloupe** colour in Map 5.5.5). For the young age group, there are about 17% of the population and 32% of the residential area associated with a high level of locational disadvantage (i.e. the 5th quintile class displayed with **Cantaloupe** colour in Map 5.5.6). There are about 12% of the adult population and 25% of the residential area associated with a high level of locational disadvantage (i.e. the 5th quintile class displayed with **Cantaloupe** colour in Map 5.5.7). And for the old age group, there are about 10% of the population and 33% of the residential area associated with a high level of locational disadvantage (i.e. the 5th quintile class displayed with **Cantaloupe** colour in Map 5.5.8).

Table 5.5.2 The summary statistics of population and residential area for the 4 age groups in the 5 locational disadvantage levels

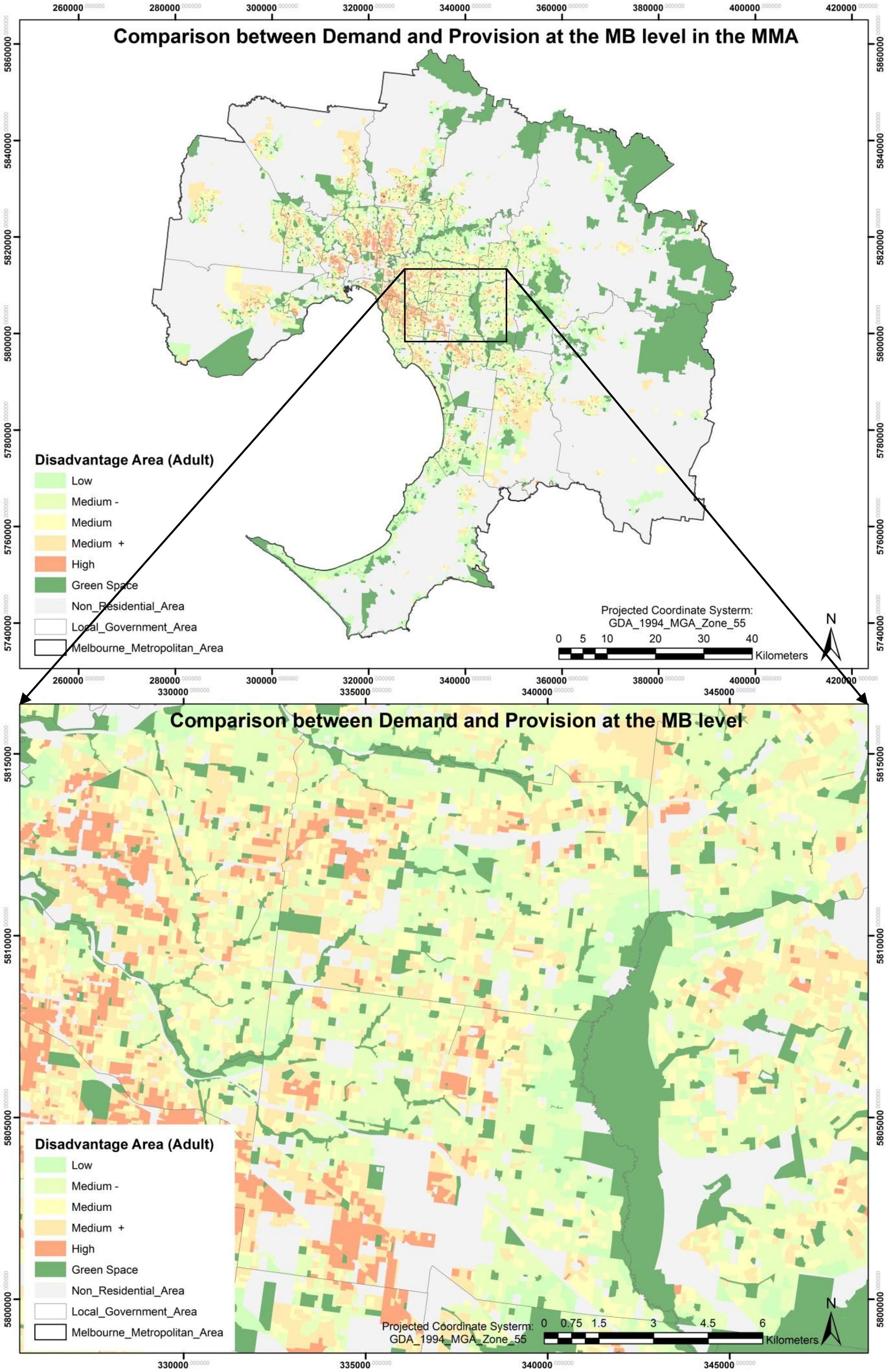
Population (persons) and residential area (ha) for the 4 age groups in 5 LD levels		Level of Locational Disadvantage (LD)										
		Low		Medium -		Medium		Medium +		High		Total
Total	Persons	569767	14.9%	1151853	30.1%	639435	16.7%	1008750	26.4%	453343	11.9%	3823148
	MB Number	5510	13.8%	11639	29.1%	6718	16.8%	10728	26.8%	5396	13.5%	39991
	MB Area	10544	6.2%	31387	18.5%	32617	19.2%	46478	27.3%	49089	28.9%	170115
Young	Persons	107021	15.0%	163040	22.9%	122207	17.2%	202876	28.5%	117310	16.5%	712454
	MB Number	3226	8.1%	7234	18.1%	6118	15.3%	13091	32.7%	10322	25.8%	39991
	MB Area	10772	6.3%	31297	18.4%	22904	13.5%	50020	29.4%	55122	32.4%	170115
Adult	Persons	389769	14.9%	803035	30.7%	443753	17.0%	673671	25.8%	302181	11.6%	2612409
	MB Number	5566	13.9%	11429	28.6%	6650	16.6%	10572	26.4%	5774	14.4%	39991
	MB Area	9827	5.8%	39980	23.5%	28456	16.7%	49134	28.9%	42718	25.1%	170115
Old	Persons	103992	20.9%	176204	35.4%	79868	16.0%	89612	18.0%	48609	9.8%	498285
	MB Number	5228	13.1%	10812	27.0%	6315	15.8%	9551	23.9%	8085	20.2%	39991
	MB Area	13478	7.9%	35306	20.8%	24329	14.3%	40942	24.1%	56060	33.0%	170115



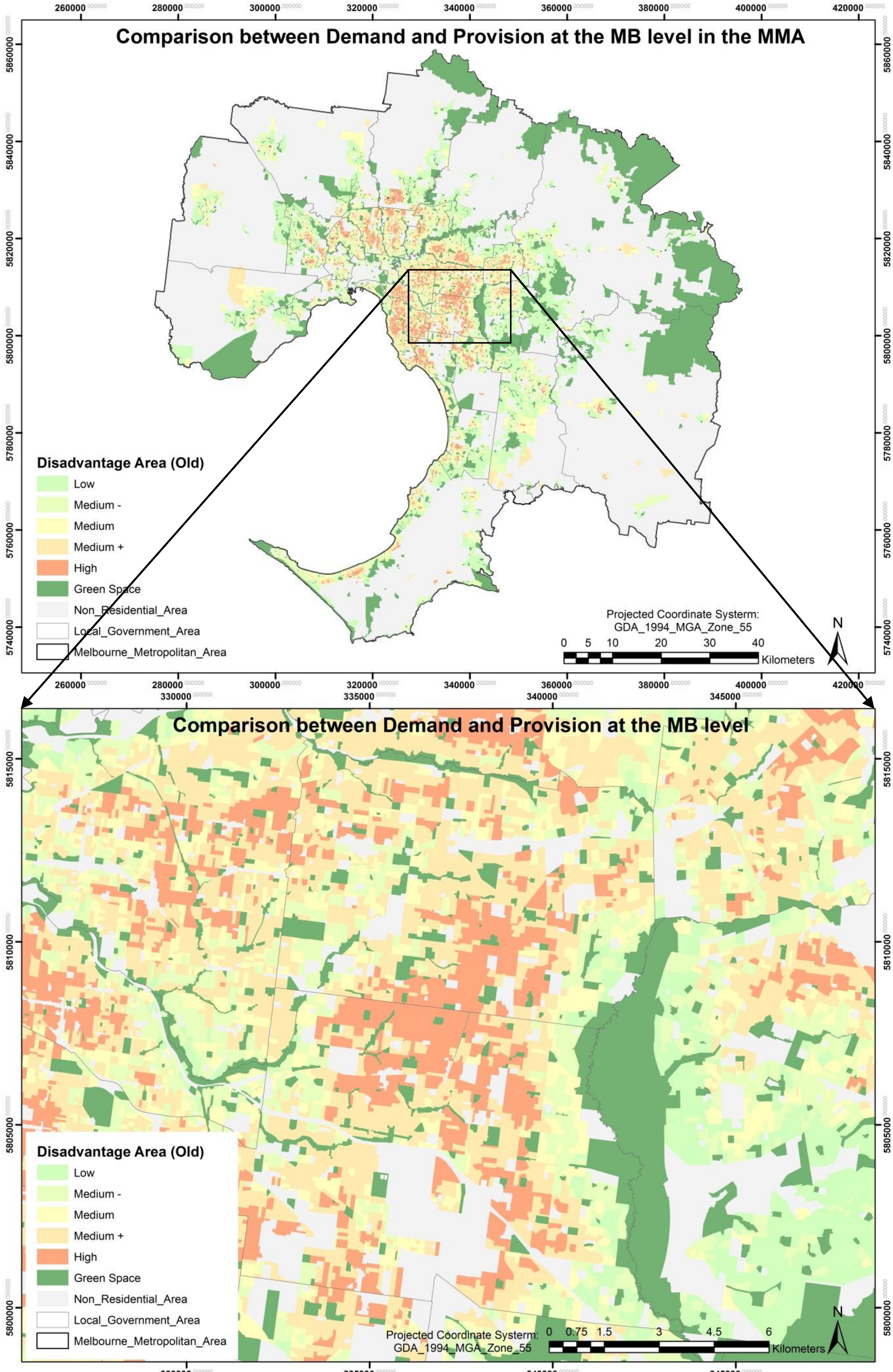
Map 5.5.5 The comparison between demand and provision of green space for Total population



Map 5.5.6 The comparison between demand and provision of green space for Young population



Map 5.5.7 The comparison between demand and provision of green space for Adult population



Map 5.5.8 The comparison between demand and provision of green space for Old population

Spatial clusters of residential MBs with a high level of locational disadvantage for accessing green space are shown in a set of thematic maps, including Maps 5.5.9 (total), Map 5.5.10 (young), Map 5.5.11 (adult) and Map 5.5.12 (old), generated with the GiZScore-based quintile break values summarised in table 5.5.3.

Table 5.5.3 The quintile class break values for age-specific level of disadvantage in green space accessibility

Age Group	Quintile Break Values of GiZScore for Locational Disadvantage in Green Space Accessibility				
	Low	Medium -	Medium	Medium +	High
T	< -4.2	[-4.2, -1.1)	[-1.1, 2.1)	[2.1, 6.3)	⩾ 6.3
Y	< -4.5	[-4.5, -1.9)	[-1.9, 0.8)	[0.8, 4.8)	⩾ 4.8
A	< -4.2	[-4.2, -1.2)	[-1.2, 1.9)	[1.9, 6.1)	⩾ 6.1
O	< -4.7	[-4.7, -1.5)	[-1.5, 2.4)	[2.4, 6.3)	⩾ 6.3

Map 5.5.13 show the spatial variation in aggregated high levels of locational disadvantage in accessing green space. The aggregated high level of locational disadvantage for each residential MB in Map 5.5.13 is defined as follows – the residential MB is ranked :

- High_4, if it has a high level of locational disadvantage for all four age groups (displayed with **Cantaloupe** colour in Map 5.5.13);
- High_3, if it has a high level of locational disadvantage for three of the four age groups (displayed with **Topaz Sand** colour in Map 5.5.13);
- High_2, if it has a high level of locational disadvantage for two of the four age groups ; (displayed with Yucca Yellow colour in Map 5.5.13);
- High_1, if it has a high level of locational disadvantage for one of the four age groups (displayed with Olivine Yellow colour in Map 5.5.13); and
- High_0, if it has a high level of locational disadvantage for none of the four age groups (displayed with **Tzavorite Green** colour in Map 5.5.13).

In summary, there are about 2% of the residential area (3381.26 ha) that have a relatively high level of locational disadvantage for at least three of the four age groups (i.e. including both the High_4 and the High_3 locational disadvantage levels). Based on the 2011 ABS census, there are about 5% of the total population (182703 persons), including 33885 young persons, 127466 adults and 21352 old persons, living in 1834 residential MBs that have a relatively high level of locational disadvantage for at least three of the four age groups.

In addition, there are about 16% of the residential area (26869.13 ha) that have a relatively high level of locational disadvantage for one or two of the age groups (i.e. including both the High_2 and the High_1 locational disadvantage levels). Based on the 2011 ABS census, there are about 26.4% of the total population (1010823 persons), including 188379 young persons, 691520 adults and 130924 old persons, living in 10228 residential MBs that have a relatively high level of locational disadvantage for one or two of the four age groups.

Several spatial clusters of residential areas with relatively high levels of locational disadvantage in accessing green space have been identified in the following parts of the MMA:

- to the southeast of the CBD, including most of the Glen Eira LGA and the Stonington LGA, part of the Mentone and Moorabbin Localities in the Kingston LGA, and most of the Noble Park Locality in the Greater Dandenong LGA;
- to the east of the CBD, including the Hawthorn East and Mount Albert Localities in the Moondarra LGA;
- to the north of the CBD, including the southern part of the Moorland LGA, the central part of the Darebin LGA and the south-western part of the Whittlesea LGA;
- to the west of the CBD, including the central part of the Maribyrnong LGA.

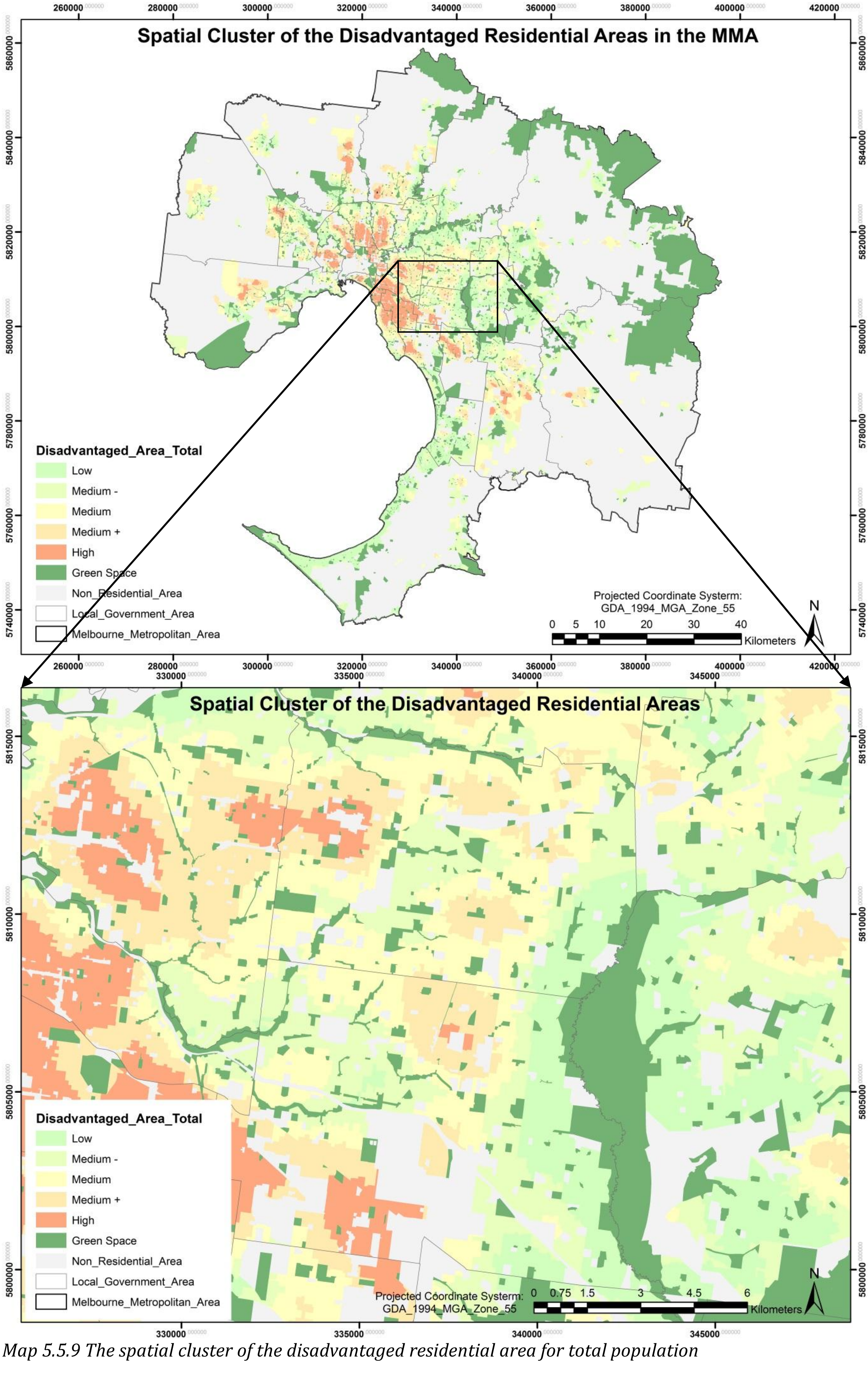
LGA rankings in terms of percentage of age group-based populations and in terms of percentage of age group-based residential areas associated with a high level of locational disadvantage in accessing green space are listed in Table 5.5.4 and Table 5.5.5, and compared with the MMA-wide mean values. In most of the cases, again, Glen Eira ranked the highest, either in terms of age group-based populations or in terms of age group-based residential areas.

Table 5.5.4 LGA rankings: based on percentage of age group-based populations associated with high level of locational disadvantage in accessing to green space

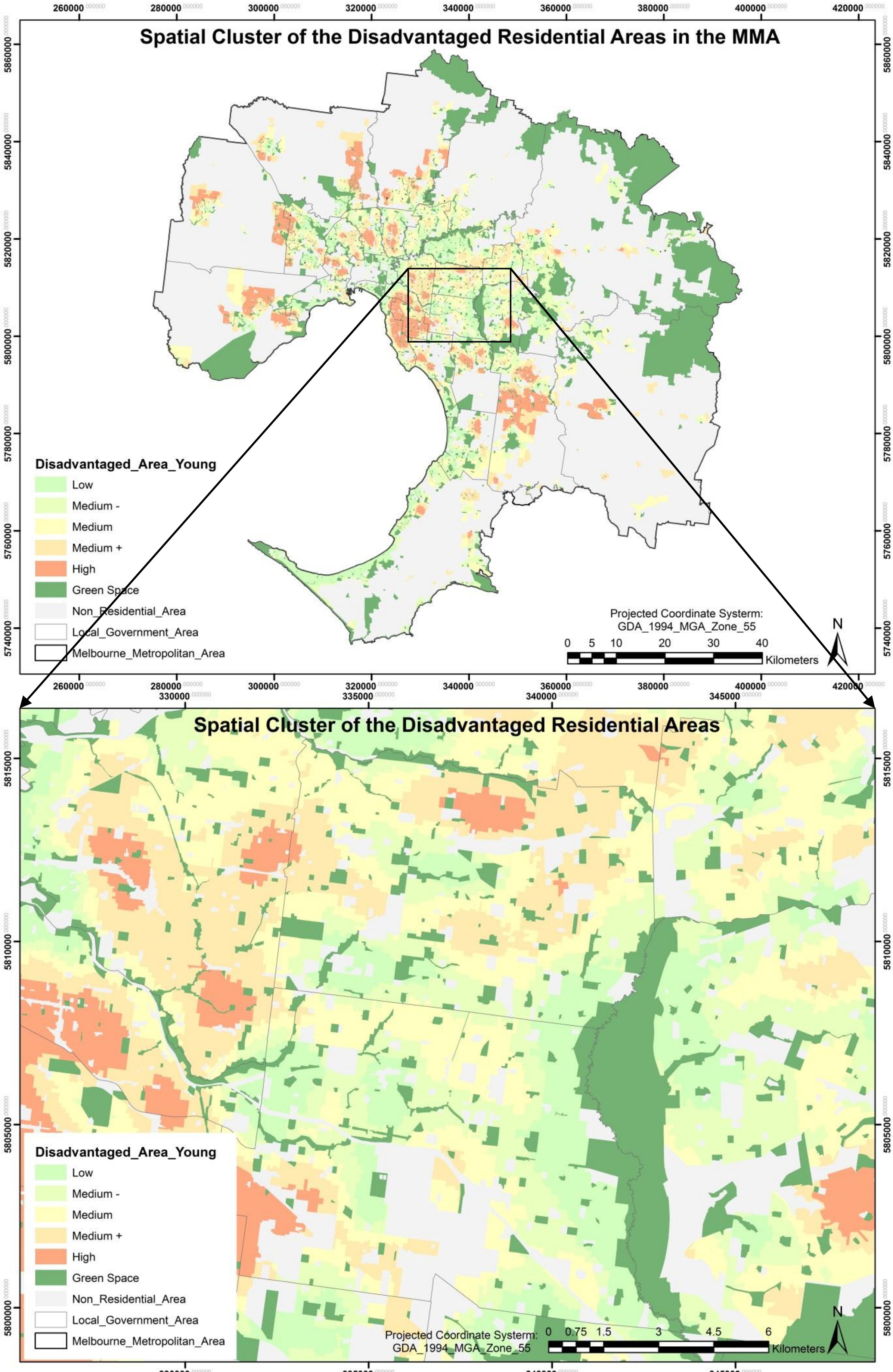
RANKING		Pop_T		Pop_Y		Pop_A		Pop_O
1	NILLUMBIK	0.54%	YARRA	0.00%	YARRA RANGES	0.34%	YARRA	0.00%
2	MORNINGTON PENINSULA	0.80%	MELBOURNE	0.00%	MORNINGTON PENINSULA	0.48%	MELBOURNE	0.49%
3	KNOX	0.98%	BANYULE	0.19%	NILLUMBIK	0.69%	NILLUMBIK	1.22%
4	YARRA RANGES	1.03%	MANNINGHAM	0.67%	MANNINGHAM	1.84%	HUME	2.82%
5	MAROONDAH	1.35%	WHITEHORSE	0.98%	FRANKSTON	2.15%	PORT PHILLIP	4.99%
6	BANYULE	1.98%	NILLUMBIK	1.64%	KNOX	2.56%	MELTON	5.17%
7	MANNINGHAM	2.54%	HOBSONS BAY	1.92%	MELTON	2.61%	CASEY	5.41%
8	HOBSONS BAY	2.72%	BOROONDARA	2.74%	BANYULE	2.82%	WYNDHAM	5.60%
9	FRANKSTON	4.33%	PORT PHILLIP	3.37%	MAROONDAH	2.86%	HOBSONS BAY	7.55%
10	BRIMBANK	7.13%	GREATER DANDENONG	3.42%	BAYSIDE	4.18%	YARRA RANGES	7.83%
11	WHITEHORSE	7.32%	MAROONDAH	3.71%	CARDINIA	4.95%	KNOX	8.00%
12	KINGSTON	11.26%	KNOX	3.93%	HOBSONS BAY	5.94%	MARIBYRNONG	8.86%
13	BAYSIDE	12.29%	MONASH	4.06%	BRIMBANK	6.72%	FRANKSTON	10.01%
14	MELTON	12.30%	MOONEE VALLEY	4.10%	WYNDHAM	7.17%	MORNINGTON PENINSULA	10.25%
15	CARDINIA	12.45%	KINGSTON	4.28%	WHITEHORSE	8.32%	BRIMBANK	13.77%
16	WHITTLESEA	14.05%	DAREBIN	5.69%	HUME	9.33%	MAROONDAH	16.38%
17	MONASH	14.58%	MORNINGTON PENINSULA	6.16%	CASEY	9.51%	BANYULE	16.79%
18	GREATER DANDENONG	14.68%	FRANKSTON	6.58%	KINGSTON	10.71%	MOONEE VALLEY	19.78%
19	MMA	14.90%	STONNINGTON	6.69%	WHITTLESEA	13.00%	CARDINIA	20.41%
20	YARRA	14.95%	MORELAND	6.94%	GREATER DANDENONG	14.81%	MMA	20.87%
21	MOONEE VALLEY	15.99%	BRIMBANK	7.01%	MMA	14.92%	GREATER DANDENONG	21.35%
22	BOROONDARA	17.45%	YARRA RANGES	7.13%	MONASH	19.63%	MANNINGHAM	23.74%
23	CASEY	18.63%	MARIBYRNONG	7.46%	BOROONDARA	21.39%	DAREBIN	26.30%
24	HUME	19.01%	BAYSIDE	11.15%	MOONEE VALLEY	21.39%	BOROONDARA	26.69%
25	MELBOURNE	19.46%	MMA	15.02%	MORELAND	31.27%	KINGSTON	26.80%
26	WYNDHAM	23.78%	WHITTLESEA	19.04%	MELBOURNE	31.80%	MORELAND	28.31%
27	PORT PHILLIP	27.10%	GLEN EIRA	29.25%	DAREBIN	33.97%	WHITTLESEA	29.41%
28	DAREBIN	27.61%	CARDINIA	37.96%	PORT PHILLIP	36.99%	WHITEHORSE	30.81%
29	MORELAND	27.87%	HUME	38.34%	YARRA	38.08%	BAYSIDE	32.69%
30	MARIBYRNONG	36.44%	MELTON	39.35%	GLEN EIRA	43.10%	MONASH	38.76%
31	STONNINGTON	44.88%	CASEY	42.62%	MARIBYRNONG	46.94%	STONNINGTON	45.56%
32	GLEN EIRA	47.88%	WYNDHAM	44.10%	STONNINGTON	47.60%	GLEN EIRA	56.14%

Table 5.5.5 LGA rankings: based on percentage of age group-based residential areas associated with high level of locational disadvantage in accessing to green space

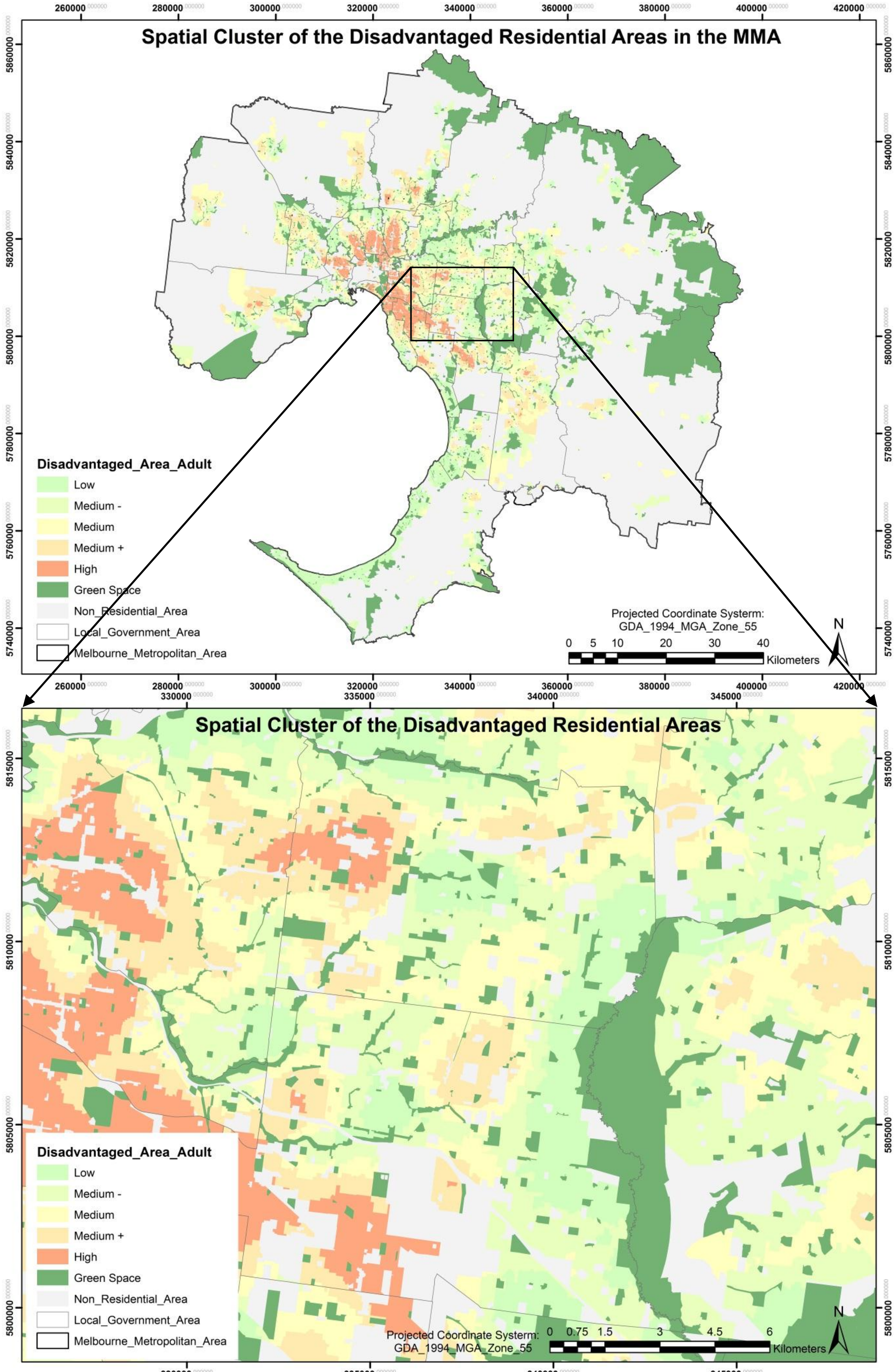
RANKING		Area_T		Area_Y		Area_A		Area_O
1	MORNINGTON PENINSULA	0.15%	YARRA	0.00%	YARRA RANGES	0.06%	YARRA	0.00%
2	NILLUMBIK	0.17%	MELBOURNE	0.00%	MORNINGTON PENINSULA	0.11%	MELBOURNE	0.33%
3	YARRA RANGES	0.19%	BANYULE	0.09%	NILLUMBIK	0.22%	NILLUMBIK	0.39%
4	KNOX	0.60%	MANNINGHAM	0.30%	MANNINGHAM	0.87%	MELTON	0.54%
5	MAROONDAH	0.61%	WHITEHORSE	0.43%	CARDINIA	0.94%	WYNDHAM	0.64%
6	BANYULE	0.91%	NILLUMBIK	0.60%	FRANKSTON	0.94%	CASEY	0.71%
7	MANNINGHAM	0.95%	HOBSONS BAY	1.12%	MELTON	1.02%	HUME	0.72%
8	FRANKSTON	1.91%	MORNINGTON PENINSULA	1.36%	BANYULE	1.58%	YARRA RANGES	1.32%
9	CARDINIA	2.20%	BOROONDARA	1.67%	MAROONDAH	1.63%	CARDINIA	2.01%
10	HOBSONS BAY	2.25%	PORT PHILLIP	1.73%	KNOX	1.83%	PORT PHILLIP	2.57%
11	WHITEHORSE	3.97%	MAROONDAH	1.91%	WYNDHAM	2.36%	FRANKSTON	3.49%
12	BRIMBANK	4.55%	YARRA RANGES	1.93%	BAYSIDE	2.94%	MORNINGTON PENINSULA	3.53%
13	MELTON	4.72%	MOONEE VALLEY	2.02%	CASEY	3.29%	HOBSONS BAY	3.86%
14	MMA	6.20%	MONASH	2.09%	HUME	3.90%	KNOX	3.91%
15	CASEY	6.30%	KNOX	2.30%	WHITEHORSE	4.90%	MARIBYRNONG	4.62%
16	WYNDHAM	7.05%	GREATER DANDENONG	2.53%	BRIMBANK	4.94%	BRIMBANK	6.49%
17	WHITTLESEA	7.36%	FRANKSTON	2.54%	HOBSONS BAY	5.05%	MAROONDAH	7.54%
18	KINGSTON	7.53%	KINGSTON	2.63%	MMA	5.78%	MMA	7.92%
19	HUME	7.63%	STONNINGTON	3.49%	WHITTLESEA	6.83%	BANYULE	8.15%
20	MONASH	8.74%	DAREBIN	3.73%	KINGSTON	7.58%	WHITTLESEA	9.11%
21	BAYSIDE	8.84%	BRIMBANK	4.09%	BOROONDARA	11.43%	MANNINGHAM	11.40%
22	BOROONDARA	9.27%	MORELAND	4.63%	GREATER DANDENONG	12.14%	GREATER DANDENONG	13.62%
23	MOONEE VALLEY	10.18%	MARIBYRNONG	4.70%	MONASH	12.46%	MOONEE VALLEY	14.36%
24	YARRA	11.10%	MMA	6.33%	MOONEE VALLEY	13.41%	BOROONDARA	15.48%
25	GREATER DANDENONG	11.88%	CARDINIA	7.81%	MORELAND	20.45%	KINGSTON	18.39%
26	MELBOURNE	16.05%	BAYSIDE	8.07%	DAREBIN	24.00%	DAREBIN	19.68%
27	DAREBIN	19.41%	WHITTLESEA	9.77%	MELBOURNE	29.56%	MORELAND	21.75%
28	MORELAND	20.41%	WYNDHAM	14.41%	STONNINGTON	29.74%	WHITEHORSE	22.12%
29	PORT PHILLIP	24.09%	CASEY	15.31%	GLEN EIRA	31.19%	BAYSIDE	24.89%
30	STONNINGTON	29.05%	HUME	16.30%	YARRA	31.42%	STONNINGTON	29.76%
31	MARIBYRNONG	29.26%	MELTON	17.66%	PORT PHILLIP	32.92%	MONASH	29.95%
32	GLEN EIRA	36.33%	GLEN EIRA	20.49%	MARIBYRNONG	38.68%	GLEN EIRA	39.99%



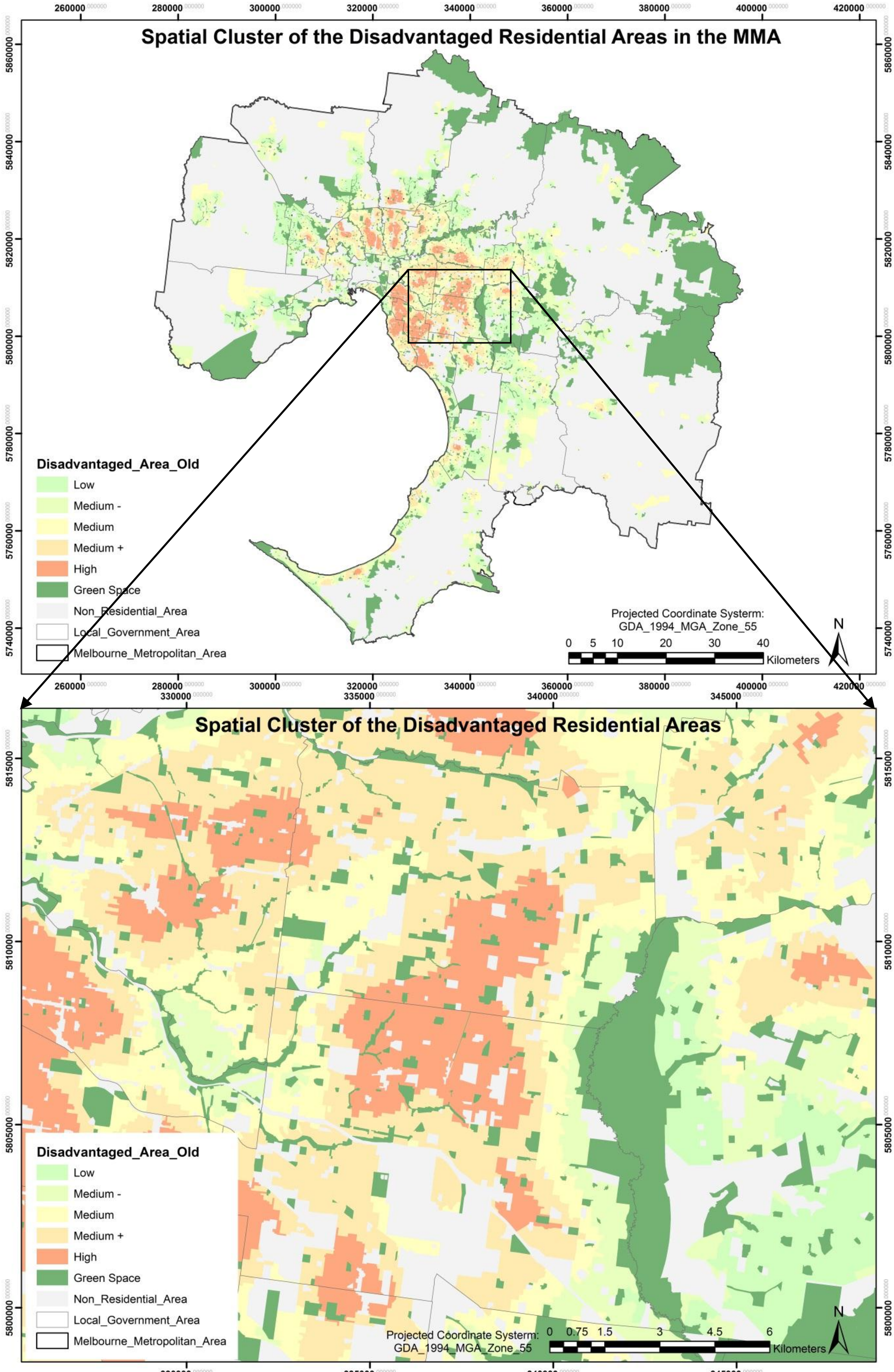
Map 5.5.9 The spatial cluster of the disadvantaged residential area for total population



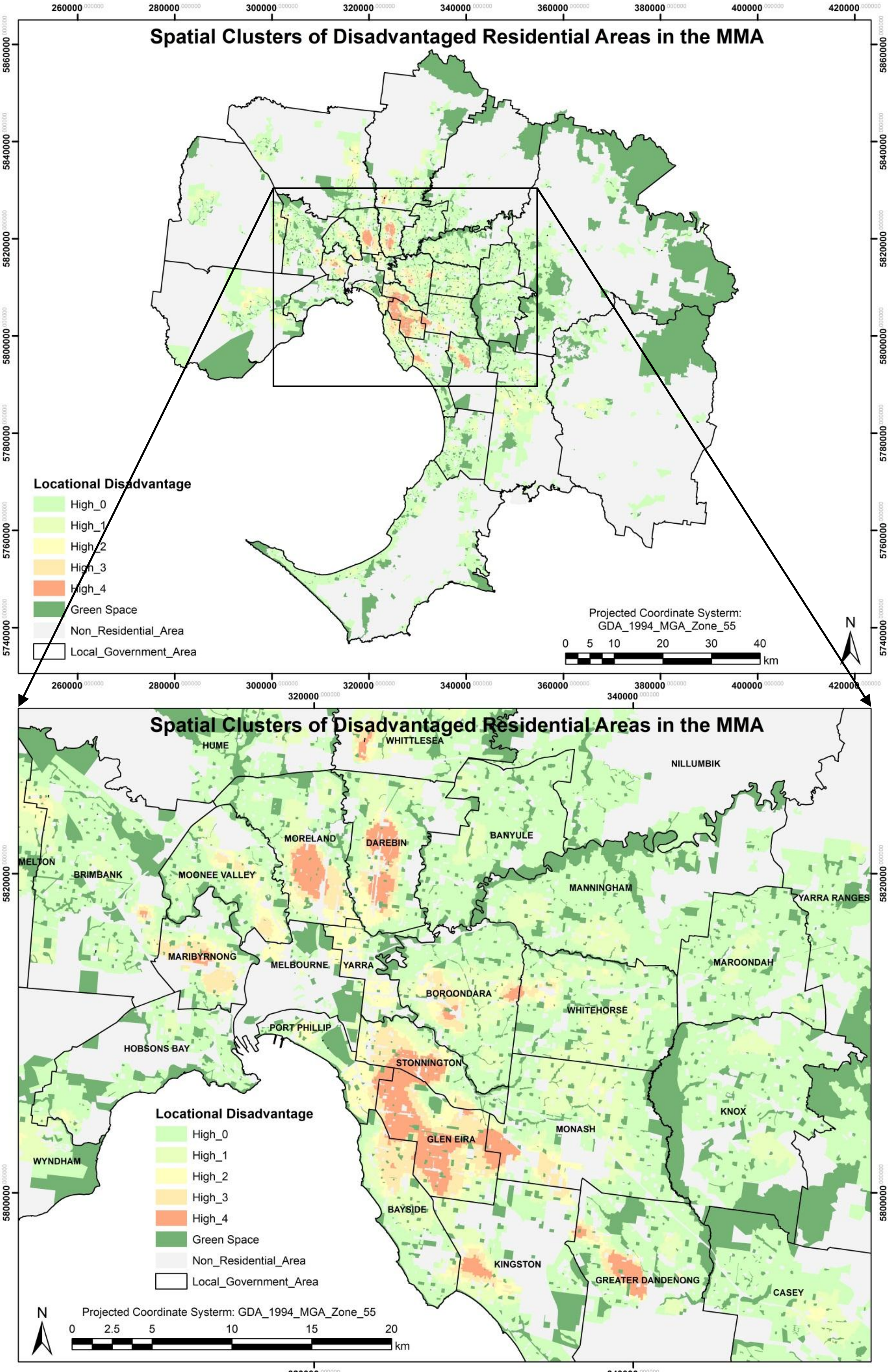
Map 5.5.10 The spatial cluster of the disadvantaged residential area for young population



Map 5.5.11 The spatial cluster of the disadvantaged residential area for adult population



Map 5.5.12 The spatial cluster of the disadvantaged residential area for old population



Map 5.5.13 Spatial clusters of residential areas with high level of locational disadvantage in the MMA.

5.6 Summary

This chapter presents spatial variations across the study area in green space accessibility, that were measured with modified floating catchment area (FCA) based methods, and spatial clusters of residential areas with high locational disadvantage, that were identified through Getis-Ord Gi* based hotspot analysis, along with a set of maps, tables and charts.

Section 5.1 presents spatial variations in travel distance from residential areas to green space, as measured by road network distance. Within its 1600 m neighbourhood, the average travel distance between all residential MBs and their respective nearest green spaces is about 431.5 m, and the average travel distance between all residential MBs and their respective neighbourhood green spaces is about 1087.4 m. In addition, each residential MB in the MMA has, on average, about 13.3 green spaces, and about 110.6 ha of green space area within its 1600 m neighbourhood.

Section 5.2 summarises spatial relationships between residential areas and green spaces for each green space and residential MB as well as their respective three different neighbourhood zones that are sized 400 m, 800 m and 1600 m (of walking distance along local roads), respectively.

In the MMA, on average, there are about :

- 5 residential MBs (or 20 ha residential area, or 480 persons) within the 400 m neighbourhood of a green space, have an average walking distance of 250 m between the MBs and the green space;
- 8 residential MBs (or 30 ha residential area, or 760 persons) within the 800 m neighbourhood of a green space, have an average walking distance of 500 m between the MBs and the green space;
- 9 residential MBs (or 35 ha residential area, or 855 persons) within the 1600 m neighbourhood of a green space, have an average walking distance of 1000 m between the MBs and the green space;
- 2 green spaces (or 16 ha green space area) within the 400 m neighbourhood of a residential MB, have an average walking distance of 220 m between the green spaces and the MB;

- 4 green spaces (or 30 ha green space area) within the 800 m neighbourhood of a residential MB, have an average walking distance of 355 m between the green spaces and the MB; or
- 13 green spaces (or 110 ha green space area) within the 1600 m neighbourhood of a residential MB, have an average walking distance of 430 m between the green spaces and the MB.

Overall, in the MMA, there is at least one green space accessible by about :

- 53% of residential MBs (or 43% of residential area, or 52% of the total population) within 400 m of walking distance along local roads;
- 88% of residential MBs (or 77% of residential area, or 87% of the population) within 800 m of walking distance along local roads; or
- 99% of residential MBs (or 94% of residential area, or 99% of the population) within 1600 m of walking distance along local roads;

and there are about :

- 91% of green spaces (or 37% of green space area) accessible within a walking distance of 400 m along local roads from at least one residential MB;
- 96% of green spaces (or 47% of green space area) accessible within a walking distance of 800 m along local roads from at least one residential MB ; or
- 98% of green spaces (or 57% of green space area) accessible within a walking distance of 1600 m along local roads from at least one residential MB.

Section 5.3 summarises a measured green space attractiveness to four types of population, namely young (0-15 years), adult (16-64 years), old (65+ years), and total population. In general, larger green spaces with more facilities associated usually have higher attractiveness than smaller green spaces with fewer facilities associated.

Section 5.4 presents spatial variations in the mean accessibility to green space for the four age groups. There are about 16% of the total population (living in 18% of the residential area) that have a relatively low accessibility to green space. Based on the 2011 ABS census, there are about 617314 persons, including 94613 young persons, 555246 adults and 64474 old persons who live in areas with relatively low accessibility to green space.

Spatial clusters of residential areas with low accessibility to green space can be found in Glen Eira, Stonington, Boroondara (Hawthorn East, Mount albert), Darebin, Moreland, Moonee Valley (Niddrie, Essendon North, Ascot Vale), Maribyrnong (Seddon, West Footscray), Kingston (Cheltenham, Mentone, Parkdale), Monash (Clayton), Greater Dandenong (Noble Park), Maroondah (Croydon), Knox (Bayswater), Manningham (Doncaster East), Casey (Cranbourne), Brimbank (Sunshine North), and Wydnham (Tarneit). Many isolated residential areas in Cardinia, Whittle Sea and Hume also have low green space accessibility.

Section 5.5 presents spatial variations in the level of locational disadvantage in accessing green space. The level of locational disadvantage in green space accessibility for a particular residential MB is determined by comparing its estimated level of green space provision and demand. For individual age groups, about 12% of the total population (living in 29% of the residential area), 17% of young persons (living in 32% of the residential area), 12% of adult persons (living in 25% of the residential area), and 10% of old persons (living in 33% of the residential area) have a high level of locational disadvantage.

In aggregation, about 5% of the total population (182703 persons, including 33885 young persons, 127466 adults and 21352 old persons) living in 2% of the residential area (3381.26 ha, or 1834 residential MBs) that have a high level of locational disadvantage for at least three of the four age groups. In addition, about 26.4% of the total population (1010823 persons, including 188379 young persons, 691520 adults and 130924 old persons) living in 16% of the residential area (26869.13 ha, or 10228 residential MBs) also have a high level of locational disadvantage for one or two of the four age groups.

Spatial clusters of residential areas with high levels of locational disadvantage in accessing green space are found in: mostly the Glen Eira LGA and the Stonnington LGA, part of the Mentone and Moorabbin Localities in the Kingston LGA, most of the Noble Park Locality in the Greater Dandenong LGA, the Hawthorn East and Mount Albert Localities in the Moondarra LGA, the southern part of the Moorland LGA, the central part of the Darebin LGA, the south western part of the Whittlesea LGA, and the central part of the Maribyrnong LGA (Map 5.5.13).

CHAPTER 6 CONCLUSIONS, DISCUSSIONS AND RECOMMENDATIONS

This study aims at the assessment of the spatial variation in accessibility to local green space in the Melbourne Metropolitan Area (MMA), using fine spatial resolution data sets and GIS-based analytical and visualisation procedures.

Floating catchment area based measures of accessibility have been used in this study for measuring, mapping and better understanding the spatial relationship between the distribution of population and the distribution of green space and green space facilities. Accordingly, spatial clusters of residential locations in the MMA with relatively low levels of accessibility to local green space, and relatively high levels of demand for local green space are identified and presented in this thesis.

Section 6.1 presents a summary of answers, drawn from the study, to the key research questions posed for the research. Section 6.2 presents some discussions on the developed methodology. And Section 6.3 presents some recommendations for further studies on issues related to data quality, accessibility measures and spatial analysis / visualisations.

6.1 Conclusions

Green spaces are defined in this study as urban areas that have green vegetation cover, that are open to, and are freely accessible by the public (i.e. domain 8 in Figure 1.1.1). Green spaces play important roles in urban life due to their ecological, social and economic functionalities.

Green spaces are a major contributor to urban residents' liveability in the MMA. The MMA green space network consists of national and state parks, major (regional) parks managed by Parks Victoria, the metropolitan trail network, linear reserve corridors including green wedges along major waterways, and green space along coastal and water foreshores.

Green spaces are usually associated with various functional facilities, including playgrounds, benches, toilets, walking tracks, sport ovals (for cricket and football), baseball fields, netball and tennis courts, and water bodies - offering services and opportunities to help fulfil individual, social, economic, and environmental benefits.

Many green space properties contribute to green space attractiveness and hence influence people's choice in whether using or not using the green space, such as the location and size of a green space, type and quality of facilities present in or near the green space, and if the green space are quiet. Green space properties considered in this study include a green space's location, area, extent, quietness, and the facilities present. Key types of facilities considered includes the playground, bench, toilet, walking track, sport oval, sport court, and water body.

In this study, green space area size is assigned with strong contribution towards the overall green space attractiveness, and green space attractiveness scores. Consequently, the levels of green space accessibility and demand as well as the level of locational disadvantage in accessing green space, are differentiated among four different age groups: total (0-115), young (0-14), adult (15-64) and old (65+). In general, green spaces with a large area and more functional facilities are more attractive than green spaces with a smaller area and fewer facilities (Section 3.4).

Accessibility is defined in this study in terms of interactions among three key elements: (1) the locations and sizes of residential populations, used for assessing the spatial variation in level of demand for green space; (2) the locations and attractiveness scores of green space, used for assessing the spatial variation in the level of green space provision; and (3) the local road network constrained walking distances between residential areas and green spaces, used for assessing the spatial variation in level of travel impedance, and hence accessibility, to neighbourhood green space by local residents.

Spatial variations in MB-level demand for green space, accessibility to green space, and locational disadvantage in the MMA for each of the four age groups are represented spatially with a set of quintiles-based thematic maps and statistically with a set of summary tables in Chapters 4 and 5. Spatial clusters of residential locations with high level of demand for green space, low level of green space provision and high level of locational disadvantage in accessing green space are identified and mapped with the Getis-Ord Gi* based hotspot analysis tool in ArcGIS, as presented in Section 5.5.

In brief, this study has designed and implemented efficient and effective GIS-based procedures for:

- disaggregating population data from SA1 units to MB units using the address point ratio method;
- enhancing the 2SFCA and the 3SFCA methods with two continuous distance decaying functions, the Gaussian Function and the Butterworth Filter;
- weighing each of the 10 types of green space facilities for specific age groups;
- assessing the impact of traffic noise on the quietness of green spaces;
- determining walking distances along local roads between entrances of green spaces and residential areas;
- determining potential demand for green space using both population density and sub-proportion concentration of specific age groups;
- identifying and mapping spatial clusters of residential areas that have both a low level of green space provision and a high level of green space demand (Figure 6.1.1); and hence,
- improving current understanding on spatial variations in population densities, sub-population concentrations, green space attractiveness, green space spatial accessibility and the level of locational disadvantage in green space access.

Although I believe that the research findings are carefully prepared, summarised and presented, this thesis should have adequately addressed the research objectives and research questions set for this study. There are some issues that emerged during this study, especially during the writing of this thesis, which deserves further discussions. I will try to present some personal views on these issues in the following section.

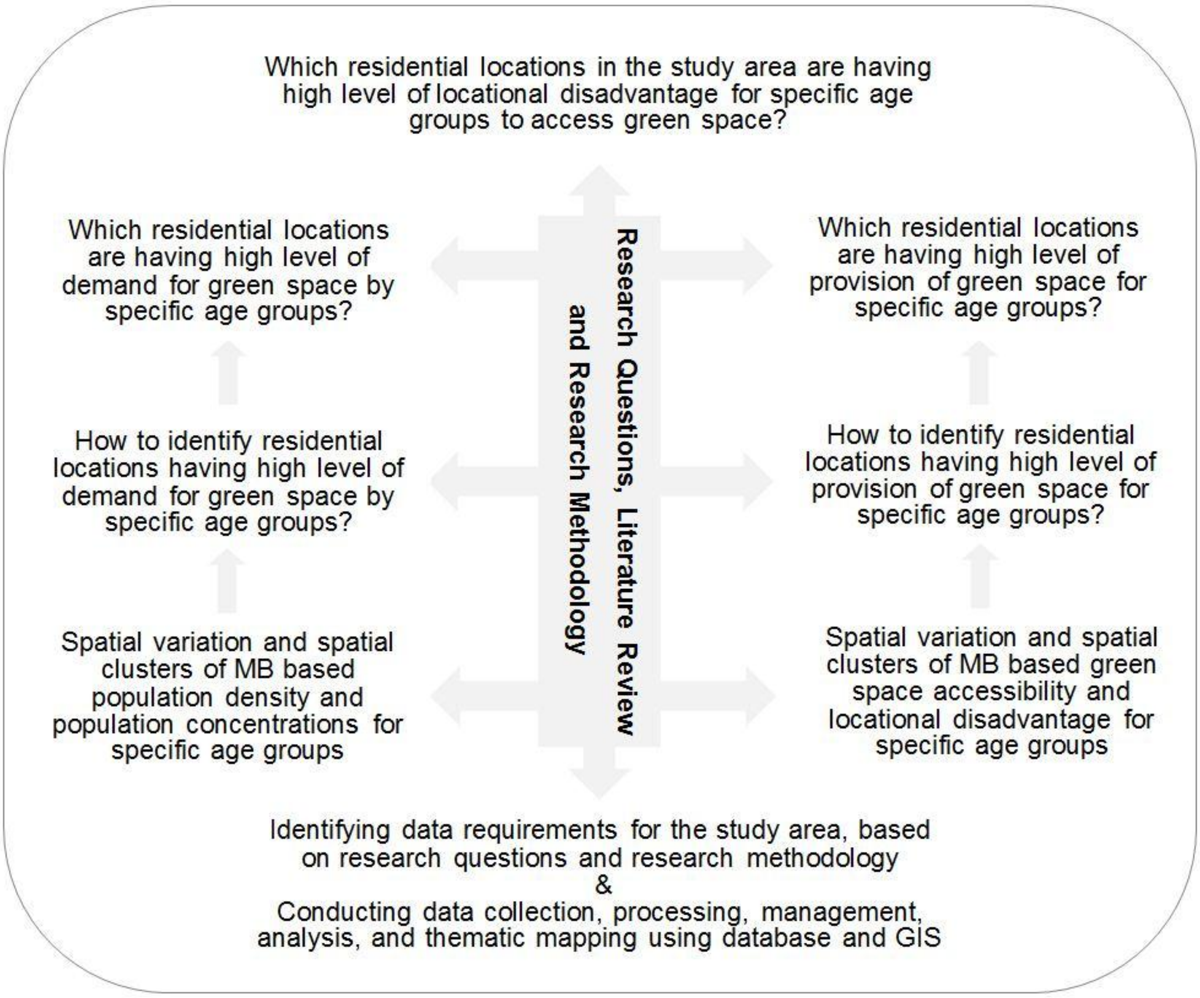


Figure 6.1.1 An overview of this study

6.2 Discussions

Many issues have emerged during the course of this research, often with a confusing and challenging flavour, such as FCA measures, distance decay parameters, network constrained travel impedance between area units, age-specific weights for green space attractiveness, impact of traffic noise on green space attractiveness, classification scheme for thematic mapping and for comparing spatial patterns. Most of these issues have been dealt with in the thesis, but two issues deserve further clarification, that is, the rationale for using FCA measures and the mean FCA measure in the study along with the use of the presented methodology for the ‘what if’ scenario simulation.

The FCA measure of accessibility is gravity-based, and incorporates differentiated opportunities, demands, and travel impedances simultaneously. Apart from this obvious theoretical strength compared to measures simply based on opportunities, ratios between opportunities and population, or travel impedances, FCA measure also has practical advantages compared to measures based on individual utility or constraints: the utility-based or constraint-based measures are more difficult to implement and less easy to explain.

Although the M3SFCA method considers the effect of competition and therefore produces a more realistic estimation than the M2SFCA method (Wan and Zou 2012), it is still difficult to realistically judge in practice if the M2SFCA method actually overestimates or underestimates the level of accessibility compared to the M3SFCA method. To understand the impact of competition on FCA measures of accessibility, both the modified 2-step and the 3-step FCA methods are implemented.

In order to reveal more smooth distance decaying effects within the set floating catchment area, two different continuous functions (i.e. the Guassian function and the Butterworth Filter) have been incorporated – the Gaussian function is a classic and widely applied distance decay function, and the Butterworth filter became popular for modelling the distance decaying effects on pedestrians' walking behaviour (Langford 2012).

Consequently, four different FCA measures are derived for each of the four age groups (Table 6.2.1), and 16 FCA measures have been generated for the four age groups (Table 3.5.3), making the result presentation a tedious challenge.

Table 6.2.1 Four modified FCA-based measures of accessibility implemented in this study

Distance decay function	**M 2-step floating catchment area (M2SFCA) method**	**M 3-step floating catchment area (M3SFCA) method**
Gaussian function	M2SFCA_G	M3SFCA_G
Butterworth Filter	M2SFCA_B	M3SFCA_B

To avoid the application of any individual measure in a mechanical and possibly biased manner, without the support of carefully designed and administered questionnaire-based surveys, it may be sensible to take a 'middle ground' position by using the mean values of the four modified FCA measures. Therefore, in this study, the mean accessibility scores are used to simplify results presentation, and at the same time hope to present results that are unbiased by using any particular measures.

The ‘middle ground’ positions taken in this study are shown in Figure 6.2.1, which contains four bar charts, one for each of the four age groups – T (total), Y (young), A (adult) and O (old). Each of the four bar charts contains five bars, one for each of the five FCA-based accessibility measures – 2G (M2SFCA_G), 2B (M2SFCA_B), 3G (M3SFCA_G), 3B (M3SFCA_B), and Mean (the Mean Accessibility as defined in Eqn 3.16). Each bar’s height indicates log-transformed mean value of accessibility scores for the residential MBs measured with a specific FCA measure.

It can be seen that the mean values for the M3-step FCA measures are generally higher compared to the mean values for the M2-step FCA measures, and that the mean values for the Butterworth filter-based FCA measures are generally higher compared to the mean values for their corresponding Gaussian decay function-based FCA measures. It is also clear that the Gaussian-based M3-step FCA measure has produced mean values that are closer to the ‘middle ground’ positions taken in this study, as indicated by the bars labelled Mean_T, Mean_Y, Mean_A and Mean_O in Figure 6.2.1, than the other three FCA measures have done.

In summary, the adoption of the mean FCA measure of accessibility in the study not only simplified the results presentation in chapter 5, provided a benchmark against which the four different FCA measures can be assessed, but also proved to be a moderate measure to indicate the average accessibility to green space at specific residential locations. Comparatively speaking, the 2-step Gaussian-based FCA measures are consistently conservative and have smaller accessibility scores, the 3-step Butterworth Filter-based FCA measures are consistently optimistic and have larger accessibility scores, and the mean measures can be regarded as a set of compromised measures.

The methodology developed in this study can be easily applied to simulate likely scenarios under alternative conditions. For example, the method may be applied to answer questions like this one: If each one of the local green spaces in the MMA is equipped with all 10 types of facilities considered in the study, what will be the likely consequences, spatially and statistically?

Table 6.2.2 presents the statistical consequences and Maps shown in Appendix 3, which presents a set of comparisons between current and simulated spatial patterns of residential areas with low green space accessibility.

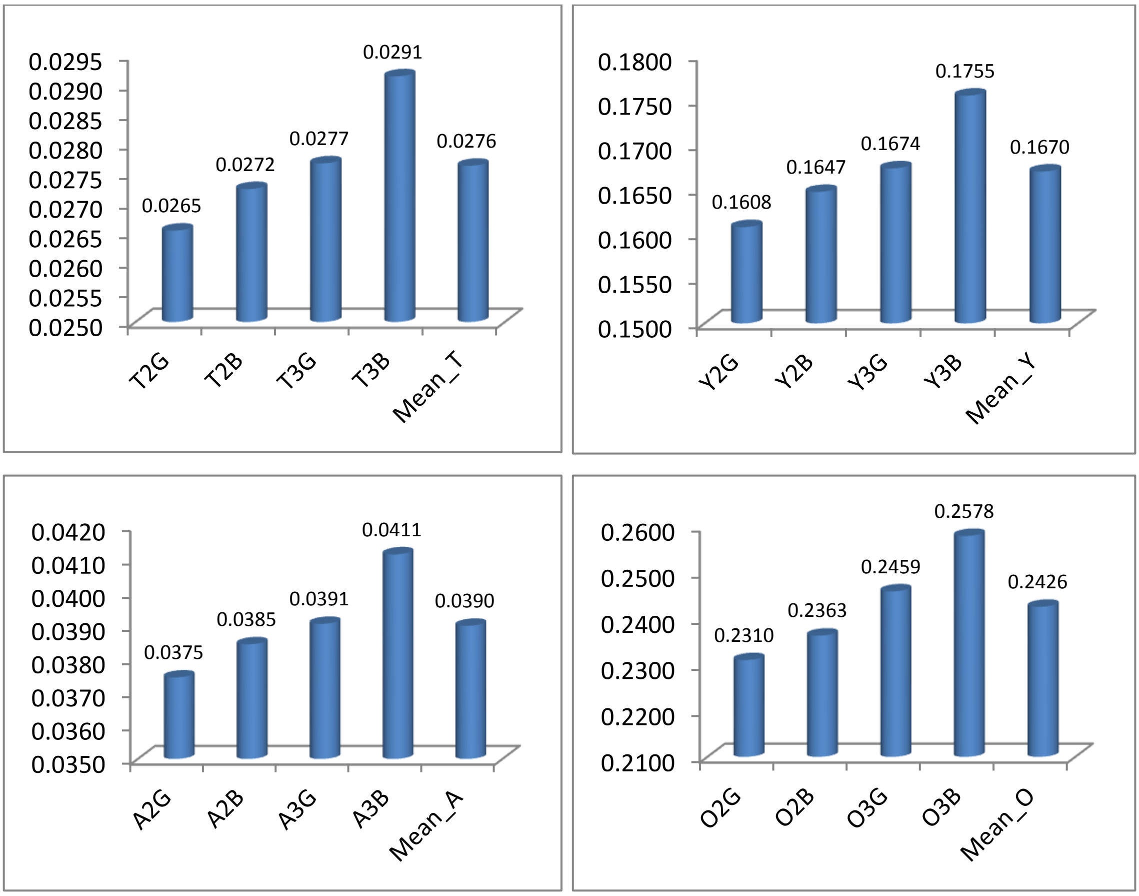


Figure 6.2.1 Mean accessibility scores for Total (top left), Young (top right), Adult (bottom left) and Old (bottom right) populations.

Table 6.2.2 Likely improvements in green space accessibility for the four age groups

		Low Accessibility			
		Current	Assumed	Improved	Improved Percentage
Total	Population	617314	320821	296493	48.03%
	MB Number	6209	3156	3053	49.17%
	Area	30676.09	20313.03	10363.06	33.78%
Young	Population	94613	62813	31800	33.61%
	MB Number	3605	2212	1393	38.64%
	Area	24648.93	19184.88	5464.05	22.17%
Adult	Population	555246	283496	271750	48.94%
	MB Number	8078	4078	4000	49.52%
	Area	36485.16	22403.91	14081.25	38.59%
Old	Population	64474	32899	31575	48.97%
	MB Number	5186	2807	2379	45.87%
	Area	25095.72	17572.18	7523.54	29.98%

6.3 Recommendations

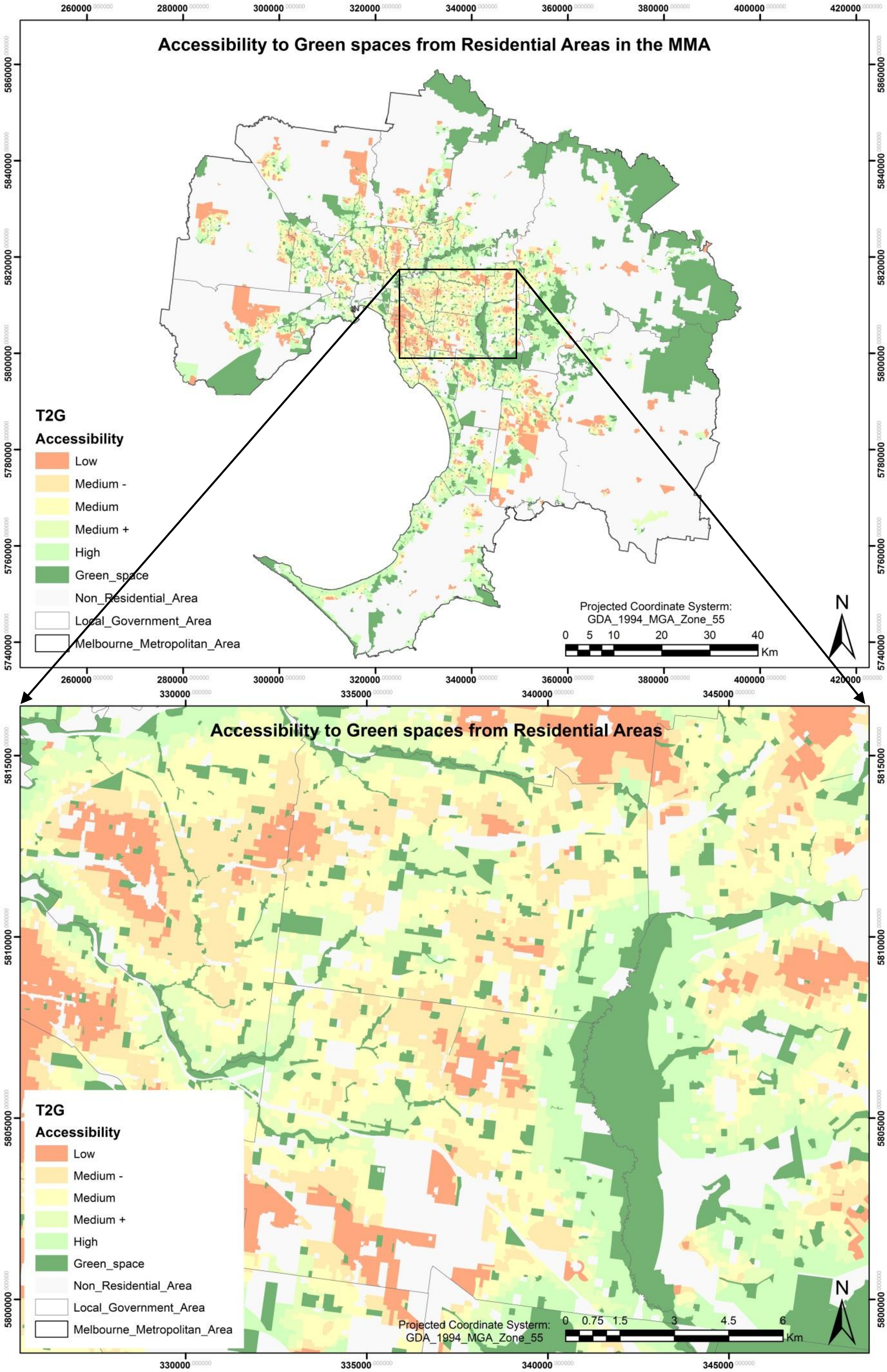
This study *could* be further improved from the following aspects:

- Using data on **floor areas** at residential addresses for improved population disaggregation with floor area ratios method;
- Using accurately located **entrances for green spaces and residential areas** for more accurate measurement of walking distances between green space and residential areas;
- Using accurately located **walking paths** and more relevant walking path attributes such as **safety and slope conditions** for a more realistic measurement of travel impedance between green space and residential areas;
- Using ranked, rather than binary, attribute values of green space properties and green space facilities collected from field surveys;
- Using questionnaire-based survey data for more realistic determination of distance decay function / parameter, threshold distance / catchment size, and specific weights of green space properties; and
- Using crowd sourced or volunteered geographical data on green space utilization to derive a better understanding of the spatial-temporal variations in green space attractiveness and walking path preferences, under different environmental conditions.

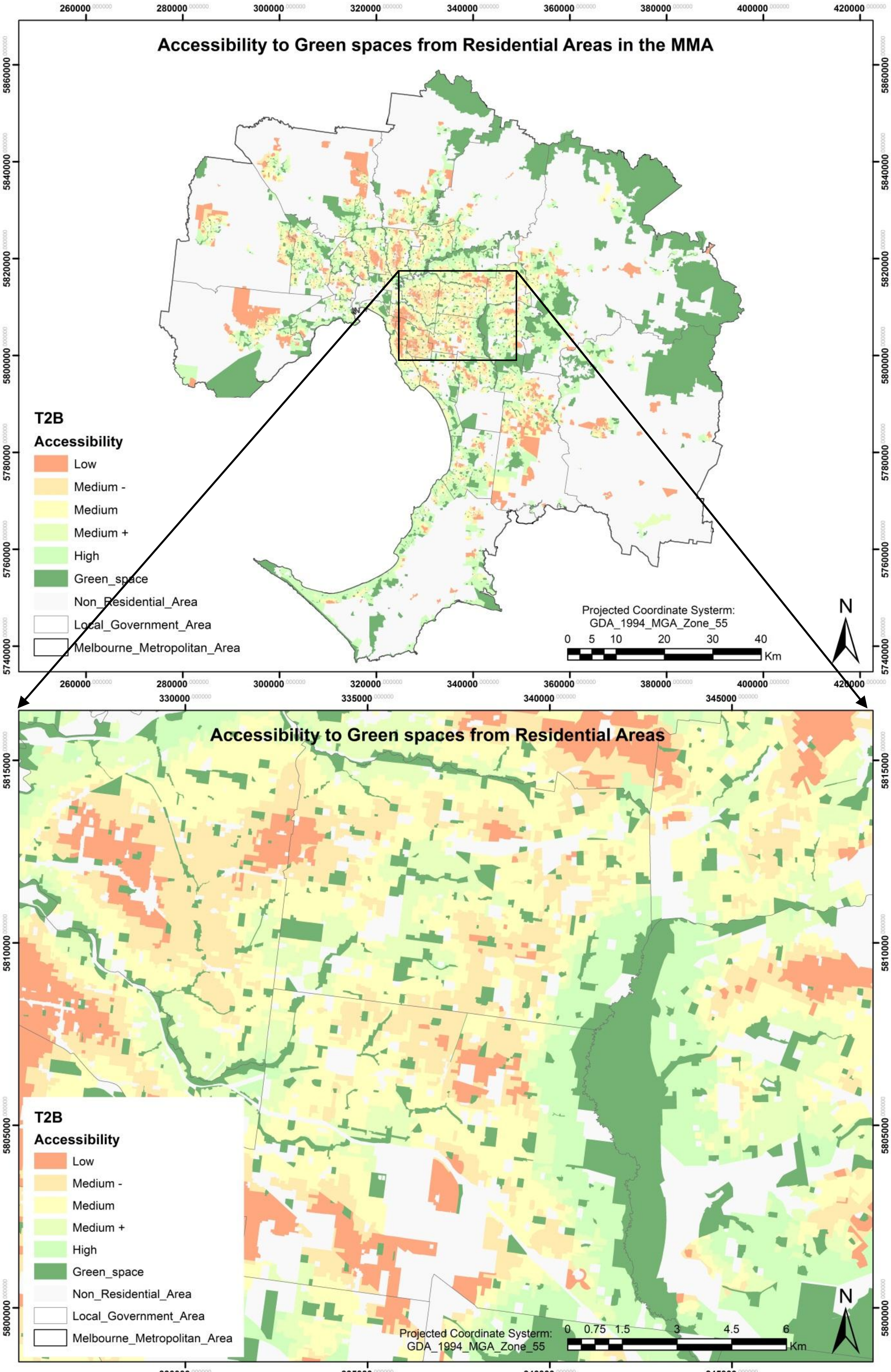
APPENDIX 1

Thematic maps on accessibility to Green space

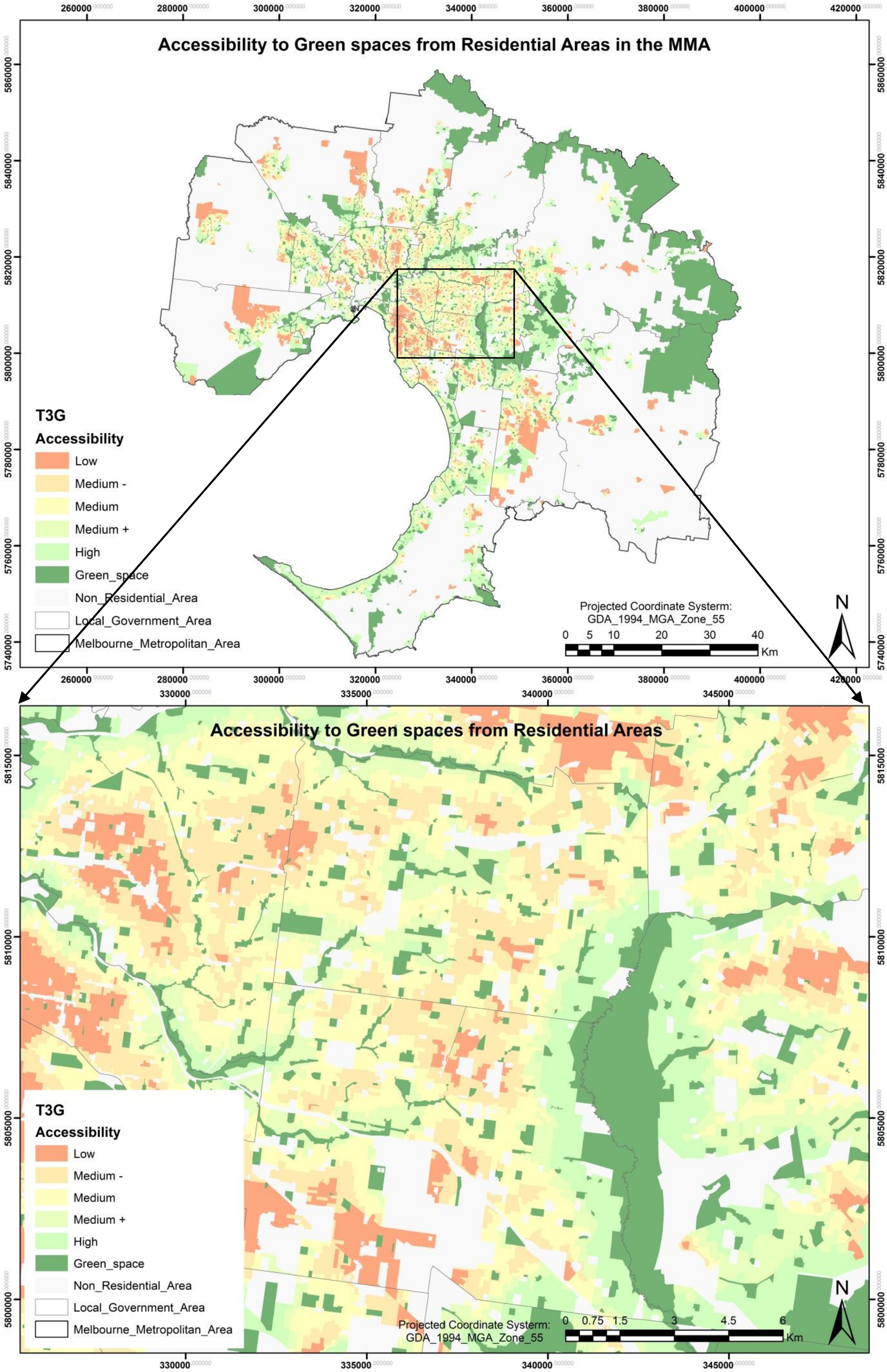
Index:



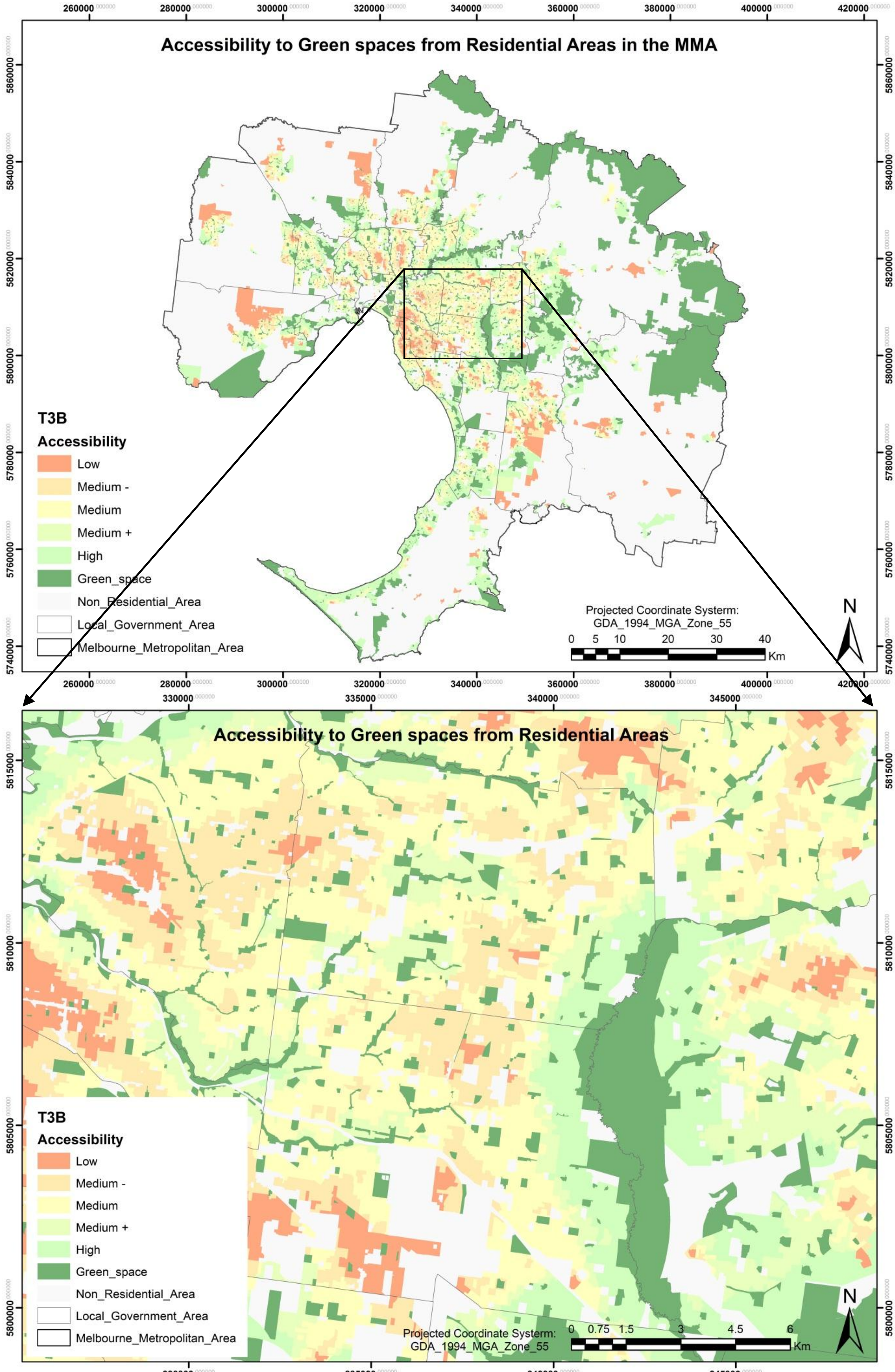
Map Appendix.1.1 The accessibility to green space for total population by 2SFCA model and Gaussian decay



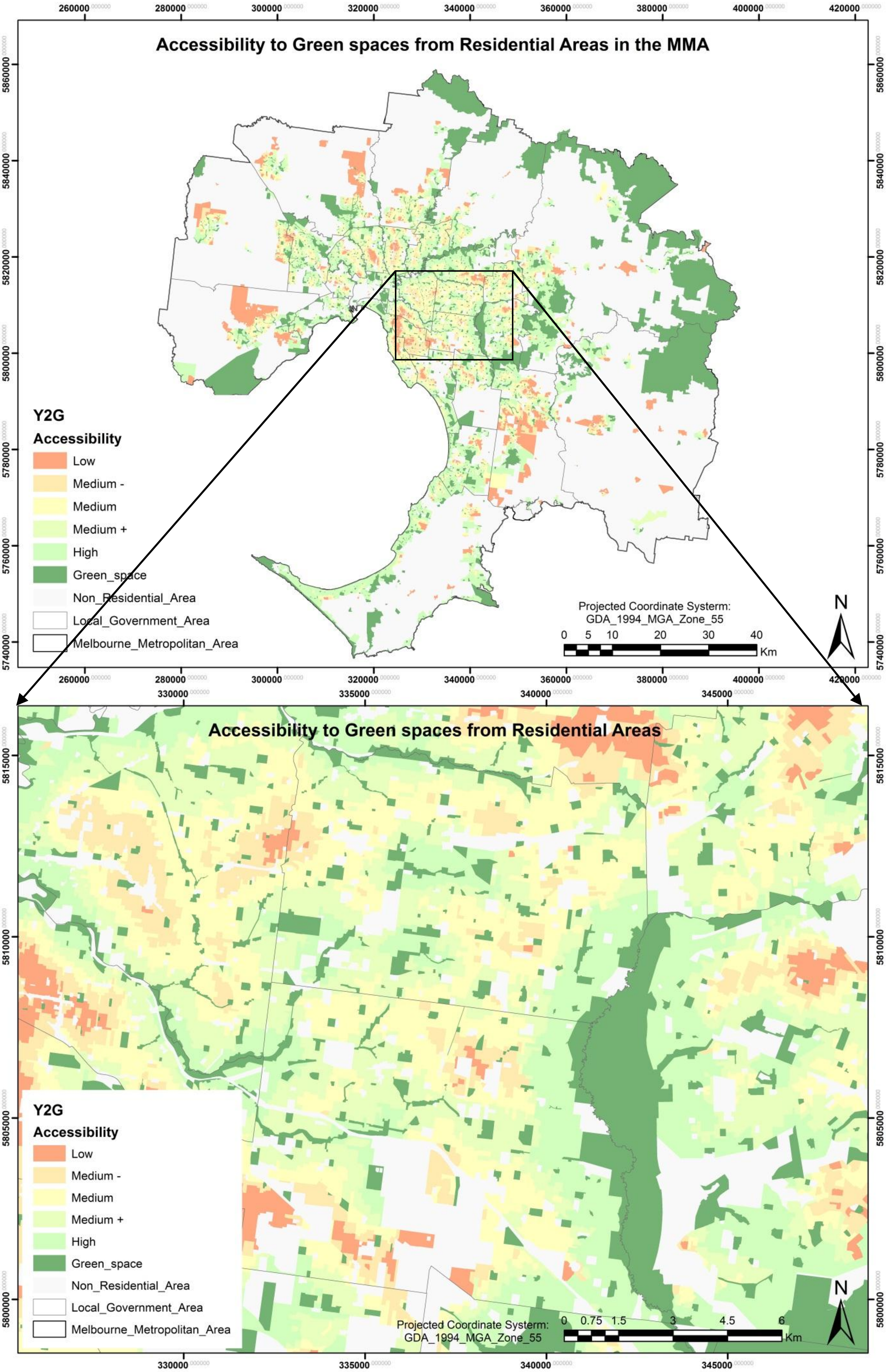
Map Appendix.1.2 The accessibility to green space for total population by 2SFCA and Butterworth filter



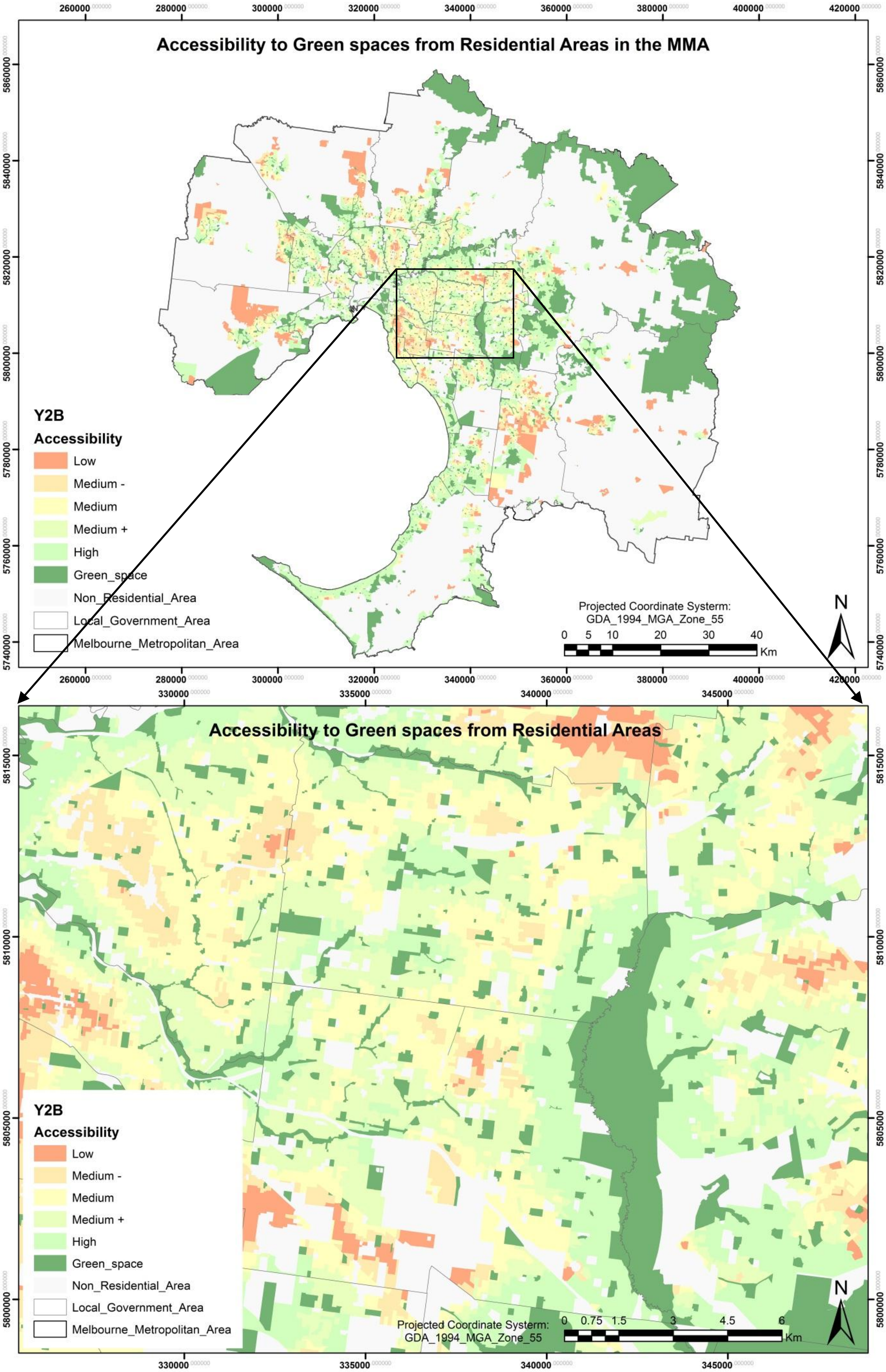
Map Appendix.1.3 The accessibility to green space for total population by 3SFCA model and Gaussian decay



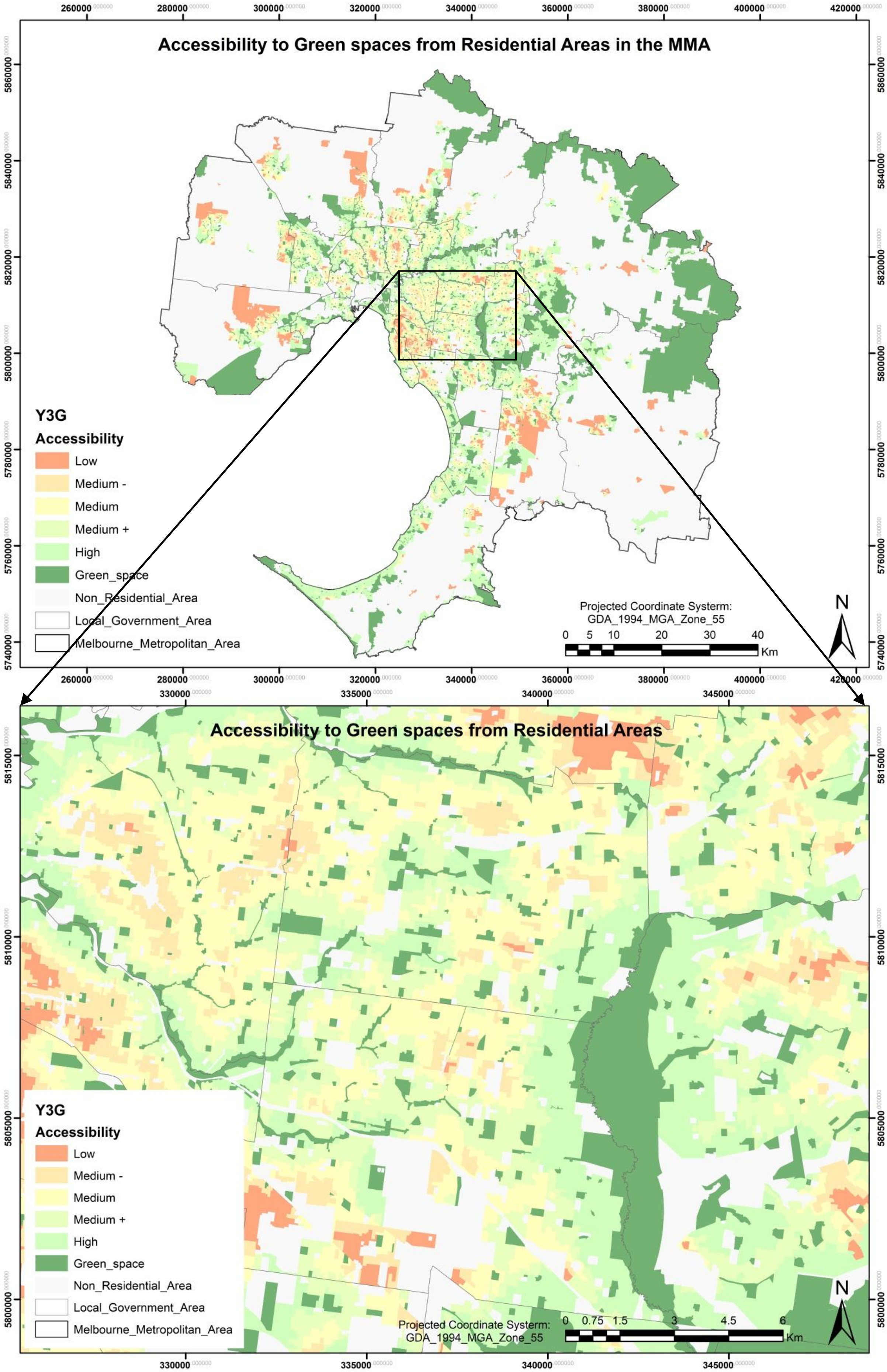
Map Appendix.1.4 The accessibility to green space for total population by 3SFCA and Butterworth filter



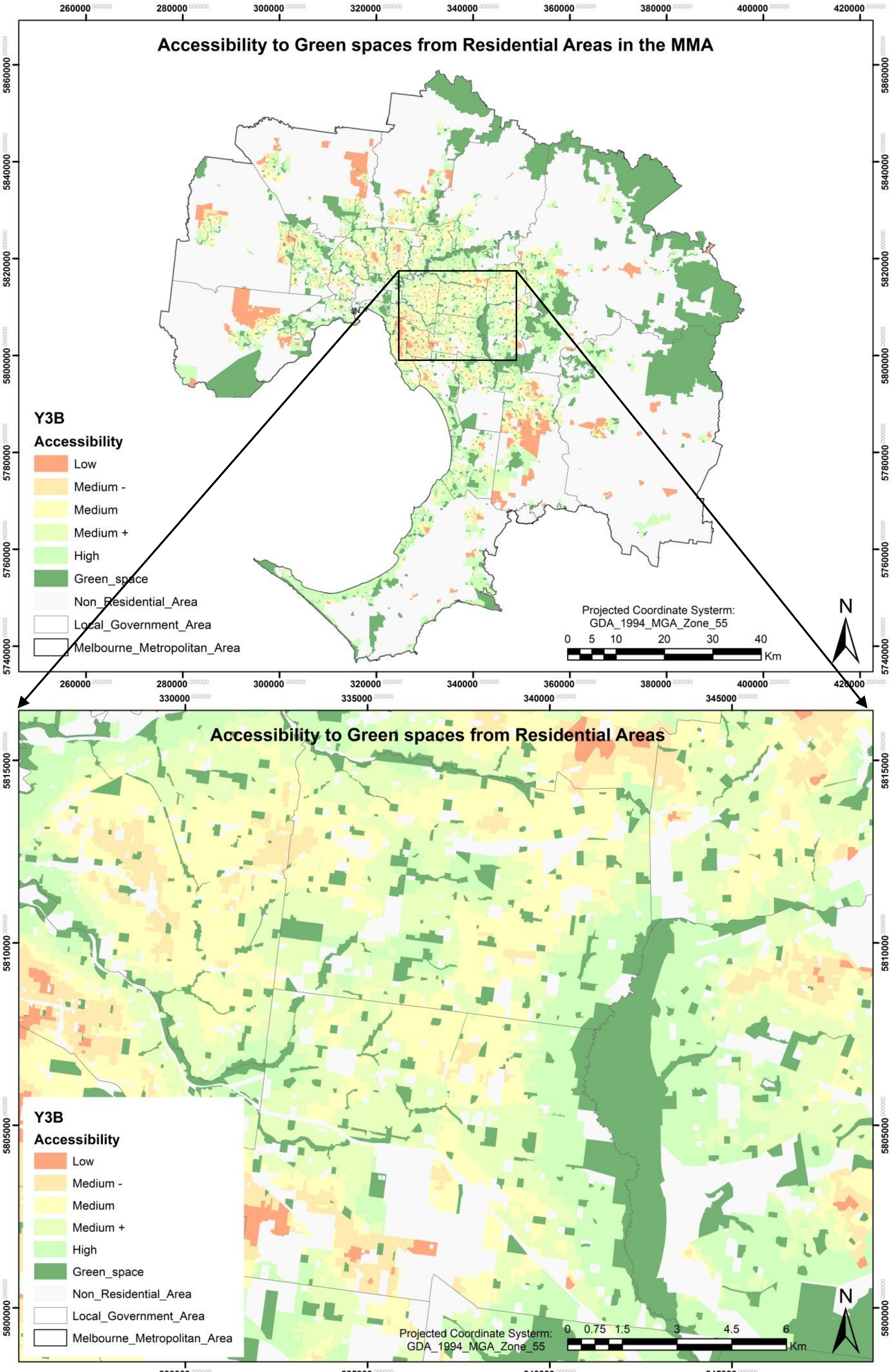
Map Appendix.1.5 The accessibility to green space for young population by 2SFCA and Gaussian decay



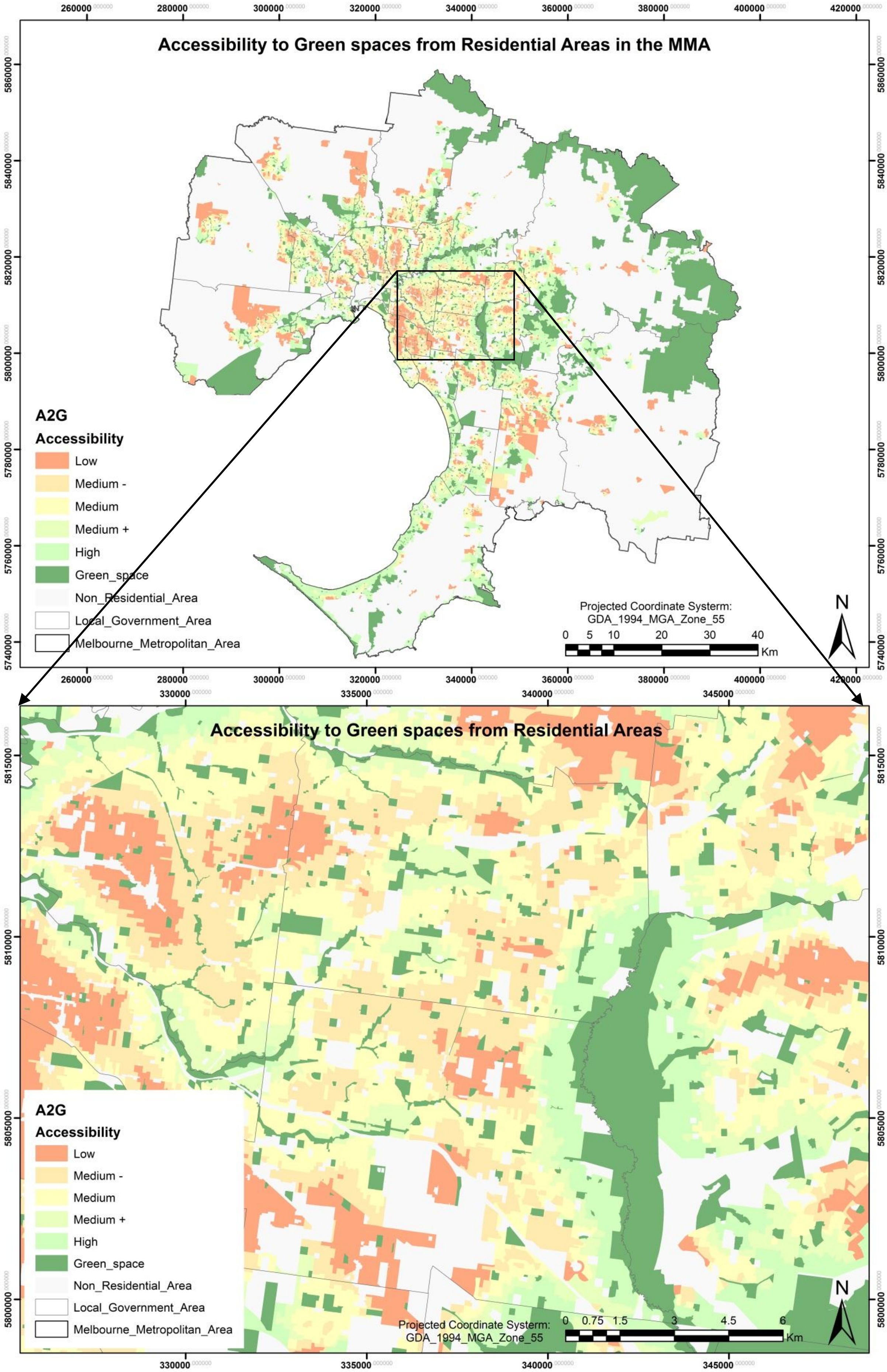
Map Appendix.1.6 The accessibility to green space for young population by 2SFCA and Butterworth filter



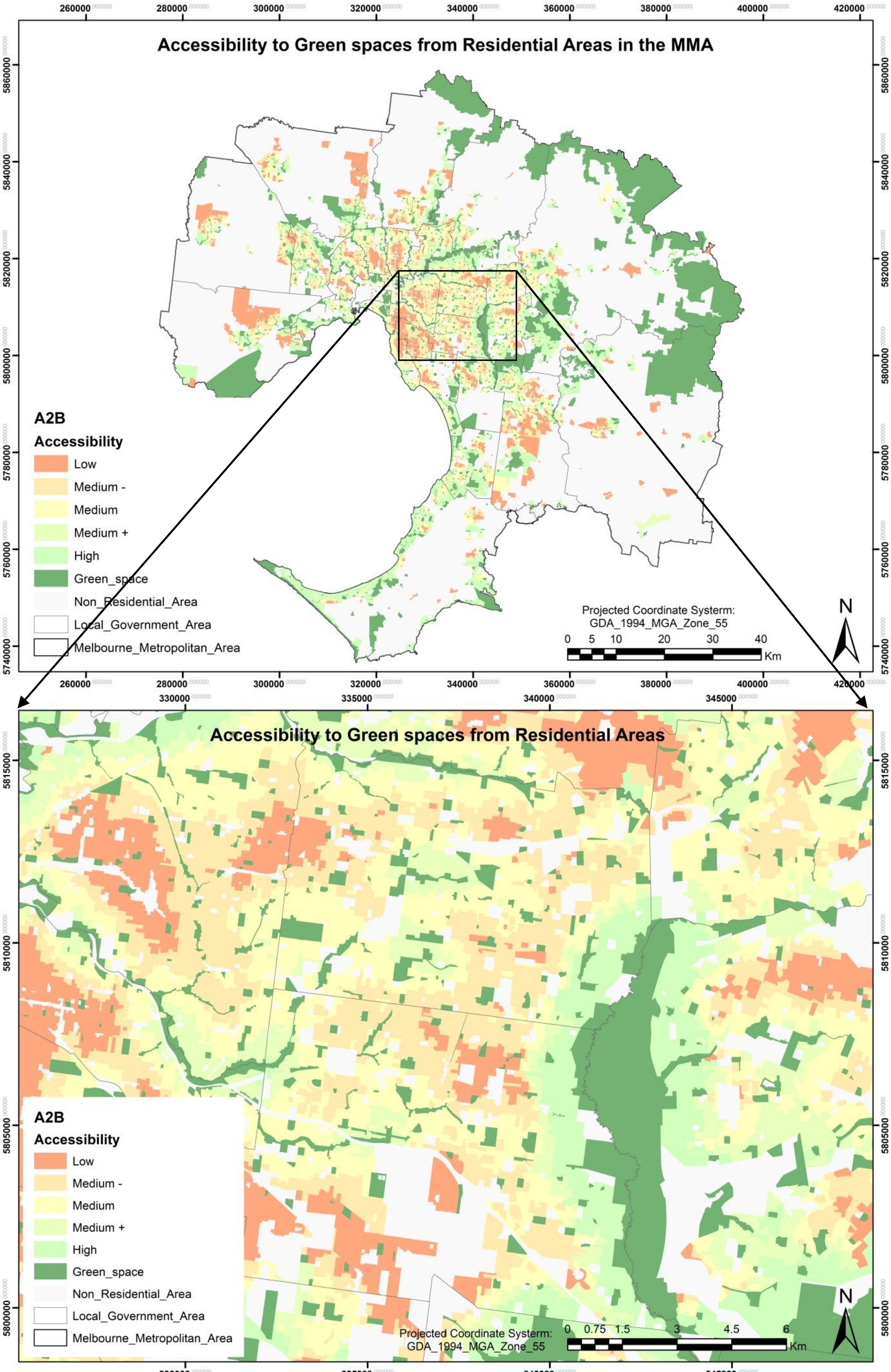
Map Appendix.1.7 The accessibility to green space for young population by 3SFCA and Gaussian decay



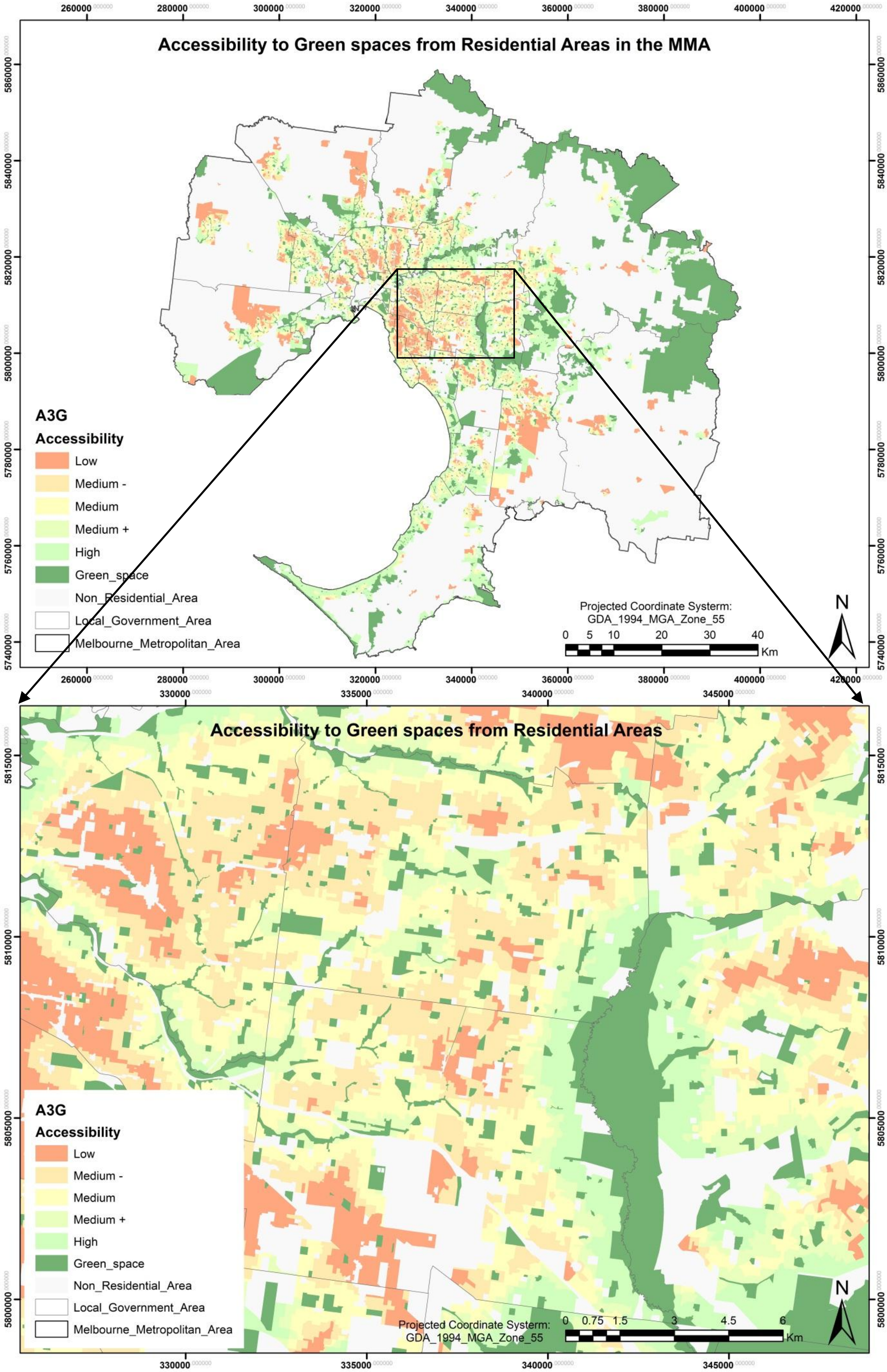
Map Appendix.1.8 The accessibility to green space for young population by 3SFCA and Butterworth filter



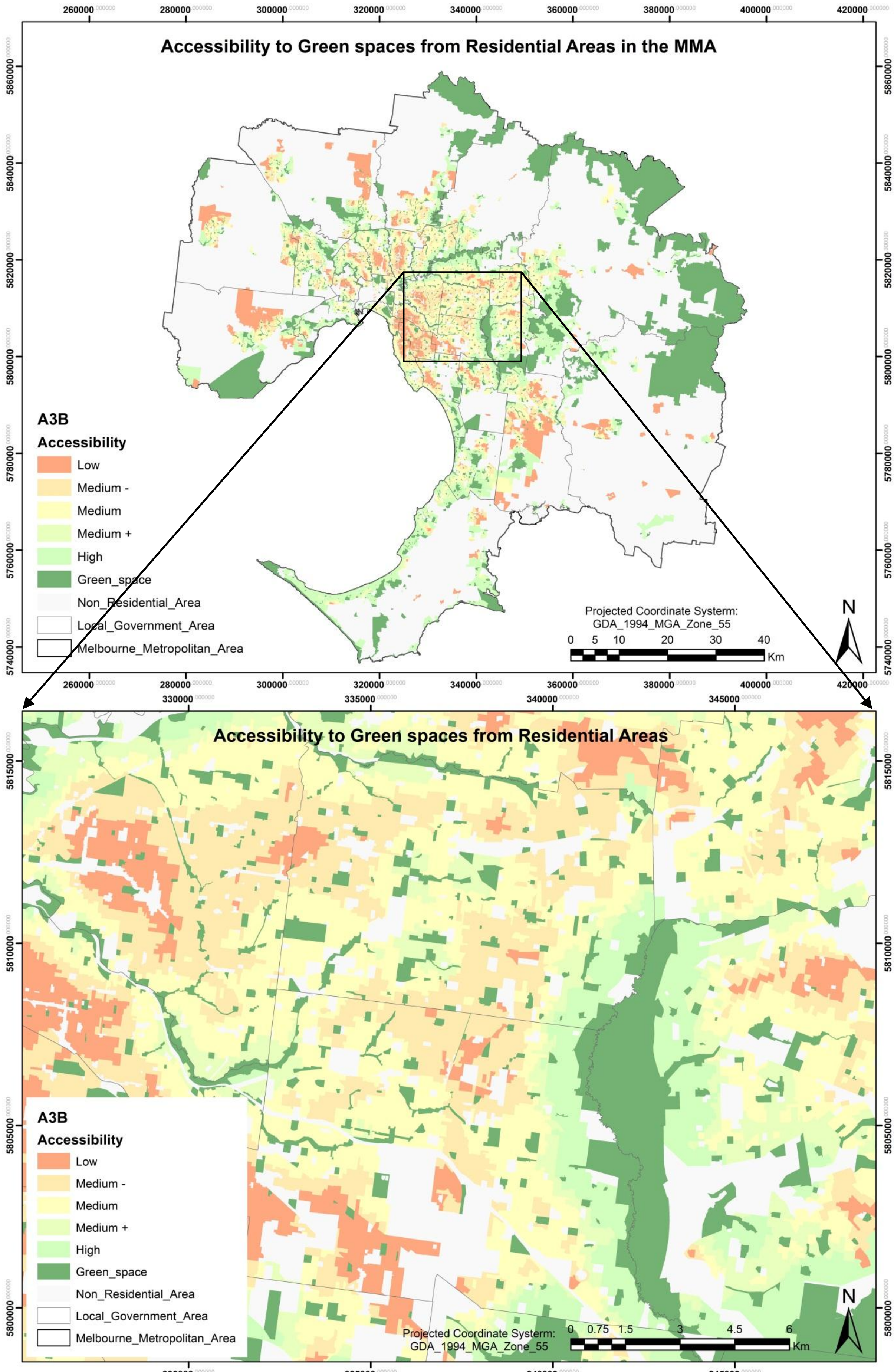
Map Appendix.1.9 The accessibility to green space for adult population by 2SFCA and Gaussian decay



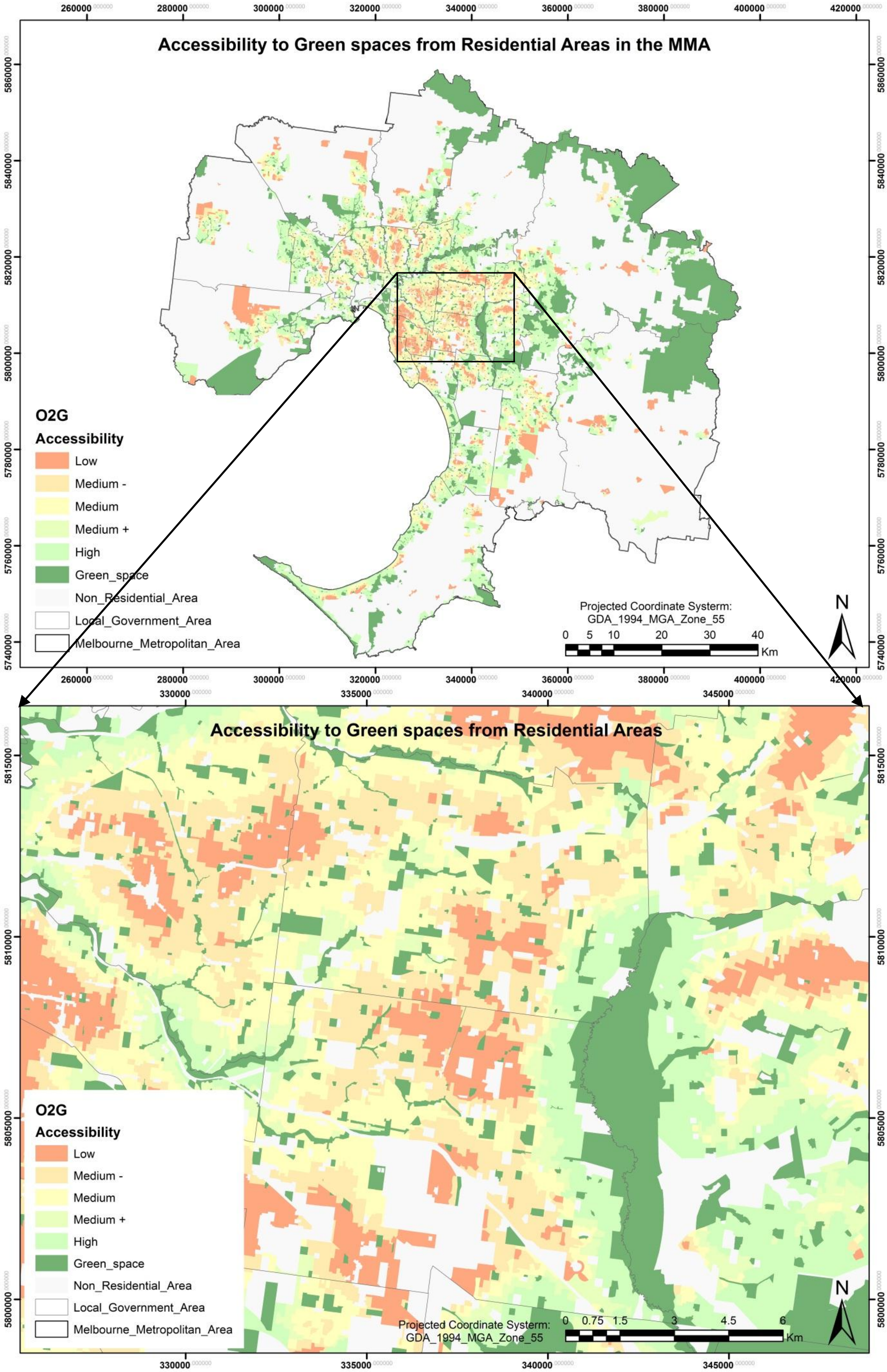
Map Appendix.1.10 The accessibility to green space for adult population by 2SFCA and Butterworth filter



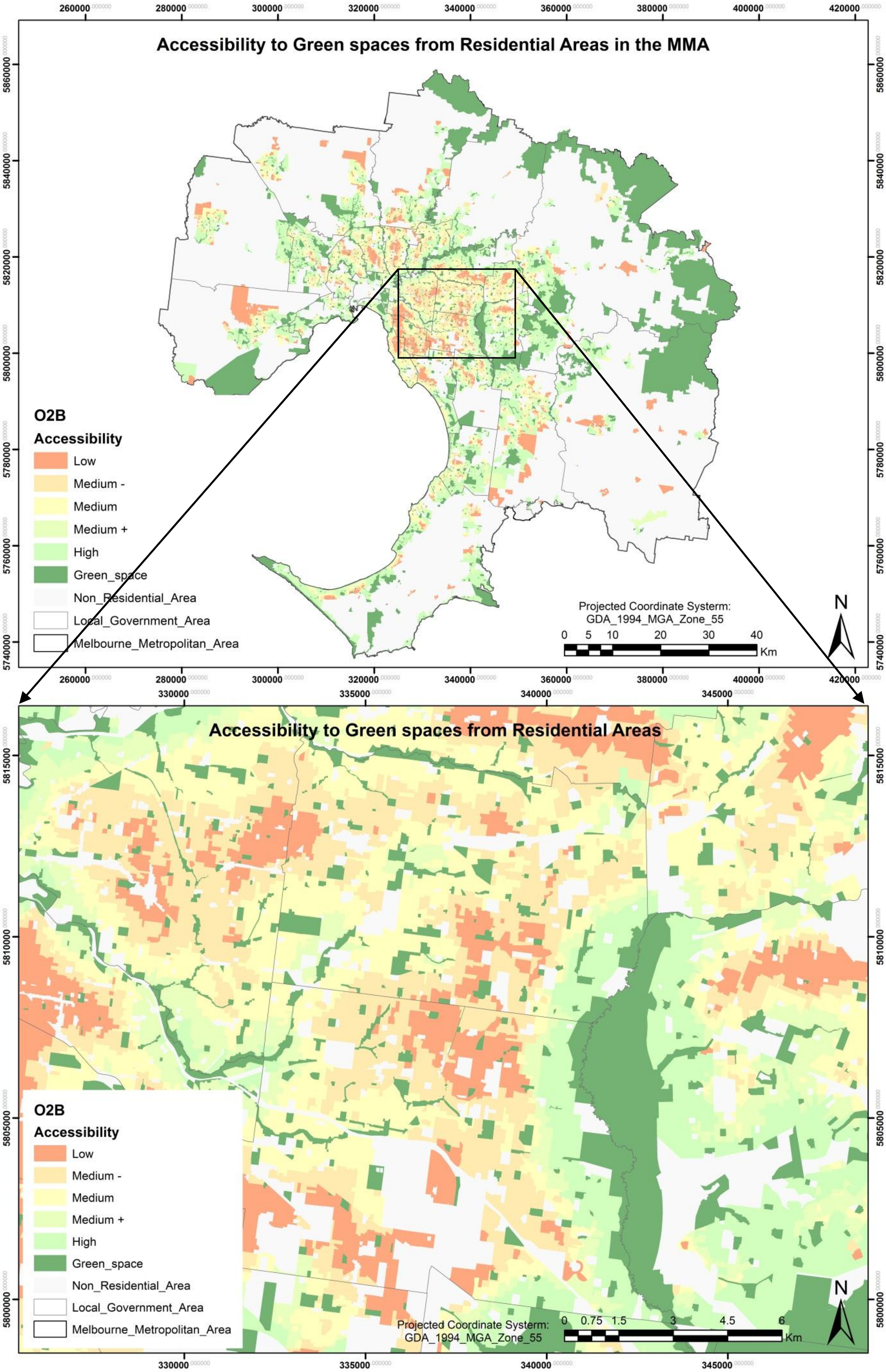
Map Appendix.1.11 The accessibility to green space for adult population by 3SFCA and Gaussian decay



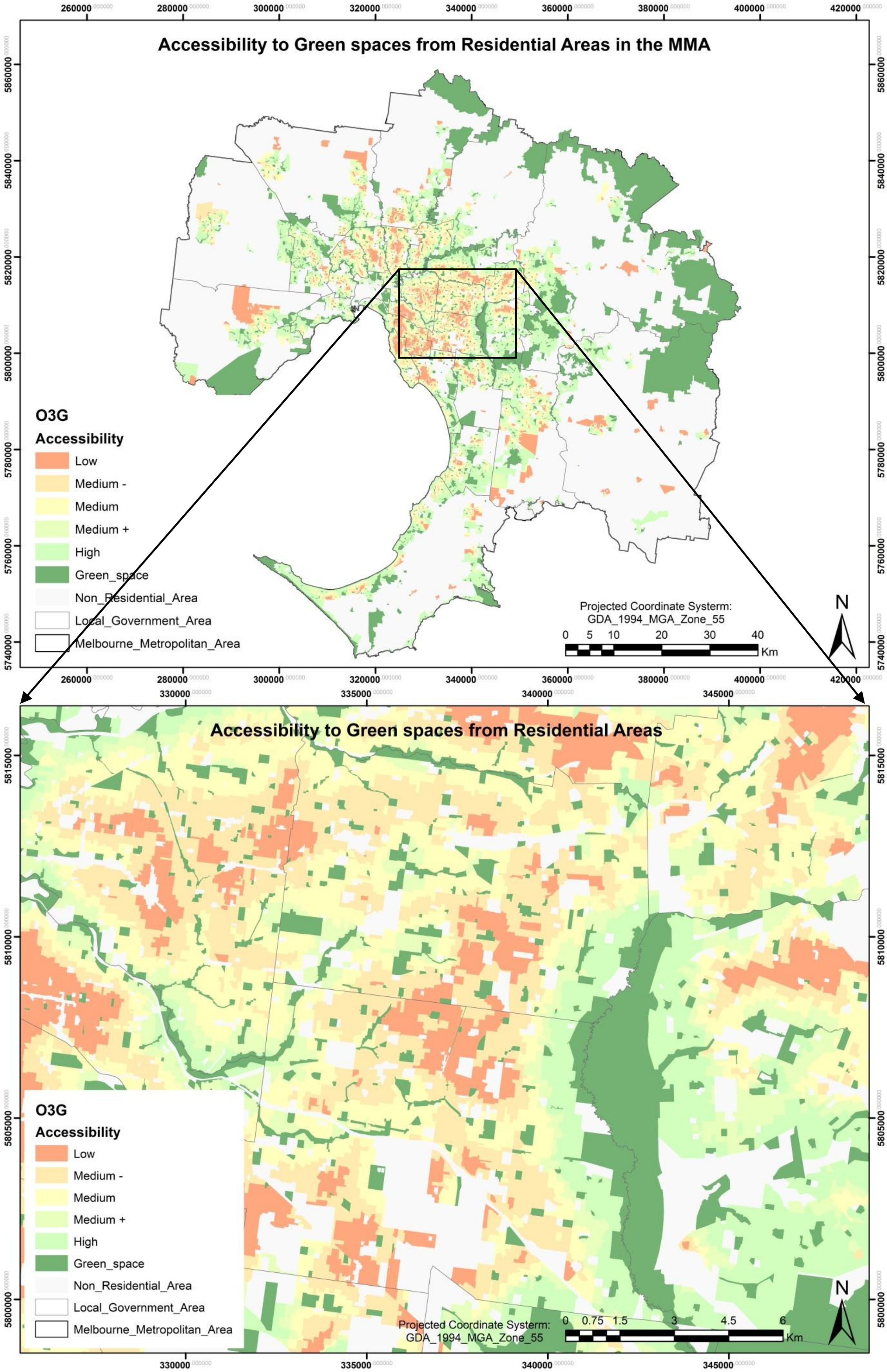
Map Appendix.1.12 The accessibility to green space for adult population by 3SFCA and Butterworth filter



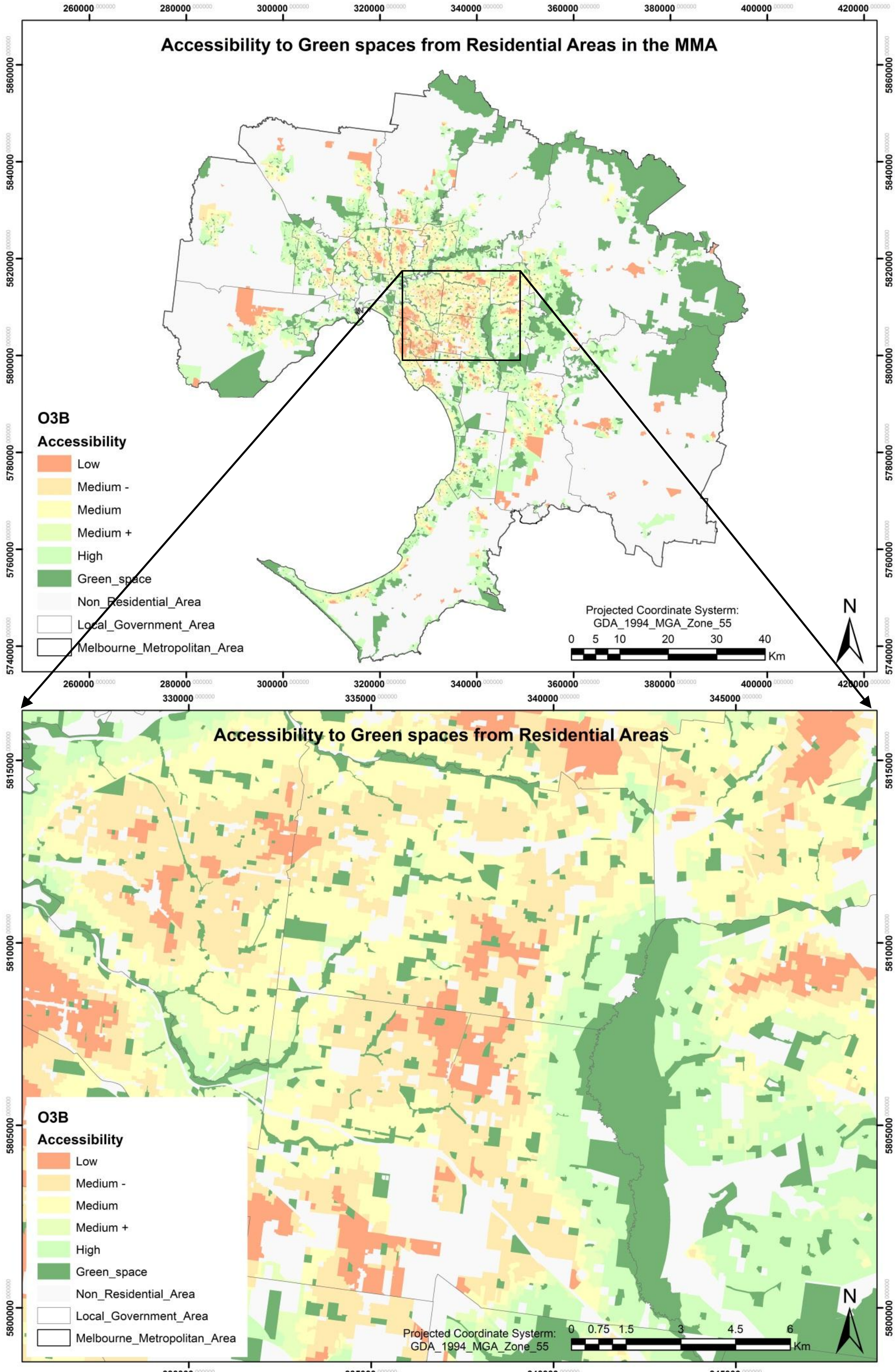
Map Appendix.1.13 The accessibility to green space for old population by 2SFCA model and Gaussian decay



Map Appendix.1.14 The accessibility to green space for old population by 2SFCA and Butterworth filter



Map Appendix.1.15 The accessibility to green space for old population by 3SFCA model and Gaussian decay



Map Appendix.1.16 The accessibility to green space for old population by 3SFCA and Butterworth filter

APPENDIX 2

SUMMARY STATISTICAL TABLES

Index

Table Appendix.2.1 The detail population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for total group

Total population		Low		Medium -		Medium		Medium +		High		Total
T2G	Persons	696648	18.2%	702760	18.4%	903946	23.6%	699300	18.3%	820494	21.5%	3823148
	MB Number	7043	17.6%	7379	18.5%	9419	23.6%	7363	18.4%	8787	22.0%	39991
	MB Area	33506	19.7%	23556	13.8%	32298	19.0%	26558	15.6%	54197	31.9%	170115
T2B	Persons	651569	17.0%	686049	17.9%	932504	24.4%	728789	19.1%	824237	21.6%	3823148
	MB Number	6561	16.4%	7217	18.0%	9777	24.4%	7611	19.0%	8825	22.1%	39991
	MB Area	31354	18.4%	23147	13.6%	33295	19.6%	26961	15.8%	55357	32.5%	170115
T3G	Persons	622164	16.3%	739819	19.4%	948805	24.8%	704043	18.4%	808317	21.1%	3823148
	MB Number	6285	15.7%	7667	19.2%	9902	24.8%	7405	18.5%	8732	21.8%	39991
	MB Area	30988	18.2%	24637	14.5%	33053	19.4%	25952	15.3%	55483	32.6%	170115
T3B	Persons	503468	13.2%	705611	18.5%	1054980	27.6%	747269	19.5%	811820	21.2%	3823148
	MB Number	5013	12.5%	7362	18.4%	11014	27.5%	7902	19.8%	8700	21.8%	39991
	MB Area	26597	15.6%	23143	13.6%	35729	21.0%	27580	16.2%	57065	33.5%	170115

Table Appendix.2.2 The detail population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for young group

Young population		Low		Medium -		Medium		Medium +		High		Total
Y2G	Persons	109262	15.3%	95034	13.3%	148955	20.9%	151434	21.3%	207769	29.2%	712454
	MB Number	4402	11.0%	5140	12.9%	8437	21.1%	9032	22.6%	12980	32.5%	39991
	MB Area	27518	16.2%	16814	9.9%	28904	17.0%	31378	18.4%	65500	38.5%	170115
Y2B	Persons	100065	14.0%	97928	13.7%	145738	20.5%	158042	22.2%	210681	29.6%	712454
	MB Number	3964	9.9%	5241	13.1%	8230	20.6%	9434	23.6%	13122	32.8%	39991
	MB Area	25408	14.9%	17511	10.3%	28160	16.6%	32342	19.0%	66694	39.2%	170115
Y3G	Persons	97598	13.7%	94724	13.3%	159484	22.4%	154161	21.6%	206784	29.0%	712454
	MB Number	3791	9.5%	5041	12.6%	8927	22.3%	9144	22.9%	13088	32.7%	39991
	MB Area	25782	15.2%	16275	9.6%	30371	17.9%	30572	18.0%	67115	39.5%	170115
Y3B	Persons	80189	11.3%	90458	12.7%	162491	22.8%	168021	23.6%	211295	29.7%	712454
	MB Number	2870	7.2%	4741	11.9%	9040	22.6%	10044	25.1%	13296	33.2%	39991
	MB Area	22294	13.1%	15148	8.9%	29620	17.4%	34721	20.4%	68330	40.2%	170115

Table Appendix.2.3 The detail population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for adult group

Adult population		Low		Medium -		Medium		Medium +		High		Total
A2G	Persons	607271	23.2%	558511	21.4%	599006	22.9%	400058	15.3%	447563	17.1%	2612409
	MB Number	8912	22.3%	8521	21.3%	9194	23.0%	6118	15.3%	7246	18.1%	39991
	MB Area	39131	23.0%	28091	16.5%	30376	17.9%	23851	14.0%	48667	28.6%	170115
A2B	Persons	575926	22.0%	558720	21.4%	616242	23.6%	409422	15.7%	452099	17.3%	2612409
	MB Number	8417	21.0%	8532	21.3%	9498	23.8%	6241	15.6%	7303	18.3%	39991
	MB Area	37026	21.8%	26963	15.8%	32239	19.0%	23907	14.1%	49981	29.4%	170115
A3G	Persons	572737	21.9%	579603	22.2%	619065	23.7%	397402	15.2%	443602	17.0%	2612409
	MB Number	8325	20.8%	8832	22.1%	9448	23.6%	6153	15.4%	7233	18.1%	39991
	MB Area	36989	21.7%	27693	16.3%	32517	19.1%	22960	13.5%	49956	29.4%	170115
A3B	Persons	478733	18.3%	586872	22.5%	689206	26.4%	409012	15.7%	448586	17.2%	2612409
	MB Number	6945	17.4%	8896	22.2%	10574	26.4%	6277	15.7%	7299	18.3%	39991
	MB Area	32281	19.0%	27646	16.3%	35456	20.8%	23284	13.7%	51449	30.2%	170115

Table Appendix.2.4 The detail population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for old group

Old population		Low		Medium -		Medium		Medium +		High		Total
O2G	Persons	76445	15.3%	98073	19.7%	117623	23.6%	85077	17.1%	121067	24.3%	498285
	MB Number	6236	15.6%	6828	17.1%	8467	21.2%	7093	17.7%	11367	28.4%	39991
	MB Area	28810	16.9%	21852	12.8%	27563	16.2%	26687	15.7%	65203	38.3%	170115
O2B	Persons	69232	13.9%	97089	19.5%	120664	24.2%	88378	17.7%	122922	24.7%	498285
	MB Number	5730	14.3%	6723	16.8%	8732	21.8%	7260	18.2%	11546	28.9%	39991
	MB Area	26932	15.8%	21020	12.4%	28731	16.9%	26860	15.8%	66573	39.1%	170115
O3G	Persons	67218	13.5%	106427	21.4%	117391	23.6%	87868	17.6%	119381	24.0%	498285
	MB Number	5163	12.9%	7227	18.1%	8576	21.4%	7287	18.2%	11738	29.4%	39991
	MB Area	24424	14.4%	22912	13.5%	28436	16.7%	26049	15.3%	68294	40.1%	170115
O3B	Persons	51571	10.3%	104269	20.9%	127001	25.5%	93159	18.7%	122285	24.5%	498285
	MB Number	4003	10.0%	7079	17.7%	9225	23.1%	7723	19.3%	11961	29.9%	39991
	MB Area	20710	12.2%	21440	12.6%	30546	18.0%	26599	15.6%	70820	41.6%	170115

Table Appendix.2.5 Comparing with the Mean accessibility, the variation ratio of population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for total group

		Low	Medium -	Medium	Medium +	High
T2G	Persons	12.9%	-1.5%	-7.5%	-1.3%	1.7%
	MB Number	13.4%	-1.0%	-7.4%	-1.8%	1.5%
	MB Area	9.2%	0.0%	-6.0%	2.8%	-2.7%
T2B	Persons	5.5%	-3.8%	-4.5%	2.8%	2.1%
	MB Number	5.7%	-3.2%	-3.9%	1.5%	2.0%
	MB Area	2.2%	-1.7%	-3.1%	4.3%	-0.6%
T3G	Persons	0.8%	3.7%	-2.9%	-0.6%	0.2%
	MB Number	1.2%	2.8%	-2.7%	-1.2%	0.9%
	MB Area	1.0%	4.6%	-3.8%	0.4%	-0.4%
T3B	Persons	-18.4%	-1.1%	8.0%	5.5%	0.6%
	MB Number	-19.3%	-1.3%	8.2%	5.4%	0.5%
	MB Area	-13.3%	-1.7%	4.0%	6.7%	2.5%

Table Appendix.2.6 Comparing with the Mean accessibility, the variation ratio of population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for young group

		Low	Medium -	Medium	Medium +	High
Y2G	Persons	15.5%	-0.5%	-4.6%	-5.0%	0.5%
	MB Number	22.1%	0.1%	-3.2%	-5.4%	0.0%
	MB Area	11.6%	0.7%	-2.3%	-5.7%	-0.6%
Y2B	Persons	5.8%	2.5%	-6.7%	-0.8%	1.9%
	MB Number	10.0%	2.1%	-5.6%	-1.2%	1.1%
	MB Area	3.1%	4.9%	-4.8%	-2.8%	1.2%
Y3G	Persons	3.2%	-0.8%	2.1%	-3.3%	0.0%
	MB Number	5.2%	-1.8%	2.4%	-4.3%	0.8%
	MB Area	4.6%	-2.5%	2.6%	-8.1%	1.8%
Y3B	Persons	-15.2%	-5.3%	4.1%	5.4%	2.2%
	MB Number	-20.4%	-7.6%	3.7%	5.2%	2.4%
	MB Area	-9.6%	-9.3%	0.1%	4.4%	3.7%

Table Appendixdix.2.7 Comparing with the Mean accessibility, the variation ratio of population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for adult group

		Low	Medium -	Medium	Medium +	High
A2G	Persons	9.4%	-2.5%	-6.4%	-0.3%	1.0%
	MB Number	10.3%	-2.7%	-6.0%	-0.6%	0.4%
	MB Area	7.3%	4.3%	-9.4%	3.4%	-2.9%
A2B	Persons	3.7%	-2.5%	-3.7%	2.1%	2.0%
	MB Number	4.2%	-2.6%	-2.9%	1.4%	1.2%
	MB Area	1.5%	0.1%	-3.8%	3.7%	-0.3%
A3G	Persons	3.2%	1.2%	-3.3%	-0.9%	0.1%
	MB Number	3.1%	0.8%	-3.4%	0.0%	0.2%
	MB Area	1.4%	2.8%	-3.0%	-0.4%	-0.3%
A3B	Persons	-13.8%	2.4%	7.7%	2.0%	1.2%
	MB Number	-14.0%	1.6%	8.1%	2.0%	1.1%
	MB Area	-11.5%	2.6%	5.8%	1.0%	2.6%

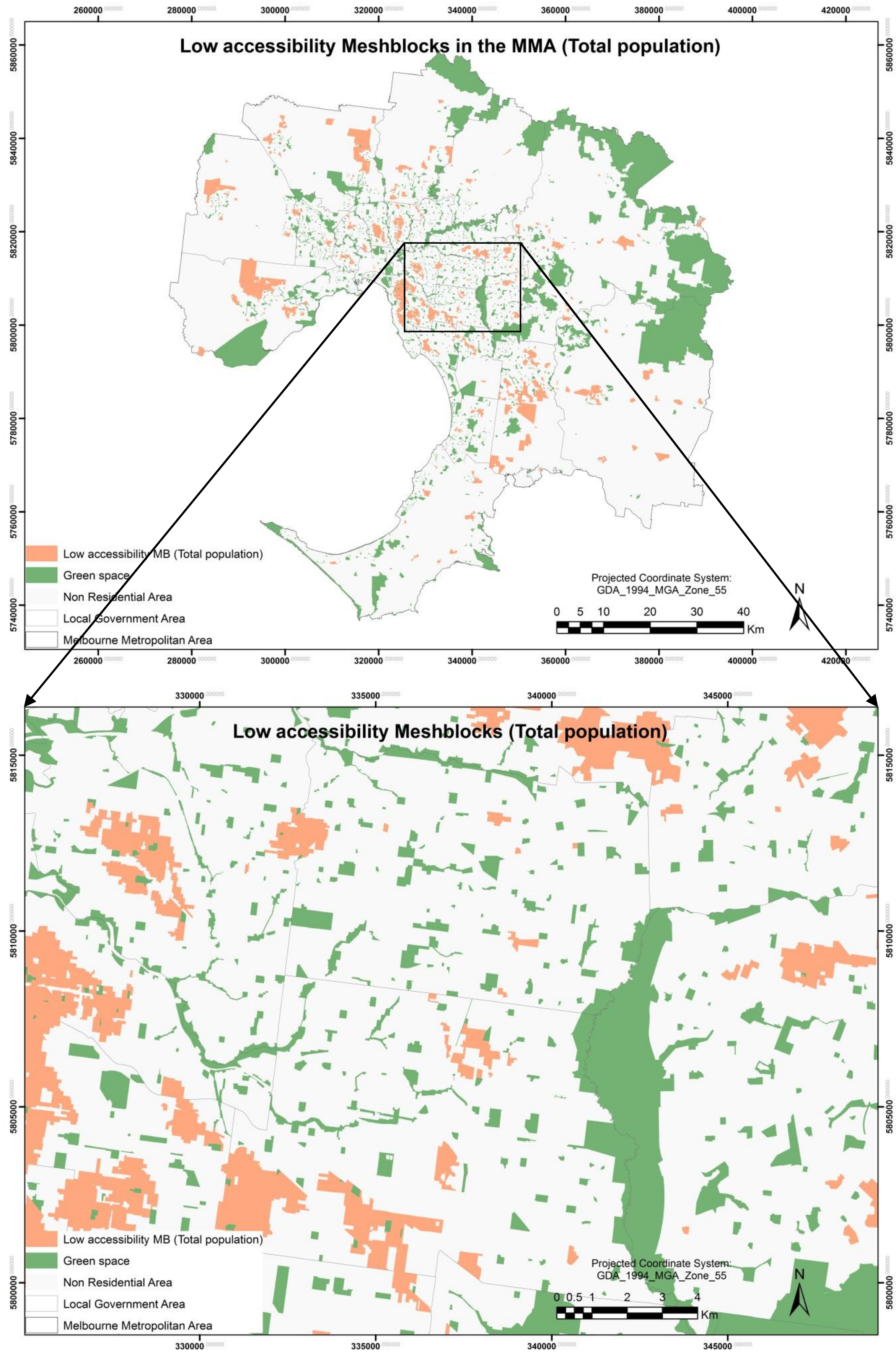
Table *Appendix.2.8* Comparing with the Mean accessibility, the variation ratio of population, MB number and MB area of M2SFCA_G, M2SFCA_B, M3SFCA_G and M3SFCA_B models for old group

		Low	Medium -	Medium	Medium +	High
O2G	Persons	18.6%	-5.1%	-3.9%	-2.4%	0.1%
	MB Number	20.2%	-4.0%	-4.1%	-3.0%	-1.6%
	MB Area	14.8%	0.1%	-5.8%	1.3%	-3.5%
O2B	Persons	7.4%	-6.0%	-1.4%	1.4%	1.6%
	MB Number	10.5%	-5.5%	-1.1%	-0.7%	0.0%
	MB Area	7.3%	-3.7%	-1.8%	2.0%	-1.5%
O3G	Persons	4.3%	3.0%	-4.1%	0.8%	-1.3%
	MB Number	-0.4%	1.6%	-2.9%	-0.3%	1.6%
	MB Area	-2.7%	4.9%	-2.8%	-1.1%	1.1%
O3B	Persons	-20.0%	0.9%	3.8%	6.9%	1.1%
	MB Number	-22.8%	-0.5%	4.5%	5.6%	3.6%
	MB Area	-17.5%	-1.8%	4.4%	1.0%	4.8%

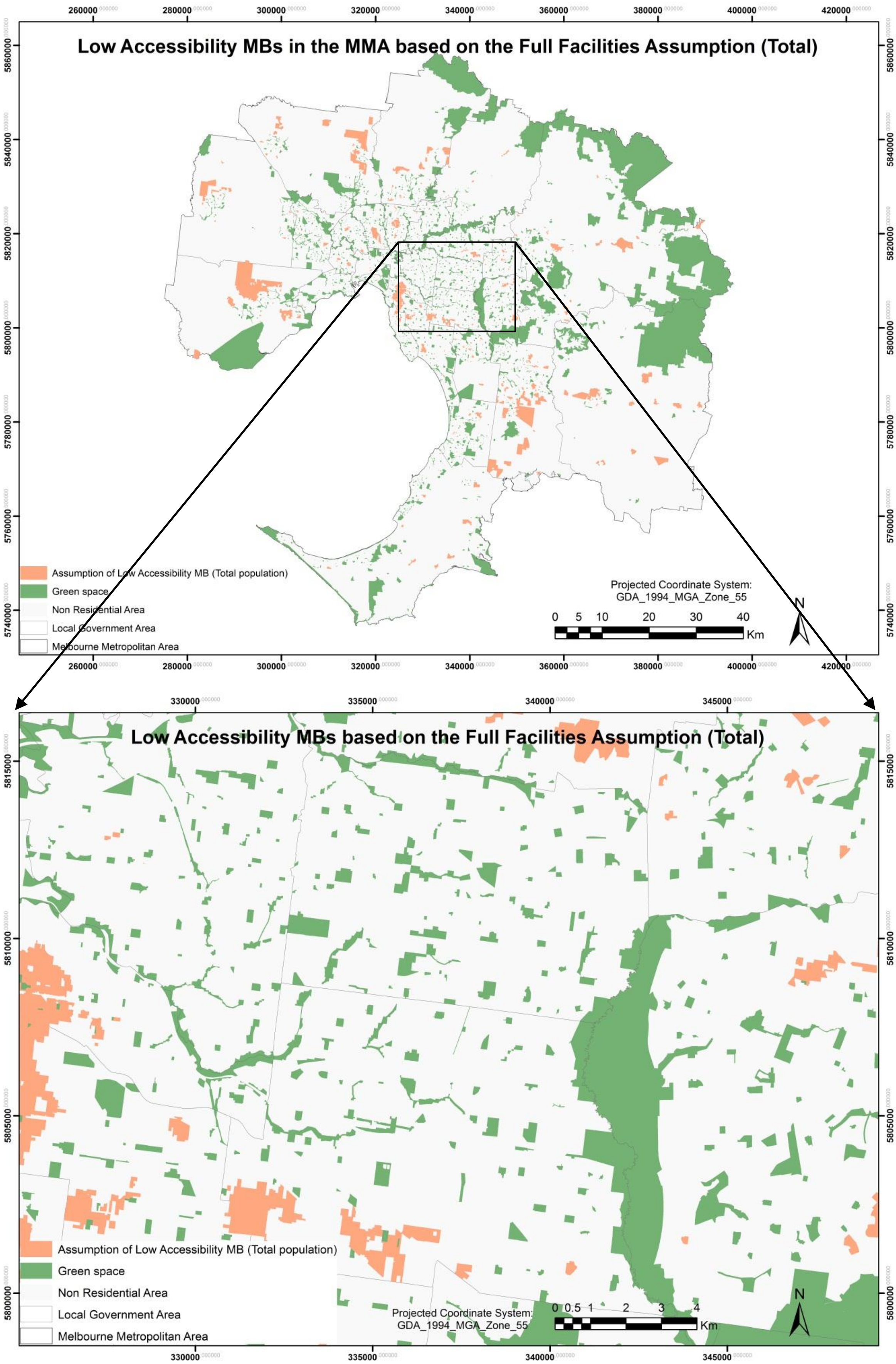
APPENDIX 3

Summary Statistical Tables

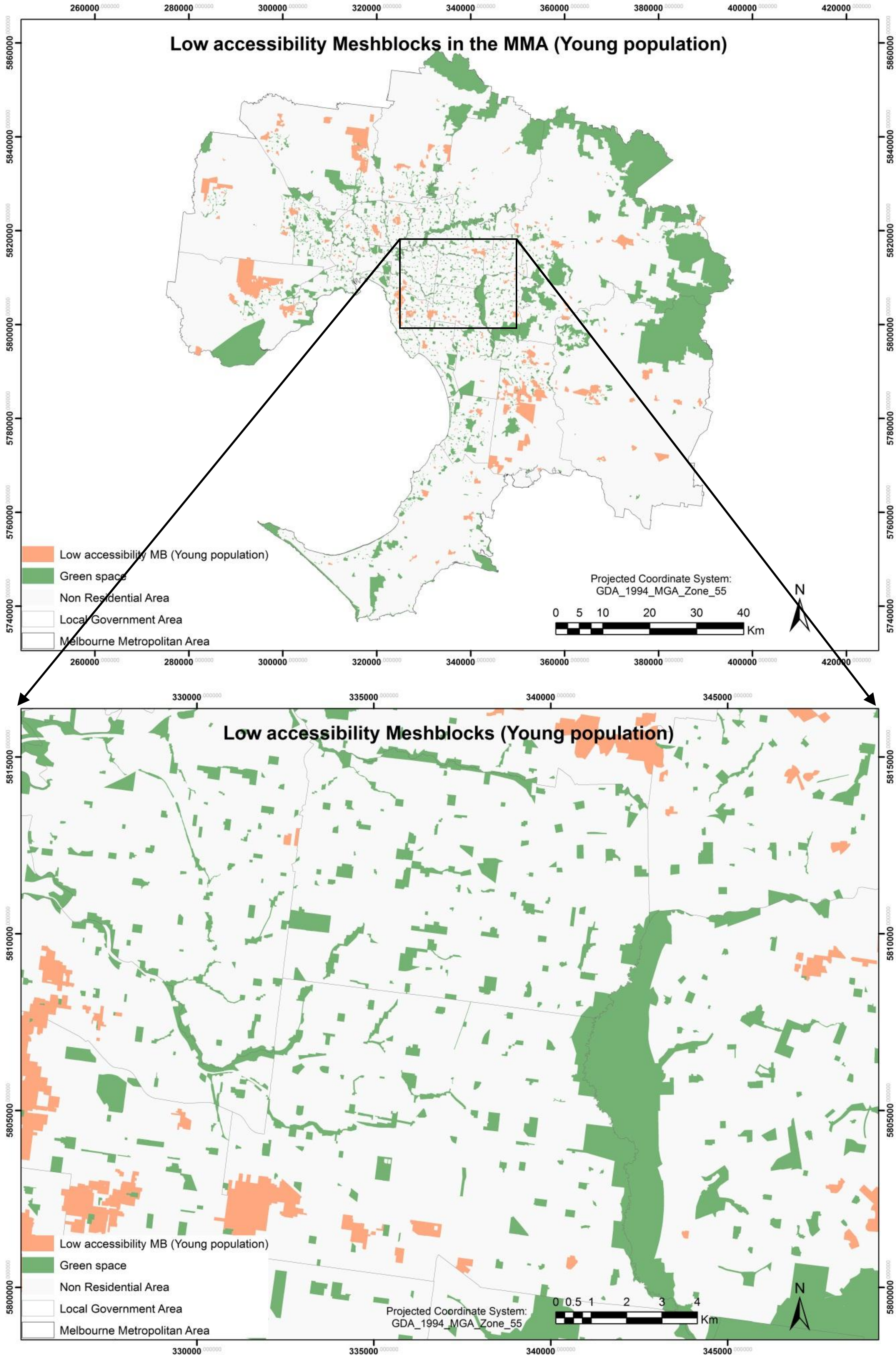
Index



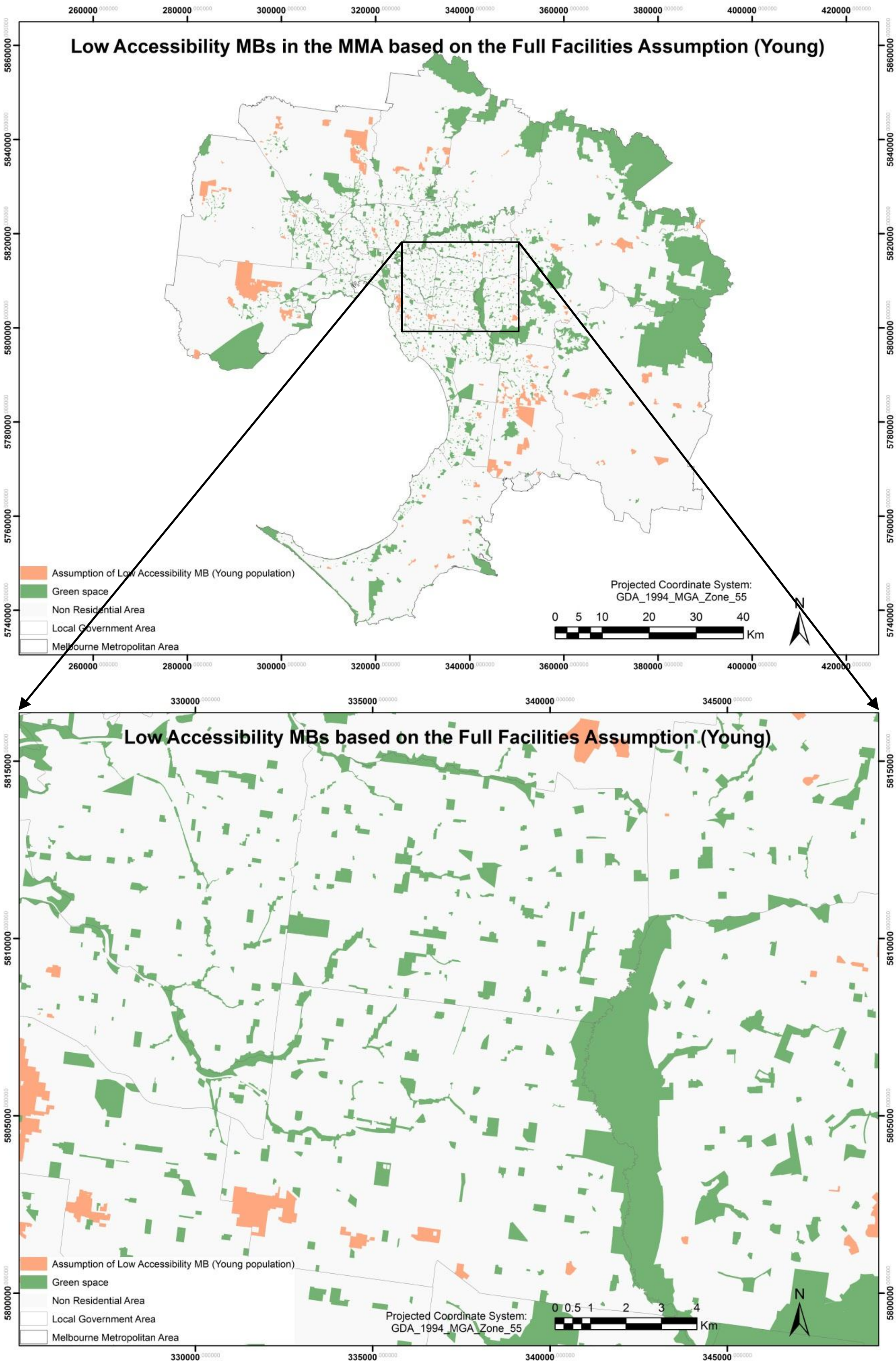
Map Appendix.3.1 Current spatial pattern of residential areas with low accessibility to green space (total population)



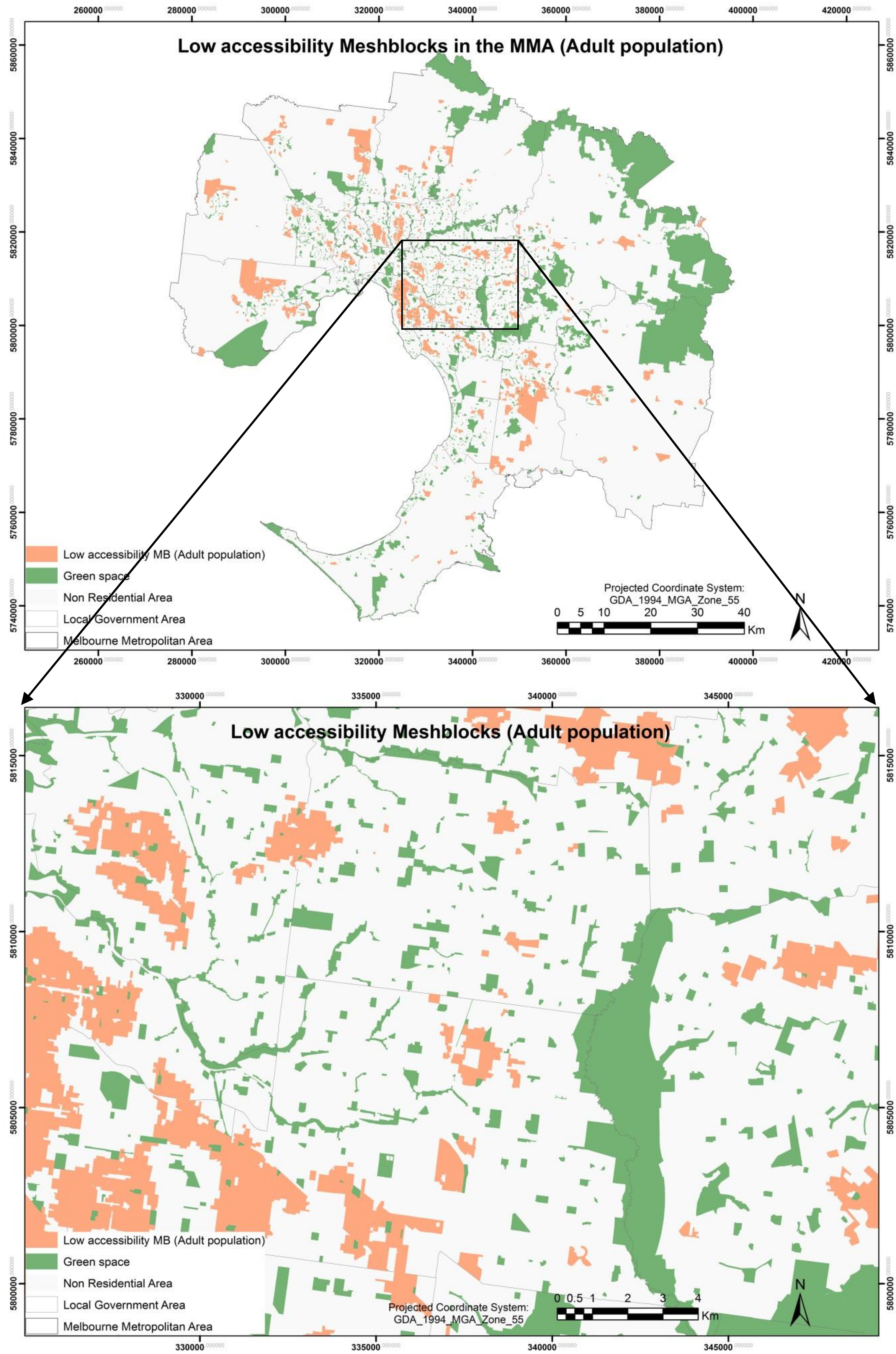
Map Appendix.3.2 Simulated spatial pattern of the low accessibility area to green space (total population)



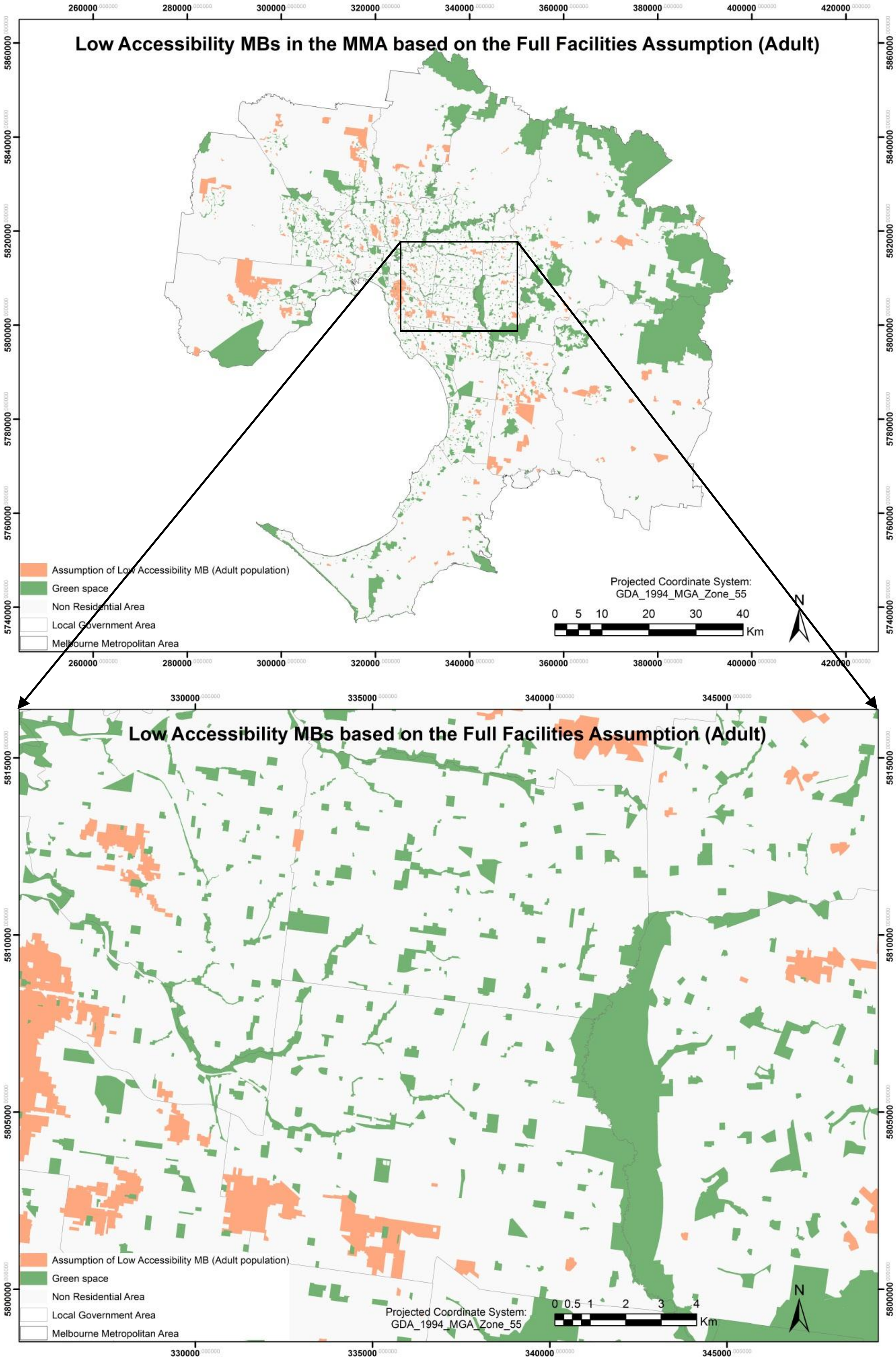
Map Appendix.3.3 Current spatial pattern of residential areas with low accessibility to green space (young population)



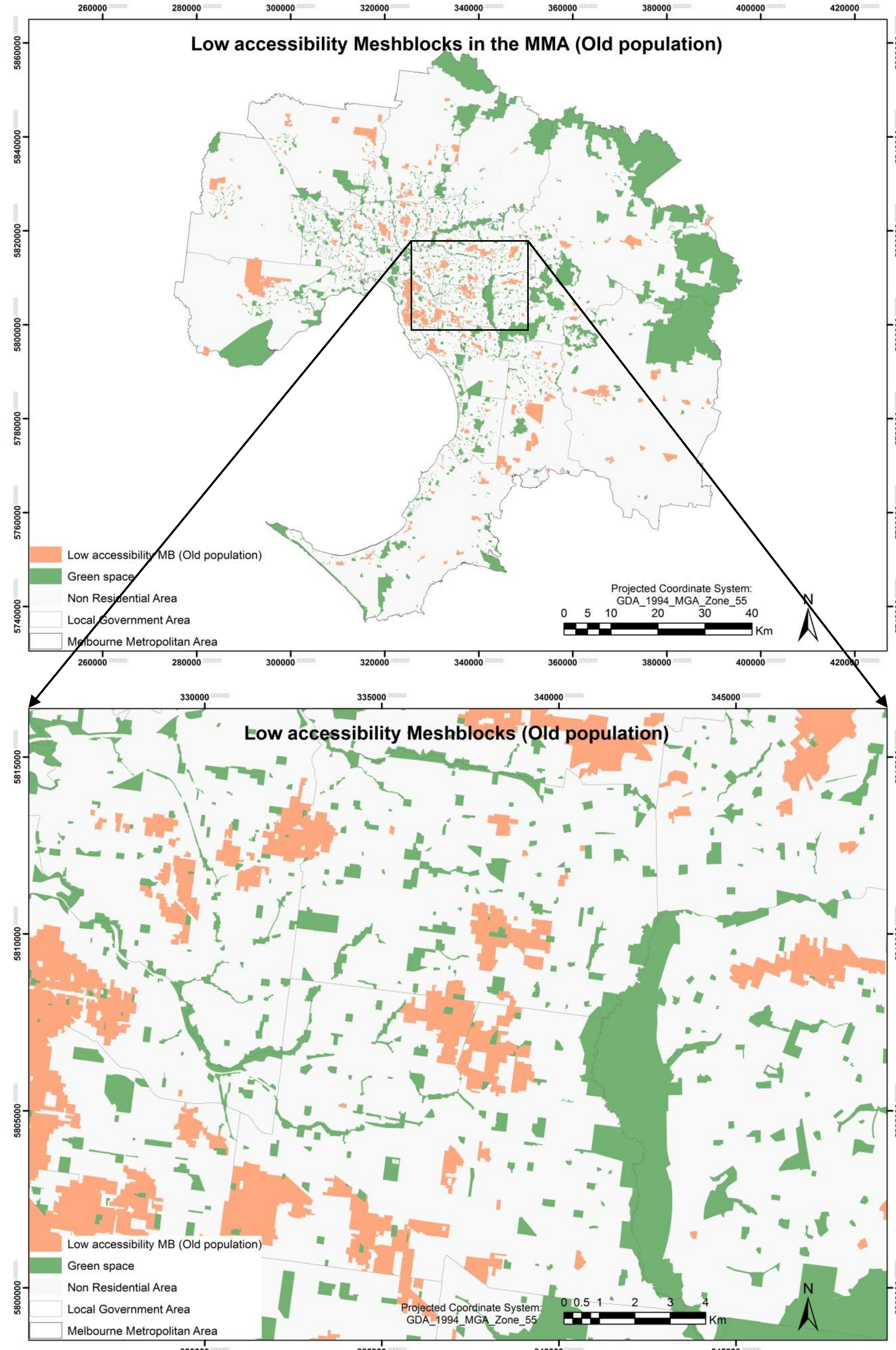
Map Appendix.3.4 Simulated spatial pattern of the low accessibility area to green space (young population)



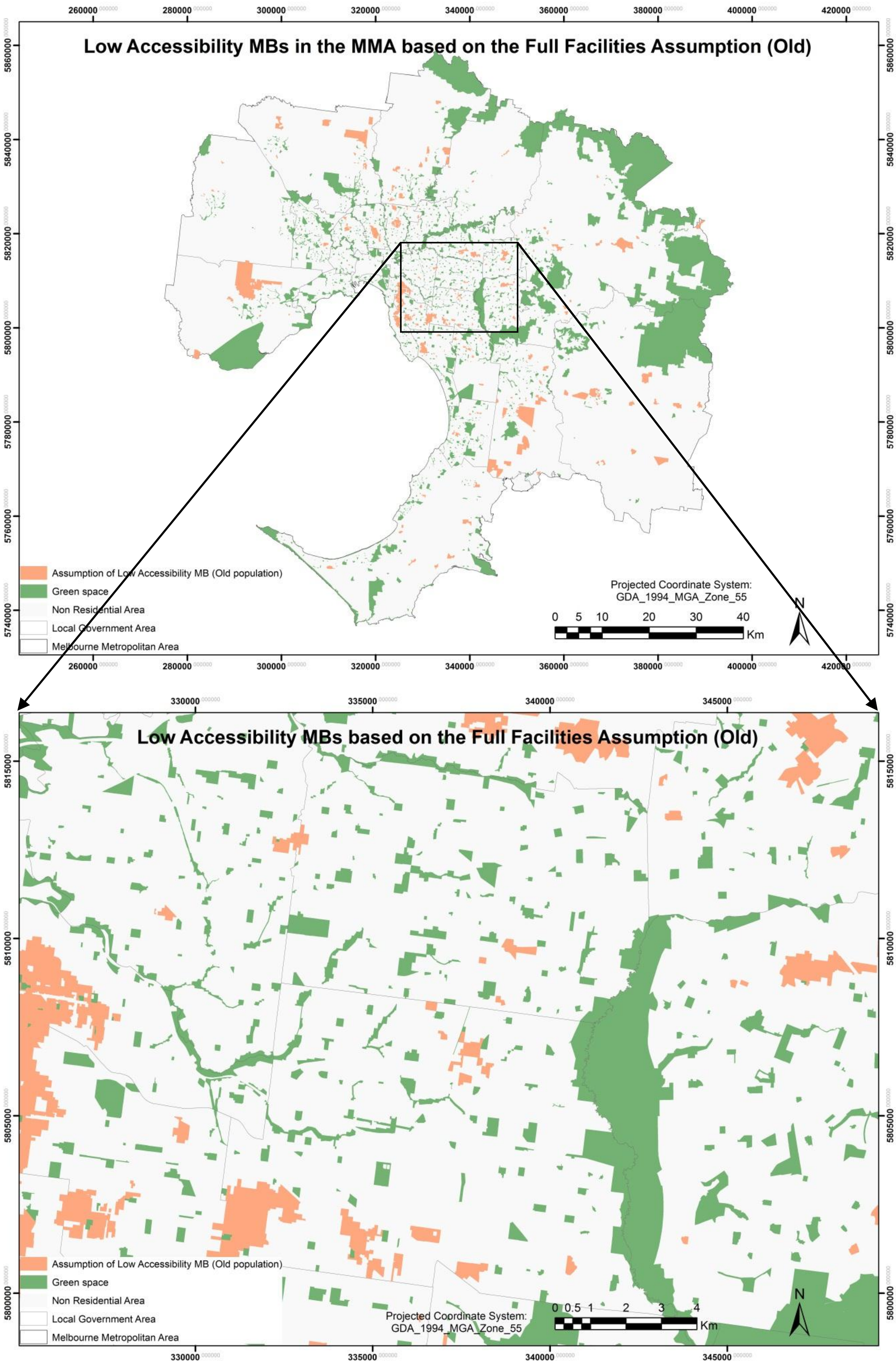
Map Appendix.3.5 Current spatial pattern of residential areas with low accessibility to green space (adult population)



Map Appendix.3.6 Simulated spatial pattern of the low accessibility area to green space (adult population)



Map Appendix.3.7 Current spatial pattern of residential areas with low accessibility to green space (old population)



Map Appendix.3.8 Simulated spatial pattern of the low accessibility area to green space (old population)

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